SORGHUM RATOONING AS AN APPROACH TO MANAGE COVERED KERNEL SMUT AND THE STEM BORER *CHILO PARTELLUS*

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DECLARATION

I certify that this work has not been accepted in substance for any degree, and is not concurrently submitted for any degree other than that of Doctor of Philosophy (PhD) of the University of Greenwich. I also declare that this work is the result of my own investigations except where otherwise identified by references and that I have not plagiarised another's work.

Student (K.S.L. Wilson) Date

Supervisor (Dr. D. Grzywacz) Date

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ABSTRACT

A three-year study on the practice of ratooning of sorghum was conducted in Eastern Kenya (1999 to 2002), with emphasis on the stem borer (*Chilo partellus*) and covered kernel smut (*Sporisorium sorghi Ehrenberg Link)*. Ratooning is the practice of stimulating tillering by cutting the old straw after harvest (Doggett, 1988). A six season on-station experiment in Machakos District showed the practice of ratooning short duration sorghum increased the reliability and yields in comparison to a direct sown with yield ranges of 1630-1778kg/ha and 0-148kg/ha, respectively. The higher number of heads and stems per unit area meant the ratooned crop had higher level of stem borers per unit area than the direct sown crop and when infected with covered kernel smut was a greater source of inoculum. Unlike the incidence of CKS, the number of stem borers had little correlation with the numbers in the previous season's crop; there was no upward trend to the number of stem borers per stem during the experiment suggesting factors other than the presence of a sorghum crop have a stronger influence on the population. Yield loss was an interaction between cultivar*incidence of stem borers * stage of infestation * rain quantity and distribution, but rain was the most important factor. An on-station trial in Kitui (2001-2) found the ratooned crop outperformed the direct sown crop in yield by a factor of three and non-cutting of stems produced a similar yield to cutting back stems after harvest. The different 'ratoon' methods did not significantly affect the incidence of covered kernel smut or level of stem borers.

On-farm trials in Mwingi District (2000-2) showed that short duration sorghum ratooned outperformed direct sown sorghum. The timing of the cutting back of the stems had an effect on plant survival and yield; cutting back stems at harvest produced higher yields than cutting the stems at the on-set of rains, however cutting the stems at the onset of rains increased plant survival when the stems were dry at harvest. A decision tree was produced outlining the decisions a farmer needs to make when deciding whether or not to practice ratooning. Four factors were identified as important for varieties to perform well under the practice of ratooning: drought tolerance, stem strength, non-senescence and the ability to produce tillers during growth stage 3.

PREFACE

Sorghum is an important traditional food crop in Kenya, especially in the semi-arid areas. It is grown mainly for home consumption and any surplus is usually marketed as a source of household cash. In eastern Kenya, the bi-modal rainfall pattern enables two cropping seasons a year. However, one season called the long rains, is erratic and crop failure is common due to poor crop establishment and/or water stress. Ratooning short duration sorghum after harvest of the short rain crop to facilitate a second crop might overcome the problems of establishment and avoid water stress at the end of the season. The ratooned crop would mature up to 20 days earlier than the direct sown crop. However, the perceived belief in the research community is that the practice of ratooning exacerbates damage by pests and diseases due to the ‘green-bridge” that ratooned plants provide between seasons. The most important pest and disease in Eastern Province, Kenya are considered by researchers and farmers to be covered kernel smut and the stem borer complex. The purpose of the study was to investigate the trade-off between potentially enhanced yield due to ratooning and the expected exacerbated losses through covered kernel smut and stem borers.

The thesis contains nine chapters that describe the research undertaken and the farmers’ perceptions in relation to the practice of ratooning. Chapter 1 presents the background to the study and the hypothesis of the study. The literature covering covered kernel smut, stem borer *Chilo partellus* and the practice of ratooning sorghum are reviewed in Chapter 2. The constraints to sorghum production are explored in Chapter 3, along with the practices associated with the declining tradition of growing local long duration sorghums. The outcomes from this study are used to identify research and the knowledge gained is incorporated into on-station and on-farm trials.

In Chapters 4 and 5, the effect of the practice of ratooning on the main disease and pest, covered kernel smut and stem borers, are explored through an on-station experiment that covered six cropping seasons. Specifically, Chapter 4 examines the influence the practice has on incidence of covered kernel smut and how this is reflected in yield. Chapter 5 examines similar issues, but concerning stem borers. The carry-over between the seasons is measured and the implications addressed and conclusions drawn.

In Chapter 6, the effect of different ratooning methods on crop performance and the incidence of covered kernel smut and stem borers were examined through on-station trials. The ratooning methods varied in the timing of the removal of the stems and the thinning of tillers. This on-station experiment ran concurrently with on-farm trials in Mwingi District. On-farm trials also investigated the effect of the different ratooning methods. The performance of the different methods under farm conditions, farmer perceptions and the acceptability of the practice of ratooning were collected and are described in Chapter 7. A second component of the on-farm trials were to investigate the performance of the short duration sorghum varieties presently available to farmers for their performance under ratooning, the results of the trials are described in Chapter 8. This includes characteristics identified by the farmers as required by a variety to perform under the practice of ratooning.

Finally, the discussion and conclusions drawn from the whole study are presented in Chapter 9.

ABBREVIATIONS

^0C	degrees Celsius
a.s.l.	above sea level
AEZ	agro-ecological zone
CAN	calcium ammonium nitrate
cm	centimetre
DAE	days after emergence
DAP	diammonium phosphate
DFID	Department for International Development
E	east
e.g.	exempli gratia (= for instance)
FAO	Food and Agricultural Organisation of the United Nations
g	grammes
ha	hectares
i.e.	id est (= that is)
ICRISAT	International Crop research Institute for the Semi-Arid Tropics
KARI	Kenya Agricultural Research Institute
kg	kilogrammes
Ksh	Kenyan shilling
LM	lower middle zone (AEZ)
m	metres
mm	millimetre
N	north
NPK	nitrogen, phosphorus, potassium
PRA	participatory rural appraisal
r	correlation coefficient
S	south
UM	Upper middle zone (AEZ)
W	west

LIST OF PLATES (plates by K.S.L. Wilson)

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BACKGROUND AND OBJECTIVES

1.1 INTRODUCTION

Sorghum (*Sorghum bicolor* (L) Monarch) is one of the world's major food crops. Global area of production is estimated to exceed 40 million hectares, ranking it fifth in importance among cereals (FAO 2006). It is particularly important in areas of high temperature and low rainfall. It can be grown in marginal, semi-arid areas where rainfall is unreliable and the cultivation of other food crops such as maize is not practical. Sorghum is very versatile and is grown as both a food and feed crop. This versatility combined with its adaptation and yield stability in marginal areas makes it an important subsistence staple. As a consequence, this crop is significant in traditional, low input, cereal based, semi-arid production farming systems in semi-arid Africa (Norman, Pearson and Searle, 1984).

The fungal disease covered kernel smut caused by *Sporisorium sorghi* Ehrenberg Link, is a major constraint to sorghum production in Eastern Africa, with reported incidence ranging from 8 - 43 % (Tarr, 1962). Covered kernel smut is seed-borne. Inoculum on the seed surface infects the seedling. Once infection has occurred, the fungus grows towards the meristem where it infects the flower primordia causing the developing grain to be replaced by silver grey sacs containing spores (Doggett 1988). Soil transmission is not thought to occur (McKnight, 1966; King, 1972).

The most important lepidopteran stem borer in Eastern Kenya is *Chilo partellus* and it is considered a major constraint to cereal production (Songa, 1999). Yield reductions have been reported in Kenya of up to 88% (Seshu Reddy, 1998). The adult moths emerge from pupae and over the next 5 days lay 80-100 eggs on the underside of leaves of suitable plant hosts. These hosts include sorghum and maize. The larvae emerge 4-8 days later and move to the leaf whorls to feed on the young leaves. The feeding causes holes in the leaves. At 3rd instar stage, the larvae penetrate into the stem tissue to feed, producing extensive tunnels in the stem. In young plants, the tunnelling can damage the growing tip causing "deadhearts". Generally, the tunnelling affects the translocation of assimilates and in older plants causes non grain bearing heads known as chaffy heads. The larval stages last approximately 28 days and pupation takes place in the tunnels. The adult moth *emerges* 8-10 days later, through pre-excavated windows.

Ratooning is a cultural practice to stimulate re-growth of the basal or lower epigeal buds at, or shortly after, the grains have been harvested by removing the photosynthetically active material. The re-growth gives a second crop during the next rains (Plucknett *et al.,* 1970). The advantages of ratoon crops are that they avoid the need for land preparation in the second season, require no new seed, reduce problems related to crop establishment particularly those of low rainfall, and reach maturity more quickly than direct sown crops (Doggett, 1988).

Hayden and Wilson (2000) identified that the majority of small holder sorghum seed was selected from the previous season's crop and the timing of seed selection had a serious affect on the incidence and severity of covered kernel smut. Selection was commonly carried out at the homestead after transportation of smutted and unsmutted heads together to the homestead. The practice of heaping infected heads with clean heads before selection allowed spores from the contaminated heads to contaminate the clean heads. The result was that although the farmers choose the next season's seed from the clean heads, these might have been contaminated. On-farm trials showed that the incidence of smut could be halved by changing the seed selection from the homestead to the field before the onset of harvest activities (Hayden and Wilson, 2000). However, a major constraint to uptake of this practice was enabling farmers to retain disease-free seed.

In Eastern Province, Kenya, the rainfall is bimodal, with the long rains (March-May) demonstratively less reliable than the short rains (October-December) (Jaetzold and Schmidt, 1982). The short rains are the main cropping season. In the long rains, crop failure is common due to unsuccessful establishment and/ or failure to reach maturity. The long rains often begin erratically resulting in dry planted seed rotting in the soil. However, farmers have to balance this danger with the need for the crop to be able to "capture" as much of the available soil moisture as possible. The result is that farmers regularly have to re-sow crops and late crops often fail to reach maturity, due to water stress. The repeated sowing and crop failures combined with storage pests, which reduce the ability to store grain over long periods, results in farmers regularly running short of food and seed (Hayden and Wilson, 2000).

The bi-modal rainfall pattern means that a sorghum crop sown for the short rains and ratooned for the long rains will have a greater capacity to use the limited soil moisture to achieve a yield than a freshly sown crop. Preliminary studies carried out in Mwingi District, Eastern Province have shown that the sorghum plants are able to survive the short dry period between the short and long rains (Karanja *et al.,* 1999). However, the agronomic practice of ratoon crops means there is a "green bridge" between seasons, which could result in increased carry-over of pests and diseases. The affect of this could be increased pest and disease pressure on sorghum yields and is considered to be a critical factor by researchers in the decision by farmers not to adopt this practice (Doggett, 1988). This was the reason given by researchers at Katumani Research Station for not investigating ratoon cropping, though Karnaja *et al.,* (1999) study had showed that there could be potential to increase yields through ratooning.

The present study is an enquiry into the practice of ratooning as a method to increase yields and therefore food and seed security. The main emphasis of the study will be on the effect of the practice of ratooning on the main pest and plant disease of sorghum in the Eastern Province of Kenya.

1.2 PROJECT OBJECTIVES

The bi-modal rainfall pattern in the eastern province of Kenya means that ratooning sorghum could be a possible strategy to improve sorghum yields and increased food security. However, the practice of ratooning may increase the occurrence and/or severity of the most important pest, the stem borer, *Chilo partellus,* and disease, covered kernel smut, *Sporisorium sorghi,* in the area. This study was initiated to investigate the potential for ratooning short duration varieties of sorghum. The main objective was:

1. To determine the effect of ratooning on the occurence of covered kernel smut and the stem borer *Chilo partellus*

The general hypothesis was that ratooned sorghum would produce higher and more reliable yields than direct sown sorghum. This increase in yield would exceed any increase in yield losses from stem borers and diseases, and therefore enable the farmers to increase seed and food security.

