EFFECT OF RATOONING AND NITROGEN APPLICATION ON LINT YIELD AND QUALITY OF COTTON VARIETIES IN CENTRAL KENYA

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DECLARATION

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

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DEDICATION

To my beloved wife Emily and my son Dan who gave me all the support and encouragement that l needed during the time of doing this work.

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ABSTRACT

About 14 percent of cotton farmers in Central, Eastern and Coastal regions of Kenya grow ratoon cotton. They cut the stalk of the main cotton crop at various heights above the ground surface after the first harvest leaving the stumps to regenerate into new shoots at the onset of the next rainy season to give the ratoon cotton crop. Performance of the ratoon cotton depends on the management of the previous season's cotton crop including the height of cutting and availability of soil moisture and plant nutrients.

Information on the effects of cut heights and nitrogen application on growth, pest incidences, seed cotton yield and quality of ratooned cotton varieties in Kenya is limited hence need for this study.

The study was conducted during the 2007/08 and 2008/09 growing seasons at Kirogo farm situated at Kenya Agricultural Research Institute (KARI) Mwea in Kirinyaga County. The objective was to evaluate the effect of cut height and nitrogen application on growth, pest incidences, yield and quality in ratoon crop of three cotton varieties (HART 89M, A540 and F962). The experimental design was a randomized complete block design using a split-split plot arrangement with four replications. The varieties were assigned to the main plots, cut heights (control, 5 cm, 10 cm and 15 cm above ground surface) to the sub plots and nitrogen (N) fertilizer application levels (0 and 110 kg N ha^{-1}) to the sub-subplots.

Data on plant height, plant count, number of sprout stems, pest counts, seed cotton yield, lint percentage, and percent of grade 'AR' seed cotton was recorded and subjected to analysis of variance using Genstat statistical software, and means compared using Fisher's least significant difference (LSD) test at a probability level of 0.05.

Cut height significantly ($P \leq 0.05$) affected many aspects of the subsequent ratoon crop including plant count, plant height, and the number of stems that sprouted from the stump, cumulative seed cotton yield, percent grade 'AR' and incidences of mealybugs, thrips and mites in cotton. The varieties differed significantly in plant count and lint percentage and not in other test parameters.

Nitrogen application significantly ($P \leq 0.05$) influenced plant height, number of sprout stems and natural infestation by cotton stainers. It did not affect natural infestation by other pests, lint percentage, and seed cotton yield. Lack of yield response from N application by both the ratoon and the control was mainly attributed to poor rains experienced during the season.

The number of regenerated ratoon cotton plants and sprouted stems increased with increases in cut height. Ratoon cotton seed cotton earlier than cotton sown directly from the seed and the yield increased with cut height. Cumulative seed cotton yield from plots cut at 15 cm was significantly higher than that of 5 cm cut height and directly seeded cotton. Ratoon cotton suffered an earlier pest attack by aphids, mites and mealybugs when compared with directly sown cotton. The reduced plant stand of ratoon cotton could lead to low cotton yields but this could probably be compensated for by the increased number of sprouted stems. Further studies are recommended to determine the maximum cut height and the number of times cotton can be ratooned without affecting yield and other lint quality parameters such as fibre strength, length and micronaire. In addition, cost benefits analysis of ratooning need to be undertaken.

CHAPTER ONE

INTRODUCTION

1.1: History of cotton production in Kenya

Cotton sub sector has been identified by the Government of Kenya as crucial in fighting poverty and in reviving the Kenya economy as stipulated in the 'Interim Poverty Reduction Strategy Paper (GOK, 2000) and the 'Economic Recovery Strategy for Wealth and Employment Creation Paper' (GOK, 2003). Cotton is considered as one of the most important industries to implement for the long term Arid and Semi Arid Lands (ASAL) development initiatives and industrialization strategy (GOK, 2007).

Cotton has been produced in Kenya since 1902 when it was introduced to the Coast, Western and Nyanza provinces. Attempts to introduce it in east and central Kenya in 1931, was abandoned due to high pest incidence. However, it was not until the early 1960s that the crop was introduced in many parts of the country and encouraged particularly in areas with low rainfall and therefore unsuitable for other cash crops (MOA, 2007). Currently cotton is grown in Nyanza, Western, Coast, Central, Eastern and rift Valley provinces, largely under rain fed conditions by small-scale farmers on land averaging one hectare. Production of this crop is mainly labour intensive with low input (fertilizers and pesticides) use and mechanization (GOK, 2005). In the year 2011, production of cotton under irrigation was reintroduced in Bura irrigation scheme after the collapse of the scheme in 1990s.

The Cotton Board of Kenya estimates that countrywide, 350,000 hectares is suitable for rain-fed cotton production with the potential to produce about 260,000 bales of lint annually, and 35,000 hectares for irrigated cotton with the potential to produce 108,000 bales of lint annually (GOK, 2005). However, of this potential only 35,927 is under cotton production, producing an average of 44,550 bales annually (CODA, 2012). These yields is still low compared with that of Egypt (550,000 bales) and South Africa (81,000 bales) (USDA, 2012). Kenya's lint yield of 191 kg ha^{-1} is also low compared to Africa's average lint yield (300 to 370 kg ha^{-1}) and world average lint yield 589 kg ha^{-1} (Ikaria and Ndirangu, 2003). Returns from cotton production are low and therefore given a low priority and will only be planted after the farmers have completed planting food crops. Intercropping of cotton with food crops is widely practiced in Kenya where the majority of farmers interplant cotton with food crops such as maize, beans, pigeon peas, green grams, cowpeas, ground nuts, millet and sorghum (GOK, 1999; and Macharia *et al.,* 2005). Consequently, despite the Government policy of seeking self-sufficiency on cotton since independence (GOK, 1999), local cotton production currently meets only 16.7% of the local demand with the balance being imported. The country imports lint and almost all other raw materials for its textile industry and finished textile products such as new and used clothes, yarn, lint, seed cake and oil. Consequently, though there were 24 ginneries in Kenya in 2005 with an estimated installed capacity of 140,000 bales per year, their average capacity utilization was about 30% (Omolo, 2006; MOA, 2007).

The cotton sub-sector started declining in the mid-1980s until 1990s when liberalization of the economy and reduction of Government support led to collapse of the local textile industry (GOK, 2005). Liberalization resulted in the Cotton Board of Kenya becoming redundant while the private sector did not have adequate capacity to provide quality planting seed, credit, guaranteed prices and efficient marketing (CODA, 2009).

Consequently, cotton production declined such that between 1998 and 1999, the amount of cotton lint produced dropped to below 20,000 bales per year (Terer, 1999).

The low and declining seed cotton yields was attributed to several factors including: lack of certified seed and late supply of seed, high production costs, low levels of farm input use due to high costs, lack of affordable credit facilities for cotton farmers, weak producer organizations hence poor bargaining power by farmers, low market prices of seed cotton, delayed payments, low and unreliable rainfall in marginal areas where most of the cotton is grown and poor agricultural practices such as late planting, poor thinning, inappropriate intercropping systems, poor pest control and ratooning (Mugo and Masake, 2002; Ikiara and Ndirangu, 2003; Wabule *et al*., 2006 and GOK, 2006). Low and unreliable rainfall in marginal areas, combined with poor quality and late supply of planting seed, encouraged production of ratoon cotton.

The area under cotton increased from 30,000 to 50,000 hectares in 2008 (MOA, 2008). This was attributed to various intervention measures taken by the government in its efforts to revive the once booming industry. Such measures included: provision of high quality seeds, the enactment of Cotton Act 2006 and establishment of the Cotton Development Authority (CODA). The functions of CODA were to undertake promotion, development and regulation of the cotton industry, provide policy advice to the government and gazette buying centers, dates for buying cotton and minimum price per kilogram of seed cotton. The Government is encouraging farmers to form farmer organization groups to improve their bargaining power, promoting research programs aimed at production of superior cotton varieties (i.e. high yielding and tolerant to pests, diseases and drought with higher fibre length, strength and ginning outturn, developing and using of modern technologies to facilitate market information flow to the stakeholders through a cotton website and print media, encouraging collaboration of stakeholders to ensure that the price of cotton and its products are determined by the forces of demand and supply in an open market system subject to the prevailing world market prices and sensitizing stakeholders on establishment of cottage industries and enhanced value addition to tap wider market and diversified cotton products (MOA, 2007).

The Government of Kenya through the Ministry of Industrialization started implementing a Pilot Value Chain Based Matching Grant Fund in 2005 focusing on coffee, cotton, and pyrethrum and leather value chains. At the farming level, the grant funds can be used to finance on-farm technical training in quality control, post-harvest handling and other activities that strengthen the backward linkages between the corporate intermediary and their growers or suppliers to ensure better response to the demands of the market. Other measures taken by the government of Kenya recently included: waiving Value Added Tax (VAT) levied on locally produced and ginned cotton, registering and licensing all cotton buyers and ginners in Kenya.

The government's interest in the revival of the cotton industry has largely been stimulated by the market opportunity presented by the United States African Growth and Opportunity Act (AGOA) of 2000 (which allows Kenya to export to USA, both duty free and large attractive quotas of textile goods) and the potential of the industry to contribute to poverty alleviation in Kenya (Ikiara and Ndirangu, 2003). The AGOA trade arrangement expires in 2015 and Kenyan cotton farmers and textile manufacturers are yet to benefit from it. This is because few cotton farmers and textile manufacturers know about it, the farmers and textile manufacturers produce too little which is sometimes of low quality and the investment in the cotton subsector is too little for the industry to prosper (Wafula, 2009). Under the "special rule" arrangement, countries like Kenya that qualified for AGOA are allowed to source for raw materials like cotton fabrics and yarn from non-AGOA qualified countries. After 2012, Kenya will only be allowed to source the raw materials from local cotton/textile industries or from other AGOA eligible countries or from the USA. This means that after the deadline, cotton farmers, ginners and textile manufactures stand to benefit more because demand for locally produced cotton and textiles will increase (Wafula, 2009).

Guidelines in many countries do not recommend ratooning because of high incidences of pests and diseases in ratoon crops which necessitate frequent spraying with pesticides, leading to pests and diseases developing resistance to pesticides. The widespread use of pesticides is known to induce the population resurgence of pests (Sinkondyobwe, 2005; Farrel, 2007; Gu *et al*., 1996 and Yin *et al.*, 2008). This means farmers incur more costs, as they would have to spray more often than usual. Indeed, the practice of ratooning is banned by law in some countries such as Zambia due to danger of carryover of pests and diseases (Sinkondyobwe, 2005). The current cotton growing recommendation in Kenya is to uproot and burn cotton stalk at the end of every growing season before ploughing the land in readiness for planting the next season (MOA, 2007). However, a survey conducted by KARI, CODA and the Ministry of Agriculture in March 2010 showed that growing of ratoon cotton has become a common practice in Central, Eastern and Coastal regions of Kenya and that 14% of the farmers practice it and that only 23% of the farmers applied the different types of fertilizers to cotton (Gitonga *et al.,* 2011). Farmers leave a portion of previous season's cotton crop to grow as a ratoon during the following season while they sowed another portion afresh. They also indicated that they were more assured of getting some yield from the ratoon crop as compared to that from cotton sown directly from seed because of low quality and late supply of seed and the unreliable rains in these areas. Production of ratoon cotton reduced labour demand for planting, land preparation, critical first weeding that coincided with peak of labour requirement for the food crops. ‘

1.2: Statement of the problem and justification

The current cotton growing recommendation in Kenya is to uproot and burn cotton stalk at the end of every growing season before ploughing the land in readiness for planting the next season (MOA, 2007). However, a survey conducted by KARI, CODA and the Ministry of Agriculture in March 2010 showed that growing of ratoon cotton has become a common practice in Central, Eastern and Coastal regions of Kenya. It also showed that only 23% of farmers applied fertilizers to cotton and very rarely to the ratoon cotton (Gitonga *et al.,* 2011). Farmers who grow ratoon usually cut the main stem of the first season crop at varying heights above the ground surface) after harvest since there are currently no guidance on the appropriate cut height. The stumps then regenerate producing new shoots at the onset of the next rainy season to give the ratoon cotton crop. Performance of this ratoon depends on the management of the previous season’s cotton crop including: the height of cutting and soil fertility.

The results from this study will establish the appropriate cutting height, quantity and quality of lint produced and level of pest occurrence in ratoon as compared to the directly seeded cotton.

1.3: Objectives of the study

This study will establish the effects of cut height and nitrogen application on performance of ratoon cotton crop. The broad objective of the study was to enhance seed cotton yield through improvement of cotton management practices. The specific objectives of the study were:

(i) To determine the effect of cut height and nitrogen application on growth of ratoon crop in three cotton varieties (HART 89M, F962 and A540) in Central Kenya.

(ii) To determine the effect of cut height and nitrogen application on natural pest incidences in ratoon crop in three cotton varieties (HART 89M, F962 and A540) in Central Kenya.

(iii) To determine the effect of cut height and nitrogen application on seed cotton yield and quality from ratoon crop in cotton varieties (HART 89M, F962 and A540) in Central Kenya.

1.4 : Hypothesis

Ratoon cotton is likely to give higher seed cotton yield than cotton crop sown directly from seed in Central and Eastern Kenya during seasons of low rainfall than in seasons of average rainfall. The increase in seed cotton yield will, however, depend on the management of the previous season's cotton crop including: the height of cutting and soil fertility as well as management of the ratoon crop itself.

CHAPTER TWO

LITERATURE REVIEW

2.1: The importance, botany and ecology of cotton

Today cotton is produced in many parts of the world. In 2006, the largest growers in descending order of production were: China, India, the United States, Pakistan, Uzbekistan, Brazil, and Turkey (USDA, 2006). Cotton is a unique agricultural crop that provides both food and fiber. It is one of the most important textile fibres accounting for about 40% of all textile use and more than half of all the fibres used in clothing and furnishing industries. The by-products of its seed provide edible oil for human consumption, soap and high protein animal feed (Valderrama, 2005). The cultivated cottons of the world are found in four species of the genus *Gossypium*. These include: *G. arboreum*, *G. herbaceum* (also referred to as the Diploid Old World cottons), *G. hirsutum* and *G. barberdense* (also referred to as the Tetraploid New World cottons) (Munro, 1987). The most widely grown cotton is *Gossypium hirsutum* (commonly known as Upland cotton, American cotton or Mexican cotton) which accounts for 90% of the world's production and *Gossypium barbadense* (commonly referred to as Creole or sea cotton, Egyptian cotton, extra long-staple cotton, Indian or Pima cotton) which accounts for 5% of the World's production (GOA, 2008). All cultivated cotton varieties in Kenya belong to the species *Gossypium hirsutum.* The principal difference between *Gossypium hirsutum* and *Gossypium barbadense* is the length of the cotton staple (individual fibres). *Gossypium barbadense* has very fine, premium and long (5 cm) staple cotton compared to *Gossypium hirsutum*'s typically shorter staple length of 2 to 3 cm (PIC, 2008). Whereas in nature the cotton plant is a perennial tree, it is mostly grown as an annual shrub under extensive cultivation. Being a perennial plant, cotton flowers and sets fruit over a long period of time. It has a strong tap root system, which penetrates to a depth roughly equal to the height of the stem and this enables it to extract water from deep layers of the soil. Cotton is adapted to a wide range of conditions because of its extremely indeterminate growth pattern that permits prolonged fruit setting (over many months), and enables the plant growth after drought.

According to Glen *et al*. (2007), branching of the main stem of cotton occurs initially from auxiliary buds of the main stem leaves generally referred to as main stem nodes giving rise to vegetative or monopodial and fruiting or sympodial branches. Below a certain point on the main stem the branches are monopodial, and above that point they are sympodial (Munro, 1987). This point is referred to as the node of the first fruiting branch. Vegetative branches just like the main stems have got one meristem. They therefore grow straight and erect and do not bear flowers directly, but produce fruiting branches which do. Fruiting branches on the other hand have multiple meristems and have a zigzag growth habit. They terminate at each node with a flower bud, and a lateral branch, which repeats the process.

Many factors such as; length of growing season, climate (including solar radiation, temperature, light, wind, rainfall), variety, soil fertility, pests and cultural practices affect cotton growth (El-Zik, 1980). Cotton in Kenya is grown in a wide range of soil types and in areas ranging from sea level to about 1400 meters above sea level with annual mean temperatures ranging from 21°C to 24°C (Brown, 1972; Wabule *et al*., 2006). Higher altitude areas (above 1400 m) experience lower temperatures (especially in July), resulting in slow vegetative growth, poor fruit set and an extended period of flowering and boll maturation in cotton. The extended vegetative growth period tends to enhance fibre immaturity, reduce lint development and also increases costs of production by increasing the number of weeding and sprays and the length of time crop is on the farm (Brown, 1972). In work on the effects of climatic factors on flower and boll production in cotton, Sawan *et al*. (2002) observed that evaporation, sunshine duration, humidity, surface soil temperature at 1800 h, and maximum air temperature, were the important climatic factors that significantly affected flower and boll production of Egyptian cotton. Cotton plant requires about 500 to 700 mm of rainfall during the growing season with about 80% or more of this being required at the flowering to maturity period. Both excess and insufficient soil moisture is both known to cause fruit shed (Wright and Sprenkler, 2003).

Cotton in Kenya is grown in the Coast, Western, and Nyanza, Rift valley, and Central and Eastern provinces (Figure 1). These areas are situated in agro-ecological zones LM 3, LM 4, L 3 and L4 (Wabule *et al*., 2006). In the unimodal rainfall areas of Western, Nyanza, Rift Valley and Coast provinces, cotton requires 500 to 750 mm of well distributed rainfall with 80% or more of this being required at flowering stage to maturity to produce an adequate crop. It is planted between mid-March and May and takes about six months in the field to mature. In the bimodal rainfall areas of central and eastern provinces where no single rainfall season is able to sustain an economical cotton crop, an additional 380-500 mm is required during March-May period. It takes 10-11 months for cotton to mature.

The date of the first flower is an indication of the earliness of the crop (Munro, 1987) and it depends on variety, sowing date, temperatures and water supply. In Kenya, the date of the first flower ranges from 68 to 73 days (Kimani *et al.*, 2004) for local cotton varieties. Shedding of squares and bolls is a common phenomenon often seen in cotton fields. This may be caused by water stress, shading (from prolonged cloudy weather, inter planted crops or too dense a stand), nutrient deficiencies (especially N), high temperatures, high plant populations, high percent fruit set and insect damage (Glen *et al*., 2007).

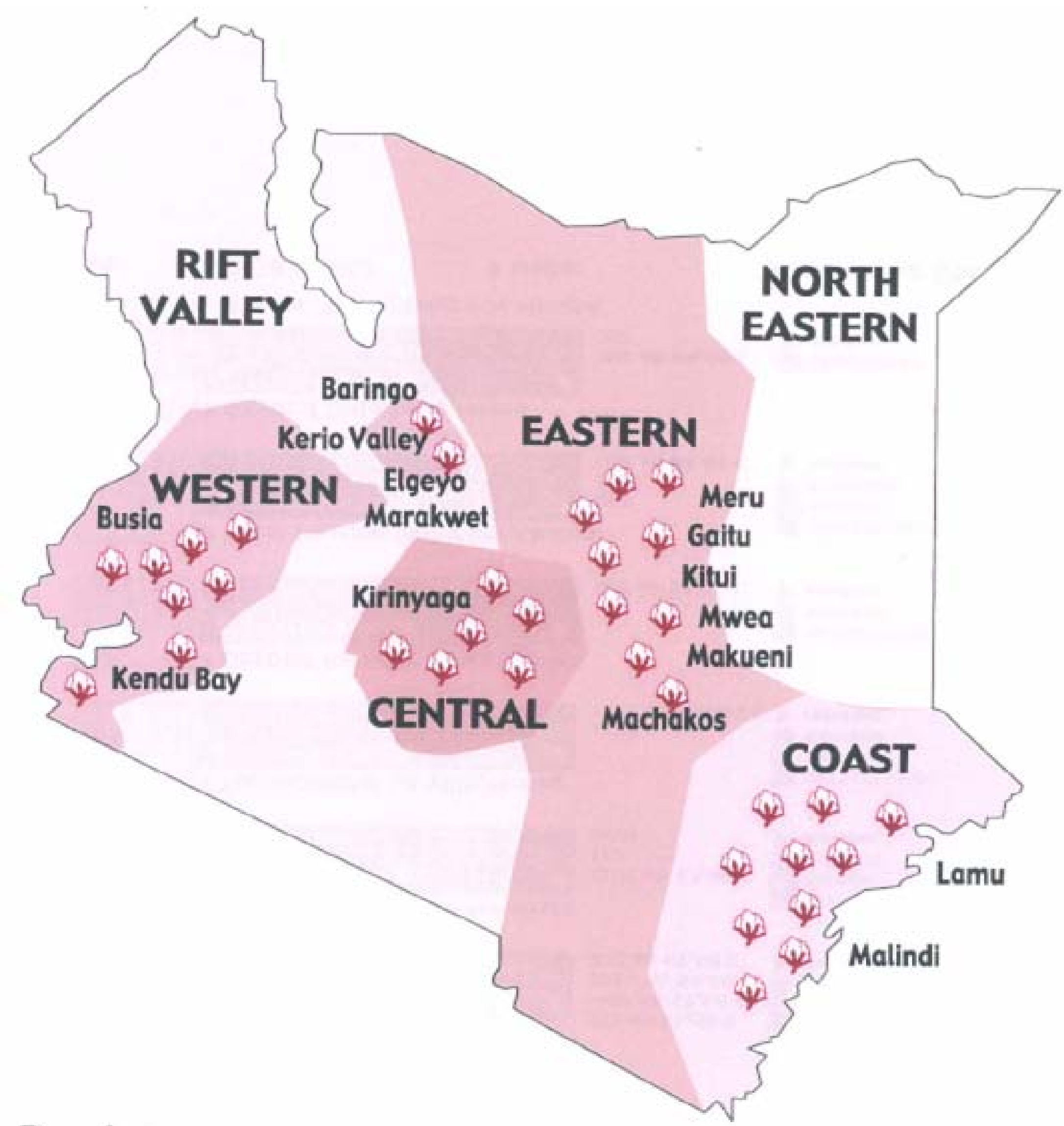

Figure 1: Map showing the main cotton growing areas of Kenya. Source: RATES Survey, 2003.