The specific objectives are:

1. To determine the incidence of stem borers and covered kernel smut in ratooned sorghum compared with direct-sown sorghum
2. To determine the effect of ratooning sorghum at different cutting times on the incidence of stem borer and covered kernel smut
3. To determine the acceptability to small holder farmers of the practice of ratooning short duration sorghum.

CHAPTER 2: LITERATURE REVIEW

1.3 SORGHUM

Sorghum (*Sorghum bicolor* (L.) Moench) belongs to the grass family Graminae, tribe Andropogoneae. It is generally cultivated in dry, hot areas (25-40^{0}C) with an average annual rainfall of 400-750 mm, though it can be grown where rainfall is higher. It can also withstand waterlogging.

1.3.1 Origin and taxonomy

It is generally agreed that cultivated sorghums arose from the wild *Sorghum bicolor* subspecies *averticilliflorum* (Stead.) Piper (Doggett, 1988). These wild forms were confined to Africa until recently, implying that domestication occurred in Africa. Both Doggett (1965) and Mann *et al.,* (1983) argued that the greatest variability in the crop and wild sorghums is found in the north-east quadrant of Africa (north of the equator, east of latitude 25^{0}E) and this was probably the centre of first domestication, approximately 5000 years ago. However, Harlan and de Wet (1972), using archaeological, palaeobotanical, anthropological and botanical evidence, suggested that domestication occurred at different times in an area extending from the Ethiopian border, west through Sudan and up to Lake Chad. Recent carbon dating of carbonized sorghum seed found on the Egyptian-Sudanese border was dated at 8000 YBP (years before present) (Wendorf *et al.,* 1992).

The movement of cultivated sorghum into eastern Africa is thought to have occurred with the migration of the Cushitic and Osmotic speakers from south-west and south Ethiopia in approximately 1000-2000 BC. At the time, the Bushmanoid hunters and gathers inhabited the area. Initially the Cushitic and Osmotic speakers migrated down the Rift valley. Other waves of migration moved through the mountains of western Kenya and Tanzania, bounded by the mountains of Mount Kenya and Kilimanjaro on the east and Lake Victoria on the west. Pottery found in West Kilimanjaro sites has been dated at 3000 BC (Maggs, 1977).

The Bantu people are thought to have migrated from the Southern Cameroons along the Congo forest belt reaching East Africa in the fifth century AD. The Bantu adopted sorghum from the local population, the Hamites, who were descendants of the Crushites. The adoption of sorghum enabled the Bantu expansion into drier, savanna countries of eastern and southern Africa over the next 1,000 years (Purseglove, 1972).

Taxonomy

Linnaeus first classified sorghum in 1753 under the name of *Holcus*. He subdivided these into three species of cultivated sorghum: *Holcus sorghum, H. saccaratus* and *H. bicolor.* In 1794, Moench separated the genus *Sorghum* from the genus *Holcus* and in 1805, Persoon created the name *Sorghum vulgare* for *H. sorghum* (L.) (Clayton, 1961). The current name *Sorghum bicolor* (L.) Moench was first considered by Clayton in 1961, and has since been widely accepted. Several authors have discussed the systematic classification and Doggett (1988) provides an overview of present-day classification. Snowden (1936) presented the most complete classification of cultivated sorghum and later schemes have been based on this work. The discussion point being the decision to treat all cultivated sorghums as a single species, or recognising the more distinct types as definite units with the status of species and associated botanical varieties and forms (Purseglove, 1972). Snowden recognized 31 species, 157 varieties and 571 forms. A more simplified classification was proposed by Harlan and de Wet (1972) and later developed by de Wet in 1978. This other system is the one presently recognised by breeders. Under this classification system, the genus *Sorghum* belongs to the tribe Andropogoneae of the greater family Poaceae. The genus *Sorghum,* which contains all wild and cultivated sorghums is subdivided into five sections: *Spriposorghum, Parasorghum, Heterosorghum, Chaetosorghum* and *Sorghum.* Section *Sorghum* contains three species *S. halepense* (L.) Person (2n=20), *S. propinquum* (Kunth) Hitchc. (2n=40) and *S. bicolor* (L.) Moench (2n=20). The species *S. bicolor* represents all annual wild, weedy and cultivated taxa. *S. bicolor* is further divided into three subspecies; *S. bicolor* subsp. *bicolor, S. bicolor* subsp. *drummondii,* and *S. bicolor* subsp. *verticilliflorum,* formally subsp. *arundinaceum.* The subspecies *bicolor* contains all domesticated grain sorghums and their closest wild relatives; subspecies *drummondii*, includes the derivatives of crosses between domesticated grain sorghums and their closest wild relatives; and subspecies *arundinaceum* groups together all the wild progenitors of grain sorghum. Harlan and de Wet (1972), using comparative morphology, further divided *S. bicolor* subsp. *bicolor* into five major races and ten hybrid races. The five races are: bicolor, guinea, caudatum, kafir and durra. The cultivated sorghums were further subdivided into 70 working groups by Murty and Govil (1967).

1.3.2 Sorghum production and uses

Sorghum is the world's fifth most important cereal, in terms of both production (56.5 million tons globally/annum) and area (41.5) million hectares planted (FAO, 2008). Approximately 90% of the world area under sorghum is in the developing countries (Figure 2.1). It is one of the main staple crops for the worlds' poorest and most food insecure people. In Africa, the cropped area increased from 13 million hectares to almost 22 million hectares between 1979-81 and 1992-94 (Table 2.1). In 1996, ICRISAT stated of the 45 million hectares cultivated, Africa accounted for 21.8 million hectares (48%), with the nine countries of East Africa representing 3.08 million hectares. In terms of yield, the 48% of crop area cultivated in Africa was responsible for 27% of the world production of sixty-three million tons (FAO and ICRISAT, 1996).

Sorghum is grown for both human food and animal feed. Sorghum is consumed directly by humans in the form of flat breads and porridges both thick and thin. This accounts for 55% of production. The stover produced is an important source of dry matter for livestock especially in India and Africa. Sorghum for livestock feed is mainly produced under intensive commercialised production systems, which utilise hybrid seed, fertiliser and probably, irrigation, giving average yields of 3-5 t/ha in the developed world and parts of Latin America and the Caribbean. The American livestock feed market accounts for 33% of production (FAO, 2008). Approximately 15% of the world sorghum area is under commercialised production, which accounts for 40% of the world output. Sorghum for human consumption is produced mainly in low-input, extensive production systems in the developing world, with low utilisation of improved seed, fertilisers and management practices giving average yields of 0.5 – 1.0 t/ha. In Africa, the average yield (1992-94) was 0.8 t/ha compared with 1.2 t/ha in Asia, and over 4 t/ha in North America (FAO and ICRISAT, 1996). In East and South Africa, area under sorghum and production has increased; there has been a marginal increase in yield from 800kg/ha in the early 1970s to just over 960kg/ha in 2003 (ICRISAT, 2006).

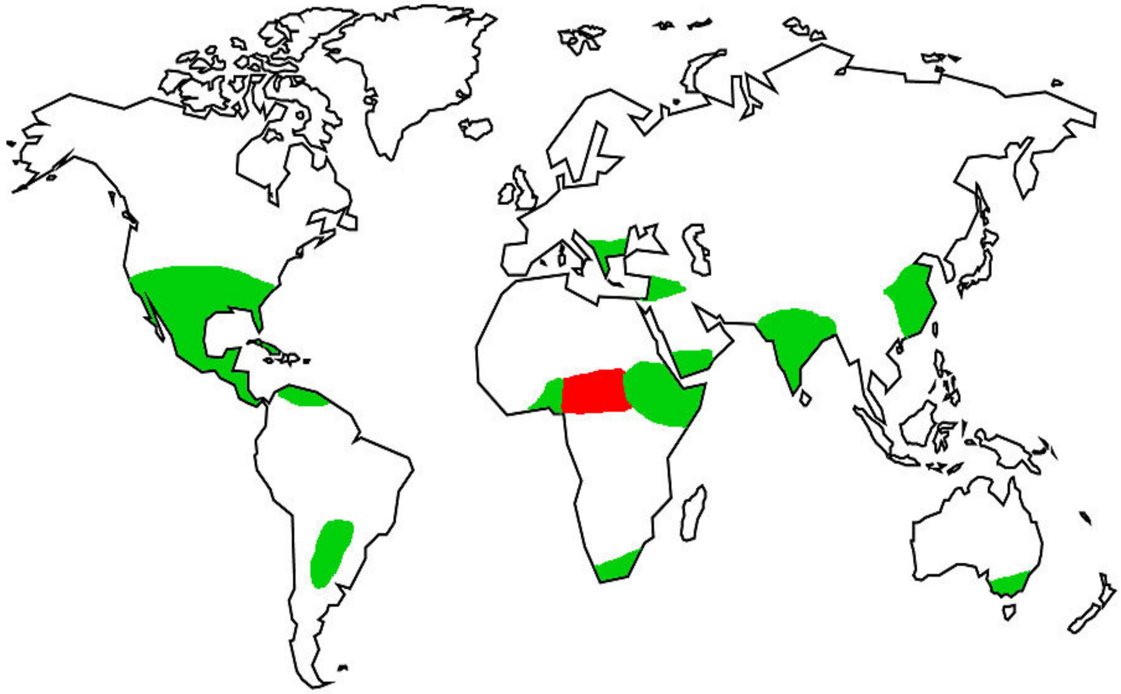

Figure 2.1: The main sorghum production areas in the world

production areas, proposed centre of origin

(Source: ICRISAT, 2008)

In Africa, sorghum has an important role in household food security and 70 % of the crop is consumed as food. A large proportion of households aim simply to produce enough grain to meet household requirements – which many often fail to do (Pretty, 1995). Only a small proportion is traded on the local food markets. Farmers at the margins of subsistence find it risky to invest in new technologies (Pretty *et al.,* 2006). Investment opportunities compete for scarce resources, thus school fees will compete directly with investments in the cropping system, and within the cropping system, subsistence crops will compete with cash crops. Farmers will allocate their capital and labour in relation to their perception of the highest return. Sorghum is perceived as having a low monetary return (Rutto, 1982).

In recent years, Africa's sorghum production has expanded mainly due to the increase in cropping area (Tables 2.1 &2.2). Yields have failed to increase or have declined, because population growth is pushing production into more marginal areas and poorer soils, where the sorghum's adaptation to drier, less fertile conditions gives it a comparative advantage over other cereals (FAO, 2008). As land constraints increase the difference between what people need to eat to survive and food production will increase and this short fall will be harder to meet with short-term measures. It is therefore expected that farmers will adopt more intensive production practices to reduce these shortfalls (FAO, 2008).

Table 1.1: Sorghum area, yield and production in Africa [1]

Location	Area (million ha)				Yields (t/ha)			
	1979-81	1981-91	1992-94	2004-06	1979-81	1989-91	1992-94	2004-06
Africa	13.40	18.30	21.80	24.48	0.89	0.75	0.78	1.00
East Africa	3.23	2.95	3.08	4.22	0.95	0.88	0.89	0.95
Kenya	0.17	0.13	0.12	0.13	0.95	0.88	1.05	0.86
Tanzania	0.71	0.53	0.66	0.83	0.76	0.99	0.90	0.99
Uganda	0.17	0.24	0.26	0.30	1.78	1.49	1.50	1.45

Location	Production (million tons)			
	1979-81	1989-91	1992-94	2004-06
Africa	11.90	13.78	17.10	24.00
East Africa	3.08	2.59	2.75	4.40
Kenya	0.16	0.11	0.12	0.12[2]
Tanzania	0.54	0.53	0.59	0.82
Uganda	0.31	0.36	0.38	0.43

Source FAO (2008)

[1] Each figure is a 3 year average for respective period

[2] 2004 production in Kenya less than half the production achieved in 2005 & 2006

Table 1.2: Sorghum production trends between 1979 and 1994

Location	Area (%/yr)	Yields (%/ha)	Production (%/yr)	Per caput production (%/yr)
Africa	0.1	-0.5	-0.4	-2.4
East Africa	-0.2	-0.6	-0.8	-3.6
Kenya	-1.5	2.4	0.8	-2.7
Tanzania	0.5	-0.2	0.3	-2.8
Uganda	2.8	-1.0	1.8	-1.5

Source FAO and ICRICAT (1996)

In Kenya, sorghum is the third most important cereal in area of production after maize and wheat, and is grown on approximately 120,000 hectares (FAO and ICRISAT, 1996). Most of the production takes place in two distinct agro-ecozones (Rutto, 1982; M'Ragwa and Kanyenji, 1987). These are the dry and hot lowlands, characterised by low and erratic rainfall, which includes most of eastern Kenya and the drier parts of south Nyansa District; and the wet humid and sub-humid zones characterised by long rainy seasons (3-5 months) with adequate rainfall, which cover most of western Kenya.

1.3.3 Agronomy

The world sorghum economy can be divided into two broad production and utilisation systems, which are: intensive, commercialised production, and low-input, extensive production. Intensive, commercialised production, mainly for livestock feed, is characteristic of developed countries and parts of Latin America and the Caribbean. Within this system all major inputs, including hybrid seed, fertiliser and improved water management systems, are used to achieve the highest production compatible with the best economic return. The average yields are 3-5 t/ha (FAO, 2008). Low-input, extensive production systems, producing mainly for human consumption are characteristic of developing countries. Within this system, management practices are less intensive, with the use of input such as fertiliser rare, though improved varieties may be deployed. The aim is to minimise yield loss from pests and diseases, or from adverse variations in environment, particularly in the amount and distribution of rainfall, thus achieving some yield every season and reducing risk (Goldsworthy, 1982). The average yields are 0.5 – 1.0 t/ha. The requirements of these two systems are very different and have significant impact on the objectives of agronomists working in the two systems. Agronomists working in high input, intensive systems maximise production by choosing more productive genotypes, better use of moisture, nutrients, herbicides, pesticides and fungicides. In low-input, extensive systems, farmers choose cultivars for their ability to withstand late weeding, drought stresses and the impact of pests and diseases. The agronomist tries to improve production by making relatively small improvements in current practices without increasing risk. Breeders try to incorporate additional resistances to those contained within the local cultivars, which enable it to produce reliably under the local conditions.

1.3.4 Sorghum morphology and physiology

Sorghum morphology and physiology have been reviewed comprehensively (Doggett, 1988, Wilson and Eastin, 1982; Peacock and Wilson, 1984; and Paul, 1990). The growth of cereals has three distinct phases: vegetative, floral initiation and grain filling. The vegetative phase is characterised by continued leaf initiation from undifferentiated apical meristem, leaf growth and absence of internode's elongation. In the floral initiation phase the panicle begins developing, the internodes elongate by differentiation of the apical meristem and the stage ends with 50% of the plants flowering. Grain filling is characterised by the development and maturation of grain, with or without the senescence of leaves. The developmental and physiological growth phases of sorghum have been described by Vanderlip and Reeves (1972) and Eastin (1972). Vanderlip and Reeves (1972) recognised ten different development stages and numbered then 0 – 9, while Eastin (1972) identified three growth stages, GS 1-3 (Table 2.3). The expressions of these phenological stages of sorghum are influenced by genotype and environmental factors (Table 2.4).

The physiological changes occurring in each of the 10 developmental stages is summarised as:

Stage 0: Emergence – the seedling emerges above ground and the coleoptile leaf is visible (Figure 2.2&2.3).

Stage 1: Third leaf – The third leaf is visible in the collar of the first and second leaf. The growing point is below ground. The radicle extends and forms the seminal root.

Stage 2: Fifth leaf – The fifth leaf is visible in the collar of the fourth leaf. The seminal root has produced some lateral roots. Two or three adventitious roots begin development at the base.

Stage 3: Panicle initiation – The vegetative shoot apex differentiates into the reproductive apex, which is demarcated as an abrupt constriction. Some leaves (six to nine) are fully expanded, while the remaining leaves envelope the panicle meristem. Up to one-third of the total leaf area is fully developed. One to three lower leaves may have senesced. The stem internodes rapidly elongate after panicle initiation. Elongation begins with the basal internode, followed by the longer upper internodes.

The root system is well established and the seminal root is prominent with many laterals. Adventitious roots are well extended.

Stage 4: Flag leaf visible – Flag leaf is visible at this stage, and all except for three or four leaves are fully expanded. Approximately 80% of the total leaf area is operational. The panicle meristem has undergone a series of developments: the primary and secondary branches and florets have been developed. Elongation of the stem internodes continues.

Stage 5: Boot – The panicle is fully developed and is nearly full size, but is covered by the sheath of the fully expanded flag leaf. Stem elongation is complete and the peduncle starts elongating, this helps the exertion of the panicle.

Stage 6: Half bloom – The panicle fully emerges from the sheath of the flag leaf. Flowering begins with the emergence of the anthers at the tip of the panicle and progresses downwards. Pollination and fertilisation takes place. When 50% of the plants in a crop have obtained some stage of flowering the crop is said to have reached half bloom. Adventitious and nodal root growth reaches its peak. At this stage, half the total dry matter has been produced. Adverse environmental conditions at this stage directly affect fertilisation and seed set thus yield.

Stage 7: Soft dough – The grains are fully visible and go through several developmental stages. The endosperm changes from a watery fluid to a milky stage. Grain formation is rapid and the culm loses dry matter. Leaves start to senescence. Eight to twelve functional leaves are present. Adventitious roots start to senescence, but nodal roots are active.

Stage 8: Hard dough – The grain is partly hard and accumulates three-quarters of final grain dry matter. More leaves and adventitious roots senescence.

Stage 9: Physiological maturity – The vascular connection and food supply to the grain is terminated, indicated by a black layer is forming in the hilar region. The black layer starts at the tip of the panicle and proceeds downwards. The grain has reached maximum total dry weight, indicating physiological maturity; grain moisture content varies from 25-35%. The remaining functional leaves may stay green or senesce.

In cereals, panicle development and productivity are the principle factors governing yield potential. The growth phase of panicle initiation and development and ultimately, the partitioning of photosynthates between grains and straw are particularly critical in determining yield outcome. The balance between and the number of sinks, their size and storage capacity varies with genotype (Ratikanta Maiti, 1996).

Table 1.3: Development stages (Vanderlip and Reeves, 1972) and physiological growth stages (Eastin, 1972) of sorghum, their influence on growth and yield of the crop; and approximate time required for each stage

Develop-mental stage	Identifying characters	Days after emergence	Growth stage	Influence on growth and yield of crop
0	Seeding emergence: coleoptile leaf visible	0		
1	Three leaf: collar of third leaf visible	5	1	Establishment of initial root system
2	Five leaf: collar of fifth leaf visible	10-15	1	Establishment of panicle bearing shoots (tillering)
3	Panicle initiation: growing point differentiation	25-30	1	Determines total number of leaves on the stem
4	Flag leaf: final leaf visible	35-50	1	
5	Boot: head extended into flag leaf sheath	40-55	2	Expansion of all the upper internodes and all culms
6	Half bloom: half the plants at bloom stage	55-65	2	Development of and growth of panicle and panicle components
7	Soft dough: milky stage	65-80	2	Potential seed number for setting Root system fully established
8	Hard dough: milky stage converted to hard dough stage	75-80	3	Seed set and seed size determined
9	Physiological maturity:	80-95	3	Development and filling of grains Length of GS3 period determines yield

Source: Ratikanta Maiti (1996)

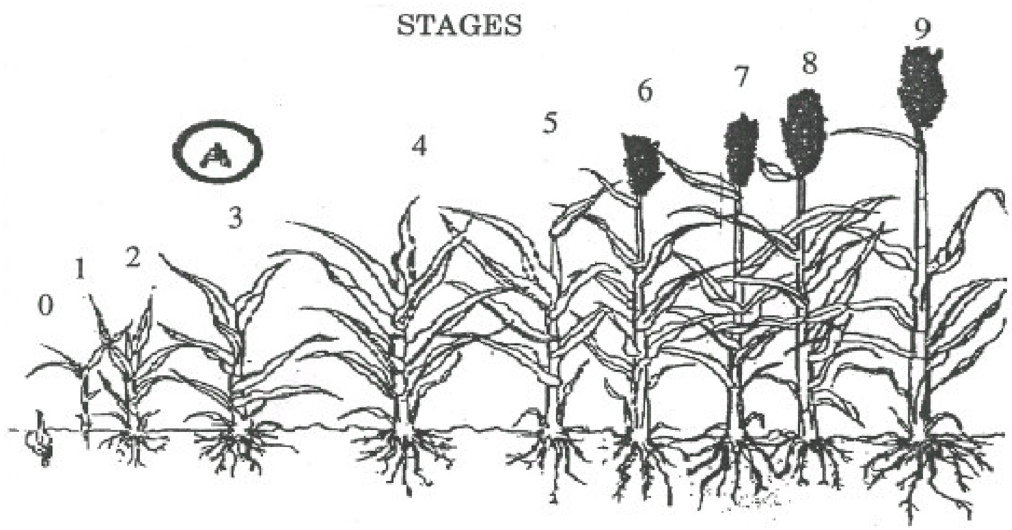

Figure 2.2: Sorghum development stages (Vanderlip and Reeves, 1972)

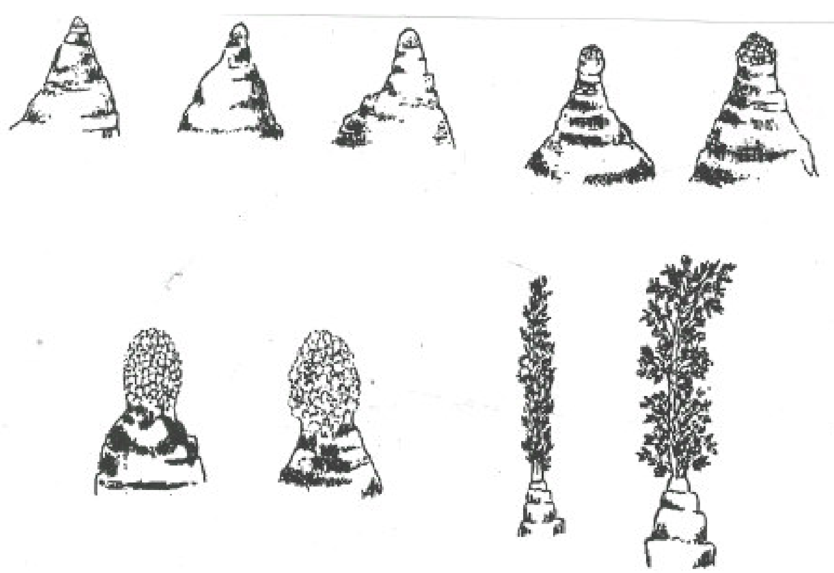

Figure 2.3: Sorghum panicle development stages (Vanderlip and Reeves, 1972)

Table 1.4: Influence of environmental factors on the growth stages of sorghum

Growth stages	Environmental factors that control GS	Factors that determine yield
GS1		
0 Emergence	Soil temperature and moisture	Growing plants, plants/ha
1 Three leaves	Soil moisture	Plantings/plant
2 Five leaves	Soil temperature and moisture	
3 Panicle initiation	Day length, soil temperature and moisture	Leaves or spikelets/ planting seed/panicle
GS2		
4 Flag leaf	Day length, air temperature, soil moisture	
5 Boot	Day length, air temperature, soil moisture	Panicle emergence
6 Half bloom	Day length, air temperature, soil moisture	Seed setting and number /panicle development
GS3		
7 Soft dough	Air temperature, soil moisture	Seed size/weight
8 Hard dough	Air temperature, soil moisture	Seed size/weight
9 Maturity	Air temperature, soil moisture	Seed size/weight

Source: Ratikanta Maiti (1996)

1.3.5 Ratooning grain sorghum

Ratooning is an old cropping system, which has been practiced for many years, especially in the tropics and is widely used in several crops e.g. sugarcane, pineapple, pigeon pea, banana, cotton and sorghum. The fundamental basis for ratooning is the ability of the plant to behave as a perennial and continue growth beyond one fruiting or harvest cycle. It is possible because after harvest basal buds develop into tillers, shoots, or sprouts to produce a new crop.