2.2: Cotton varieties and the recommended agronomic practices in Kenya

The current commercial cotton varieties grown in Kenya are HART 89M and KSA 81M with the former recommended for cultivation in eastern, central, and coastal regions and the latter recommended for Nyanza, rift valley and western regions of Kenya. Both varieties have a potential seed cotton yield of 2,500 kg ha^{-1} ginning outturn of 40% to 42% (Ngigi, 1997) and are resistant to cotton Jassids (*Empoasca* spp.) and bacterial blight caused by *Xanthomonas malvacearum* (Ikitoo and Waturu, 1999).

There are other promising cotton varieties (F962 and A540) that are undergoing field evaluation as possible replacements for HART 89M and KSA 81M. The four varieties have similar yield potential but F962 and A540 have higher lint outturn ranging from 41% to 45% (Ngigi *et al*., 2006). Field studies conducted from 1999 to 2003 showed that of the nine cotton varieties evaluated, HART 89M, KSA 81M, F962 and A540 had higher mean seed cotton yield than E790, H314, CS189+, Siokra L22, and Sicala v-1 across locations (Kimani *et al.*, 2003). Varieties E790, A540, H314 and F962 were the improved Kibos cotton varieties while CS189+, Siokra L22, and Sicala v-1 were introduced Australian varieties (Opondo *et al*., 1999).

The optimum sowing date for cotton depends mainly on the quantity and timing of water supply. In areas of low rainfall (less than 1000 mm per annum) like in east and central Kenya the sowing date should be chosen to make the maximum use of the moisture available (Munro, 1987). The current commercial cotton variety HART 89M is therefore planted in mid-October, at the onset of the short rains. The short rains season (October-December) is used mainly for establishing the cotton plant although sometimes a small crop is also formed over this period and harvested between March and April (generally referred to as short rains season crop). The main long rains season is formed during the long rains (March to May), when growth and flowering start again after the dry months of December to March. This is harvested between July and August (Brown, 1972; Munro, 1987; Wabule *et al.,* 2006).

The land for cotton production should be prepared early and ploughed to a depth of at least 15 cm. Dry planting is encouraged. Alternatively planting should be undertaken as soon as rainfall is adequate for the germination and growth of the crop. Planting of cotton is commonly delayed, because the food crops are given priority. It is planted by hand using oxen, panga or hand hoe (Gitonga *et al.*, 2011). It is usually sown at a seed rate of 10 kg ha^{-1} (undelinted seed) and 3 to 4 kg ha^{-1} (certified delinted) and at a depth of about 3 to 5 cm with 2 to 3 delinted seeds per hole in rows or ridges. Munro (1987) noted that a uniform planting depth gave regular and good emergence of seedlings which are all at the same stage of development. In an experiment on sowing depth (2.3 cm, 4.6 cm and 9.2 cm) Mullins *et al.* (2001) observed that emergence of cotton seed decreased with increased sowing depth and there was no emergence at 9.2 cm depth. Ridges are an advantage as they can be tied to conserve water under dry conditions and aid drainage under wet conditions. Reductions in seed cotton yield from waterlogging has been associated with reduced mineral uptake especially nitrogen, phosphorus, potassium, calcium, boron, magnesium and iron (Conaty *et al*., 2008; Milroy *et al.*, 2008).

Thinning is undertaken immediately following the first weeding when seedlings are about 15 cm or three weeks old and preferably when fields are wet, and should not be delayed beyond four weeks (Brown, 1972; Wabule *et al*., 2006).

According to Munro (1987), cotton is usually adaptable to a wide variation in population density because of indeterminate habit of growth, its ability to produce both vegetative and fruiting branches, and its characteristic of shedding buds and young bolls. The acceptable plant population varies with location, environment and cultivar (Silvertooth *et al*., 1999). The optimum spacing depends on the size and fruitfulness of the plant permitted by local conditions. The inter-row spacing in Kenya varies from 90 to 120 cm while the intra-row spacing is between 30 and 60 cm (Wabule *et al*., 2006). However, in Tewe areas of Lamu west district some farmers use an inter-row spacing of 300 to 400 cm (Gitonga *et al.,* 2011). Cotton plant populations can be lowered, given planting and environmental conditions conducive to achieving uniform plant distribution, to 50 958 plants ha^{-1} drilled or 76 466 plants ha^{-1} hill-dropped (3 plants $hill^{-1}$, 40-cm hill spacing) with no adverse effects on yield (Siebert *et al*., 2005). Many studies report that the highest yields occur in plant populations ranging from 49 000 to 256 000 plants ha^{-1} (Kittock *et al*., 1986).

Munro (1987) observed that the value of re-sowing gaps in the stand is doubtful, but the sort of gap worth refilling is a length of a row which has been left unsown or failed to germinate or a noticeably large empty space. This should be conducted immediately after seedling emergence but not more than 10 days from the original sowing. Early filling of gaps ensures a good crop stand as early gapped plants catch up in growth with the rest of the crop.

Cotton is sensitive to weed competition because it grows relatively slowly in the early stages Munro (1987). He noted that the critical period for weed competition was between two and four weeks after crop emergence and that the effects of delayed weeding were however much greater in a drier season. An effective weed control program should aim at a weed free period of 6 to 8 weeks directly following planting. Timely weed control should start two weeks after emergence or when the weed reaches the second leaf stage (MOA, 2006; Wabule *et al.,* 2006).

Cotton in Kenya is normally harvested during the dry months by hand picking. This is conducted once every 3-4 weeks, so that open cotton is not left in the field for too long as this may result in a change of the colour and reduced lint quality. Harvesting begins at about four months after sowing in unimodal rainfall areas of Coast, Western and Nyanza Provinces and lasts for about 2 months (August to September). However, in bimodal rainfall areas, of Eastern and Central provinces, harvesting takes place from January to March (may sometimes extends to April) and then from July to August (MOA, 2006; Wabule *et al*., 2006).

2.3: Cotton pests and their management

Cotton has a wide spectrum of successive pests which affects it from time of emergence to harvest. Insect pests represent a severe limitation for cotton production in many regions of the world. The effective management of most of the cotton pests depends on the use of chemical insecticides, but its use should be based on Economic threshold levels (ETL) concept (Bheemanna *et al*., 2010). The major cotton pests in Kenya include: African bollworm (*Helicoverpa armigera*), red spider mites (*Tetranychus* spp.), aphids (*Aphis gossypii*), stainers (*Dysdercus* spp) and thrips (*Frankliniella* spp). The sporadic pests include the pink bollworm (*Pectinophora gosspiella*), spiny bollworm (*Earias* spp.*)*

and the tobacco whitefly (*Bemisia tabaci)* (Waturu *et al.,* 2000). These pests reduce quality and quantity of cotton lint. Roberts *et al.* (2005) found that boll feeding resulted in reduced fiber length and fiber length uniformity. Aphids and whiteflies are the main causes of sticky cotton with their honeydew deposits. They release a sticky honeydew excretion as they feed. This substance contaminates lint, creating special lint handling and processing for ginners and resulting in reduced cotton marketability. Aphids not only reduce yields by sucking life-giving nutrients from host plants, but they also reduce fiber colour and quality due to the sticky honeydew.

The most common pest management strategy for cotton pests continues to be insecticides but the emerging era of insect resistant transgenic cottons offers real prospects to provide a foundation for more sustainable, economically acceptable Integrated pest management (IPM) with the integration of a range of non-chemical tactics and much less reliance on pesticides (Fitt, 2000).

In Kenya, cotton pests are mainly managed by application of synthetic pesticides from flowering (coinciding with the 8 to 9 weeks after plant emergence) to boll split (Kambo *et al.*, 2007). The number of sprays per crop season varies from place to place and from year to year. Typically, cotton producers in Kenya spray about 5 to 6 times per season, but as many as ten sprayings can be required (Kambo *et al.,* 2007).

According to Ikiara and Ndirangu (2003), pest control costs constitute the highest component of the cost of cotton production in Kenya at 57% (Figure 2). This comprises the cost of pesticides and labour (29%), and spraying equipment (28%). A rationalized pesticide application strategy which entails a system of scouting for various pests in the cotton crop could form the basis for the choice of insecticides and the timing of spraying (Waturu *et al.,* 2000). However, this has not been fully adopted by the farmers.

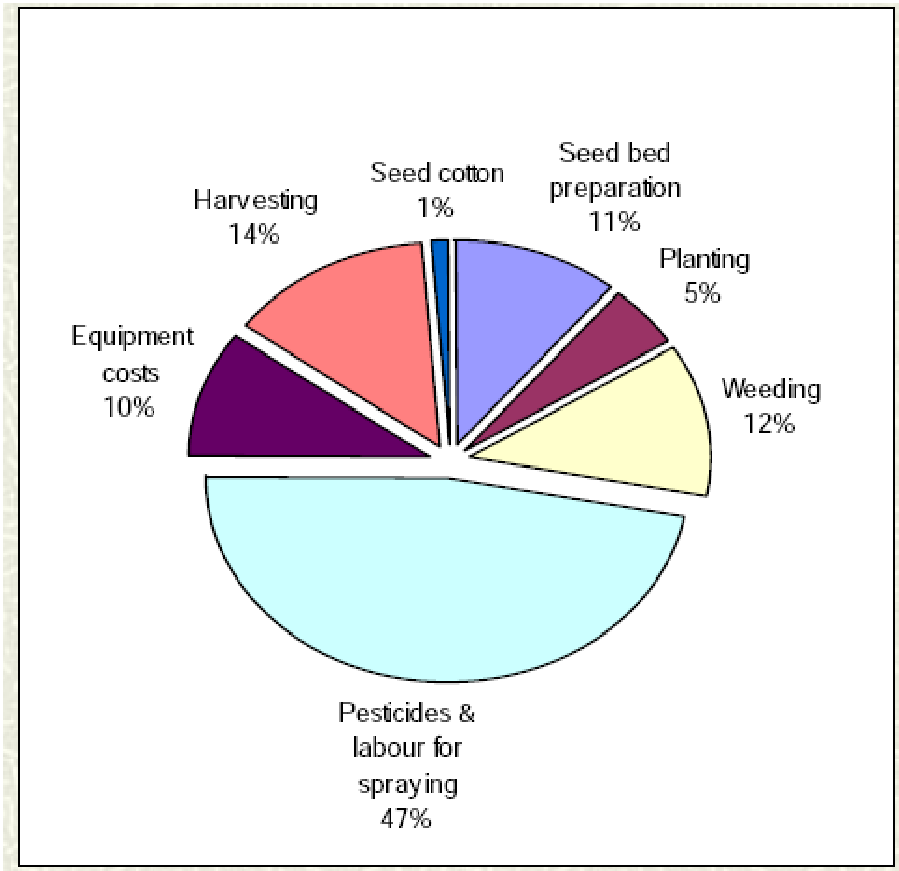

Figure 2: Costs of production for cotton growing in Kenya. Source: KIPPRA Survey (Ikiara and Ndirangu, 2003)

Vitale *et al.* (2007) reported that even after spraying at the recommended rate of about six times per season, about 23% of the seed cotton yield would still be lost through pest damage. This implies that a successful economical control of cotton pests requires use of integrated pest control (IPM) methods. This is a multi-tactical approach where use of insecticides is just one component.

There are many components of IPM that must be used to effectively manage cotton insect pests. These includes use of resistant cotton varieties, managing for an early crop maturity, various cultural practices, management of insect resistance, use of economic thresholds through scouting and timely application of pesticides when needed (Angus, 2007).

The African bollworm (*Helicoverpa armigera*) causes substantial yield reduction in cotton ranging from 40 to 70% (Waturu and Njoka, 1988) and a reduction of lint quality by 10% to 20% (Sithanantham, 2005). In central and eastern Kenya cotton growing zones, African bollworm is a major problem in early January after a lush growth during the short rains coinciding with squaring (flower bud formation) of the short rains season crop while red spider mites and aphid become a major problem during the dry spell between January and mid March. Bollworms only cause damage in the larval stage. Its damage to cotton plants is characterized by feeding activity on squares (flower buds), flowers, and cotton bolls (Farrel, 2007). Flower and boll damages are the most severe as they result in the shedding of the plant's reproductive parts hence reduced potential yield (Vitale *et al.*, 2007). The main control methods of bollworms include uprooting of alternative hosts plants, use of trap crops such as pigeon peas, and use of synthetic pyrethroids. Insecticides are needed only if the population exceeds the treatment threshold while the crop has a significant number of squares or green bolls that will have time to develop into mature bolls by season's end. Bollworms are likely to cause economic damage at 2 larvae per 3 plants during seedling to flowering stage or at 5 larvae per 3 plants at 15% to 40% open boll stage (Farrel, 2007). However according to Godfrey *et al.* (2009) there is no need to treat once bolls begin cracking, because most bolls are too mature by that time to be susceptible and squares still present will not have time to mature.

Bt cotton varieties have been engineered to express a gene derived from soil bacterium, *Bacillus thuringiensis* (Bt), which is an effective agent in killing bollworms and other insect pests that afflict cotton (Vitale *et al.*, 2007). Monsanto's line of Bt cotton products, Bollgard, has been undergoing field testing at KARI Mwea since 2005. The results indicated that Bt-cotton varieties did not have significant effect on the populations of non-target cotton pests including aphids, red spider mites and stainers. Similarly, it had no significant effect on beneficial arthropods such as the lady bird beetles but caused mortality to the larvae of target pest *Helicoverpa armigera* (Waturu *et al*., 2005; 2006; 2008 and Kambo *et al.*, 2009). The introduction of Bt cotton in small-scale African farming systems raises the question of the technological efficacy of such cultivars in low-input rain fed agriculture conditions (Hofs *et al*., 2006). Developing new cotton varieties with more powerful resistance, applying certain plant growth regulators, enhancing intra-plant defensive capability, and maintenance of general health of the transgenic crop are important in realizing the full transgenic potential in Bt cotton (Dong and Li, 2007).

Cotton stainers *Dysdercus* spp. feed on the developing and mature cotton seed (Munro, 1987; Sprenkel, 2000). Severe attack on young green bolls up to two weeks old can kill the developing seeds leading to boll shedding. Yellow staining of lint has also been observed. According to Munro, 1987, penetration of bolls creates entry of fungus *Nematosphora gossypii* whose spores are found in the gut and salivary glands of the stainers. Other researchers have indicated that the stain is from excrement from the stainers (Wilson *et al.*, 2008).

Preventive control can be obtained by observing good farm hygiene, such as proper storage of fuzzy cotton seed, weeding, avoiding ratoon cotton and cotton volunteers (Wilson *et al.*, 2008). The many close relatives to cotton occurring in the same or adjacent ecological areas can be a source of insect pests, especially stainers. In Kenya, the cotton stainers appear during splitting of the short and long rains seasons when damage is done on young bolls (Waturu *et al*., 2001).

Mites feed on cotton and a wide range of other plants including: African nightshade, amaranth, avocados, beans, cassava, coffee, cucumber, eggplant, groundnut, maize, mango, okra, papaya, passion fruit, peas, peppers, pigeon pea, various weeds and ornamentals. They feed on epidermal cells on the underside of the leaves, leading to premature drying and shedding (Steinkraus *et al.*, 2000). The initial infestation occurs along leaf midribs. Loss of leaf surface reduces energy available to maturing fruit, so squares and bolls may fail to develop and may eventually drop (Steinkraus *et al.*, 2000; Zhaohui *et al.*, 2011). Low plant vigour, water stress and extensive use of broad-spectrum insecticides promote outbreak of red spider mite (Goodel, 2002). Hot, dry, dusty conditions favour spider mites. Managing spider mites requires preserving natural enemies as long as possible each season and anticipating outbreaks following insecticide applications. The natural enemies can be preserved by avoiding early season, broad-spectrum insecticide applications (Godfrey *et al.*, 2009). Applying miticides to the affected areas controls it. Rotating miticides (with a different mode of action) may help to reduce resistance to any one of them and slow the development of resistance in areas where it is not yet a problem. Sometimes field margins are much more severely infested than the remainder of the field, particularly when another host crop, such as alfalfa, beans, or safflower, is grown next to the cotton. In such cases, treatment of a field margin may be justified (Godfrey *et al.,* 2009). Other recommended cultural practices for control of mites include: keeping perennial hedges such as pigeon peas to encourage predatory mites, keeping the field free of weeds and removal and burning of infested crop residues immediately after harvest. Zhaohui *et al*. (2011) observed that selective breeding and application of red spider mite-resistant cotton is the most effective method for prevention and control of mites.

Aphid populations prefer cotton plants that are well watered and highly fertilized (Olson, 1999). Their ability to move among asynchronous suitable habitats in response to changes in resource availability enables aphids to exploit unstable cropping systems (Brevault *et al.,* 2008). Cotton aphid can cause direct damage to cotton seedlings by sucking juice from the phloem tissues, resulting in leaf curling, distorted plants and indirect damage to cotton fibre by honeydews (Wu *et al*., 2006; Farrel *et al.,* 2007)). Aphids secrete honey dew on the leaves which provides a suitable media for the growth of moulds leading to deterioration of lint quality while the sticky seed cotton is difficult to gin. Nymphs and wingless adults of cotton aphid cause early to late season damage on terminals leaves, buds and stems (Farrel *et al*., 2007). Wingless aphids are more effective in transmitting cotton vein mosaic virus than nymphs (Michelotto and Busoli, 2003). Heavy aphid population cause crinkling and cupping of leaves, defoliation, and severe stunting during seedling stage, decrease the size of bolls, and increase square and boll shedding during midseason and secret honeydew that contaminate the exposed cotton lint making harvesting and ginning difficult (Slosser *et al*., 1989; Wu *et al*., 2006). Due to its high sugar content, honeydew supports growth of a sooty mold fungus which forms a dark coating over the surface of the leaves which interferes with leaf transpiration and reduces photosynthetic efficiency (Munro, 1987). Aphids cause higher yield losses in crops growing under drought stress conditions than crops growing under optimal conditions. Since aphids primarily feed from the underside of leaves, only systemic pesticides can give adequate coverage necessary to control them. In addition, because of their high reproductive potential, they multiply very first after insecticide treatment. Cultural control of aphids includes: crop rotation, control of weeds, cotton stubble and cotton volunteers. Natural control is mainly by the parasitic wasps, the lady beetles, hoverfly larvae and the predatory larvae of syrphid flies (Farrel, 2007).

Pink bollworm is controlled by use of a closed season between cotton crops, sanitation on and off the field and finally use of pesticides. Sanitation on and off the field is effective in destroying resting larvae (Munro, 1987; Angus, 2007). Early termination of the cotton crop and prompt plough down after harvest suppresses pink bollworm by reducing the number of pink bollworms entering diapauses (Goodel, 2002). Planting one row of maize or tobacco after every 20 rows of cotton or a row of sunflower or cowpeas after 5 rows of cotton controls *Heliothis* spp. (OSIAT, 2005). Application of nuclear polyhedrosis virus (NPV) is one of the bio-control agents that work with stunning effect in managing the boll worms (The Hindu, 2002). Although assassin bug, *Pristhesancus Plagipennis* can be used as a bio control agent in bollworm IPM control program, its use remain unlikely due to inudative release costs relative to other control costs such as insecticides and Bt cotton.