Ratooning of grain sorghums is undertaken in India, Hawaii, and Australia, Philippines, in the states of Arizona, California in USA, and Africa. However, little has been published on ratooning of grain sorghums, and these publications mostly originate from the USA and focus on management practices for intensive commercial production (Enserink, 1995).

The 'average' sorghum plant undergoes a sequential leaf senescence in which the older leaves at the base of the culm senesce and die. By physiological maturity, most leaves will be senescent, but the basal and lower epigeal buds are initiated, and tillers produced. These tillers will grow until either physiological maturity is reached or severe stress conditions kill them. The speed and timing of leaf senescence and tiller production varies with genotype. Ratooning of grain sorghum may be defined as the action to stimulate re-growth from the basal or lower epigeal buds. This involves removal of the majority of the photosynthetic active material at or shortly after grain has been harvested (Plucknett *et al.*, 1970). Basal buds are attached to short and narrow internodes at the plants base, while epigeal buds are attached to elongated, thicker internodes situated higher on the plant (Escalada and Plucknett, 1975).

The root system of sorghum dies after harvest and the speed and extent of the re-establishment of the new root system has a direct relationship with the performance of the ratoon crop of both grain and forage sorghums (Plucknett *et al.,* 1970).

Two basic processes have been identified as of equal importance to the ratooned plant's survival and re-growth (Enserink, 1995). The first process covers the content of soluble carbohydrates in stubble ('food stocks') at the time of stover removal. Sufficient food stock is required to maintain the living stump and to support the buds, which have no roots, or leaves (Oizumi, 1977). The second process deals with the physiological activity of stumps. After the removal of the stover the stumps must maintain the ability to transport water, minerals and carbohydrates to the growing tillers until they are established (Duncan *et al.*, 1981). The two processes are influenced by internal (heredity) and external factors (Figure 2.4).

One of the most important internal factors is the relative strength of the plant organ sinks. A strong head sink will 'pull' carbohydrates from the stems and roots, especially in times of stress e.g. drought, resulting in the depletion of the 'food stock' required by the plant to re-grow, thus reducing the chance of survival. Sorghum cultivars that remain green after grain maturity have been identified as retaining higher food stocks (McBee *et al.,* 1983). These non-senescent cultivars can remain physiologically active longer under stress (Duncan *et al*., 1981). Non-senescent cultivars have also been shown to establish adventitious root system earlier and for the root system to decline slower after grain filling (Zartman, 1979).

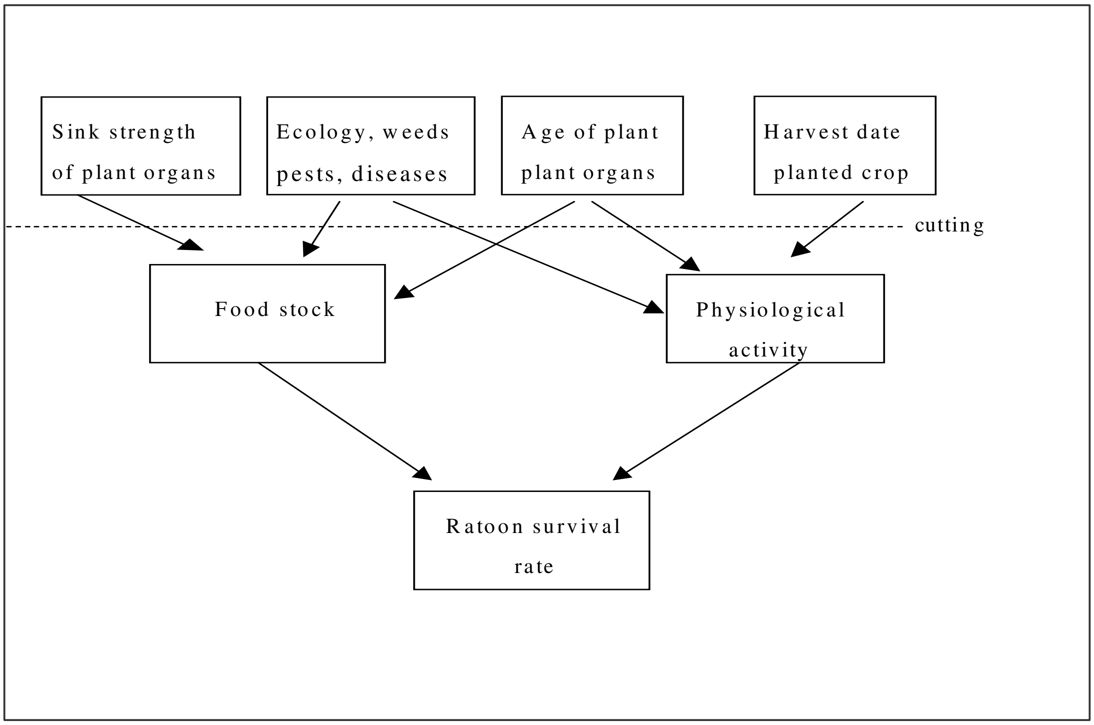

Figure 2.4: Flow diagram of the factors that influence the rate of plant survival after ratooning (Enserink, 1995)

Sorghum plants do not produce rhizomes or stolons, so the tiller is the organ responsible for the perenniality of the crop, and the ability of the plant to produce productive tillers determines the yield of the ratoon crop. Too early production of tillers can result in non-survival, if the soil moisture is not sufficient, while late development could result in immature tillers at harvest. In grain sorghum, a successful ratoon crop depends upon the production and development of healthy, grain-bearing tillers from the stubble of the preceding crop.

The growth of tillers is supported by the main culm, and Miltrope and Davidson (1966) and Williams (1966) speculated that tillers, which develop when the main culm is not established, die or become retarded in growth. Escalada and Plucknett (1975) found the first two tillers often died. This was attributed to unestablished parent shoots being unable to support tillers and that during grain filling the available nutrients are predominantly utilised in grain-filling and are therefore unavailable for tiller development.

Comparisons of the phenology of planted and ratoon crops suggest that the grain-forming ratoon tillers and the direct sown crop's primary shoot are similar (Gerik *et al*., 1990). However, the degree of tillering and the partition of above ground biomass to grain are influenced by genotype, which is significantly dependent on the environment. Environmental factors include photoperiod, light intensity, temperature, soil moisture and fertility (Langer, 1963; Gerik and Miller, 1983; Gerik and Neely, 1987).

The density of tillers has been shown to be inversely proportional to planting density and yield (Plucknett *et al.,* 1970). However, grain sorghum yields have a wide tolerance to varying plant populations due to the ability of sorghum plants to compensate by producing more tillers and / or larger heads at low plant populations (Grimes and Musick, 1960). Tiller development is delayed, slower, with fewer and smaller panicles, at higher plant populations due to competition for nutrient and light. However, increased plant population results in increases in grain yields and stover yields, due to the large number of plants per unit area compensating for the low yield factors (Escalada and Plucknett, 1975). Tabo *et al.,* (2002) reported similar results in Nigeria under residual soil moisture conditions. The number of seeds per panicle produced by the tillers represents a small fraction of that produced by the main culm and the contribution of tillers to grain yield decrease with increasing plant density (Gerik and Neely, 1987). Yield compensation is primarily derived from the main culms as tillers are unable to fully compensate for the difference in plant density. The seed numbers per panicle in both main culm and tillers are reduced as the plant density increased. Gerik and Neely (1987) have suggested that sorghum tillering may be governed by a biophysical phenomenon similar to the light mediated mechanism controlling the tillering of wheat.

Sorghum tiller density shows a strong interaction between temperature and day length, with cool temperature/short day length and high temperatures/long day length prior to panicle initiation resulting in retarded tiller development (Gerik and Neely, 1987). In pastures, light intensity and photoperiod affects tillering, showing strong interactions with genotype, temperature and plant age (Langer, 1963). In field experiments in Hawaii, the date of planting had a marked effect on subsequent performance of the ratooned sorghum. Sorghum planted in January performed better than that planted in October, though January is in the short-day period (low solar radiation). However, rain and soil moisture conditions are more favourable and growth was more rapid and vigorous in January than December. Langer (1963) reported that moisture stress reduced the amount of tillering in grasses.

The ability of sorghum to withstand moisture stress after harvest and before sprouting is an important factor in the survival of the ratoon crop and the adoption of the practice of ratooning in the tropics. The compaction of soil has been found to reduce root system development and the breaking up of soil between rows to increase soil aeration and water penetration, is recommended in Australia (Plucknett *et al.,* 1970). The apparent formation of a new root system in sorghum coupled with the rapid decomposition and deterioration of the old root system, effects the management of the crop after harvest. Microbial activity will be high in the root zone as a result of decomposition of the old roots, therefore higher nitrogen levels may be required to overcome microbial tie-up (Plucknett *et al.,* 1970). However, in sugarcane, if nitrogen levels are equal to those used in the planted crop ratoon yields will exceed planted crop yields. In fact, nitrogen responses in some soils may be greater in the ratooned crop than in the direct sown crop as nitrogen not leached away in the direct sown crop season is available to the ratoon (Enserink, 1995). The sugarcane response to nitrogen has been reported to increase with age and phosphorous has been shown to be important for the rapid establishment and development of the new root system. Placing of the fertiliser as near to the stump as possible has been recommended, to increase uptake by the roots (Plucknett and Young, 1963).

Escalada and Plucknett (1977) found tillering capacity and yields are affected by the cutting height. Low cutting heights (3cm) produced fewer tillers, because there were fewer buds to develop and insufficient food stocks to support tiller development. The short length of stubble also, allowed disease in the form of anthracnose (*Colletotrichum graminicola*) to reach the basal buds quicker than in longer stubble. Longer stubble (8 or 15cm) had more nodes to penetrate before the basal buds are reached. However, stubble cut at 15 cm produced tillers from the upper nodes and often the supporting adventitious roots did not develop quickly enough to support the tillers resulting in breakage. These tillers were also less uniform in height and maturity causing the panicles to have a range of ripening times. Gerik and Neely (1987) found tillers extended the flowering period by 7-10 days. However, variability between tiller and main culm dates of flowering often resulted in simultaneous flowering of tillers and main culm.

One of the main disadvantages that are stated against ratooning sorghum is that it encourages build up of pests and diseases (Doggett, 1980). However, very little work has been carried out to investigate the effects pests and diseases would have on ratooned sorghum grown in the semi-arid regions of Africa.

1.4 SORGHUM DISEASES

Sorghum is attacked by an unusual number of diseases (Doggett, 1988). This and the wide range of environments in which it is cultivated means it is constantly under attack by pathogens. In traditional areas of cultivation, including East Africa, plants may be challenged by up to six foliar pathogens, an array of soil borne organisms, several viruses, a phytoplasma, at least two systematic fungal pathogens and several panicle fungal pathogens (Frederiksen and Odvody, 2000). Surveys carried out by ICRISAT/SAFGRAD have identified that within East Africa sorghum in most countries was suffering from similar diseases, with some variation due to ecological zone and the level of improvement in the sorghum lines. The important diseases identified in East Africa are presented below:

Panicle and heads diseases:	• ergot (*Claviceps sorghi*)
	• grain mould (complex of fungal species)
	• covered kernel smut (*Sporisorium sorghi*)
	• loose kernel smut (*Sporisorium cruentum*)
Foliar diseases	• anthracnose (*Colletotrichum graminicola*)
	• leaf blight (*Exserohilum turcicum)*
	• grey leaf spot (*Cercospora sorghi*)
	• rusts (*Puccinia purpurea*)
	• sorghum downy mildrew (*Peronosclerospora sorghi*)
Stalk rots	• charcoal rot (*Macrophomina phaseolina*)

Source: Hulluka and Esele (1992)

This review will concentrate on the panicle disease covered kernel smut, because this is the most important disease identified by the farmers in region the study was conducted.

1.4.1 Covered kernel smut

The seedborne panicle disease known as covered kernel smut (CKS) is caused by *Sporisorium sorghi* Ehrenberg Link (syn. *Sphacelotheca sorghi* (Link) G.P. Clinton), which is classified within the order Ustilaginales, class Basidiomycetes (Duran, 1969, Vanky, 1987 and Perez *et al.,* 2002). It occurs in every sorghum-growing region of the world and causes greater grain loss than any other disease in tropical zones (Frowd, 1980; Frederiksen and Odvody, 2000). The pathogen was thought to be specific to the genus *Sorghum*, however the weed *Cynodon dactylon* has been identified as an alternative host (Marley, 1995).

Distribution and significance in East Africa

Covered kernel smut (CKS) is widely distributed in all sorghum growing areas. The most northern reports have been in Denmark and Canada and the most southern reports are from Chile and Australia (CMI Map No. 220, 1974, and Perez *et al*., 2002). Frederiksen (1982) reviewed the present prevalence and importance of CKS taking into account the control practices available and practised within the different agro-ecological zones of sorghum production. He concluded that within the temperate (outside 34^{o} lat.) and sub-tropical zones (within 34^{o} lat.) CKS was occasionally present and of minor importance, due to the application of seed dressings. However, in the tropical highlands 1000 (+) m, tropical winter 1000 (-) m and tropical summer 1000 (-) m (within the 23.15 ^{o} lat) zones, where seed dressings were not utilised, CKS was commonly present and was a major deterrent at times to crop production.

Published data on the actual incidence and severity of CKS in East Africa are limited. Tarr (1962) reported incidences of CKS in Africa of between 8-43%, while Selvaraj (1980) estimated losses up to 50% in some parts of Africa. Doggett (1980) in a review of sorghum diseases in East Africa wrote that CKS was conspicuous and it was worth utilising seed dressings. However, he was unaware of any estimates of yield loss, except for Wallace and Wallace (1953), who reported incidences ranging from 8-100%

and losses greater that 30% in Tanzania. The ICRISAT/SAFGRAD's eastern Africa surveys of 1986 reported that CKS was an important disease in the region. In Ethiopia, Kenya, Rwanda, Somalia and Uganda, the disease was ranked within the top five diseases including *Striga*, (Hulluka and Esele, 1992). Mbwaga *et al.,* (1993) reported between 1986-1990, that CKS was absent or below 5% incidence in the Tanzanian sorghum growing districts of Dodoma and Morogoro, though reached 40% in one farmer's field in the district of Singida.

In work conducted by staff from NRI in Kenya, Tanzania and Uganda between 1995-2002, CKS was found at high levels of incidence. This was causing high yield loss as farmers usually discard sorghum heads showing symptoms of CKS. This is because during harvesting and threshing the CKS spores are released, thus contaminating the whole grain batch and the flour prepared from this grain is discoloured and tastes mouldy (Doggett, 1988). To avoid this tainting farmers usually discard the whole head, even when smut has only replaced a small proportion of the grain, thus yield loss is high even at low incidence (Karanja *et al.,* 1999). In Dodoma Region, Tanzania, a survey carried out in 1996, found an average incidence of 17.2%, of which 9.5% of the heads had a severity greater than 50% (Hayden and Wilson, 2000). In the Districts of Teso Region, Uganda, a survey conducted in 2000 found the occurrence of CKS ranged from 26 – 97%. Incidence within a field ranged from 2.5% to 22.5%, with severity ranging from 1.3 – 43% (Hayden, 2002). In the Eastern Province, Kenya, CKS was present in 41% of the sites assessed in the lower midland agro-ecological zone. In the upper midland agro-ecological zone and lower agro-ecological zone, the levels were 15% and 13%, respectively (Bock *et al.,* 2001). In discussions with farmers in Mwingi District, Eastern Province, Kenya, CKS was listed by 50% of the farmers, as a constraint to sorghum production, with farmers estimating incidences from rare to 40% (Hayden and Wilson, 2000). In Western Kenya, surveys conducted in 1996 and 1997 found that CKS occurred in 47% of the fields assessed, with 3% having a severity greater than 60% (Hayden and Wilson, 2000).

Biology of Sporisorium sorghi

The fungus *S. sorghi* produces diploid teliospores that are approximately spherical with a diameter of 4-7 µm (Frowd, 1980). When they germinate, they produce a four-celled basidium, which bears monosporidia that fuse to produce the pathogenic dikaryon

(Rodenhiser, 1932, Fischer and Holton, 1957; Frowd, 1980). Recent work by Munkacsi *et al*., (2007) shows that *S. sorghi* diverged from other crop smuts, *Ustilago maydis, U. scitaminea,* and *Sporisorium reilanum* occurred prior to domestication and modern agriculture and in the ecological context of the host plant and fungal population.

In the 1920s, five races were identified in the USA (Tisdale *et al.,* 1927) and these have well characterised differences in colour, length and manner of rupture of the sori. In India, Vaheeduddin (1951) reported five races on sorghum, of which two were similar to USA races, a third resembled a synthetic hybrid between two races of USA origin and the others were described as new races. Further work in India distinguished another five races. These included three races from Uttar Pradesh (Dasgupta and Narain, 1960) and two races from Karnataka (Ranganathaiah, 1969). In South Africa, two races have been distinguished through their reactions to White Yolo and hegari sorghums. However, there is some doubt over whether they are distinct from the races identified in USA (Vaheeduddin, 1951). The relationship between American, Indian and South African races has not been determined in detail, though Gorter (1961) incorporated all the races into a race nomenclature. About 66 sexual groups have been described in *S. sorghi*, which can be accounted for genetically by a two loci system (Burnett, 1976). This diversity is attributed to the ability of *S. sorghi* to undergo intraspecific and interspecific hybridization with *S. cruenta*. However, hybrids often show irregularities, and can be sterile or fail to develop sporidia (Rodenhiser, 1934).

Infection of the sorghum plant occurs as the sorghum seed germinates. Until recently, it was reported the coleoptile was invaded by the smut mycelium (Doggett, 1988), but Malaguti (2004) has reported that only the embryo is penetrated during germination. The most effective place for teliospores to cause smutted panicles is on the testa (Nzioki *et al.,* 2000). Nzioki *et al*. (2000) reported that *S. sorghi* was able to colonise sorghum plants and move systemically through to the ovary and initiate infection when the plants were inoculated with sporidia from teliospores at boot stage of growth above the 6-10 leaf stage. However seeds germinating in the presence germinating teliospores on water agar did not develop smutted panicles. Inside the plant, the fungus establishes itself in the primary meristem and the infection becomes systemic with the fungus growing with the differentiating meristem. The infection travels upwards in the meristematic tissue colonising very little of the vegetative parts, until differentiation of the floret. As the florets form, the fungus rapidly invades the tissue, causing the developing grains to be replaced with smut sorus (Fischer and Holton, 1957; Frederiksen and Odvody, 2000). The sori are covered with a persistent peridium, which often turns from white to pale brown with age, the tip becoming darker than the base. The length of the sori varies from slightly longer than the grain to slightly shorter. From milk stage onwards the sori rupture, releasing teliospores. These ruptures develop at the tip, resulting in the shedding of membrane and the exposure of the spores. The released teliospores adhere to the surface of the grains and the disease cycle begins again. The ideal position of the teliospore to infect a sorghum plant is on the testa of the seed. The coleoptile is easily infected up to 5mm in length, after which infection is rarely achieved. The longest reported coleoptile length at which infection occurred is 20mm (McKnight, 1966). Soil transmission has never been recorded.

The number and distribution of smutted florets within a panicle varies from all to a few, and there is great variation in the sori/grain ratio (King, 1972). Sorus production depends on the pattern of early infection. The main heads can escape infection if the upper parts of the meristem are not invaded (Melchers *et al.*, 1933). Therefore, in good growing conditions, where the apex of the plant is able to keep ahead of the smut mycelium the panicle will not show any symptoms (Doggett, 1988). However, tillers may express smut symptoms as they develop later from lateral buds (Doggett, 1988). Ramakrishnan (1963) reported that though slow seed germination may promote infection, it does not mean that rapid germination will reduce infection. Soils that are cool, damp and slightly acidic prior to emergence are conducive to infection (Kulkarrni, 1918 & 1922; Reed and Faris, 1924a&b; Hsi, 1958; Sundaram, 1972). High temperatures in the range of 34-42^{o}C are reported to reduce rates of infection compared with temperatures of 22-29^{o}C (Adlakha and Munjal, 1963). The optimum temperature for infection seems to vary with variety, from 15 to 27^{o}C (Reed and Faris, 1924a&b; Melchers and Hansing, 1938). Bag and Agarwal (2003) reported the best temperature for spore germination as 25^{o}C at neutral pH followed by 20^{o}C when comparing germination at 5^{o}C intervals. Nzioki *et al.,* (2000) found sorghum planted in warm (>20 ^{o}C) soil had the greatest incidence of covered kernel smut compared to soil below >20 ^{o}C. Relatively dry soils are recognised to promote smut infection, though infection can occur over a wide range of soil moistures (Reed and Faris, 1924a&b, and Tarr, 1962). Melcher and Hansing (1938) concluded that soil moisture above 25% saturation reduced smut infection.

Teliospores can germinate as soon as they have formed; no resting phase is required and the spores can remain viable under dry conditions for up to 13 years (Sundaram, 1972). Smut incidence has been shown be affected by the level of contamination of the seed by spores. El-Helaly (1939) obtained good infection rates at 1:100 and 1:1000 by weight of spores per seed, reducing to zero at 1:1,000,000. Thus, lightly contaminated seed, which visually will look clean, can give rise to significant smut infection.

A single infected head releases spores over a long period, as never more than 10% of the sori are at the stage, where the membranes are ruptured at the tip and/or extending to expose the spores (Shenoi and Ramalingam, 1976). Sampling of aerial spores indicates that the teliospores are released over a wide range of temperatures (16-24^{o} C) and humidity (51-100%). Two circadian patterns of spore release have been reported. Sreeramulu (1962) and Sreeramulu and Vittal (1972) found a single noon or early afternoon peak; and Shenoi and Ramalingam (1976) and Pady and Kramer (1960) reported a double peak, with the second peak occurring in the late afternoon. The first peak was related to the swelling of the sori caused by absorption of dew and the second peak to a dry, afternoon wind. The majority of spores caught by Shenoi and Ramalingam (1976) were single spore (80.8%), with clumps of 2, 3, and 4 spores accounting for 11.1, 3.6 and 1.4% units trapped respectively. The maximum number of spores in a clump was 60, but clumps containing more than 4 spores accounted for less than 5% of the counts. During the cropping season, three peaks of airborne spores have been recorded, at the ripening stages of the crop, harvest and threshing operations, with the highest concentrations at harvest. The release of spores is, therefore, related to the agitation of the plant (Shenoi and Ramalingam, 1976). This agitation can take the form of changing environmental conditions i.e. temperature or moisture, which encourage the rupture of the peridium; wind currents that shake the plant; or mechanical agitation through farming operations, i.e. harvesting and threshing. By the time threshing takes place the seed can be carrying high levels of *S. sorghi* spores (Shankara and Ramalingam, 1988).