Mealybugs (*Maconellicocus hirsutus)* are polyphagous and multiply on different hosts including weeds such as datura, milkweed, *and Chenopodium* sp. and on crops such as okra, mango, soybean, pigeon peas, tomatoes and brinjal. They feed directly on young growth (stems, leaves and flowers) causing severe stunting and distortion including crinkling of the leaves, thickening of stems and a bunchy-top appearance of shoots; in severe cases the leaves may fall when they subsequently expand, while established infestation can cause total defoliation and even death of the whole plant. Bolls are deformed, fewer and smaller in affected plants. Mealybugs, like aphids, excrete copious amounts of honeydew that contribute to the development of a black sooty mould which inhibits the plant's ability to manufacture its food. Nymphs can crawl from infected to healthy crop and are readily transported by wind, rain, birds, irrigation water, clothing and equipment due to their waxy coating (Nagrare *et al*., 2007. Ants feed on the honeydew produced by mealybugs and help to spread the infestation. The waxy coating protects them from insecticides and other mortality factors (Nagrare *et al.*, 2007). Ants also protect mealybugs from predatory ladybird beetles, parasites and other natural enemies.

2.4: Effect of ratooning on seed cotton yield and quality

Ratoon cotton is a crop in which the stalks are cut down after harvest, but the root stock is left in the ground to re-grow the following season. These plants are more prostrate and bushy than the original crop, as all branches from the main stem are vegetative (Munro, 1987). It has been demonstrated that when a ratoon crop is properly managed to avoid pests, disease and weed incidence, seed cotton yields are at least equal to and often better than those of cotton sown directly from seed (Evenson, 1970). Ratoon cotton plants get an earlier start and flower earlier than cotton grown from seed (Evenson, 1969; Munro, 1987). Cotton has been shown to flower earlier by as much as six weeks in Egypt

(Templeton, 1925) but more commonly by two to three weeks. This is an advantage in marginal areas where rainfall is low and unreliable. The already established cotton roots draw on the moisture, which is present at depth before the onset of the rains. The early start of the ratoon crop, the savings on land preparation and need for early first weeding and reduced competition for labour required for planting between cotton and other food crops are added advantages. Munro (1987) noted that the compact plants from the ratoon produce a concentration of boll, which makes picking easier. Other advantages of ratoon cropping includes: the reduced cost of production through savings in land preparation and care for the plant, less use of irrigation water and fertilizer than main (original) crop because of a shorter growing period (Glen, 2007).

Failure to control insect pests or the fear of carryover has been one of the most potent reasons for the abandonment of ratoon cotton (Evenson, 1970; Sinkondyobwe 2005). Ratooning may result in buildup of insect pests and harmful weeds, increased disease problem and loss of crop density (Glen, 2007). While investigating on possible sources of carry-over of spiny bollworm, Ahique *et al.* (2001) observed that the left-over bolls of cotton stalks kept horizontally, 3.5% bollworm larvae survived in the lower part of the heap but mortality was 100% when cotton stalks were stored in small bundles vertically. There was no major alternate host and very negligible infestation was found on ratoon cotton.

Grant *et al*. (2002) had earlier noted that the pathogens that cause the diseases like black root rot, *verticillium* wilt, alternaria leaf spot and *fusarium* wilt are easily transferred from one season to the next via ratoon cotton. In addition, ratoon plants could act as hosts for aphids, spider mites, whitefly and *Helicoverpa*. According to Sinkondyobwe (2005), ratooning in cotton should not be promoted as diseases and pests can develop resistance to chemicals necessitating increases in spray dosage. This means farmers will incur more costs, as they will spray more often than usual.

In North Western Australia, some cotton varieties maintained or slightly increased yields in the ratoon over the cotton sown directly from seed crop, while others showed a marked decline in yields (Evenson, 1970). Preliminary research on ratooning cotton variety HART 89M conducted at Mwea during 2005/ 2006 cotton season indicated that a cut height of 15 cm above the ground surface gave a seed cotton yield of 1383 kg ha^{-1} while the cotton sown directly from seed (control) had 667 kg ha^{-1} (Macharia *et al*., 2006). Cotton plants cut at 10 and 15 cm above the ground surface had significantly higher yield and mealybug infestation than non-ratoon cotton plants (Macharia *et al.,* 2006).

There are conflicting reports of the effect of ratooning on fibre quality. In north Western Australia, lint of ratoon cotton was found to have higher micronaire value than that of cotton sown directly from seed of comparable age (Evenson, 1970). This was considered to be due to the fact that the earliness of the ratoon crop caused the bolls to develop under conditions of higher temperatures than those of the cotton sown directly from seed crop, in an environment where micronaire value and staple length are known to decline markedly as season progresses (Evenson, 1969). In Israel, ratooning cotton reduced lint length while in Morocco lint length was increased by ratooning (Evenson, 1970). Munro (1987) indicated that ratooning could cause deterioration of cotton fibre quality due to consequent poor timing of dry period during harvesting. This has not been established in Kenya. Cotton Lint sand Seed Marketing Board used to enforce observance of ‘closed season’ in Kenya before liberalization of the cotton sub-sector in the early 90s.

However, according to a survey conducted by KARI, CODA, CABI and MOA in six cotton growing districts in Kenya, 14% of the farmers interviewed indicated that they grew ratoon cotton and 23% applied different types of fertilizers to cotton (Gitonga *et al.*, 2011). Their reasons for growing ratoon cotton were as follows: increased seed cotton yields, cushioning from lack of seeds for planting at the beginning of the season, assurance of a crop despite the unreliable rains and saving on labour for land preparation, planting and thinning.

2.5: Factors affecting quality of lint and seed cotton

Quality of the seed cotton or lint is an important consideration since it is a major determinant of its price in the international markets. Lint quality parameters are controlled by both genotypic and environmental factors. The main criteria for judging quality of cotton lint are colour, absence of foreign matter, quality of ginning process, and length of lint (USDA, 1980). The lint quality parameters which currently influences price of cotton in Kenya are colour and trash counts. However in addition fibre strength, fibre length, micronaire and extraneous matters are important quality parameters in international market (Baird, 2007). In general, cotton fibre value increases as the bulk-average fibres increase in whiteness, length, strength and micronaire (Bradow and Davidonis, 2000). While color and trash content are basically affected by field environmental factors, lint uniformity, strength and micronaire are strongly influenced by genotype. These environmental factors include soil fertility, moisture, and temperature. The quality of cotton lint is also affected by every production step including variety selection, cultural practices, harvesting and post harvest practices, and ginning technology (Reed, 2002; Meredith, 2005). The two ginning practices that impact quality most are (1) fiber moisture regulation, and (2) degree of cleaning used (Reed, 2002).

The colour of cotton fibres is primarily determined by conditions of temperature and/or humidity, cotton lint exposure to sunlight, and cotton varieties. Other factors that affect lint colour includes: action by parasites or micro-organism, as well as technical defects in harvesting and subsequent storage and transport (Munro, 1987, Reed, 2002 and Law *et al*., 2007). When plant growth is stopped prematurely by drought or other weather conditions, the cotton may have a yellow colour that varies in intensity (Reed, 2002). Fungal development or sugars on the lint due to honeydew from aphids can also produce gray cotton (Baird, 2007). Cotton could also be stained by contact with soil, grass, or the cotton plant's leaf (Law *et al*., 2007).

Lint leaf grade describes the leaf or trash content in the cotton representing the non lint particles such as leaf, bracts, bark and grass. Leaf material is waste in the spinning industry and removing it increases costs and fiber quality degradation (Reed, 2002). Trash content is mainly influenced by environmental factors, harvesting method, defoliation techniques, and weed infestations and, to a lesser degree, the type and amount of cleaning and drying equipment used before ginning (Munro, 1987; Reed, 2002; Baird, 2007). Since cotton in Kenya is usually handpicked, the leaf content is not much of a problem (Ikiara and Ndirangu, 2003).

Lint length or staple length is an important cotton quality characteristic, because both fibre fineness and tensile strength are associated with it (Law *et al*., 2007). Lint length is also correlated with processing efficiency and the quality of the yarn produced (Bradow *et al*., 1997) since it affects yarn strength, evenness, fineness and the efficiency of the spinning process (Cotton Incorporated, 2005). Staple length ranges from short (less than 25 mm), medium (25 to 30 mm), long (30 to 37 mm) and extra long (above 37 mm). Usually, longer staples are finer and stronger than the shorter ones. Fibre length is determined by variety, extreme temperatures, water stress, or nutrient deficiencies such as potassium and ginning process (Reed, 2002). During elongation, length is decreased by high temperatures, very severe water stress and potassium deficiency and increased by moderate temperatures during that same period (Baird, 2007).

Cotton in Kenya is mainly ginned by use of roller gins. These gins are superior in terms of maintaining the fibre length during the ginning process (gentler on cotton fibres) as compared to saw gins. Roller gin is suitable to gin longer staple cotton, and roller ginned lint is (generally speaking) rewarded by a premium (Munro, 1987).

Ginning percentage, also known as lint percentage or ginning outturn (GOT), is the weight of lint expressed as a percentage of the seed cotton. It is an inherent character of cotton. The roller gin produces between I and 2 per cent more lint than a saw gin from a given quantity of seed cotton. The average GOT achieved by most ginneries in Kenya is 33% against a potential GOT of 40% to 42% for the two cotton varieties grown in Kenya namely HART 89M and KAS 81M. Oad *et al*. (2002) concluded that GOT decreased with late sowing.

Kimani *et al*. (2003) observed that GOT of cotton varieties HART 89M, F962 and A540 varied with site and season as follows; HART 89M; 36% to 41%, F962; 39 to 42% and A540, from 36 to 40%. Delayed planting reduces lint yield due to either reduced growing season or lowered plant populations resulting from the low temperatures (Kittock *et al*., 1987).

Lint strength refers to the tearing strength of the cotton fibre and determines the strength of the yarn spun from them (Munro, 1987). It is primarily determined by 'genotype' and by climatic conditions. The fibre strength is reported in terms of grams per Tex (a tex unit is equal to the weight in grams of 1,000 millimeters of fibre) and has the following classifications: less than 17 very weak, 18 to 21 weak, 22 to 25 medium strong, 26 to 29 strong and more than 30 being very strong (Baird, 2007).

Micronaire is a measure of fibre fineness and maturity (Baird, 2007). Low micronaire values indicate fine and or mature fibres (Bradow and Davidonis, 2000) and produces stronger yarns. The greater the fibre maturity the better its dye absorbency and retention (Cotton Incorporated, 2005). Micronaire readings below the optimum range may indicate immaturity; those above it may indicate the fiber is too coarse for manufacturing many high-quality products (Reed, 2002).

Low (<3.5) micronaire indicates fine (immature) lint while high (>4.9) micronaire indicates coarse lint. The desired range is from 3.5 to 4.9 micronaire (Baird, 2007). Optimum micronaire is influenced by the variety and environmental conditions moisture, temperature, sunlight, plant nutrients, and extremes in plant density or boll population (Jenkins *et al*., 1990; Jones and Wells 1998).

According to Baird 2007, the common causes of low micronaire include: cool temperature during fibre wall development, potassium deficiency, dense plant stands, high nitrogen, excess irrigation/rainfall, favorable fruit set and high boll retention, early cut-out due to frost, hail, disease or early defoliation. The most common causes of high micronaire include: poor boll set, small boll size due to hot weather or water stress and variety (Reed, 2002). Time of planting cotton has been shown to affect fibre quality. Late planting of cotton affects fibre. Late planting of cotton affects fibre maturity in long season cotton varieties and results in late harvest and low fiber quality (Silvertooth, 1998). Early planting can potentially increase seed cotton yield and improve fiber quality by avoiding the effects of drought and high temperatures. A number of studies indicated that late plantings usually resulted in reduced yield and fiber properties due to a shortened fruiting period and delayed maturity relative to normal planting (Bauer *et al*., 2000; Bange and Milory, 2004; Davidonis *et al*., 2004). Plant density affects penetration of sunlight and rate of photosynthesis. Reduced sunlight conditions results in weaker fiber than that produced in normal sunlight (Pettigrew, 1995).

Worldwide, cotton classification is either manual or a combination of manual and instrument, commonly referred to as high volume instrument (HVI). In industrial uses of cotton, grades defined by the US Department of Agriculture (USDA) are generally accepted as the world standards for cotton fibre quality (Reed, 2002). The HVI is able to measure virtually all fibre properties using only one automatic operation and in a very short time, giving users more exact descriptions of the relevant fibre properties.

2.6: Effect of soil fertility on seed cotton yield and quality

Lint yield and quality is mainly affected by several factors including: crop management practices, pests, weather, harvesting and post-harvest practices, ginning technology, cotton varieties and soil fertility (Sawan *et al*., 2002; Meredith, 2005). Reports of fibre property trends in studies of cotton nutrition are sometimes contradictory due to the interactive effects of genotype, weather, and soil (Minton and Ebelhar, 1991). There is a complicated relationship between fiber quality and environmental factors such as soil water content and soil nutrients. Johnson *et al*. (2002) reported that cotton fiber quality had a positive correlation with soil P, organic matter (OM), pH, K, and Na, as well as water content. Primarily they found that lint strength and elongation factors were well correlated with soil moisture content. Application of farm yard manure improves lint yield by way of improved GOT and maintaining a positive nutrient balance in the soil (Blaise *et al*., 2005). The availability of nitrogen, phosphorus, potassium and water are the major limiting constraints to cotton production in most cotton producing environments (Morrow and Krieg, 1990). Nutrient stress depresses lint yield, particularly of late-season fruit (bolls), and may disrupt fibre development (Reddy *et al.,* 1999; Meredith, 2005). Seed cotton yield is determined by boll weight and the number of bolls produced per plant, which is influenced by flowering rate and boll retention. The enlargement phase of boll development lasts approximately 3 weeks after flowering while filling phase continues into the sixth week after pollination. During this time low water availability, extremes in temperature and nutrient deficiencies (especially potassium) can reduce the final fiber length (Glen *et al.,* 2007). Henderson (2008) indicated that the cotton boll is most susceptible to shedding the first one to two weeks following blooming. Stress during this time will cause excessive boll shedding resulting in lower yields.

Nitrogen (N) management is one of the important practices in high-yielding cotton production systems (Gerik *et al.,* 1998). Nitrogen deficiency and excess negatively affects plant growth, boll retention, lint yield, and fiber quality (Gerik *et al.,* 1998; Reddy *et al.*, 2004). Insufficient N supply often results in smaller leaf area and lower leaf photosynthesis and biomass production (Fernandez *et al.,* 1996). This reduces both vegetative and reproductive growth and induces premature senescence resulting in reduced lint yield and poor fiber quality (Gerik *et al*., 1994; Heagle *et al.*, 1999; Reddy *et al*., 2004; Kefyalew *et al*., 2007; Read *et al*., 2006). Deficiency of nitrogen (N) in cotton limits yield and fibre quality through decreased leaf area expansion and carbon dioxide assimilation capacity (Bradow and Davidonis, 2000). While working on the effect of different N rates (0, 45, 90, 135, 180, and 225 kg ha^{-1} at a fixed 20 kg ha^{-1} P and 75 kg ha^{-1} K, on a soil with total N of 750 g kg^{-1} Kefyalew *et al.* (2007) found no relationship between fibre strength and N application rate but observed lower lint quality, including fibre length, length uniformity, and fibre strength, in plots where N rates were greater than 90 kg ha^{-1}. In their study, Bauer and Roof (2004) observed lower lint quality including fibre length, length uniformity and fibre strength in plots that did not receive N fertilization. Read *et al*. (2006) concluded that N stress indirectly affects cotton growth, as N deficiency decreased fibre length, strength and micronaire primarily in flowering plants with large percentage of bolls. Fertilizer application rates for cotton in Kenya are based on major soil types with a recommendation of 26 kg N ha^{-1} for most areas (MOA, 2006).

Supply of nitrogen in excess of cotton crop requirement promotes vegetative development often at the expense of reproductive development especially at bloom or at early boll fill (Mullins and Burmester, 1990). It also increases shading and increased fruit shed (Wright and Sprenkler, 2003). It indirectly affects lint yield by enhancing aphid (*Aphis gossypii*) infestation, which produces honeydew secretions that cause sticky cotton (Cisneros and Godfrey, 2001). Potassium (K) deficiency, unlike N deficiency, restricts fruit production to a greater extent than vegetative growth (Pettigrew, 1999). The positive effect of K on lint quality characteristics have been documented in several reports (Pettigrew and Meredith, 1997; Pettigrew, 1999). According to these authors, the effect of K on fibre quality characteristics tended to be more critical than its effect on lint yield, especially when deficiency is expected in a field. Growth rate and maturity of cultivars were reported to be important factors associated with K and its effect on fibre quality (Pettigrew *et al*., 1996; Pettigrew, 1999). Early maturing genotypes of cotton are more susceptible to K deficiency than late maturing cultivars. Early maturing cultivars grown under limited K will become deficient in the nutrient, and force the plants to terminate reproductive growth and subsequently reduce lint yield (Pettigrew *et al*., 1996) to some extent and quality to a larger extent. Kefyalew *et al.* (2007) observed that K fertilization is the key to long fibres. According to Minton and Ebelhar (1991), K deficiency is also known to affect lint yield and quality indirectly through exacerbating root-knot nematode (*Meloidogyne incognita)* injury.

Kefyalew *et al*. (2007) reported some positive and notable P effects on lint fibre quality factors, although both lint yield and lint quality were driven more by moisture availability than by P. Knowles *et al*. (1999) indicated that zinc and boron deficiencies can affect earliness by delaying flowering and fruiting of cotton plants. Zinc has been reported to increase fruit retention of cotton grown on Mohave Valley soils in Arizona USA.

Irrigation can positively influence seed cotton yield and fiber quality. Soil moisture deficits promote stunted growth, aborted bolls, and decreased leaf area leading to reduced photosynthesis (Pettigrew, 2004). Davidonis *et al*. (2004) reported that adequate soil water along with high ambient temperatures before and during boll development increased fiber maturity. Micronaire often has a negative correlation with soil water content. This is explained by Elms *et al*. (2001) as increased boll retention on the second and third positions on the cotton plant due to increased soil water. It also increases the boll load further up the plant (Pettigrew, 2004). These bolls tend to be less mature at harvest, and therefore, have a lower value for micronaire. If the number of immature bolls is high at harvest then the micronaire values are generally negatively affected. While increased soil water content may delay maturity, inadequate soil water can reduce fiber length (Ritchie *et al*., 2004). It has also been reported by Johnson *et al*. (2002) that too much water can reduce fiber length. Occurrence of moisture deficit during the early flowering period reduces number of flowers and bolls but did not alter fiber length (Marani and Amirav, 1971). However when drought occurred later in the flowering period, it reduced number of bolls, boll weight and fiber length (Bradow, 2000). Lint yield was reduced significantly in both cases (Marani and Amirav, 1971).

Grimes *et al*. (1969) reported that lint percentage decreased as the soil moisture level increased; however Kimball and Mauney (1993) found no response in lint percentage to varying moisture levels.

CHAPTER THREE

MATERIALS AND METHODS

3.1: Experimental Site

The study was conducted at the Kenya Agricultural Research Institute's Kirogo farm in Mwea East district in Kirinyaga County from October 2007 to September 2009 under rain fed conditions. Kirogo farm is situated in LM4 Agro ecological zone and lies on latitude 0° 37' S and longitude 37° 20' E at an elevation of 1159 m above sea level.

The average rainfall is about 890 mm with a range of 500-1250 mm divided into two rainfall peaks. The long rains start from mid-March to June with an average of 450 mm, while the short rains start in mid-October to December with an average of 350 mm. The rainfall is characterized by uneven distribution in total amounts in time and space. During the 2007/2008 main cotton crop season, rainfall values at Mwea Kirogo farm site were very low at 373.9. Similarly, during the second cotton crop season (2008/2009), rainfall was slightly lower than the average (890 mm) at 790 mm (appendix 2). The rainfall distribution was also poor with the long rains ending early in May instead of June. This may have affected the growth of main crop during the first season and yield response to nitrogen during the second season.

The temperatures range from 15.6 to 28.6 °C with a mean of about 22 °C (Ngigi, 2004). The soils in Kirogo farm experimental site have been described by Jaetzold *et al*. 2006 as imperfectly drained, very deep, dark grey to black, firm to very firm, boulder and stony cracking clay; in places with a calcareous, slightly saline deeper subsoil:-pellic VERTISOLS, stony phase and partly saline phase.

Soil from Kirogo farm trial site was sampled in September 2008 at a depth of 0 to 45 cm and analyzed for pH, macronutrients and micronutrients at the National Agricultural Laboratories Kabete before planting (Table 1). Based on these soil fertility results, application of 110 kg N ha^{-1} was recommended for growth of cotton.