Assessment of the dispersal of smut spores in and beyond infected sorghum fields indicates that the greatest release and diffusion occurs during harvest. In the study by Shenoi and Ramalingam (1976) spore densities of 75,218 spores/m^3 were recorded in infected fields at harvest and 53 spores/m^3 at 200m from the field. The greatest concentration of spores in and 30m from the field were found at 0.5m above ground level, though spores were present at measurable amounts at 5m above ground level. Studies in USA indicate that teliospores from the Ustilaginales are found in high numbers in the air and that air-borne smut spores can play a role in the spread of smuts (Crotzer and Levetin, 1996). This suggests that air-borne *S. sorghi* smut spores have a role in infecting 'clean' heads.

Control

Covered kernel smut can be controlled with seed treatments (Leukel, 1942; Doggett, 1988; Hansing and King, 1958; and Frederiksen and Odvody, 2000). These include thiram at 1:400 (w:w), copper carbonate, sulphur and some systemic fungicides e.g. Benomyl or Carboxin. In areas where seed dressings are used, CKS has become a minor problem, however, in the countries where seed dressings are unavailable or too expensive, losses are still significant (Mughogho, 1982). The success of seed treatments in the control of CKS has resulted in little recent research being undertaken to exploit the available host resistance or to understand the physiological races of *S. sorghi* (Omer and Frederiksen, 1992). Resistance to CKS is contained in every sorghum group, but resistance available in the Feterita group has been used most by breeders. This is because it is derived from allelic genes (Frowd, 1980). A review of available resistance and its inheritance is covered by Frowd (1980), Casady (1961), Khaleeque *et al.,* (1995) and Oleinik (2000).

There is no standard protocol to screen for resistance to CKS. The most common method is to mix dry teliospores with dry seed prior to planting and assess the percentage of infected plants. It is important that every plant is exposed to adequate amounts of inoculum. However, researchers have utilised different ratios and the results are often inconsistent, with escapes common (Claflin and Ramundo, 1996). Even when the same methods are used, disease incidences vary over seasons, making it difficult to compare results. Researchers have designated different infection rates to distinguish between resistance and susceptibility, especially when the infection rates are low (Gorter, 1961). For example, Mathur *et al.* (1964) and Singh and Yadar (1966) assigned an infection point below 10% as resistant and above 15% as very susceptible, while Ranganathaiah and Govindu (1970) assigned resistant at 0-1% and susceptible at above 10%. This has resulted in sorghum lines being assigned different properties. For example, sorghum line 510-z has been classified as resistant by Mathur *et al*. (1964) and moderately resistant by Singh and Yadav (1966) and by Ranganathiah and Govindu (1970). In 1961, Gorter (1961) proposed a formula to enable the comparison of seasons and experiments, but this has not been accepted as standard practice. The formula is

= 0.1 x percent infection

where x is the highest percent infection obtained on the most susceptible variety in the same experiment.

The formula tries to remove the arbitrariness out of the point of distinction between the designations of resistant and susceptible.

1.5 INSECT SORGHUM PESTS IN EAST AFRICA

Insect pests and the damage they cause are considered a major factor limiting sorghum yields in eastern Africa (Seshu Reddy, 1983 & 1985). These pests can be divided in to leaf and shoot feeders, shoot and stem borers, head feeders and stored grain pests. The most important field pests in the region are shoot flies and a range of lepidopterous stem borers, which include *Busseola, Chilo, Eldana* and *Sesamia* species. The shoot fly, *Antherigona soccara*, is an important seedling pest of sorghum. The stem borer, *Busseola fusca*, is the most important widespread and destructive pest. *Chilo partellus*, a pyralid stem borer, is widely distributed in the region and growing in importance, while *C. orichalcociliellus* is confined to the coastal regions. This review will concentrate on stem borers.

1.5.1 Stem borers

Of the various insect pests attacking cereals in Africa, the lepidopteran stem borers cause the most damage (Kfir, 1998). Twenty-one stem borer species have been identified, as pests to cultivated grasses in Africa and all but two are indigenous to Africa. The exceptions are *Chilo partellus*, which is indigenous to India and *C. sacchariphagus. C. partellus* is now displacing the native stem borers in southern and eastern Africa. In East Africa*, C. partellus, C. orichalcociliellus, Eldana saccharina, Busseola fusca*, and *Sesamia calamistis* are reported to be important and widely distributed stem borers of maize and sorghum (Seshu Reddy, 1998). In Eastern Kenya, *C. partellus* replaced *Busseola fusca* as the dominant species during the mid-nineties

(Songa, 1999). This review will concentrate on *C. partellus*, the major stem borer found during this study. The taxonomy of *C. partellus* is that it is categorised within the super family Pyraloidea, family Crambidae, sub-family Crambinae.

Biology of Chilo partellus

The life cycle of *C. partellus* varies in detail between locations due to climatic and other factors. The life cycle described here is based on work carried out in South Africa. The adult moths emerge from pupae during late afternoon and early evening and are active at night. The female moths tend to emerge after the males. This ensures that mating occurs during the night of eclosion (Pats, 1991). Adults generally live for 2-5 days and do not disperse far from their emergence site, though there are records of moths flying up to a few kilometres. During the day, they are inactive, resting on plants and plant debris. The moth's colouring and size means they are well camouflaged. Females release pheromones containing the compounds (Z)-11-hexadecenal and (Z)-11-hexadecen-1-01 to attract male moths (Nesbitt *et al*., 1979). Female moths usually mate once, while male moths mate repeatedly (Unnithan and Paye, 1991). After mating, the pre-oviposition period is 24 hours. Then over the next 2-3 nights the female locates suitable host plants and lays batches of 8-10 overlapping eggs, parallel to the long axis of the underside of the leaves. The total number of eggs laid has been reported as 10 batches (Harris, 1990) and 183-256 eggs per moth (Mbapila *et al.,* 2002). The number of eggs laid is affected by temperature, with the optimal temperature being 28^{o}C (Mbapila *et al.,* 2002). Newly laid eggs are translucent, turning white after a day and becoming grey before hatching.

Larvae emerge from the eggs 4-8 days after being laid (Ochieng *et al.,* 1985), usually in the early morning before sunrise. In the next few hours the larvae disperse to adjacent plants and move to the leaf whorls to feed on the young leaves. In artificially infested sorghum 30% of the larvae established in the whorl of the plant, 25% were recovered from surrounding plants within 50cm of the infested plant, and 45% were lost (Ampongo-Nyarko *et al.,* 1994). The successful establishment of the early instars mainly determines deadheart incidence and subsequent yield loss (Chapman *et al*., 1983). The larvae disperse by crawling or ballooning (Berger, 1992). Ballooning involves spinning thin silk threads and attaching one end to the leaf, and being carried by the wind to neighbouring plants (Revington, 1986). Revington (1986) has described this as an instinctive dispersal mechanism to reduce competition between larvae and increase survival rates. When larvae disperse they are attracted to sorghum foliage by ordour and surface wax chemicals (Bernays *et al.,* 1985). The larvae's urge to disperse declines with age (Sithole, 1987), though they move from older plants parts to younger ones probably following a nitrogen gradient as the plant is increasingly translocating nitrogen from the leaves to the stem to the grain (Ndemah *et al.,* 2001).

The 1^{st} and 2^{nd} instars feed in the leaf whorls by scraping off the epidermal and parenchyma cells on one side of the leaf, often leaving the epidermal cells on the other side intact. When the leaves unfurl this damage is seen and called window-paning. When no epidermal cells are left the damage is called shot-holes or pinholes, often a leaf will have a series of these holes across the blade. The 3^{rd} instar penetrates into the stem tissues to feed, producing extensive tunnels in stems. In young plants, the tunnelling may kill the central leaves and growing tip causing 'deadhearts'. The larval stages last 28-33 days and the pre-pupal stage 24 hours. The number of instars stages can vary from 4-8 with six the average (Mbapila *et al.*, 2002)

The larvae pupate in the tunnels after excavating emergence windows to facilitate the exit of the moth. The adult moth emerges 8-10 days later and survives for one week (Alghali, 1988). Under favourable conditions the life cycle is continuous and lasts 25-50 days (Harris, 1990; Neupane *et al*., 1985; Ingram, 1958). Mbapila *et al.,* (2002) reported the duration between egg and adult fell from 58.96+/- 7.95 days at 21^{o}C to 31.73+/- 3.03 days at 31 ^{o}C.

During unfavourable conditions mature larvae enter facultative diapause in stems and stubble for up to six months. This enables them to overcome unfavourable conditions. Conditions associated with entering diapause include prolonged drought (Mathez, 1972), senescence of the host plant (Nye, 1960) and general defesation of the nutritive environment (Scheltes 1978). In Western Kenya, Scheltes (1978) found that *C. partellus* did not enter diapause and development was continuous while there was sufficient moisture available for plant growth. On cessation of rain the larvae lost cuticular pigmentation, ceased to feed and became resistant to drought. Temperature, relative humidity and day length had no effect. When conditions became favourable the diapause is broken and the larvae pupate. The breaking of diapause has been linked to rain after a dry season (Chapman, 1982, Scheltes 1978 and Kfir 1993). Scheltes (1978) demonstrated that moist conditions induced a rapid decrease in juvenile hormone content in the diapausing larvae, which stimulated the termination of diapause. Van Rensburg *et al.* (1987) suggested that pupation could be induced by certain physical conditions only after a set period under specific conditions, although Usua (1974) suggested it might be under genetic control. Female moths that have been through diapause have been found to have a lower body mass, fewer oocytes in their ovaries and produce fewer eggs after long periods of larval diapause (Kfir, 1991).

The natural mortality of stem borers in the field can be very high. For instance, Mathez (1972) found only 5% of eggs laid produced adults that survived to die of old age, while partial life table studies showed that less than 1% of eggs survived to become adults (Oloo, 1989). In Kenya and Uganda, 18 to 90% of *C. partellus* eggs died (Mohyuddin and Greathead, 1970; Oloo, 1989). The egg stage is highly vulnerable to natural mortality as they are exposed and immobile. Factors causing mortality include rain, which washes the eggs off the plant (Niyibiigira *et al.,* 2001), exposure to solar radiation (Banhof and Overholt, 2001) and predatation by ants, ladybirds, beetles, earwigs and crab spiders (Midega *et al*., 2005). Midega *et al* (2005) attributed 15% of egg mortality to predation.

Mortality rates of larvae and pupae have been reported over a wide range, as high as 90% (Mohyuddin and Greathead, 1970; Girling, 1978), and less than 10% Midega *et* al., (2005). In West Kenya under natural conditions less that 10% of 1^{st} and 2^{nd} *Chilo partellus* instars survived to adult stage, with the lowest mortality at pupal stage (Oloo, 1989). In these studies, mortality was almost entirely attributed to 'disappearance'. Midega *et al.,* (2005) concluded that parasitism contributed insignificantly to the mortality rate.