Table 1: Soil chemical characteristics at Kirogo field experimental site

	Soil Attribute	**Levels**	**Class**
1	Soil pH	5.63	Slightly acidic
2	Total Nitrogen %	0.11	Low
3	Org. Carbon %	0.97	Low
4	Phosphorus (ppm)	170	High
5	Potassium (me %)	1.50	Adequate
6	Calcium (me %)	5.0	Adequate
7	Magnesium (me %)	5.76	High
8	Manganese (me %)	1.23	Adequate
9	Copper (ppm)	3.6	Adequate
10	Iron (ppm)	84.6	Adequate
11	Zinc (ppm)	3.2	Low
12	Sodium (me %)	0.14	Adequate

The trial site was surrounded by a maize crop to the north and west while the eastern and southern sides were fallow. The fallow areas were inhabited by various weeds including: Amaranthus species, *Bidens pilosa*, *Commelina benghalensis*, *Datura stramonium*, *Euphorbia heterophylla*, *Oxygonum sinuatum*, *Portulaca Oleraceae*, *Tagetes minuta*, *Digitaria velutina*, *Setaria verticillata* and *Cyperus esculentus* (Waturu *et al.*, 2004).

3.2: Experimental Design, Treatments and Crop Husbandry

The trial design was a randomized complete block, with a split-split plot arrangement of treatments and replicated four times. The treatments comprised three cotton varieties (HART 89M, A540 and F962), four cut back heights of the main cotton crop (5 cm, 10 cm, 15 cm and control which was sown directly from seed) and two N application levels (0 and 110 kg N ha^{-1}). The varieties comprised the main plot while cut heights were assigned to the sub plots and nitrogen assigned to the sub-subplots. HART 89M is the current recommended commercial variety for the area while A540 and F962 are the promising cotton varieties for the area. The N rate adopted for the study was a recommendation based on the results of soil fertility analysis conducted at KARI Kabete. Each replicate contained three main plots (24 rows of 4 m long for each variety), four subplots (6 rows 4 m long) and eight sub-subplots (3 rows 4 m long).

The experimental area measuring 26 m by 80 m was ploughed using a tractor. The three cotton varieties were randomly assigned to the main plots and hand-planted in three subplots at the beginning of short rains season in October 2007. An intra and inter-row spacing of 30 and 100 cm respectively was adopted. The subplot for the control treatment was left bare until October 2008 when cotton was sown after the onset of the short rains.

The recommended time for planting cotton in Mwea is in October at the onset of the short rains season. It takes 10 to 11 months to reach full maturity and is harvested in two peak seasons i.e. March-April and July- August commonly referred to as the short rains season crop (bottom crop) and the long rains season crop (top crop) respectively (Brown, 1972; Munro, 1987; Wabule *et al.*, 2006).

All the cultural practices and plant protection measures were adopted in all plots uniformly as outlined in "cotton growing recommendations handbook" (Wabule *et al.,* 2006; GOK, 2006) were adopted. The seedlings were thinned to one plant per hole three weeks after emergence. Weeds were controlled by hand weeding two times during short rains crop season (November to December 2007) and three times during the long rains season (March to June 2008). Pests were controlled by spraying with Omite (Propargite) 57% Emulsifiable Concentrate (EC) for control of red spider mites *Tetranychus* spp. while Dimethoate (Danadim 40% EC) and Polytrin (Cypermethrin)17.5 EC were used for control of the other cotton pests. A knapsack (Solo) sprayer fitted with a hollow cone nozzle set at a spray pressure of 4 bars was used to apply the pesticides. Polytrin 17.5 EC was applied twice between November and December 2007 and again applied four times between April and June 2008 while Omite 57% EC was applied once in January 2008.

Harvesting of seed cotton from the main cotton crop (i.e first season) was completed in August 2008 and the seed cotton bulked. The remaining cotton plant stalks were then cut at three heights (5 cm, 10 cm and 15 cm above ground surface) by use of secateurs in mid-September 2008, piled together and later burnt. The three cut heights were randomly assigned to the subplots in every main plot. The fourth subplot (control plot) was ploughed by use of hand hoe and cotton planted afresh from seed of the three varieties (as per the treatments) at the onset of short rains in mid-October 2008 at 4 weeks after ratooning (WAR). An intra and inter row spacing of 30 and 100 cm respectively were adopted. The control plots were thinned to one plant per hole three weeks after emergence at 7 WAR. The trial was hand weeded three times during October to December 2008 period at 3rd to

10th WAR, and four times between February and June 2009. The experiment was rain-fed with no supplementary irrigation during the two seasons (Figure 3).

Figure 3: Cotton trial site at Kirogo farm (KARI Mwea) in December 2008

Pests were controlled once a month by use of pesticides and were based on pest scouting. The crop was sprayed three times with polytrin 17.5EC between October and December 2008 to control aphids and bollworms. The heavy attack by mites in February and early March 2009 was controlled by use of Omite 57% EC. The unusually heavy infestation of cotton by thrips in June 2009 resulted to a heavy leaf fall and shedding of young cotton bolls squares and flowers though the pest is currently not considered to be a major cotton pest in Kenya. The crop was sprayed with confidor as a control measure.

The fertilizer, 26% CAN (calcium ammonium nitrate) was applied to the crop in a single dose (110 kg ha^{-1}) three weeks after the onset of the long rains season in April 2009 at 29 WAR. The short rains season crop was harvested by hand picking (5 times) from the 12^{th} to 27^{th} week after ratooning (WAR) while the long rains season crop was picked three times from the 28^{th} to 43^{rd} week after ratooning.

3.3: Data Collection

Experiment began in mid-October 2007, but no data was taken on that crop since the treatments (cut height and nitrogen) were applied later during the second crop season. Data collection started after ratooning (i.e. at the beginning of second crop season) in mid September 2008. In order to determine the effects of the treatments on cotton growth, pest incidences, cotton yield and quality, various parameters were measured. These data were collected in two sets, covering the two rainfall seasons (short and long rains seasons) in eastern and central Kenya.

The short rains season data was collected from November 2008 to April 2009 i.e. 6^{th} to 29 WAR in split plot design factors: variety and cut height. The long rains season data was taken from May 2009 to August 2009 in split split plot design factors: variety, cut height and nitrogen application level. The short rains season data was taken from the subplots and therefore showed the effects of cotton variety and cut heights on ratoon cotton.

The long rains season data was taken from the sub-subplot level, and in addition showed the effects of nitrogen application on ratoon cotton. This is because cotton was top dressed in mid April 2009 at WAR. Consequently, the effect of nitrogen application on cotton growth, seed cotton yields, pest counts and cotton quality was assessed between May and August 2009 (31 to 43 WAR).

3.3.1: Cotton growth

The cotton growth parameters considered during this study were: plant height, plant count and the number of stems that sprouted from the stub of the ratoon cotton plant. Data on plant count shows the ability of the cotton variety to regenerate into new plant shoots while the number of stems per cotton plant and plant height gives an indication of how bushy a variety can become on ratooning. Data on plant count was collected once every month from the whole plot during the short rains season and at the end of the long rains season. Data on plant height and number of stems per cotton plant were taken monthly from ten randomly selected and earlier tagged plants from the two center rows of each subplot during the short rains season and from five plants from the center row of each sub-subplot during the long rains season. The height was measured as the distance between ground surface and the uppermost plant terminal by use of a 2-meter ruler after every two months. Plant height data taken at the end of March 2009 at 23^{rd} WAR, was used to give the height indication at the end of short rains season. Data on number of stems that had sprouted from the stub of the cut main stem gave an indication of ratooning ability of the three varieties. This data was collected by taking monthly counts of all stems (more than 15 cm tall) produced at or below the cut heights from 11^{th} WAR to 23^{rd} WAR and from 31^{st} to 39^{th} WAR. Mean for the season were calculated by dividing the cumulative monthly treatment totals either by four or three for short and long rains seasons respectively.

3.3.2: Pest incidence

Cotton has a wide spectrum of successive pests which naturally infests it from time of emergence to harvest. These pests were monitored during the study (after ratooning starting from the fourth week after emergence of cotton in the control plots) as a measure of pest infestation or pest incidences in cotton. The main pests observed were: aphids, red spider mites, African bollworms, stainers, thrips and the number of cotton plants infested by mealybugs. Monthly pest counts were taken from randomly selected and earlier tagged plants before each spray. The short rains season pest data were collected from ten plants from two centre rows (from 4^{th} to 8^{th} plant) in every subplot starting from 10 to 15 WAR. The long rains season pest data were collected from five plants from the centre row of every sub-subplot from 31 WAR to 35 WAR. The plants were selected using a stratified random sampling technique whereby they were thoroughly scrutinized and counts of bollworm larvae, stainers, aphids, red spider mites and thrips recorded (Kogan and Pitre, 1980). These were counted from 5 leaves per plant from the apex. Data on aphids, mites and thrips was taken by placing a hand lens near the mid-rib of the leaf and the pest count recorded. The average level of pest infestation over the season was obtained by adding up the number of pests per plant per scouting and then divided by the number of times scouting was conducted during that season.

Percent mealybug infestation was estimated by counting the number of mealybug-infested cotton plants within the subplot (during short rains season) or within the sub-subplot (during the long rains season) divided by the total number of plants in those units multiplied by a hundred.

3.3.3: Seed cotton yield and quality

The yield parameters considered consisted of seed cotton and lint percentage. Seed cotton was harvested (immediately after boll split) by hand-picking from six rows 4 m long and from 3 rows 4 m long during the short rains and the long rains seasons, respectively. Seed cotton was picked four times during the short rains season i.e. at 15, 19, 23 and 27 WAR and three times during the long rains season i.e. at 35, 39 and 43 WAR. The weight of seed cotton picked every month from each subplot or sub-subplot was determined by use of a 10-kg Avery balance. Seed cotton harvested during the short rains season from each plot was pooled over the four pickings to give cumulative seed cotton yield for the short rains. Similarly, seed cotton harvested during the long rains season from each plot was pooled over the three pickings to give cumulative seed cotton yield for the long rains. Both cumulated seed cotton yield for the short and long rains were pooled to give the yield data for the entire sampling period.

A sub-sample of 500 g seed cotton from each plot was collected and ginned by use of a single roller gin to calculate the lint percentage as = (weight of lint in sample/ weight of seed cotton in that sample x 100 (Singh, 2004).

The effects of cotton variety and cut heights on quality of seed cotton was monitored by sorting out the harvested seed cotton into two commercial grades currently used in Kenya i.e. grades ‘AR’ and ‘BR’. Grade ‘AR’ seed cotton is the clean and pure white cotton completely free of trash and without any signs of stain from any cause. Grade ‘BR’ has some impurities such as small pieces of dried leaves, soil dust and discoloration or staining from whatever source. Seed cotton harvested from each plot was weighed and then separated into the two grades through hand-sorting after every picking throughout the sampling period. The total weight of the two grades from each plot gave the weight of unsorted seed cotton harvested from that plot. The total weight of grade 'AR' seed cotton divided by the weight of the un-sorted seed cotton expressed as a percentage gave the percent of grade 'AR' from that plot. Similarly, percent of grade 'BR' seed cotton was determined as the total weight of grade 'BR' seed cotton divided by the weight of the un-sorted seed cotton expressed as a percentage.

3.4: Data analysis

All data were subjected to analysis of variance (ANOVA) using Genstat statistical software, and treatment means compared using Fisher's least significant difference (LSD) test at $p \leq 0.05$ (Gomez and Gomez, 1984). The data collected during the short and long rains seasons were analyzed separately**.** The data denoted to represent the 'entire sampling period' was obtained by combining the short and long rains seasons' data.

CHAPTER FOUR

RESULTS

4.1.0: Effect of variety cut height and nitrogen application on growth of ratoon cotton

4.1.1: Effect of variety and cut height on plant height of ratoon cotton

The height of cutting the main cotton crop had a significant ($P \leq 0.05$) effect on the plant height of the ratoon crop but there were no significant variations in height among the three varieties during short rains season (Table 2). There was no significant interaction between cut height and variety with respect to plant height except at 10 WAR during the short rains season (Appendices 1 to 6).

Cutting the cotton stalk at 5 cm above ground surface resulted to the shortest ratoon cotton plants whereas cutting at 15 cm resulted to the tallest plants during the short rains season (10 and 23 WAR). The directly seeded control plots had taller cotton plants than those cut at 5 cm in all the varieties. HART 89M had significantly taller plants than the other two varieties only at a cut height of 5 cm. At 15 WAR, cut heights of 5 and 15 cm had the lowest and the highest plant heights, respectively. There was no significant difference in plant height between directly seeded plants and cut at a height 10 cm. At 19 WAR, the 5 cm cut height had a significantly shorter plant height while control, 10 and 15 cm cut heights were not significantly different in this parameter. At 23 WAR, the 15 cm cut height had significantly taller plants than cut height of 5 cm but it was at par with the control. Averaged across the varieties, the directly seeded cotton plants were taller than those cut at 5 cm, whereas those cut at 10 and 15 cm above ground surface had taller plants than the control during the short rains season.

Table 2: Effect of variety and cut height on cotton plant height (cm) during the short rains season

Cotton variety (Var)	Cut height (Ht)				
	Sown cotton	5 cm	10 cm	15 cm	Mean
		10 weeks after ratooning			
HART 89M	56.1	36.9	62.0	80.2	58.8
A540	56.1	27.0	72.2	80.6	59.0
F962	54.9	24.0	76.1	83.1	59.5
Ht-Mean	55.7	29.3	70.1	81.3	59.1
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	4.8				
$LSD_{0.05}$ (Var X Ht)	8.8				
		15 weeks after ratooning			
HART 89M	81.9	67.4	83.8	95.9	82.3
A540	75.4	59.1	88.4	94.9	79.5
F962	80.9	58.0	80.8	91.2	77.7
Ht-Mean	79.4	61.5	84.3	94.0	79.8
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	7.0				
$LSD_{0.05}$ (Var X Ht)	NS				
		19 weeks after ratooning			
HART 89M	96.9	88.0	90.4	101.8	94.3
A540	84.6	79.9	96.4	97.0	89.5
F962	93.5	76.0	87.1	91.2	87.0
Ht-Mean	91.7	81.3	91.3	96.7	90.2
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	7.5				
$LSD_{0.05}$ (Var X Ht)	NS				
		23 weeks after ratooning			
HART 89M	100.2	95.8	94.8	106.9	99.4
A540	93.6	93.1	103.2	105.4	98.8
F962	99.5	84.6	93.9	97.5	93.9
Ht-Mean	97.8	91.2	97.3	103.3	97.4
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	7.9				
$LSD_{0.05}$ (Var X Ht)	NS				

Var- cotton variety; Ht- cut height above ground surface; NS- Not significant

Height of cutting the main cotton crop had a significant effect on height of the resultant ratoon cotton crop at 39 and 43 WAR and not at 35 WAR during the long rains season. Variety and cut height had a significant interaction on ratoon plant height (Table 3).

Table 3: Effect of cut height and variety on cotton plant height (cm) during the long rains season

Variety (Var)	Cut height				Variety
	Control	5 cm	10 cm	15 cm	Mean
35 weeks after ratooning					
HART 89M	116.4	109.2	107.4	114.0	111.8
A540	109.3	111.4	114.2	113.9	112.2
F962	122.8	102.4	105.5	102.3	108.3
Ht-Mean	116.2	107.7	109.0	110.1	110.7
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	6.5				
$LSD_{0.05}$ (Var X Ht)	13.3				
39 weeks after ratooning					
HART 89M	120.6	111.5	111.5	117.8	115.4
A540	113.1	115.4	117.7	119.3	116.4
F962	124.7	105.5	107.6	106.8	111.2
Ht-Mean	119.5	110.8	112.3	114.6	114.3
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	5.6				
$LSD_{0.05}$ (Var X Ht)	13.4				
43 weeks after ratooning					
HART 89M	124.1	111.6	114.1	118.9	117.2
A540	115.8	116.0	118.7	119.9	117.6
F962	126.6	108.0	109.9	109.0	113.4
Ht-Mean	122.2	111.9	114.2	115.9	116.1
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	5.5				
$LSD_{0.05}$ (Var X Ht)	13.3				

Var- cotton variety; Ht- cut height above ground surface; NS- Not significant

At 35 WAR, cotton variety F962 had significantly taller plants than variety A540 in control plots than at any other cut height. The height of ratoon cotton plants was not significantly influenced by cut height of the main cotton crop in varieties HART 89M and A540. Similar observations were made at 39 and 43 WAR.

4.1.2: Effect of nitrogen application on plant height of ratoon cotton

Nitrogen application had a significant ($P \leq 0.05$) effect on height of the ratoon cotton plants during the long rains season at 35, 39 and 43 WAR (Table 4). Nitrogen application increased the cotton plant height across all cut heights. There was no significant interaction between nitrogen and cut height with respect to height of ratoon cotton plants (Appendices 7-10).

Table 4: Effect of nitrogen application on plant height (cm) during the long rains season

	Weeks after ratooning		
N- Rate	35	39	43
0	107.6	110.0	113.0
110	113.9	117.7	119.8
Mean (Ht)	110.8	113.9	116.4
$LSD_{0.05}$ (N)	1.7	1.6	1.6

N- Rate - Nitrogen application (Kg ha^{-1})**;** NS – Not significant

4.1.3: Effect of variety, cut height and nitrogen on the number of sprout cotton stems

Cut height had a significant ($P \leq 0.05$) effect on the number of sprout stems across all varieties during the short rains season. There was a general increase in the number of sprout stems per plant with increase in cut height (Table 5).

Table 5: Effect of cut height on sprouted stems per cotton plant during the short rains season

	Weeks after ratooning			
	10	15	19	23
Control	1.0	1.0	1.0	1.0
5 cm	3.0	4.1	4.4	4.6
10 cm	4.3	4.6	4.9	5.2
15 cm	4.6	5.4	5.7	5.9
$LSD_{0.05}$ (Ht)	0.44	0.32	0.28	0.30

Ht- Cut height above ground surface

There were no significant variations among the varieties or interactions between variety and cut height with respect to number of sprout stems (Appendices 11- 16).

At 10 WAR, the sprout stems count in plants cut at 10 and 15 cm above ground surface were at par but were significantly higher than those from plants cut at 5 cm and the directly seeded cotton (Figure 4). However, cut height of 5 cm above ground surface had a significantly higher number of stems than the directly seeded control plots.

Figure 4: Stem sprouts from HART 89M cotton variety cut at 10 cm cut height

Cutting cotton plants at 15 cm above ground surface during ratooning led to a significantly higher number of sprout stems per plant than all other cut heights while cut height of 10 cm above ground surface resulted in a significantly more sprout stems per plant than heights 5 and 0 cm at 15, 19 and 23 WAR. Similar observations were made during the long rains season i.e. 31, 35 and 39 weeks after ratooning (Table 6).

Table 6: Effect of cut height on sprouted stems per cotton plant during the long rains season

	Weeks after ratooning		
Cut height	31	35	39
Control	1.0	1.0	1.0
5 cm	5.0	5.3	5.5
10 cm	5.5	5.8	6.0
15 cm	6.4	6.6	6.8
$LSD_{0.05}$ (Ht)	0.4	0.3	0.4

Ht- Cut height above ground surface

There was a significant increase in the number of sprout stems per cotton plant due to nitrogen application during the long rains season at 31, 35 and 39 WAR (Table 7).

Table 7: Effect of nitrogen application on sprouted stems per cotton plant during the long rains season

	Weeks after ratooning		
N- Rate	31	35	39
0	4.3	4.6	4.7
110	4.6	4.8	4.9
Mean (N)	4.5	4.7	4.8
$LSD_{0.05}$ (N)	0.07	0.10	0.10

N- Rate - Nitrogen application (Kg ha^{-1})**;** NS – Not significant

There was no significant variation in number of sprout stems among the cotton varieties. Similarly, there was no significant interaction between nitrogen and variety with respect to the number of sprout stems (Appendices 15 to 17).

4.1.4: Effect of variety and cut height on plant count of ratoon cotton

Cut height had a significant ($P \leq 0.05$) influence on survival and regeneration of the ratoon cotton crop as indicated by the plant count data during the short and long rains seasons. There was no significant variation in plant count among the cotton varieties except at 23 and 43 WAR (Table 8).