Symptoms and yield loss

The foliar feeding of the larvae reduces photosynthetic area. Stem tunnelling weakens the stem, and interferes with the translocation of metabolites and nutrients within the plant, resulting in reduced grain production. Other symptoms are deadhearts, stem or peduncle breakage and stunted growth of the whole plant. Attack on the unexpanded internode below the immature head can cause poor head emergence or chaffiness.

There are few objective assessments of sorghum yield losses directly attributed to *C. partellus*. In Botswana, Flattery (1982) noted that often there was an increase in yield when a *C. partellus* attack resulted in tillering. This depended on the cultivar's ability to tiller and the resultant tillers compensating for reduced yield by the main stem. Doggett (1988) also thought that sorghum could produce a good crop and feed a large borer population, but that compensatory growth following borer damage was reduced under physiological stress. A study at Mbita Point, Kenya, suggested that infestations later than 60 DAE did not result in significant reduction in grain yields (2-13%). However, grain losses reached 75% when plants were infested with 5 larvae/plant at 10 DAE, which increased to 88% when plants were infested with 10 larvae/plant at 10 DAE (Seshu Reddy, 1987). In Uganda, Starks (1969) reported a 56% reduction in yield, when sorghum was infested with *C. partellus*, 20 days after emergence. In Western Kenya, the range was 2- 88%, but there was statistically no loss if infested at 60 DAE (Seshu Reddy, 1998).

Damage symptoms in relation to life cycle

In South Africa, diapause is broken when sufficient moisture is available. The first generation's egg masses can be found on sorghum seedlings 10-15 days after emergence. The first indications for the presence of *C. partellus* are pin-holes in the leaves as they unfurl. At 2^{nd} and 3^{rd} instar stage, the larvae stop feeding in the whorl and migrate to the base of the seedling or a few centimetres above soil level (van Hamburg, 1980). Entry takes place above 8-10 days after hatching, depending on temperature. If the apical meristem has moved upwards, larvae will feed only on the initial stem and the symptoms will be stem tunnelling. The larvae will continue to tunnel below the growing point until pupation. If the apical meristem is present where the larva enters, it will be destroyed and the symptom will be a deadheart. This usually occurs 18-25 days after egg laying. Death of the apical meristem removes apical dominance and the sorghum plant will usually produce a number of tillers. The earlier these tillers form the more synchronised they will be with the rest of the crop. Tunnelling weakens the stem making it susceptible to lodging.

The second generation of moths infests the crop 45-55 days after crop emergence. Usually there are overlapping generations. The infestation pattern is the same, though the 2^{nd} and 3^{rd} instars move 1-2 internodes below the whorl and enter the stem at a leaf axis. The larvae will cause stem tunnelling. Tunnelling in specific parts of the stem can cause different effects; when the larvae feed on the non-elongated peduncle the head may fail to emerge from the leaf whorl, or if the peduncle has elongated the tunnelling can disrupt translocation resulting in the poor head formation, incomplete grain filling or complete chaffiness. In addition, weakened stems may be unable to support the weight of the head and the peduncle breaks (Leuschner, 1989).

Other factors can influence the severity of the symptoms, for example low fertility, drought and moulds. When plant growth is slow, the feeding of the larvae can be more rapid than development of new plant material, resulting in damage to the apical meristem. Larvae feeding on the stem pith do not normally affect plant growth, but if after the feeding larvae fungi causing rots invade the stem the vascular tissue can be damaged.

Chemical control

Chemical control is the only effective method available to control stem borer, especially during an epidemic (Kfir *et al., 2002*). Use of chemicals depends on the farmers' perception of the problem and the potential result. Large-scale farmers, where sorghum is planted as a cash crop, are more likely to use insecticides than small-scale farmers, where grain sales are a small component of income (Goldman, 1996). The ability of the farmer to compensate for yield loss due to stem borer damage by increasing the area of land under the crop is also an important factor in using chemicals. In the highly populated areas of central Kenya 76% of farmers use chemicals to control stem borers on maize. In the lower populated regions of western Kenya the use drops to 20% (Goldman, 1996). Other factors that may contribute to a lower usage of chemical inputs are availability of insecticides and incomes.

Application of insecticides to control stem borers has to coincide with larvae feeding in the whorls. *C. partellus* spends up to 2 weeks feeding in the sorghum leaf whorls after hatching, though a high percentage of the larvae feed behind the leaf sheaths of sorghum, where they are protected from insecticide application. However, their migratory behaviour during the two weeks after egg hatching increases the likelihood of the larvae coming into contact with insecticide (van den Berg and Nur, 1998).

Economic thresholds for the application of insecticides to control stem borers in commercially grown sorghum have been calculated using percentage of plants showing whorl damage. The thresholds are 16% in Zimbabwe for *B. fusca* (Sithole, 1994), and 10% in South Africa for *B. fusca* and *C. partellus* (van den Berg *et al.*, 1997). These thresholds are low to enable the farmer to apply timely applications of control measures, but avoid unnecessary applications. For small holder farmers these thresholds are commonly reached or exceeded and the perceived lower cash value of the crop means that it is not economically feasible to use this threshold. Sorghum is able to tolerate some degree of damage before yield losses occurs (Flattery, 1982; and van Rensburg and van den Berg, 1992).

Several insecticides have been screened for the control of stem borers in various regions of Africa. These include beta-cyfluthrin, carbofuran, carbaryl, deltamethrin, endosulfan, trichlorfon and synthetic pyrethroids (Seshu Reddy, 1983 & 1985; Ajayi, 1998; Minja, 1990; Sithole, 1990; van Rensburg and van den Berg, 1992). The placement of insecticides in the whorls of sorghum is considered the most effective method for controlling *C. partellus* (van den Berg and Nur, 1998).

Plate 2.1: Intensive sorghum production in Mexico (2002)

Plate 2.2: Small-holder sorghum production in Mwingi District, Kenya. A millet: sorgum intercrop with local sorghum variety Muveta. Note the poor head emergence due to stem borer damage and drought stress (2001)

AN ASSESSMENT OF SORGHUM RATOONING IN LOCAL FARMING SYSTEM, MWINGI DISTRICT, EASTERN KENYA

1.6 INTRODUCTION

In eastern Kenya, crop establishment has been identified as a problem, particularly in the long rains (March-July) (Hayden and Wilson, 2000). Data is available on the role of sorghum within the cropping system (Hayden and Wilson, 2000; Karanja *et al*., 1999; M'Ragwa and Kanyeni, 1987). However, little information was gathered on the practices used in growing the local two-season sorghum within Mwingi District. To address this, a small focused survey was undertaken prior to field experiments to gather baseline information on the role of two-season sorghum within the farming system and to understand the current practices, with regard to its production. In discussions with the local extension officers, it became clear that they were unaware of the practice of ratooning sorghum. To improve their knowledge and triangulate the focus study several on-farm studies were set-up to enable them to interact with farmers growing the two-season sorghum and to gain a deeper understanding of the associated practices.

1.7 STUDY AREA

Mwingi District is located in Eastern province on the southern side of the Yatta Plateau with an altitude ranging from 1000 – 1400m (a.s.t). It covers an area of 9911Km^2 and in the 1998 consensus had a population of 335,202 in 55,735 households. The district is divided into eight administrative divisions; Kyuso, Central, Migwani, Mumoni, Nuu, Nguni, Tseikuru and Ngomeni; 31 locations and 125 sub-locations. The District contains six agro-ecological zones (AEZ)[1]: UM3-4 (a very small area), UM4, LM4, LM5, IL5 and IL6 (Figure 3.1). In the dry zones of LM5 and LM6, seasonal rainfall is below 300mm and success of producing a crop depends on synchronising the crop growth cycle with the rainfall (Jaetzold and Schmidt, 1983). The upper and lower zones differ in terms of rainfall, temperature and soils, which in turn affects the importance of different crops and the varieties of sorghum grown.

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[1] LM = lower midland zone: ann. Mean >24^{o}C, mean min >14^{o}C, UM = upper midland zone: ann. Mean 18-21^{o}C, mean min 11-14^{o}C, IL = inner lowland zone: ann. Mean >24^{o}C, mean max >31^{o}C
3 = semi-humid, 4 = transitional, 5 = semi-arid, 6= arid.

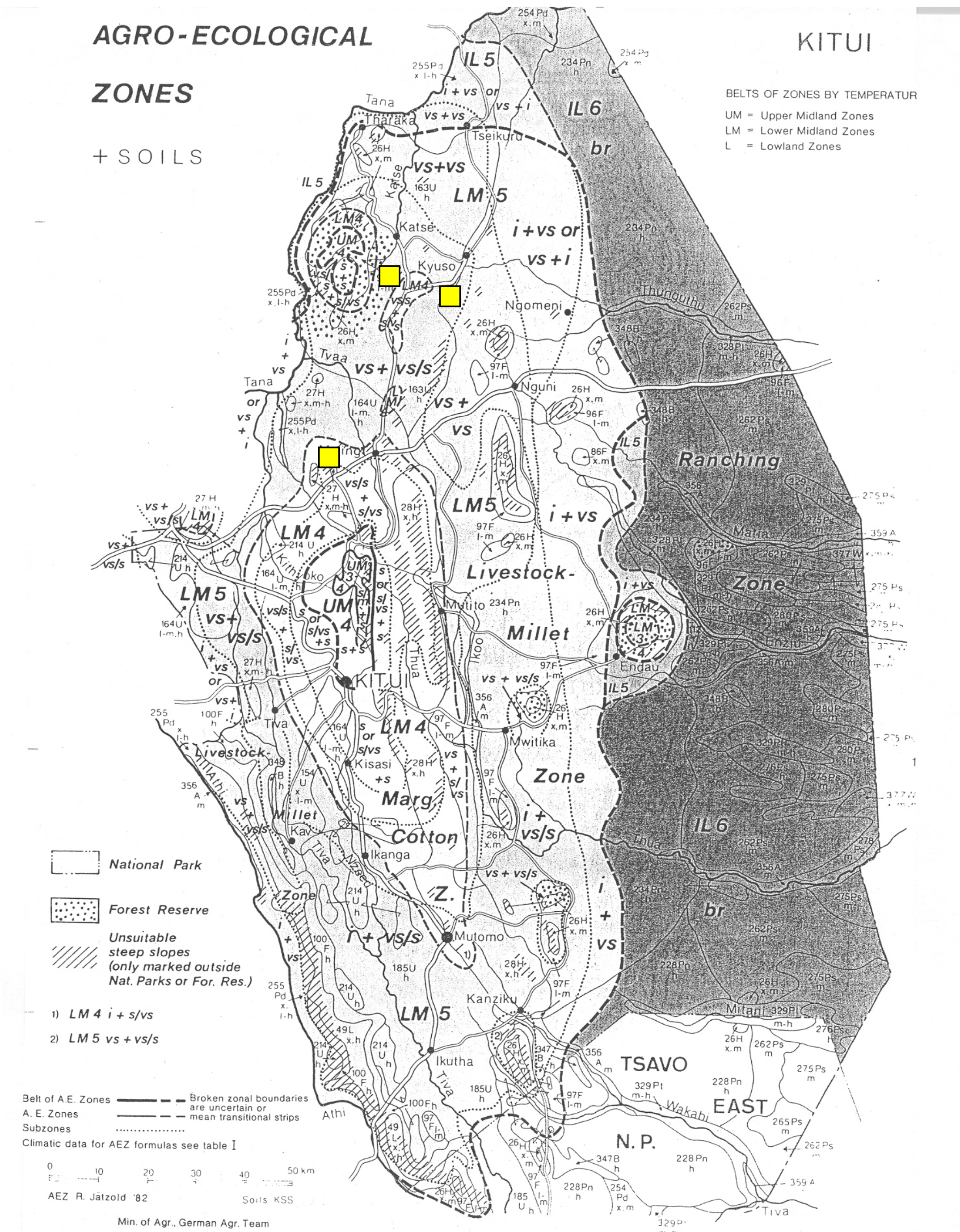


Figure 3.1: Map of the area showing the agro-ecological zones in Mwingi and Kitui Districts (Jaetzold and Schmidt, 1983).