Table 8: Effect of variety and cut height on cotton plant count plot^{-1} at 10, 15, 19, 23 and 43 weeks after ratooning (WAR)

Variety (Var)	Cut height				
	Control	5 cm	10 cm	15 cm	Variety mean
			10 weeks after ratooning		
HART 89M	67.8	17.2	45.8	68.2	49.8
A540	79.5	20.8	45.0	60.0	51.3
F962	77.0	14.2	40.5	75.0	51.7
Ht-Mean	74.8	17.4	43.8	67.7	50.9
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	5.8				
$LSD_{0.05}$ (Var X Ht)	10.1				
			15 weeks after ratooning		
HART 89M	71.5	39.3	55.0	74.3	60.0
A540	80.0	42.0	50.1	65.0	59.4
F962	79.0	49.3	56.3	76.0	65.1
Ht-Mean	76.8	43.5	53.9	71.8	61.5
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	4.6				
$LSD_{0.05}$ (Var X Ht)	NS				
			19 weeks after ratooning		
HART 89M	73.8	47.2	56.2	74.5	60.4
A540	79.2	48.5	50.5	65.0	61.8
F962	79.5	49.3.	54.2	75.5	64.3
Ht-Mean	77.5	47.9	53.6	71.6	62.7
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	11.7				
$LSD_{0.05}$ (Var X Ht)	NS				
			23 weeks after ratooning		
HART 89M	74.0	47.3	61.0	74.5	68.2
A540	80.3	48.8	53.0	65.3	61.9
F962	79.0	52.0	60.0	76.5	66.9
Ht-Mean	77.8	49.8	58.0	72.1	64.3
$LSD_{0.05}$ (Var)	3.7				
$LSD_{0.05}$ (Ht)	5.0				
$LSD_{0.05}$ (Var X Ht)	NS				
			43 weeks after ratooning		
HART 89M	36.0	23.0	28.0	35.0	30.5
A540	41.0	21.0	24.0	31.0	29.3
F962	40.0	27.0	31.0	37.0	33.8
Ht-Mean	39.0	23.7	27.7	34.3	31.2
$LSD_{0.05}$ (Var)	1.9				
$LSD_{0.05}$ (Ht)	2.5				
$LSD_{0.05}$ (Var X Ht)	NS				

Var- cotton variety; Ht- cut height above ground surface; NS- Not significant

There was no significant interaction between the cut height and the variety with respect to plant count during entire sampling period except at 10 WAR (Appendices 18 to 23).

There was a general increase in plant count with increase in height of cutting above the ground surface (15 cm >10 cm >5 cm) across the varieties.

At 10 WAR, the directly seeded control plots and those with cotton cut at 15 cm above ground surface had significantly higher plant counts than those cut at 5 and 10 cm cut heights in all the varieties. Cut height of 10 cm had a significantly higher plant count than 5 cm. Variety F962 had significantly higher plant count than A540 at 15 cm cut height.

At 15 WAR, directly seeded control plot had a significantly higher plant count than other cut heights with 15 cm cut height having a higher plant count than 10 cm and 5 cm cut heights. At 19 WAR, plant count in the directly seeded control plots and 15 cm cut height were at par but were significantly higher than that at 5 and 10 cm cut heights.

At 23 WAR, varieties HART 89M and F962 had significantly higher plant count than A540 whereas at 43 WAR, variety F962 had significantly higher plant count than A540 but was at par with plant count in variety HART 89M. In addition, the directly seeded control plots had a higher plant count than all other cut heights at 43 WAR with 15 cm cut height having a higher plant count than 10 and 5 cm with 10 cm cut height having a higher count than 5 cm.

4.2.0: Effect of variety, cut height and nitrogen application on pest incidences in ratoon cotton

4.2.1: Effect of variety and cut height on aphid (*Aphis gossypii)* counts in ratoon cotton

Cut height had a significant *(P* $\leq$ 0.05) influence on aphid count in cotton during the short rains season (Table 9). However, there was no significant difference among the cotton varieties and no significant interaction between the cotton variety and cut height on aphid counts during the season (Appendices 23 to 25).

Table 9: Effect of cut height on aphid counts plant^{-1} during the short rains season

	Weeks after ratooning		
Cut height	6	10	15
control	20.0	16.2	10.7
5 cm	19.3	14.6	11.4
10 cm	22.2	13.5	7.0
15 cm	25.3	11.1	6.9
Mean count	21.7	13.9	9.0
$LSD_{0.05}$ (Ht)	4.4	3.1	1.6

Ht- Cut height above ground surface

At 6 WAR, aphid count in plants cut at 15 cm above ground level was not significantly different from aphid counts in plants cut at 10 cm. However, it was significantly higher than aphid counts in control plots and 5 cm cut height.

At 10 WAR, aphid counts in control plot were significantly higher than in cut heights of 10 and 15 cm above ground level but there was no significant differences in aphid count between control and 5 cm cut height.

At 15 WAR, aphid count in plants cut at 15 cm above ground level was at par with aphid counts in plants cut at 10 cm and was significantly lower than aphid counts in control plots and 5 cm cut height.

The variety and cut height did not have a significant ($P \leq 0.05$) effect on aphid count at 31 and 35 WAR during the long rains season (Table 10). There was no significant interaction between varieties and cut height on aphid counts except at 31 WAR during the long rains season (Appendices 26 and 27).

Table 10: Effect of variety and cut height on aphid counts plant^{-1} during the long rains season.

Variety (Var)	Cut height			
	Control	5 cm	10 cm	15 cm
	31 weeks after ratooning			
HART 89M	49.5	59.8	51.0	54.0
A540	61.2	60.1	55.4	48.4
F962	58.4	50.8	61.0	60.8
Ht-Mean	56.4	56.9	55.8	54.4
$LSD_{0.05}$ (Var)	NS			
$LSD_{0.05}$ (Ht)	NS			
$LSD_{0.05}$ (Var X Ht)	10.7			
	35 weeks after ratooning			
HART 89M	7.6	8.3	6.0	8.1
A540	5.4	4.9	5.0	6.1
F962	6.3	5.3	3.8	4.9
Ht-Mean	6.4	6.2	4.9	6.4
$LSD_{0.05}$ (Var)	NS			
$LSD_{0.05}$ (Ht)	NS			
$LSD_{0.05}$ (Var X Ht)	NS			

Var- cotton variety; Ht- cut height above ground surface; NS- Not significant

At 31 WAR, aphid counts in variety HART 89M was significantly ($P \leq 0.05$) lower than aphid that in variety A540 but the latter was at par with cotton variety F962 in control plots. However, at 15 cm cut height, variety F962 had a significantly higher aphid counts than that in variety A540 but the latter was at par with the aphid count in variety HART 89M. There were no aphid infestations at 39 and 43 WAR.

4.2.2: Effect of nitrogen application on aphid (*Aphis gossypii*) incidences in ratoon cotton

Nitrogen application increased aphid count significantly ($P \leq 0.05$) during the long rains season at 35 WAR and not at 31 WAR (Table 11). There was no significant ($P \leq 0.05$) interaction between the cut height and nitrogen application on aphid counts during the same period (Appendices 26 and 27).

Table 11: Effect of nitrogen application on aphid counts plant^{-1} during the long rains season

	Weeks after ratooning		
N- Rate	31	35	
0	11.2	5.2	
110	11.1	6.7	
Mean (N)	11.1	6.0	
$LSD_{0.05}$ (N)	NS	1.5	-

N- Rate - Nitrogen application (Kg ha^{-1})**;** NS – Not significant

4.2.3: Effect of variety and cut height on red spider mite (*Tetranychus* species) incidences in ratoon cotton

Main effects of cut height, variety and nitrogen application did not have a significant ($P \leq 0.05$) effect on spider mite count (Table 12). There was a significant interaction between cut height and variety on spider mite counts at 10 and 15 WAR (Appendices 28 to 30). At 10 WAR, mite count at heights 10 and 15 cm was at par and significantly higher than that of control and 5 cm in varieties HART 89M and F962.

Cut height of 15 cm had a significantly higher spider mite count in variety A540 than the other cut heights. Cut heights of 5 and 10 cm had the lowest mite counts.

At 15 WAR, 5 and 15 cm cut heights resulted in a significantly higher mite count in variety F962 than in variety A540, whereas mite count was at par at 10 cm cut height and in control plot across all varieties. Cut height, cotton varieties and nitrogen application did not have significant influence on mite counts at 31 and 35 WAR during the long rains season (appendices 31 and 32). There were no incidences of red spider mites at 43 WAR.

Table 12: Effect of variety and cut height on spider mite counts plant^{-1} at 10, 15, 31 and 35 weeks after ratooning (WAR)

Cotton variety (Var)	Cut height (Ht)				Var-Mean
	Control	5 cm	10 cm	15 cm	
		10 weeks after ratooning			
HART 89M	9.8	7.0	13.8	13.3	11.0
A540	9.3	4.5	7.5	12.5	8.5
F962	7.3	5.5	13.3	12.5	9.7
Ht-Mean	8.8	5.7	12.6	12.8	9.7
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	1.7				
$LSD_{0.05}$ (Var X Ht)	3.1				
		15 weeks after ratooning			
HART 89M	13.9	14.7	13.6	14.3	14.1
A540	14.7	11.8	13.7	12.6	13.2
F962	14.2	16.8	15.2	18.8	16.3
Ht-Mean	14.3	14.4	14.2	15.2	14.5
$LSD_{0.05}$ (Var)	2.3				
$LSD_{0.05}$ (Ht)	NS				
$LSD_{0.05}$ (Var X Ht)	3.2				
		31 weeks after ratooning			
HART 89M	33.5	21.1	19.6	30.9	26.3
A540	21.3	21.6	38.0	27.8	27.2
F962	15.3	11.8	20.5	19.9	16.9
Ht-Mean	23.4	18.2	26.0	26.2	23.4
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	NS				
$LSD_{0.05}$ (Var X Ht)	NS				
		35 weeks after ratooning			
HART 89M	26.8	24.0	27.1	26.3	26.0
A540	24.9	18.5	23.4	18.1	21.2
F962	28.8	29.9	26.0	38.8	30.9
Ht-Mean	26.8	24.1	25.5	27.7	26.0
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.0\,5}$(Ht)	NS				
$LSD_{0.05}$ (Var X Ht)	NS				

Var- cotton variety; Ht- cut height above ground surface; NS- Not significant

4.2.4: Effect of variety and cut height on bollworm (*Helicoverpa armigera*) incidences in ratoon cotton

Bollworms were noted in cotton at 6, 10 and 15 weeks after ratooning. There were no incidences of bollworms during the rest of cotton growth season. Cut height and its interaction with variety had a significant ($P \leq 0.05$) effect on bollworm count at 6 WAR (Table 13) and not at 10 and 15 WAR (Appendices 32 to 34).

At 6 WAR, bollworm counts in variety A540 were significantly higher at 10 and 15 cm cut heights than at 5 cm cut height and in control. Similarly, bollworm counts in variety F962 was significantly higher at 15 cm cut height than at other cut heights. Bollworm counts at 10 cm cut height were significantly higher in variety A540 than HART 89M and F962. Natural bollworm infestation in cotton variety HART 89M was not influenced significantly by the height of cutting the main cotton crop at the time of ratooning.

Table 13: Effect of variety and cut height on bollworm counts plant^{-1} during the short rains season

Cotton variety (Var)	Cut height (Ht)				
	Control	5 cm	10 cm	15 cm	Var-Mean
	6 weeks after ratooning				
HART 89M	0.8	1.5	1.7	2.0	1.3
A540	0.0	0.3	3.5	3.3	1.8
F962	0.3	0.3	1.0	3.5	1.3
Ht-Mean	0.4	0.7	1.8	2.9	1.4
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	0.9				
$LSD_{0.05}$ (Var X Ht)	1.7				

Var- cotton variety; Ht- cut height above ground surface; NS- Not significant

4.2.5: Effect of variety and cut height on mealybug (*M. hirsutus*) incidences in ratoon cotton

Cut height had a significant ($P \leq 0.05$) effect on mealybug incidences during the entire cotton crop season. There was no significant variation in level of infestation among the varieties (Table 14). There was a no significant interaction between cut height and variety with respect to mealybug infestation at 10, 15, 31 and 43 WAR (Appendices 35 and 36).

Table 14: Effect of cut height on percent mealybug-infested cotton plants plot^{-1} at 10, 15, 31 and 43 weeks after ratooning (WAR)

	Weeks after ratooning				
Cut height	10	15	31	43	
control	0.0	0.0	0.8	2.3	
5 cm	4.8	3.2	11.2	14.3	
10 cm	26.9	26.7	37.7	45.7	
15 cm	39.6	47.0	50.7	64.0	
Mean	17.8	19.2	25.1	31.6	
$LSD_{0.05}$ (Ht)	7.1	6.8	6.7	6.5	-

Ht- cut height above ground surface

There was a general increase in percent mealybug infestation with increase in cut height at 10, 15, 31 and 43 WAR and a higher percent mealybug infestation in ratoon than in non-ratoon cotton. At 10 and 15 WAR, cut heights of 10 and 15 cm had a significantly higher percent mealybug infestation than 5 cm and control plots. The percent mealybug-infestation at 15 cm cut height was significantly higher than at 10 cm whereas the level of infestation in the directly seeded control plots was at par with that at 5 cm cut height. At 31 and 43 WAR, mealybug infestation at cut heights 15, 10 and 5 cm was significantly higher than that in control plots. There was a significant increase in mealybug infestation with each increase in cut height (5 to 15 cm). There were no significant differences in mealybug infestation among the cotton varieties (Appendices 37 and 38).

4.2.6: Effect of variety and cut height on stainer (*Dysdercus* species) incidences in ratoon cotton

Stainer infestation appeared late in the season and was noted at 31 and 35 weeks after ratooning. Nitrogen application significantly reduced the stainer counts across all varieties at 31 WAR and not at 35 WAR (Table 15). Cut height and varieties and their interactions did not have a significant ($P \leq 0.05$) effect on stainer counts (Appendices 39 and 40).

Table 15: Effect of nitrogen application on stainer counts plant^{-1} at during the long rains season

	Cotton varieties		
N- (Kg ha^{-1})	HART 89M	A540	F962
0	13.2	10.2	18.9
110	11.1	8.6	6.7
Mean (Var)	12.2	9.4	12.8
$LSD_{0.05}$ (N)	5.0		
$LSD_{0.05}$ (Ht)	NS		
$LSD_{0.05}$ (N X Ht)	NS		

Ht- Cut height above ground surface**;** NS **–** Not significant

4.2.7: Effect of variety and cut height on thrips (*Frankliniella* species) incidences in ratoon cotton

Thrips infestation on cotton was first observed at 35 weeks after ratooning and there was no infestation during other sampling periods over the whole the season . There was no significant ($P \leq 0.05$) difference in thrip counts among the varieties, cut heights, fertilized and non fertilized plots (Appendix 41).

There was no significant interaction between cut height and variety, nitrogen and variety with respect to thrip infestation.

4.3.0: Effect of variety and cut height on seed cotton yield and quality

4.3.1: Effect of cotton variety and cut height on seed cotton yield

Cut height had a significant ($P \leq 0.05$) effect on seed cotton yield during the entire sampling period whereas the yield differences among the varieties were not significant except at 15 and 23 WAR (Table 16).

Table 16: Effect of variety and cut height on seed cotton yield (kg ha^{-1}) at 15, 19, 23, 27, 35 and 43 weeks after ratooning

Cotton variety (Var)	Cut height (Ht)				Var- mean
	Control	5cm	10 cm	15 cm	
15 weeks after ratooning					
HART 89M	0.0	8.0	163.0	309.0	120.0
A540	0.0	30.0	200.0	378.0	152.0
F962	43.0	21.0	182.0	527.0	193.3
Ht-Mean	14.3	19.7	181.7	404.7	155.1
$LSD_{0.05}$ (Var)	45.1				
$LSD_{0.05}$ (Ht)	69.5				
$LSD_{0.05}$ (Var X Ht)	NS				
19 weeks after ratooning.					
HART 89M	70.0	189.0	788.0	1098.0	536.5
A540	114.0	171.0	558.0	767.0	402.5
F962	90.0	85.0	593.0	952.0	430.0
Ht-Mean	91.3	148.3	646.3	939.0	456.3
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	132..0				
$LSD_{0.05}$ (Var X Ht)	NS				
23 weeks after ratooning					
HART 89M	207.0	155.0	228.0	191.0	195.3
A540	183.0	60.0	71.0	33.0	86.8
F962	165.0	63.0	114.0	33.0	93.8
Ht-Mean	185.0	92.7	137.7	85.7	125.3
$LSD_{0.05}$ (Var)	59.0				
$LSD_{0.05}$ (Ht)	50.0				
$LSD_{0.05}$ (Var X Ht)	NS				
27 weeks after ratooning					
HART 89M	760.0	297.0	193.0	102.0	338.0
A540	413.0	276.0	83.0	37.0	202.3
F962	488.0	245.0	106.0	59.0	224.5
Ht-Mean	553.6	272.6	127.3	66.0	254.9
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	188.0				
$LSD_{0.05}$ (Var X Ht)	NS				
35 weeks after ratooning					
HAR T89M	104.0	378.0	260.0	310.0	263.0
A540	345.0	340.0	365.0	378.0	357.0
F962	261.0	331.0	437.0	505.0	383.5
Ht-Mean	236.7	349.7	354.0	397.7	334.5
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	87.0				
$LSD_{0.05}$ (Var X Ht)	NS				
43 weeks after ratooning					
HART 89M	675.0	402.0	478.0	561.0	529.0
A540	491.0	279.0	337.0	246.0	338.3
F962	552.0	351.0	329.0	419.0	412.8
Ht-Mean	572.7	344.0	381.3	408.7	426.7
$LSD_{0.05}$ (Var)	NS				
$LSD_{0.05}$ (Ht)	135.0				
$LSD_{0.05}$ (Var X Ht)	NS				

Var- cotton variety; Ht- cut height above ground surface; NS- Not significant

There was no significant interaction between variety and cut height with respect to seed cotton yield (Appendices 42 to 45). Initially, seed cotton yield from ratoon was higher than that of directly seeded cotton but the situation was reversed as the season progressed.

At 15 and 19 weeks after ratooning, cut heights of 10 and 15 cm had significantly ($P \leq 0.05$) higher seed cotton yield than control and cut height 5 cm. Seed cotton yield in control plots was at par with that of 5 cm cut height whereas 15 cm cut height had significantly higher seed cotton yield than 10 cm. At 15 WAR, variety F962 had significantly higher seed cotton yield than HART 89M but the yield difference between HART 89M and A540 was not significantly different. However, at 19 WAR, there were no significant differences among the varieties with respect to seed cotton yield.

At 23 WAR, variety HART 89M had significantly higher seed cotton yield than both varieties F962 and A540 but the yield of the later two did not differ significantly. Cut height of 10 cm and control had significantly higher seed cotton yield than cut heights 5 and 15 cm.

At 27 WAR, directly seeded cotton (control) had significantly ($P \leq 0.05$) higher seed cotton yield than the ratoon at all cut heights. Cut height 5 cm had significantly higher seed cotton yield than cut heights 10 and 15 cm.

There were no significant differences in seed cotton yield between cut heights of 10 and 15 cm. At 35 WAR, the directly seeded cotton (control) had a significantly ($P \leq 0.05$) lower seed cotton yield than the ratoon at all the other cut heights. There was no significant difference in seed cotton yield between 5, 10 and 15 cm cut heights.

At 43 WAR directly seeded cotton had a significantly higher cotton yield than the other cut heights. There was no significant difference in seed cotton yield between 5, 10 and 15 cm cut heights.

Nitrogen application and its interaction with cut height and varieties did not have a significant effect on seed cotton yield during the long rains season (Appendices 46 to 49).

Cut height significantly ($P \leq 0.05$) affected the cumulative seed cotton yield over the short rains season and not during the long rains season (Table 17).

Table 17: Effect of cut height on cumulative seed cotton yield (kg ha^{-1}) during short and long rain seasons

	Cumulative seed cotton yield (Kg ha^{-1})		
Cut height	Short rains season	Long rains season	Entire season
control	856.7	1633.0	2241.3
5 cm	531.0	1526.0	1802.0
10 cm	1119.7	1571.0	2428.3
15 cm	1389.3	1720.0	2822.0
Mean	974.2	1612.5	2323.4
$LSD_{0.05}$ (Ht)	327.0	NS	481.0

Ht – Cut height above ground surface

There were no significant yield differences among the varieties and no significant interaction between cut height and variety with respect to cumulated seed cotton yield (Appendices 50 to 52).

Cut height of 15 cm above ground surface resulted in a significantly higher cumulative seed cotton yield than that of 5 cm and control during the short rains season. The yield from the control plot was at par with that in plots cut at 5 and 10 cm above ground surface during the same period. However, the cut height did not have significant influence on cumulative yield during the long rains season.

Cut height of 15 cm had significantly higher cumulative seed cotton yield than cut heights of 5 cm and control but was at par with that of 10 cm cut height during the entire cotton crop season.

4.3.2: Effect of cotton variety and cut height on lint percentage and lint yield

There was a significant ($P \leq 0.05$) variation in lint percentage among the cotton varieties during the short rains season and not during the long rains season (Table 18).

Table 18: Effect of variety and cut height on lint percentage during the short and long rain seasons

Cotton variety (Var)	Cut height (Ht)				
	Control	5 cm	10 cm	15 cm	Var- Mean
		Short rains season			
HART 89M	35.7	37.9	36.3	34.6	36.1
A540	38.4	36.7	36.7	36.9	37.1
F962	38.3	39.3	38.9	38.4	38.7
Ht-Mean	37.6	37.9	37.3	36.6	37.3
$LSD_{0.05}$ (Var)	1.3				
$LSD_{0.05}$ (Ht)	NS				
$LSD_{0.05}$ (Var X Ht)	NS				
		Long rains season			
HART 89M	36.5	35.9	36.5	36.1	36.2
A540	38.6	35.5	35.8	35.8	36.4
F962	37.9	38.7	38.6	38.6	38.4
Ht-Mean	37.6	36.7	36.9	36.8	37.0
$LSD_{0.05}$ (Var)	0.9				
$LSD_{0.05}$ (Ht)	0.6				
$LSD_{0.05}$ (Var X Ht)	1.1				

Var- cotton variety; Ht- cut height above ground surface; NS- Not significant

There was a significant interaction between varieties and cut height with respect to lint percentage during the long rains seasons and not during the short rains season .Cut height did not have any significant effect on lint percentage (Appendices 53 and 54).

Variety F962 had significantly ($P \leq 0.05$) higher lint percentage than HART 89M and A540 but the latter two did not differ significantly from each other during the short rains season.

There were no significant differences between ratoon and (control) directly seeded cotton with respect to lint percentage across the varieties during both short and long rains season.

During the long rains season, cut height did not significantly affect lint percentage in variety F962 since lint percent range 38.7 to 38.6 was similar to that of control at 37.9%. Also in HART 89M, cut height did not affect lint percentage whereas in A540 control had significantly high lint percentage.

Cut height had a significant ($P \leq 0.05$) effect on cumulative lint yield during the short rains and not during the long rains season (Table 19).

Table 19: Effect of cut height on cumulative lint yield (kg ha^{-1}) during short and long rain seasons

	Cumulative lint yield (Kg ha^{-1})		
Cut height	Short rains season	Long rains season	Entire season
control	322.0	523.7	844.7
5 cm	198.7	468.3	670.7
10 cm	417.0	485.3	903.3
15 cm	508.3	531.3	1040.3
Mean	361.5	502.2	864.8
$LSD_{0.05}$ (Ht)	117.8	NS	176.0

Ht – Cut height above ground surface

There were no significant interactions between cut height and variety on lint yield during the entire cotton crop season. Similarly, there was no significant variation in lint yield among the three cotton varieties during the entire crop season (Appendices 54 and 56).

4.3.3: Effect of cotton variety and cut height on percent of grade ‘AR’ seed cotton

Cut heights of 10 cm and 15 cm above ground surface led to a significantly higher percent grade ‘AR’ seed cotton as compared to 5 cm and control during both short and long rains seasons (Table 20).

Table 20: Effect of cut height on percent grade ‘AR’ seed cotton during short and long rain seasons.

	Percent grade ‘AR’ seed cotton	
Cut height	Short rains season	Long rains season
control	69.0	72.7
5 cm	65.0	73.5
10 cm	86.0	85.0
15 cm	87.0	87.9
Mean	76.8	79.8
$LSD_{0.05}$ (Ht)	6.0	3.9

Ht – Cut height above ground surface

The percent grade ‘AR’ seed cotton in control plots was at par with that of cut height of 5 cm, whereas that of cut height of 10 cm was at par with that of 15 cm. There was no significant variation in percent grade ‘AR’ seed cotton between the three cotton varieties and no significant interaction between cut height and variety on percent grade ‘AR’ seed cotton (Appendices 60 and 61).

CHAPTER FIVE

DISCUSSION

5.1: Effect of cut height and nitrogen application on growth of ratoon cotton varieties HART 89M, F962 and A540

Cut height of the main cotton crop had a significant influence on the growth of the subsequent ratoon cotton crop in terms of: plant height, regeneration rate and re-growth shoots or number of sprout stems per cotton plant. Initially, the plant height of the ratoon increased with increase in cut height but thereafter, plants from directly seeded cotton became significantly taller than ratoon by the end of the long rains season (43 WAR). The initial rapid growth in ratoon as compared to directly seeded cotton could have been due to the ratoon having an already established root system for water and mineral uptake and a readily available supply of carbohydrates from the stump. This allowed the ratoon crops to continue growing while the directly seeded crop was developing a new root system. Gibb *et al.* (2005) noted that during the pre-flowering stages of cotton growth, production of carbohydrates through photosynthesis is in excess of demands, and as a result vigorous vegetative growth occurs. They indicated that once reproductive structures begin to develop, the high priority structures or preferred carbohydrate sinks are bolls, and the growth of new main stem nodes become secondary and stem growth then stops. Since the ratoon cotton had set the bolls earlier as compared to control, its vegetative growth including increase in height slowed down earlier.

Lack of significant variation in ratoon plant height among the three cotton varieties suggests that the varieties responded in a similar manner to ratooning.

Increased cut height led to increased survival of ratoon crop, increased cotton plant count and increased re-growth shoots or stems per plant in the three varieties. Flinn and Mercado (1986) noted that the growth of the ratoon rice largely depended on the reserve of the total available carbohydrates on the stub which in turn depended on the cut height of the main crop. According to Glen *et al*. (2007), branching on the main stem occurs initially from auxiliary buds of the main stem leaves generally referred to as main stem nodes giving rise to vegetative or monopodial and fruiting or sympodial stems. Wrigt *et al.* (2003) indicated that the cotyledonary or seed leaves are on node number 0 while on the lower nodes (i.e. nodes 2 through 5 or 6) give rise to vegetative branches and nodes 6 or 7, and above, are generally fruiting branches. The significant increase in number of sprout stems with increase in cut heights of the main cotton crop could be attributed to the increased available nodes and buds for regeneration along the stump due to increased cut height.

The data from the current study showed that nitrogen application increased the ratoon plant height and the re-growth shoots or number of stem sprouted from the cotton stump significantly but did not affect the plant count. Lack of significant effect of nitrogen on plant count could be attributed to the fact that the N fertilizer was applied 27 WAR, long after the crop stand had been established. Reddy *et al.* (2007) observed that regardless of the source, application of nitrogen at 40, 80 and 120 kg ha^{-1} significantly increased cotton growth and lint yield compared to control.

Variety F962 had a higher rate of plant regeneration thus a higher plant count than varieties HART 89M and A540. This indicates that variety F962 would be better for ratooning as compared to the other since it has better survival rate. This could probably mean that F962 has a more vigorous soot system or shorter main stem nodes as compared to A540 and HART 89M.

5.2: Effect of cut height and nitrogen application on pest incidences in ratoon cotton varieties HART 89M, F962 and A540

Lack of significant variation among the varieties with respect to pest incidences, could suggests that there was no differential pest preference to the cotton varieties. This calls for more work on induced pest infestations on these varieties for comprehensive conclusion. It is however evident that there is need for more breeding work to come up with pest resistant varieties cotton. Use of such varieties would encourage the build up of beneficial arthropods which include natural enemies and hence reduce pesticide application thus improving cotton productivity, farmer incomes and conserve the environment.

The type of pest and intensity of infestation on cotton varied with the cut height and time of the season. Aphids were the first cotton pests to appear on cotton. At 6 WAR or one week after emergence of cotton in control plots, significantly higher aphid counts were found in plants cut at 10 and 15 cm than in control. This could be attributed to the fact that the re-growth shoots from stumps cut at these heights were produced three weeks before germination of cotton in control plots resulting to a prolonged movement of this pest from other host plants to these plots. It has been indicated that ratooning may result in buildup of insect pests, harmful weeds, increased disease problem and loss of crop density (Glen, 2007). Cotton aphid has a broad host range, including crops like beans and weeds like nightshades which are common in Mwea. Aphids could easily transfer to cotton during the early stages of cotton growth (Farrell, 2007). According to Munro (1987), cotton Aphid

(*Aphis gossypii*) preferred to feed on young and soft leafy shoots and leaves rather than on old ones. It was observed that the ratoon cotton produced young shoots early enough when there were no other young plants in Kirogo farm.

There was a general increase in mites count with increase in cut height. Ratoon cotton had a higher mite count than the directly seeded cotton. This could also be due to carryover of the pest from ratoon cotton and other alternative hosts.

Although cotton stainers are ordinarily considered as late season cotton pests, they were observed early in the ratoon at 8 WAR. This could be attributed to the early boll formation by the ratoon as compared to directly seeded cotton thus leading to either early stainer invasion from other host crops, or carryover from the ratoon. Wilson *et al*. (2008) observed that usually cotton becomes infested by old stainers that fly into fields around the time of first boll open though sometimes, perhaps due to seasonal conditions, populations can be found early during boll maturation.

There was a general increase in bollworm counts with increase in cut height during the short rains season. This could have been due to migration of bollworms from the surrounding crops to the already regenerated cotton plants from heights 10 and 15 cm. The trial site was surrounded by maize and soybeans which are some of the preferred sites for reproduction and source of food for bollworms (Campbell, 2004).

Since ratoon cotton get an earlier start and flowers earlier than the directly seeded cotton (Evenson, 1969; Munro, 1987), it is subjected to early bollworm infestation. There is therefore need for earlier bollworm control in ratoon than in non-ratoon cotton.

Mealybug infestation was higher and appeared earlier in the ratoon than in directly seeded cotton. The level of infestation increased with the increase in cut height and progression of the season. Mealybug has many alternative hosts including cotton, papaya, citrus, pigeon peas and many weeds and has been found to overwinter as eggs on stems, in soil, in cracks and crevices in stems and inside crumpled leaves (Khaskheli, 2011). The increase of mealybug infestation with increase in cut height could be a result of earlier shoot re-growth associated with increased cut height and consequently extended exposure period to mealybug infestation. Application of pesticides has been ineffective in control of mealybugs due to their heavy wax layers hence the continued pest build up. Biological control that involves use of natural enemies may offer the safest, most economical and long term solution to this problem (Murray and Charleston, 2010).

Figure 5: Mealybug-infested ratoon cotton plant at Mwea 43 weeks after ratooning

The fact that thrips infestation appeared late in the season i.e. at 35 WAR could be attributed to a possible migration of the pest from alternative host plants such as maize (next to the experiment site) to cotton as the former became less attractive on drying up.

The experimental site was adjacent to a maize crop which dried earlier than usual due to the shortage of the rains.

Pest count data indicated that application of N did not affect the level of infestation by cotton aphids, mites, bollworms, mealybugs, stainers and thrips. This could be attributed to the fact that long rains disappeared three weeks after application of nitrogen causing lack of pest response N fertilization. Other researchers have observed increased pest incidences with increases of nitrogen application (Rustamani *et al.*, 1999). Godfrey (1998) observed approximately 300 aphids per leaf on plants fertilized with 91.0 Kg N per acre and 75 aphids per leaf on plants fertilized with 34 Kg N per acre. Other researchers have observed that excess nitrogen application is likely to enhance aphid (*Aphis gossypii*) infestation (Cisneros and Godfrey, 2001) in cotton. Working on impact of different doses of N fertilizer (50, 100, 150 and 200 kg ha^{-1}) on sucking insect pests in Pakistani, Ahmed *et al.* (2010), noted that 200 kg ha^{-1} resulted in higher leaf mean population of thrips compared to 50 kg ha^{-1}.

Increasing application of nitrogen from 18 to 55 Kg per acre has been found to produce taller cotton plants with more nodes and bolls but there were no significant differences in number of pests with increase in nitrogen (Robertson and Bednarz, 2005).

5.3: Effect of cut height and nitrogen application on yield and quality of seed cotton and lint in ratoon cotton varieties HART 89M, F962 and A540

Cotton variety F962 had significantly higher seed cotton yield than HART 89M but the yield difference between HART 89M and A540 was not significantly different during the first picking at 15 WAR (Table 16). This yield difference between varieties F962 and HART 89M could be attributed to difference in earliness associated with time of first boll split. Kimani *et al*. (2004) indicated ‘days to first boll split’ were 120.5, 116.2 and 114.0 for HART 89M, A540 and F962 as respectively. The directly seeded plots were first harvested at 19 WAR in HART 89M and A540 whereas that of F972 was harvested at 15 WAR. Ratoon cotton was first harvested at 15 WAR in the three varieties. This is an indication that ratoon cotton produced cotton earlier by one month as compared to directly seeded cotton. Variety F962 produced cotton one month earlier than varieties HART 89M and A540.There was need to breed superior cotton varieties in terms of earliness in order to reduce the current long growing period from 10 to 6 months in eastern and central Kenya.
It had been reported earlier that ratoon cotton plants got an earlier start and flowered earlier than cotton grown from seed (Evenson, 1969; Munro, 1987). Ratoon cotton flowered earlier by as much as six weeks in Egypt (Templeton, 1925) but more commonly by two to three weeks.

Increase in cutting height led to increased cumulated seed cotton yield, with 15 cm cut height having significantly higher yield (2822 kg ha^{-1}) than control (2241.3 kg ha^{-1}). This could be attributed to the earlier start of the ratoon, higher plant regeneration and number of sprout stems per plant associated the 15 cm cut height. Low seed cotton yield from plots where cotton had been cut at 5 cm could be attributed to the low plant population associated with that cut height (Table 8). These suggest that ratooning of cotton could be used to boost cotton yields by cutting at cut height of 15 cm. Several researchers have concluded that seed cotton yield and plant density are unrelated (Buxton *et al.,* 1977; Jones and Wells, 1998; Bednarz *et al*., 2000; Craig *et al.,* 2000). Other researchers, however, have observed reduced yields with extremely high or low plant densities (Bridge *et al*., 1973; Smith *et al.*, 1979). Bednarz *et al.* (2000) noted that as cotton plant density increased, this led to reduced boll retention and boll weight and less seed cotton as per plant basis. It had earlier been observed that when a ratoon crop is properly managed to avoid pests, disease and weed incidence, seed cotton yields are at least equal to and often better than those of cotton sown directly from seed (Evenson, 1970).

The results of this study indicated that nitrogen application did not affect seed cotton yield. Influence of N fertilizers on seed cotton yield across different soil types and climatic conditions has been reported by many researchers. Ikitoo (1985) reported that the variation in cotton response to nutrients over the years in one place appeared to be due mainly to differences in soils and climate. While investigating the impact of nitrogen on cotton plants *Gossypium hirsutum* at Riverside California, Bi *et al.,* (2000) observed that applications of 112, 168 and 224 kg nitrogen per hectare had no significant effect on seed cotton yield. In a three-year experiment Fritschi *et al.* (2003) found that lint yield was increased linearly each year with N fertility levels, attaining a maximum yield of 1842 kg ha^{-1} at the 224 kg N ha^{-1} rate. In a different experiment, Sawan *et al.* (2006) observed that there were significant increases in seed cotton yield per hectare with increases in nitrogen application rate from 95 to 143 kg N ha^{-1}. Ernest *et al.* (2005) observed significant increases in lint yield with each increases in nitrogen application rate (0, 50, 101 and 151 kg ha^{-1})

suggesting that the optimal N rate had not been surpassed. Working on the effect of nitrogen levels (0, 60, 120 and 180 kg N ha^{-1}) on cotton yield and quality in Pakistan; Saleem *et al.* (2010) observed that 120 kg N ha^{-1} had significantly higher seed cotton yields than all other levels. He concluded that when nitrogen is applied above the optimum level for crop performance, it reduced seed cotton yield.

The yield advantages due to optimal N application were attributed to larger bolls at a greater number of fruiting sites (Bouquet and Breitenbeck, 2000; Bouquet *et al.,* 1994; Moore, 1999). However Bouquet (2005) reported that increasing N rates from 90 to 157 kg N ha^{-1} did not result in increased lint yield in irrigated or rain-fed cotton. Lack of significant differences in seed cotton yield between fertilized and non-fertilized plots during the long rains season could be attributed to the low rainfall experienced during the long rains season (Appendix 2). The fertilizer Calcium Ammonium Nitrate was applied to in a single dose during the long rains season but the rains were too short and gradually ended earlier than usual. Split application of nitrogen into two (applying during both short and long rains season) should be explored.

During the 2007/2008 and 2008/2009 crop seasons, rainfall values at Mwea Kirogo farm site were lower at 373.9 and 790 mm respectively than the expected annual rainfall of 890 mm (appendix 2). The rainfall distribution was also poor with the long rains ending early in May instead of June. This may have affected the growth and yield response to nitrogen application. The cool night temperatures experienced during the season may have affected cotton yield negatively.Cool temperatures have been reported to be a major limitation on cotton productivity (Gipson, 1986; Ramey, 1986; Winter & Koniger, 1991). Gipson & Joham (1968) reported that cool temperatures (less than 20^{0}C) at night hinder cotton boll development. The production of successive nodes on the main stem and the time interval between the production of successive flowers on the successive fruiting branches on the main stem and between the first two flowers on the same fruiting branch is temperature dependent (Hesketh, *et al., 1972).*

There was a general increase in lint yield with increase of cut height during the short rains and not during the long rains season. Ratooning cotton varieties at 15 cm above ground surface increased lint yield significantly as compared to directly seeded cotton. Lint yield is a factor of lint percentage and seed cotton yield. Therefore all factors that affect lint percentage and seed cotton yield have an indirect effect on lint yield. Working on heritability of lint yield and its component traits in Pakistan, Saeed *et al*. (2007) observed that lint percentage had the greatest direct effect on lint yield. Other factors like delayed planting also reduces lint yield due to either reduced growing season or lowered plant densities (Kittock *et al*., 1987; Oaf *et al*., 2002).

The ultimate objective of cotton production is to produce lint. In order to increase lint production, seed cotton yield and or lint percentage must be improved or maintained. Cut height did not affect lint percentage in varieties HART 89M and F962 throughout the sampling period but lowered lint percentage in variety A540 during long rains season (Table 18). Lint percentage differed significantly among the three varieties with variety F962 having significantly higher lint percentage (38.7%) than HART 89M (36.1%) but was not different from that of variety A540 (37.1%). Similar trend had been reported earlier by Kimani *et al.* (2004) who observed that variety F962 had significantly higher lint percentage (40.1%) than HART 89M (37.4%) which was not different from that of A540 (37.2%). Although lint percentage is an inherent cotton quality, Kimani *et al*. (2003)

observed that ginning outturn of varieties HART 89M, F962 and A540 varied with site and season.

Data from this study indicated that nitrogen application did not affect lint percentage in the three varieties. The fact that rains disappeared three weeks after application of nitrogen (Appendix 2) could probably result to lack of any effect on lint percentage. Other researchers reported conflicting results on effect of nitrogen application on lint percentage. Thomson (1984) noted that nitrogen fertilizer reduced lint percentage, though there was no consistent relationship between rate of nitrogen application and lint percentage decrease. Working on the effect of nitrogen levels (0, 60, 120 and 180 kg N ha^{-1}) on cotton yield and quality in Pakistan; Saleem *et al.* (2010) observed that nitrogen had a significant effect on lint percentage and recorded the highest value for 120 kg N ha^{-1} which was at par with that of 180 kg N ha^{-1}.

Colour and trash are currently the main criteria used in classifying commercial seed cotton in Kenya into grades 'AR' and 'BR'. The quality of cotton lint is however affected by every production step including variety selection, cultural practices, harvesting and post harvest practices, ginning technology and contact with soil, grass or plant leaves (Munro, 1987; Reed, 2002; Meredith, 2005; Law *et al*. 2007). Grade 'AR' is the clean and pure white seed cotton completely free of trash and without any sign of stain from any cause and its price is 3 to 4 times higher than that of grade 'BR'. Grade 'BR' has soil dust or stains from whatever source.

Cut heights of 10 cm and 15 cm above ground surface had significantly higher percent grade 'AR' seed cotton than control and 5 cm cut height during both rain seasons. The significantly shorter cotton plants associated with cut height of 5 cm and control as compared to that of 10 and 15 cm could have led to staining by soil from the rain splash and other foreign matter.

The main effects of the variety and nitrogen did not have significant effect on percent grade ‘AR’ seed cotton. This indicates that the commercial grade of seed cotton is not genetically controlled but is mainly dependent on crop management and farm hygiene.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1: Conclusions

Ratoon cotton is not stand over cotton i.e. cotton allowed to grow for two years or more without being touched in any way. Ratoon cotton in this study referred to a re-growth from a small stump above the ground left over after cutting the previous season's main cotton crop and the rest of the stalk burnt. Therefore performance of the ratoon is dependent on adoption of appropriate management practices of the previous season's crop as well as the ratoon itself. These practices will include land preparation, adequate plant density, right cultivars, adequate fertilization, and appropriate cutting height, control of weeds, pests and diseases.

The survival and growth of the ratoon was highly influenced by the cut height of the main cotton crop. Increase in cutting height led to increased plant height, plant count, stems per plant and cotton yield from ratoon. However, increase in survival of ratoon cotton plants and sprout stems may result to increased bushiness of the ratoon crop. This may consequently lead to poor chemical coverage during spray and cumbersome harvesting process. On the other hand, the 5 cm cut height had a negative influence on regeneration of ratoon in all the varieties. This could lead to a decrease in plant count of the ratoon as compared to that of directly seeded cotton (control) resulting to decreased yield.

The three varieties tested did not vary significantly in plant height and the number of sprout stems. Variety F962 had significantly higher regeneration rate and hence plant count (33.8) than variety A540 (29.3) at the end of long rains season which was at par with that of HART 89M (30.3). This suggests that ratooning of varieties F962 and HART 89M would not adversely affect the plant density of the ratoon but would significantly reduce the plant density in variety A540.

Fertilizer application (110 kg N ha^{-1}) had a positive impact on cotton plant height, the number of sprout stems but did not affect the seed cotton yield. The soil fertility analysis results had shown that, the experimental site had 0.11% total nitrogen which was classified as low. It was therefore expected that N application would have a positive response in various parameters including seed cotton yield. The fact that rains disappeared three weeks after application of nitrogen (Appendix 2) could probably cause the lack of yield response. It may be necessary to apply N in two splits, relative to a single application rate.

Ratoon cotton crop suffered an earlier attack from aphids, bollworms, and mealybugs when compared to directly seeded cotton (control). Level of natural infestation by aphids, mealybugs, stainers and thrips did not differ significantly among the three varieties during short rains season. Mite infestation was however significantly lower in variety A540 than in HART 89M and F962 during the same period. This suggests that there were no varietal preferences by the pests except mites which had higher preference for HART 89M and F962 than A540. Similarly, bollworms had a higher preference for variety A540 (1.8) than for HART 89M (1.3) and F962 (1.3). The findings may be useful in breeding programs for pest tolerance against mites and bollworms in cotton.

There were significantly higher counts of aphids, red spider mites, bollworms and mealybugs at cut heights 15 and 10 cm than at heights 5 cm and control during the early stages of short rains season. However as the season progressed, the trend was reversed with control and 5 cm cut heights showing a higher pest count than 10 and 15 cm cut heights. These pests therefore seemed to prefer the young shoots to older ones.

The natural infestation of cotton by the stainers and thrips occurred during the long rains season only with a similar count among the varieties and across the cut heights. Application of CAN fertilizer did not have a significant effect on the level of infestation by the bollworms, thrips, mealybugs and mites but it seemed to decrease infestation by aphids and stainers.

Cotton variety F962 produced seed cotton earlier by 4 weeks compared to varieties HART 89M and A540. This quality can be used in breeding to produce shorter duration maturing cotton varieties. Among the tested varieties HART 89M showed the maximum cumulative seed cotton yield (2452 kg ha^{-1}) followed by F962 (2440 kg ha^{-1}) whereas A540 had the lowest (2079 kg ha^{-1}). Though the difference in yield was not statistically significant, farmers would rather grow HART 89M which they are already used to.

Cut height of 15 cm above ground surface gave significantly higher seed cotton yield (2822 kg ha^{-1}) than the directly seeded cotton (2241 kg ha^{-1}) and 5 cm cut height (1802 kg ha^{-1}) across all varieties. This was however not different from that of 10 cm cut height (2428 kg ha^{-1}). This data suggests that cut height of 15 cm above ground surface would be the best cut height for seed cotton yield improvement in ratoon production systems. The low plant counts associated with 5 cm cut height could have led to the low seed cotton yields at that cut height.

Variety F962 had a higher lint percentage (38.7%) followed by A540 (37.1%) and HART 89M (36.1%) across the cut heights during short rains season with similar trend during the long rains. Based on lint percentage alone, variety F962 would have been the best variety for ratooning followed by A540 and finally HART 89M. However, on ratooning, lint percentage in variety A540 was reduced significantly to 35.7% but not that of varieties HART 89M and F962 during long rains season. These results suggest that although lint percentage is mainly genetically controlled, ratooning had a negative influence on lint percentage in variety A540.

Cut height of 15 cm showed significantly higher cumulative lint yield than 5 cm and directly seeded cotton. This supports the fact that ratooning cotton at 15 cm improved lint output as compared to 5 and 10 cm. The variation in cumulative lint yield among the varieties was not significant. However, F962 showed the maximum (940.5 kg ha^{-1}) followed by HART 89M (885.5 kg ha^{-1}) and finally A540 (768.5 kg ha^{-1}). This indicates currently, variety F962 is the best for ratooning, followed by HART 89M but there is need for breeding better varieties that are better adapted to ratooning.

Ratooning cotton at cut heights of 10 and 15 cm above ground surface showed significantly higher percent grade 'AR' seed cotton than control and 5 cm cut height. This is an indication that due to the taller ratoon plants, cut heights of 10 and 15 cm may have reduced the chances of staining of cotton by the soil and getting into contact with foreign materials. Commercial grade of seed cotton is mainly influenced by crop management and not the genetic composition.

6.2: Recommendations

Cotton growing is a viable enterprise in arid and semi arid districts in Kenya with low and unreliable rains. There are no short duration maturing cotton varieties currently and farmers in these areas occasionally suffer from total crop failure due to drought. The results of this study implies that those farmers can avert the risks of drought and consequent poor cotton germination by ratooning the previous season's cotton crop at 15 cm above ground surface. At this cut height seed cotton yield (2822 kg ha^{-1}) was significantly higher than that of directly seeded cotton (2241 kg ha^{-1}). In addition, lint yield (1040 kg ha^{-1}) was significantly higher than that of directly seeded cotton (845 kg ha^{-1}). Farmers would therefore be certain of getting a crop from the ratoon during times of drought. They would also save on labour required for land preparation, planting, thinning and on money required for purchasing of seed. Since ratooning did not affect the quantity of commercial grade (grade 'AR') cotton, farmers would get more income.

Variety F962 would be a better replacement for HART 89M (the current commercial variety for the region) since it responded well to ratooning, has a higher lint percentage, lint yield and regeneration capacity than the other two varieties.

Ratooning led to earlier infestation of cotton by aphids, bollworms, stainers and mealybugs. These calls for a regular pest scouting program so as to undertake timely detection and control. There is need for further research on ratoon cotton cropping systems so as to take advantage of ratoon cotton such as early yield production and put up measures to address the disadvantages of ratooning in arid and semi arid regions. It would be necessary to establish the appropriate time for cutting the main crop, maximum cut height and the number of times cotton can be ratooned without affecting pest incidences, yield and other quality parameters such as fibre strength, length and micronaire. Suitable agronomic practices covering, fertilizer application (time of application, types and quantities) should also be worked out. Weather patterns of different regions should be considered to guide on the timing of these agronomic practices to ensure that harvesting time does not coincide with the wet period. In addition, different rainfall patterns and quantities could lead to very different yield responses by the ratoon crop.

It is important to evaluate the optimal N requirement for growth and yield of the ratoon crop in the major soils of cotton growing areas including advantages of split application of nitrogen relative to single application and time of application.

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APPENDICES

Appendix 1: Soil chemical characteristics at Kirogo field experimental site

Soil attribute	Levels
Soil pH	5.63
Total Nitrogen %	0.11
Org. Carbon %	0.97
Phosphorus (ppm)	170
Potassium (me %)	1.50
Calcium (me %)	5.0
Magnesium (me %)	5.76
Manganese (me %)	1.23
Copper (ppm)	3.6
Iron (ppm)	84.6
Zinc (ppm)	3.2
Sodium (me %)	0.14

Appendix 2: Weather data for Kirogo field experimental site during the 2007/08 and 2008/09 crop seasons

	RAINFALL (mm)				TEMPERATURE (^{0}C)			
Year	2007/2008		2008/2009		2007/2008		2008/2009	
Month	mm	rain day	mm	rain day	max	min	max	Min
Oct	104	7	210	11	28.6	18.5	29	18.2
Nov.	77	7	70	10	27.6	17.2	28	18.4
Dec.	30	4	0	0	27.5	15.1	29	15.0
Jan.	39	3	98	3	28.2	15.3	29	15.6
Feb.	13.4	1	0	0	28.2	15.3	27	15.0
Mar	104.2	11	120	3	30.5	18.0	31	17.1
Apr.	0	0	205	8	26.9	18.0	28	18.4
May	1.5	1	87	9	28.0	18.0	27	19.0
June	0	0	0	0	26.0	17.2	28	16.5
July	4.8	1	0	0	27.0	16.5	27	15.2
Aug.	0	0	0	0	27.0	16.5	28	17.0
Sept	0	0	0	0	29.7	17.6	28	17.0
Total	**373.9**	**35**	**790**	**44**	**335.2**	**203.2**	**339**	**202.4**
Mean	**31.1**	**2.9**	**65.8**	**3.7**	**27.9**	**16.9**	**28.2**	**16.8**

Appendix 3: ANOVA Table for the effects of variety and cut height on cotton plant height at 10 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	55.14	18.38	
Variety (Var)	2	4.45	2.22	0.957
Residual error (A)	6	298.22	49.7	
Cut height (Ht)	3	18190.93	6063.64	<.001
Variety X Cut height (Var X Ht)	6	808.43	134.74	0.004
Residual error (B)	27	868.95	32.18	
Total residual error	47	20226.12		

Appendix 4: ANOVA Table for the effects of variety and cut height on cotton plant height at 15 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	739.88	246.62	
Variety (Var)	2	165.01	82.51	0.266
Residual error (A)	6	297.66	49.61	
Cut height (Ht)	3	6682.63	2227.54	<.001
Variety X Cut height (Var X Ht)	6	308.03	51.34	0.629
Residual error (B)	27	1895.22	70.19	
Total residual error	47	10088.42		

Appendix 5: ANOVA Table for the effects of variety and cut height on cotton plant height at 19 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	776.35	258.78	
Variety (Var)	2	438.01	219.01	0.233
Residual error (A)	6	701.86	116.98	
Cut height (Ht)	3	1494.19	498.06	0.002
Variety X Cut height (Var X Ht)	6	579.66	96.61	0.338
Residual error (B)	27	2179.91	80.74	
Total residual error	47	6169.98		

Appendix 6: ANOVA Table for the effects of variety and cut height on cotton plant height at 23 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	639.96	213.32	
Variety (Var)	2	296.53	148.27	0.296
Residual error (A)	6	593.26	98.88	
Cut height (Ht)	3	878.87	292.96	0.034
Variety X Cut height (Var X Ht)	6	496.72	82.79	0.483
Residual error (B)	27	2376.91	88.03	
Total residual error	47	5282.25		

Appendix 7: ANOVA Table for the effects of variety, cut height and nitrogen application on cotton plant height at 31 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	784.63	261.54	
Variety (Var)	2	359.05	179.52	0.5
Residual error (A)	6	1383.57	230.59	
Cut height (Ht)	3	980.95	326.98	0.06
Variety X Cut height (Var X Ht)	6	1819.92	303.32	0.042
Residual error (B)	27	3179.16	117.75	
N - Rate	1	783.76	783.76	<.001
Variety X N Rate	2	5.78	2.89	0.8
Cut height X N_Rate	3	125.87	41.96	0.032
VAR x Cut height X N Rate	6	39.14	6.52	0.799
Residual error (C)	36	462.74	12.85	
Total Residual	95	9924.54		

Appendix 8: ANOVA Table for the effects of variety, cut height and nitrogen application on cotton plant height at 35 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	1072.86	357.62	
Variety (Var)	2	298.08	149.04	0.626
Residual error (A)	6	1760.92	293.49	
Cut height (Ht)	3	1013.03	337.68	0.059
Variety X Cut height (Var X Ht)	6	1840.5	306.75	0.044
Residual error (B)	27	3252.34	120.46	
N - Rate	1	931.26	931.26	<.001
Variety X N Rate	2	0.33	0.17	0.99
Cut height X N_Rate	3	59.2	19.73	0.31
VAR x Cut height X N Rate	6	42.08	7.01	0.847
Residual error (C)	36	573.62	15.93	
Total Residual	95	10844.24		

Appendix 9: ANOVA Table for the effects of variety, cut height and nitrogen application on cotton plant height at 39 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	1181.86	393.95	
Variety (Var)	2	482.65	241.32	0.553
Residual error (A)	6	2207.35	367.89	
Cut height (Ht)	3	1039.11	346.37	0.021
Variety X Cut height (Var X Ht)	6	1622.85	270.48	0.023
Residual error (B)	27	2446.91	90.63	
N - Rate	1	1073.34	1073.34	<.001
Variety X N Rate	2	9.44	4.72	0.742
Cut height X N_Rate	3	36.03	12.01	0.521
VAR x Cut height X N Rate	6	87.06	14.51	0.49
Residual error (C)	36	565.62	15.71	
Total Residual	95	10752.24		

Appendix 10: ANOVA Table for the effects of variety, cut height and nitrogen application on cotton plant height at 43 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	1119.04	373.01	
Variety (Var)	2	425.15	212.57	0.588
Residual error (A)	6	2193.27	365.55	
Cut height (Ht)	3	1188.79	396.26	0.01
Variety X Cut height (Var X Ht)	6	1326.77	221.13	0.043
Residual error (B)	27	2337.94	86.59	
N – Rate	1	1107.04	1107.04	<.001
Variety X N Rate	2	23.9	11.95	0.416
Cut height X N_Rate	3	64.12	21.38	0.204
VAR x Cut height X N Rate	6	66.69	11.11	0.55
Residual error (C)	36	478.25	13.28	
Total Residual	95	10330.96		

Appendix 11: ANOVA Table for the effects of variety and cut height on sprouted stems per cotton plant at 10 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	2.1356	0.7119	
Variety (Var)	2	0.6837	0.3419	0.38
Residual error (A)	6	1.7963	0.2994	
Cut height (Ht)	3	97.7006	32.5669	<.001
Variety X Cut height (Var X Ht)	6	3.2763	0.546	0.115
Residual error (B)	27	7.7006	0.2852	
Total residual error	47	113.2931		

Appendix 12: ANOVA Table for the effects of variety and cut height on sprouted stems per cotton plant at 15 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	2.0123	0.6708	
Variety (Var)	2	1.2837	0.6419	0.2
Residual error (A)	6	1.8046	0.3008	
Cut height (Ht)	3	132.2623	44.0874	<.001
Variety X Cut height (Var X Ht)	6	1.2596	0.2099	0.249
Residual error (B)	27	4.0356	0.1495	
Total residual error	47	142.6581		

Appendix 13: ANOVA Table for the effects of variety and cut height on sprouted stems per cotton plant at 19 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	1.7083	0.5694	
Variety (Var)	2	1.7529	0.8765	0.064
Residual error (A)	6	1.1704	0.1951	
Cut height (Ht)	3	152.8717	50.9572	<.001
Variety X Cut height (Var X Ht)	6	1.3321	0.222	0.112
Residual error (B)	27	3.1012	0.1149	
Total residual error	47	161.9367		

Appendix 14: ANOVA Table for the effects of variety and cut height on sprouted stems per cotton plant at 23 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	2.1056	0.7019	
Variety (Var)	2	1.8904	0.9452	0.092
Residual error (A)	6	1.5512	0.2585	
Cut height (Ht)	3	172.4156	57.4719	<.001
Variety X Cut height (Var X Ht)	6	1.3263	0.221	0.16
Residual error (B)	27	3.5156	0.1302	
Total residual error	47	182.8048		

Appendix 15: **ANOVA Table for the effects of variety, cut height and nitrogen application on sprouted stems per cotton plant at 31 WAR**

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	2.59458	0.86486	
Variety (Var)	2	2.98312	1.49156	0.105
Residual error (A)	6	2.67104	0.44517	
Cut height (Ht)	3	403.7513	134.5838	<.001
Variety X Cut height (Var X Ht)	6	1.47187	0.24531	0.681
Residual error (B)	27	10.01437	0.3709	
N – Rate	1	1.55042	1.55042	<.001
Variety X N Rate	2	0.01646	0.00823	0.768
Cut height X N_Rate	3	0.63125	0.21042	<.001
VAR x Cut height X N Rate	6	0.17688	0.02948	0.471
Residual error (C)	36	1.115	0.03097	
Total Residual	95	426.9763		

Appendix 16: **ANOVA Table for the effects of variety, cut height and nitrogen application on sprouted stems per cotton plant at 35 WAR**

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	3.05698	1.01899	
Variety (Var)	2	3.43187	1.71594	0.138
Residual error (A)	6	3.67396	0.61233	
Cut height (Ht)	3	457.9803	152.6601	<.001
Variety X Cut height (Var X Ht)	6	1.27063	0.21177	0.68
Residual error (B)	27	8.62031	0.31927	
N – Rate	1	1.6801	1.6801	<.001
Variety X N Rate	2	0.05396	0.02698	0.556
Cut height X N_Rate	3	0.59115	0.19705	0.01
VAR x Cut height X N Rate	6	0.06354	0.01059	0.962
Residual error (C)	36	1.62625	0.04517	
Total Residual	95	482.0491		

Appendix 17: ANOVA Table for the effects of variety, cut height and nitrogen application on sprouted stems per cotton plant at 39 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	3.1125	1.0375	
Variety (Var)	2	2.38083	1.19042	0.21
Residual error (A)	6	3.4875	0.58125	
Cut height (Ht)	3	488.1358	162.7119	<.001
Variety X Cut height (Var X Ht)	6	1.32167	0.22028	0.716
Residual error (B)	27	9.655	0.35759	
N – Rate	1	1.30667	1.30667	<.001
Variety X N Rate	2	0.25083	0.12542	0.106
Cut height X N_Rate	3	0.56583	0.18861	0.023
VAR x Cut height X N Rate	6	0.13167	0.02194	0.861
Residual error (C)	36	1.885	0.05236	
Total Residual	95	512.2333		

Appendix 18: ANOVA Table for the effects of variety and cut height on cotton plant count at 10 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	54.7	18.06	
Variety (Var)	2	33.79	16.9	0.721
Residual error (A)	6	292.71	48.78	
Cut height (Ht)	3	24300.0	8100.0	<.001
Variety X Cut height (Var X Ht)	6	873.37	145.56	0.023
Residual error (B)	27	1313.62	48.65	
Total residual error	47	1815.3		

Appendix 19: ANOVA Table for the effects of variety and cut height on cotton plant count at 15 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	45.17	15.06	
Variety (Var)	2	318.5	159.3	0.052
Residual error (A)	6	189.8	31.64	
Cut height (Ht)	3	8660.2	2886.7	<.001
Variety X Cut height (Var X Ht)	6	420.3	70.06	0.065
Residual error (B)	27	826.0	30.59	
Total residual error	47	1815.3		

Appendix 20: **ANOVA Table for the effects of variety and cut height on cotton plant count at 19 WAR**

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	29.2	9.7	
Variety (Var)	2	123.5	61.8	0.154
Residual error (A)	6	142.8	23.8	
Cut height (Ht)	3	3847.7	1282.6	0.002
Variety X Cut height (Var X Ht)	6	587.3	97.9	0.803
Residual error (B)	27	918.5	34.02	
Total residual error	47	1739.5		

Appendix 21: ANOVA Table for the effects of variety and cut height on cotton plant count at 23 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	55.08	18.36	
Variety (Var)	2	308.29	154.15	0.018
Residual error (A)	6	109.04	18.17	
Cut height (Ht)	3	7615.4	2538.47	<.001
Variety X Cut height (Var X Ht)	6	495.21	82.53	0.058
Residual error (B)	27	942.88	34.92	
Total residual error	47	1620.1		

Appendix 22: ANOVA Table for the effects of variety cut height and nitrogen application on plant count at 43 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	9.42	3.14	
Variety (Var)	2	358.6	179.3	0.003
Residual error (A)	6	57.1	9.5	
Cut height (Ht)	3	3325.6	1108.5	0.001
Variety X Cut height (Var X Ht)	6	244.7	40.8	0.072
Residual error (B)	27	496	18.4	
N – Rate	1	4.17	4.17	0.576
Variety X N Rate	2	11.08	5.54	0.66
Cut height X N_Rate	3	42.08	14.03	0.37
VAR x Cut height X N Rate	6	82.7	13.7	0.41
Residual error (C)	36	470.5	13.07	
Total Residual	95	5101.8		

Appendix 23: ANOVA Table for the effects of variety and cut height on aphid counts at 6 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	229.17	76.39	
Variety (Var)	2	59.04	29.52	0.624
Residual error (A)	6	346.96	57.83	
Cut height (Ht)	3	260.5	86.83	0.043
Variety X Cut height (Var X Ht)	6	332.12	55.35	0.105
Residual error (B)	27	756.88	28.03	
Total residual error	47	1984.67		

Appendix 24: ANOVA Table for the effects of variety and cut height on aphid counts at 10 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	295.17	98.39	
Variety (Var)	2	78.79	39.4	0.508
Residual error (A)	6	310.71	51.78	
Cut height (Ht)	3	164.17	54.72	0.019
Variety X Cut height (Var X Ht)	6	45.21	7.53	0.773
Residual error (B)	27	376.62	13.95	
Total residual error	47	1270.67		

Appendix 25: ANOVA Table for the effects of variety and cut height on aphid counts at 15 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	29.488	9.829	
Variety (Var)	2	0.061	0.031	0.998
Residual error (A)	6	75.555	12.593	
Cut height (Ht)	3	206.41	68.803	<.001
Variety X Cut height (Var X Ht)	6	41.879	6.98	0.103
Residual error (B)	27	94.966	3.517	
Total residual error	47	448.36		

Appendix 26: ANOVA Table for the effects of variety, cut height and nitrogen application on aphid counts at 31 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	615.67	205.22	
Variety (Var)	2	291.02	145.51	0.758
Residual error (A)	6	3015.15	502.52	
Cut height (Ht)	3	97.5	32.5	0.799
Variety X Cut height (Var X Ht)	6	1818.31	303.05	0.018
Residual error (B)	27	2605.69	96.51	
N – Rate	1	4.17	4.17	0.787
Variety X N Rate	2	121.9	60.95	0.347
Cut height X N_Rate	3	142.33	47.44	0.477
VAR x Cut height X N Rate	6	813.1	135.52	0.045
Residual error (C)	36	2014.5	55.96	
Total Residual	95	11539.33		

Appendix 27: ANOVA Table for the effects of variety, cut height and nitrogen application on aphid counts at 35 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	5485.08	1828.36	
Variety (Var)	2	115.65	57.82	0.742
Residual error (A)	6	1105.1	184.18	
Cut height (Ht)	3	35.92	11.97	0.166
Variety X Cut height (Var X Ht)	6	23.02	3.84	0.739
Residual error (B)	27	177.06	6.56	
N – Rate	1	54	54	0.054
Variety X N Rate	2	4.69	2.34	0.842
Cut height X N_Rate	3	16.25	5.42	0.755
VAR x Cut height X N Rate	6	128.31	21.39	0.183
Residual error (C)	36	488.75	13.58	
Total Residual	95	7633.83		

Appendix 28: ANOVA Table for the effects of variety and cut height on spider mite counts at 10 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	41.83	13.94	
Variety (Var)	2	50.04	25.02	0.076
Residual error (A)	6	36.79	6.13	
Cut height (Ht)	3	356.5	118.8	0.001
Variety X Cut height (Var X Ht)	6	74.62	12.43	0.025
Residual error (B)	27	114.88	4.25	
Total residual error	47	674.67		

Appendix 29: ANOVA Table for the effects of variety and cut height on spider mite counts at 15 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	51.998	17.333	
Variety (Var)	2	77.493	38.746	0.046
Residual error (A)	6	43.38	7.23	
Cut height (Ht)	3	8.342	2.781	0.59
Variety X Cut height (Var X Ht)	6	63.017	10.503	0.05
Residual error (B)	27	115.466	4.277	
Total residual error	47	359.697		

Appendix 30: ANOVA Table for the effects of variety, cut height and nitrogen application on spider mite counts at 31 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	11067.7	3689.23	
Variety (Var)	2	2092.58	1046.29	0.22
Residual error (A)	6	3210.33	535.06	
Cut height (Ht)	3	1008.53	336.18	0.243
Variety X Cut height (Var X Ht)	6	2020.00	336.67	0.223
Residual error (B)	27	6151.84	227.85	
N – Rate	1	0.09	0.09	0.964
Variety X N Rate	2	54.25	27.12	0.556
Cut height X N_Rate	3	76.61	25.54	0.64
VAR x Cut height X N Rate	6	263.67	43.94	0.461
Residual error (C)	36	1635.88	45.44	
Total Residual	95	27581.49		

Appendix 31: ANOVA Table for the effects of variety, cut height and nitrogen application on spider mite counts at 35 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	12768.86	4256.29	
Variety (Var)	2	1482.25	741.12	0.53
Residual error (A)	6	6284.92	1047.49	
Cut height (Ht)	3	175.36	58.45	0.797
Variety X Cut height (Var X Ht)	6	881.92	146.99	0.54
Residual error (B)	27	4642.09	171.93	
N – Rate	1	10.01	10.01	0.48
Variety X N Rate	2	78.08	39.04	0.151
Cut height X N_Rate	3	253.95	84.65	0.011
VAR x Cut height X N Rate	6	35.08	5.85	0.934
Residual error (C)	36	706.38	19.62	
Total Residual	95	27318.91		

Appendix 32: ANOVA Table for the effects of variety and cut height on bollworm counts at 6 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	9.167	3.056	
Variety (Var)	2	2.667	1.333	0.556
Residual error (A)	6	12.333	2.056	
Cut height (Ht)	3	49.167	16.389	<.001
Variety X Cut height (Var X Ht)	6	26.333	4.389	0.008
Residual error (B)	27	32	1.185	
Total residual error	47	131.667		

Appendix 33: **ANOVA Table for the effects of variety and cut height on bollworm counts at 10 WAR**

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	5.0625	1.6875	
Variety (Var)	2	0.375	0.1875	0.857
Residual error (A)	6	7.125	1.1875	
Cut height (Ht)	3	4.5625	1.5208	0.153
Variety X Cut height (Var X Ht)	6	1.625	0.2708	0.91
Residual error (B)	27	21.5625	0.7986	
Total residual error	47	40.3125		

Appendix 34: ANOVA Table for the effects of variety and cut height on bollworm counts at 15 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	0.4167	0.1389	
Variety (Var)	2	0.2917	0.1458	0.523
Residual error (A)	6	1.2083	0.2014	
Cut height (Ht)	3	0.4167	0.1389	0.768
Variety X Cut height (Var X Ht)	6	1.7083	0.2847	0.594
Residual error (B)	27	9.875	0.3657	
Total residual error	47	13.9167		

Appendix 35: ANOVA Table for the effects of variety and cut height on mealybug incidences in cotton at 10 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	213.08	71.03	
Variety (Var)	2	96.29	48.15	0.656
Residual error (A)	6	637.54	106.26	
Cut height (Ht)	3	12519.08	4173.03	<.001
Variety X Cut height (Var X Ht)	6	598.04	99.67	0.248
Residual error (B)	27	1911.88	70.81	
Total residual error	47	15975.92		

Appendix 36: ANOVA Table for the effects of variety and cut height on mealybug incidences in cotton at 15 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	85.75	28.58	
Variety (Var)	2	44.67	22.33	0.813
Residual error (A)	6	626	104.33	
Cut height (Ht)	3	17451.58	5817.19	<.001
Variety X Cut height (Var X Ht)	6	86.17	14.36	0.967
Residual error (B)	27	1753.75	64.95	
Total residual error	47	20047.92		

Appendix 37: ANOVA Table for the effects of variety, cut height and nitrogen application on mealybug incidences in cotton at 31 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	1181.85	393.95	
Variety (Var)	2	1054.77	527.39	0.198
Residual error (A)	6	1473.58	245.6	
Cut height (Ht)	3	38420.47	12806.82	<.001
Variety X Cut height (Var X Ht)	6	1196.73	199.46	0.194
Residual error (B)	27	3430.97	127.07	
N – Rate	1	4.17	4.17	0.76
Variety X N Rate	2	37.21	18.6	0.659
Cut height X N_Rate	3	101.49	33.83	0.519
VAR x Cut height X N Rate	6	489.19	81.53	0.116
Residual error (C)	36	1584.59	44.02	
Total Residual	95	48975.02		

Appendix 38: ANOVA Table for the effects of variety, cut height and nitrogen on mealybug incidences in cotton at 43 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	220.71	73.57	
Variety (Var)	2	194.81	97.41	0.791
Residual error (A)	6	2402.85	400.48	
Cut height (Ht)	3	57835.21	19278.4	<.001
Variety X Cut height (Var X Ht)	6	1669.6	278.27	0.062
Residual error (B)	27	3237.44	119.91	
N – Rate	1	100.04	100.04	0.216
Variety X N Rate	2	106.9	53.45	0.438
Cut height X N_Rate	3	556.21	185.4	0.046
VAR x Cut height X N Rate	6	619.35	103.23	0.166
Residual error (C)	36	2274.5	63.18	
Total Residual	95	69217.62		

Appendix 39: ANOVA Table for the effects of variety, cut height and nitrogen application on stainer counts at 31 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	1647.6	549.2	
Variety (Var)	2	209	104.5	0.711
Residual error (A)	6	1735	289.2	
Cut height (Ht)	3	49.7	16.6	0.979
Variety X Cut height (Var X Ht)	6	1116.8	186.1	0.64
Residual error (B)	27	7018.7	260	
N – Rate	1	672	672	0.04
Variety X N Rate	2	582	291	0.154
Cut height X N_Rate	3	276.9	92.3	0.603
VAR x Cut height X N Rate	6	420.3	70.1	0.822
Residual error (C)	36	5307.8	147.4	
Total Residual	95	19035.8		

Appendix 40: ANOVA Table for the effects of variety, cut height and nitrogen application on stainer counts at 35 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	3248.11	1082.70	
Variety (Var)	2	22.40	11.20	0.66
Residual error (A)	6	154.10	25.68	
Cut height (Ht)	3	130.53	43.51	0.068
Variety X Cut height (Var X Ht)	6	19.19	3.20	0.975
Residual error (B)	27	440.91	16.33	
N – Rate	1	0.51	o.51	0.876
Variety X N Rate	2	2.90	1.45	0.933
Cut height X N_Rate	3	124.11	41.37	0.133
VAR x Cut height X N Rate	6	102.35	17.06	0.561
Residual error (C)	36	747.62	20.77	
Total Residual	95	4992.74		

Appendix 41: ANOVA Table for the effects of variety, cut height and nitrogen application on thrip counts at 35 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	30571.75	10190.58	
Variety (Var)	2	170.77	85.39	0.953
Residual error (A)	6	10459.81	1743.3	
Cut height (Ht)	3	2703.92	901.31	0.059
Variety X Cut height (Var X Ht)	6	1437.15	239.52	0.619
Residual error (B)	27	8695.94	322.07	
N – Rate	1	0.17	0.17	0.96
Variety X N Rate	2	190.4	95.2	0.241
Cut height X N_Rate	3	311.08	103.69	0.203
VAR x Cut height X N Rate	6	479.85	79.98	0.307
Residual error (C)	36	2312.5	64.24	
Total Residual	95	57333.33		

Appendix 42: ANOVA Table for the effects of variety and cut height on seed cotton yield at 15 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	12709	4236	
Variety (Var)	2	43514	21757	0.02
Residual error (A)	6	16293	2716	
Cut height (Ht)	3	1213726	404575	<.001
Variety X Cut height (Var X Ht)	6	64204	10701	0.199
Residual error (B)	27	185821	6882	
Total residual error	47	1536267		

Appendix 43: ANOVA Table for the effects of variety and cut height on seed cotton yield at 19 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	47001	15667	
Variety (Var)	2	160233	80117	0.173
Residual error (A)	6	201910	33652	
Cut height (Ht)	3	5965593	1988531	<.001
Variety X Cut height (Var X Ht)	6	212049	35341	0.244
Residual error (B)	27	673314	24938	
Total residual error	47	7260101		

Appendix 44: ANOVA Table for the effects of variety and cut height on seed cotton yield at 23 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	28220	9407	
Variety (Var)	2	118566	59283	0.007
Residual error (A)	6	27838	4640	
Cut height (Ht)	3	77224	25741	0.001
Variety X Cut height (Var X Ht)	6	28166	4694	0.291
Residual error (B)	27	97584	3614	
Total residual error	47	377598		

Appendix 45: ANOVA Table for the effects of variety and cut height on seed cotton yield at 27 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	56746	18915	
Variety (Var)	2	169251	84626	0.423
Residual error (A)	6	509855	84976	
Cut height (Ht)	3	1700039	566680	<.001
Variety X Cut height (Var X Ht)	6	138198	23033	0.835
Residual error (B)	27	1365277	50566	
Total residual error	47	3939366		

Appendix 46: ANOVA Table for the effects of variety, cut height and nitrogen application on seed cotton yield at 31 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	1167530	389177	
Variety (Var)	2	378890	189445	0.09
Residual error (A)	6	307011	51168	
Cut height (Ht)	3	150260	50087	0.187
Variety X Cut height (Var X Ht)	6	246400	41067	0.248
Residual error (B)	27	788195	29192	
N-Rate	1	4955	4955	0.581
Variety X N-Rate	2	44996	22498	0.258
Cut height X N_Rate	3	27365	9122	0.638
VAR x Cut height X N Rate	6	40460	6743	0.859
Residual error (C)	36	574852	15968	
Total Residual	95	3730914		

Appendix 47: ANOVA Table for the effects of variety, cut height and nitrogen application on seed cotton yield at 35 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	192550	64183	
Variety (Var)	2	257354	128677	0.222
Residual error (A)	6	394482	65747	
Cut height (Ht)	3	340605	113535	0.006
Variety X Cut height (Var X Ht)	6	275229	45872	0.085
Residual error (B)	27	587642	21765	
N-Rate	1	21210	21210	0.243
Variety X N-Rate	2	20602	10301	0.51
Cut height X N_Rate	3	18277	6092	0.75
VAR x Cut height X N Rate	6	40285	6714	0.842
Residual error (C)	36	540793	15022	
Total Residual	95	2689029		

Appendix 48: ANOVA Table for the effects of variety, cut height and nitrogen application on seed cotton yield at 39 WAR

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	43944	14648	
Variety (Var)	2	15111	7555	0.892
Residual error (A)	6	390245	65041	
Cut height (Ht)	3	82414	27471	0.227
Variety X Cut height (Var X Ht)	6	198167	33026	0.126
Residual error (B)	27	481735	17842	
N-Rate	1	51	51	0.96
Variety X N-Rate	2	6663	3331	0.85
Cut height X N_Rate	3	19318	6439	0.813
VAR x Cut height X N Rate	6	23306	3884	0.977
Residual error (C)	36	732430	20345	
Total Residual	95	1993384		

Appendix 49: ANOVA Table for the effects of variety, cut height and nitrogen application on seed cotton yield at 43 WAR.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	148027	49342	
Variety (Var)	2	591805	295902	0.071
Residual error (A)	6	416629	69438	
Cut height (Ht)	3	732782	244261	0.009
Variety X Cut height (Var X Ht)	6	120842	20140	0.879
Residual error (B)	27	1395843	51698	
N-Rate	1	76722	76722	0.075
Variety X N-Rate	2	9529	4765	0.813
Cut height X N_Rate	3	125089	41696	0.16
VAR x Cut height X N Rate	6	115677	19280	0.544
Residual error (C)	36	821627	22823	
Total Residual	95	4554572		

Appendix 50: ANOVA Table for the effects of variety and cut height on cumulative seed cotton yield during short rains season

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	527640	175880	
Variety (Var)	2	676689	338345	0.201
Residual error (A)	6	956013	159336	
Cut height (Ht)	3	4846237	1615412	<.001
Variety X Cut height (Var X Ht)	6	567259	94543	0.712
Residual error (B)	27	4112413	152312	
Total residual error	47	11686252		

Appendix 51: ANOVA Table for the effects of variety, cut height and nitrogen application on cumulative seed cotton yield during the long rains season.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	2153863	717954	
Variety (Var)	2	1122784	561392	0.315
Residual error (A)	6	2389457	398243	
Cut height (Ht)	3	385679	128560	0.498
Variety X Cut height (Var X Ht)	6	1366794	227799	0.236
Residual error (B)	27	4266396	158015	
N-Rate	1	97353	97353	0.344
Variety X N-Rate	2	181411	90706	0.432
Cut height X N_Rate	3	141387	47129	0.722
VAR x Cut height X N Rate	6	322580	53763	0.798
Residual error (C)	36	3805848	105718	
Total Residual	95	16233551		

Appendix 52: ANOVA Table for the effects of variety, cut height and nitrogen application on cumulative seed cotton yield during the entire sampling period.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	3840555	1280185	
Variety (Var)	2	2884609	1442305	0.36
Residual error (A)	6	7115004	1185834	
Cut height (Ht)	3	12921405	4307135	0.002
Variety X Cut height (Var X Ht)	6	2050759	341793	0.789
Residual error (B)	27	17784461	658684	
N-Rate	1	97353	97353	0.344
Variety X N-Rate	2	182411	90706	0.432
Cut height X N_Rate	3	141387	47129	0.722
VAR x Cut height X N Rate	6	322580	53763	0.798
Residual error (C)	36	3805848	105718	
Total Residual	95	51145372		

Appendix 53: **ANOVA Table for the effects of variety, cut height and nitrogen application on lint percentage during short rains season**

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	2.157	0.719	
Variety (Var)	2	52.383	26.191	0.009
Residual error (A)	6	13.592	2.265	
Cut height (Ht)	3	10.981	3.66	0.232
Variety X Cut height (Var X Ht)	6	22.619	3.77	0.196
Residual error (B)	27	65.118	2.412	
Total residual error	47	166.85		

Appendix 54: ANOVA Table for the effects of variety, cut height and nitrogen application on lint percentage during long rains season

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	9.944	3.315	
Variety (Var)	2	94.046	47.023	0.001
Residual error (A)	6	11.582	1.93	
Cut height (Ht)	3	12.454	4.151	0.01
Variety X Cut height (Var X Ht)	6	42.604	7.101	<.001
Residual error (B)	27	24.569	0.91	
N-Rate	1	0.26	0.26	0.616
Variety X N-Rate	2	0.275	0.138	0.874
Cut height X N_Rate	3	4.567	1.522	0.231
VAR x Cut height X N Rate	6	8.027	1.338	0.274
Residual error (C)	36	36.53	1.015	
Total Residual	95	244.86		

Appendix 55: ANOVA Table for the effects of variety and cut height on cumulative lint yield during short rains season

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	70188	23396	
Variety (Var)	2	64256	32128	0.324
Residual error (A)	6	140924	23487	
Cut height (Ht)	3	633485	211162	<.001
Variety X Cut height (Var X Ht)	6	100381	16730	0.546
Residual error (B)	27	533887	19774	
Total residual error	47	15431122		

Appendix 56: **ANOVA Table for the effects of variety, cut height and nitrogen application on cumulative lint yield during long rains season.**

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	317243	105748	
Variety (Var)	2	2611782	130891	0.177
Residual error (A)	6	335570	55928	
Cut height (Ht)	3	65632	21877	0.4
Variety X Cut height (Var X Ht)	6	221898	36983	0.155
Residual error (B)	27	580666	21506	
N-Rate	1	14667	14667	0.332
Variety X N-Rate	2	24400	12200	0.456
Cut height X N_Rate	3	16272	5424	0.784
VAR x Cut height X N Rate	6	45217	7536	0.807
Residual error (C)	36	546812	15189	
Total Residual	95	2430159		

Appendix 57: **ANOVA Table for the effects of variety, cut height and nitrogen application on cumulative lint yield during entire sampling period**

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	565670	188557	
Variety (Var)	2	493329	246665	0.314
Residual error (A)	6	1045204	174201	
Cut height (Ht)	3	1688070	562690	0.002
Variety X Cut height (Var X Ht)	6	397489	66248	0.616
Residual error (B)	27	2391243	88565	
N-Rate	1	14023	14023	0.348
Variety X N-Rate	2	23128	11564	0.482
Cut height X N_Rate	3	16470	5490	0.787
VAR x Cut height X N Rate	6	43715	7286	0.826
Residual error (C)	36	558311	15509	
Total Residual	95	7236651		

Appendix 58: ANOVA Table for the effects of variety and cut height on percent grade 'AR' cotton during short rains season.

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	49.18	16.39	
Variety (Var)	2	19.23	9.62	0.886
Residual error (A)	6	467.69	77.95	
Cut height (Ht)	3	4635.96	1545.32	<.001
Variety X Cut height (Var X Ht)	6	588.58	98.1	0.116
Residual error (B)	27	1388.67	51.43	
Total residual error	47	7149.32		

Appendix 59: ANOVA Table for the effects of variety, cut height and nitrogen application on percent grade 'AR' cotton during the long rains season

Source	d.f.	s.s.	m.s.	F pr.
Replications	3	180.81	60.27	
Variety (Var)	2	9.934	4.967	0.949
Residual error (A)	6	567.182	94.53	
Cut height (Ht)	3	2433.544	811.181	<.001
Variety X Cut height (Var X Ht)	6	279.911	46.652	0.385
Residual error (B)	27	1138.851	42.18	
N-Rate	1	4.463	4.463	0.373
Variety X N-Rate	2	8.865	4.433	0.453
Cut height X N_Rate	3	9.413	3.138	0.636
VAR x Cut height X N Rate	6	23.57	3.928	0.638
Residual error (C)	36	197.076	5.474	
Total Residual	95	4853.62		