■ = Sites of on-farm trails

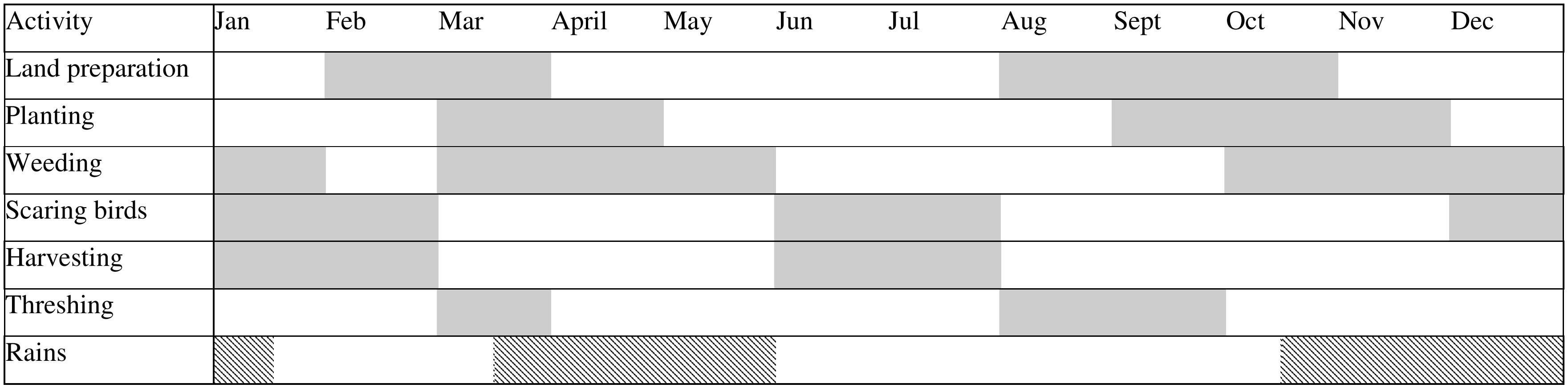
Mwingi District has a bimodal rainfall pattern with most of the rainfall in April and November. The two growing seasons are March-July (long rains) and October-February (short rains) (Figure 3.2). The short rains begin in mid-October and continue through November into late December / early January. While the long rains begin mid-March and may continue to May. Average annual rainfall is between 600-800mm. There is a 60% probability that the short rains will receive 250mm and the long rains 150mm (Jaetzold and Schmidt, 1983). Sorghum production requires an average of 250 to 525 mm in either the first or second rains (Karanja *et al.,* 1999). The average monthly temperatures range from 24 – 34^0C, with the hottest period the two months before rains commence. In 95% of the seasons, soil moisture is a limiting factor to cereals, which mature at 100 days or longer. On average maize crops fail to reach maturity in 5 out of 8 seasons (M'Ragwa and Kanyeni, 1987). This frequent failure has encouraged the Kenyan Government to encourage the production of drought tolerant crops i.e. millet, sorghum and cowpeas within the district.

1.8 APPROACH

1.8.1 A survey of farmers on sorghum production and the practice of ratooning

Data collection was carried out on two levels, personal interview and farmer group level. At farmer level, respondents were a mixture of farmers, who had previously participated in project activities and non-participants. The farmers were interviewed using a semi-structured interview technique (Pretty *et al.,* 1995). The interviews covered the role of sorghum, in particular two-season sorghum in their farming system and the methods used in its cultivation. These baseline data were collected in two locations from 28 farmers and triangulated with two womens' groups. The locations, Nguuku and Kamuwongo were selected as they are considered "hotspots" for the cultivation of the two-season sorghums. The focused survey was carried out in October – November 2000.

Figure 3.2: Generalised seasonal calendar of agricultural activities in the semi-arid areas of Mwingi District, Kenya (Hayden and Wilson, 2000)



1.8.2 On-farm study

In Nguuku and Kamuwongo location, ten farmers were identified through existing women's groups. Data were collected between December 2000 and July 2001 with the assistance of local extension officers.

1.9 RESULTS

1.9.1 Survey on sorghum production and the practice of ratooning

The farming systems in the study area are agro-pastoral. Most households have semi-subsistent production systems. Crop production tends to be of greater importance in areas of higher rainfall and populations. The crop enterprises involve rainfed production of drought tolerant crops, for example pearl millet, sorghum, cowpea, green grams and maize. The main constraint to crop production is considered to be low and erratic rainfall. Traditionally, pearl millet and sorghum have been the main starch staples, but maize production has grown in importance in the last 2-3 decades, resulting in a decline in sorghum production during the 1970s and 1980s and a stabilisation in the 1990s (Wilson and Kavoi, 2001). Most farmers grow all three cereals, maize, sorghum and millet. The relative importance of these cereals is affected by local agro-ecological conditions and farmer preference (Hayden and Wilson, 2000).

Table 3.1: Proportion of cultivated land under sorghum in Nguuku and Kamuwongo

Cultivated land	Number of farmers		
under sorghum (%)	Nguuku (12)	Kamuwongo (18)	Both
<25%	5	0	5
≈25%	3	6	9
≈50%	3	6	9
≈75%	0	1	1
≈100%	1	3	4
No data	0	2	2

Table 3.2: Sorghum production trends by respondents in Nguuku and Kamuwongo

Production trends	Number of farmers		
	Nguuku (n=12)	Kamuwongo (n=18)	Both
Increasing	11	16	27
Same	0	2	2
Decreasing	1	0	1

Table 3.3: Recent changes in cropping patterns by the respondents in Nguuku

Changes in cropping patterns	Number of farmers (n=12)
Started / returned to growing millet*	3
Started to grow sorghum*	2
Started to grow beans*	2
Started to grow green grams*	1
Long duration sorghum production decreasing	2
Stopped growing Dolicos	1
Stopped growing local millets	1
Stopped growing local cowpeas	1
Stopped growing local maize	1

*improved varieties with shorter cropping periods recently promoted in area

Sorghum is well adapted to semi-arid conditions; 250 – 525mm rainfall per season, that are found in the study area. Sorghum is grown in both cropping seasons (though traditionally more emphasis was placed on drought tolerant crops during the long rains). The area under, which the respondents have under sorghum varied from one quarter to all cultivated land (Table 3.1). The majority of sorghum is inter-cropped with other crops with each farm producing between 5-10 90Kg bags per season. Recently, respondents have been shifting to more drought tolerant crops and varieties. The increasing crops are sorghum and millets, while the increasing varieties are those with a shorter cropping period (Tables 3.2&3.3). This has meant a move away from long maturing local varieties to improved shorter duration cultivars i.e. the move to composite maize varieties KCB and Makuweni, and the millet variety ICMV221 (Table 3.4).

Table 3.4: Number of respondents, who have recently started to grow improved crop varieties in Nguuku and Kamuwongo

Crop	New varieties	Number of farmers		
		Nguuku (n=12)	Kamuwongo (n=18)	Both
Millets	ICMV221	6	10	16
Sorghums	Serena	2	2	4
	Serado	2	3	5
	Kari-mtama 1	2	0	2
Maize	Katumani maize	2	4	6
	Mukueni	0	7	7
Cowpeas	M66	0	1	1
	Kenkundie	0	6	6
Beans	GLP92	3	8	11
	KB1	2	0	2
Green grams	N26	2	1	3
Pigeon peas	60/8	0	1	1
No new varieties		3	0	3

The women's group at Nguuku explained that a decade ago, farmers held sorghum in very low esteem. Sorghum was planted when there was no other seed available. It was planted last and in the poorest part of the farm. Eroded land was always planted with sorghum, as it is the only crop, which can produce a yield on this type of land. The stover produced was incorporated into the soil to improve the fertility. The role of sorghum stover in revitalising soil was considered important and farmers would plant sorghum even when they would not expect to reap a yield, so the trash would be available as a soil improver. Historically, the farmers initially relied on the long duration sorghum varieties, Muhuu and Muruge, which were ratooned between the short and long rains, and the local short maturing variety Muveta, which was not ratooned, because the stems dry very fast. The yields achieved from these long duration varieties are low. Their main harvest is in the long rains seasons, and unless the short rains are particularly good the crop produces no harvest during the short rains.

The present situation in Nguuku, is that farmers set aside good land for sorghum to ensure food security. The recent Food for Work programme, which paid farmers in food to terrace their land, has meant that there is more good land available for planting. However, though the farmers are planting sorghum on better land to improve food security, inputs such as fertiliser or manure are not used on the crop. This is mainly due to the low market price, which ranges from 2-10p per kg, depending on the supply. Sorghum is usually planted with millet at a ratio 1:9. The seed is mixed before planting and 3-6 seeds of the mixture are placed in each planting hole. A few farmers plant improved sorghum varieties in pure stands or inter-cropped with legumes.

In Nguuku, the farmers identified several factors that caused the change in their perception of sorghum. These included:

1. Arrival of posho mills making the milling of sorghum easier.
2. Utilisation courses introducing new methods to consume sorghum, thus making it a more versatile food.
3. Arrival of new sorghum varieties increasing yields and versatility of sorghum.
4. Availability of seed through the setting up of local seed bulkers and local seed stores.
5. Ability of sorghum to produces higher yields than other crops on poor land, as land becomes more of a constraint, more poor land is coming under cultivation.
6. Increased frequency of poor rains making food security an important issue.
7. Campaigns by the extension service to increase the profile of sorghum, by addressing many of the above issues affecting the perception of sorghum in the area.

In the focused survey, all the farmers interviewed cultivated sorghum. This was not a pre-determined selection policy. The varieties grown include improved, local, and one and two-season cultivars (Table 3.5). Most farmers grew a mixture of varieties. Serena and Muveta were the main one-season varieties of sorghum. Variety Muveta is a local variety with a maturity date slightly longer than Serena's 120 days, and produces semi-compact heads, with large, white grains.

Table 3.5: Varieties grown by respondents and proportion (%) of respondents growing improved and two-season sorghums

Sorghum type	Variety	Number/*percentage* of farmers		
		Nguuku (n=12)	Kamuwongo (n=18)	Both (n=30)
Improved	Serena	10	13	23
	Serado	4	4	8
	Kari-mtama-1	2	0	2
		*100%**	*94%**	
Local	Muveta	9	17	26
	Kavula	2	0	2
		100%	*94%*	
Two-season	Muruge	12	3	15
	Muhuu	4	10	14
	Mukomo	1	0	1
	Kateng'u	1	0	1
		100%	*56%*	

* *The percentage of farmers growing improved sorghum varieties is 33 in both Nguuku and Kamuwongo if the variety Serena is excluded from the total.*

In Kamuwongo location, the two-season variety Muhuu was the third most popular variety, with 56% of the farmers growing it. Two farmers only grew the other two-season variety Muruge. In Nguuku, the variety Muruge, was the most common variety, with Serena second and Muveta third. Several local varieties, Kavula, Mukomo and Kateng'u, were described by the Kivonia women's group, as in decline due to their inability to cope with the drier seasons the area is now experiencing.

Of the interviewees, 90% were increasing sorghum production, although there had been a shift in the varieties grown. The local two-season variety Muruge has declined. Previously, whole terraces were planted with Muruge or Muhuu; farmers now tend to plant these varieties along the edges of the terraces, due to their susceptibility to drought. The local variety Muveta is also decreasing on some farms, though it is relatively drought tolerant. The reason given by the farmers is that the birds like its large white grains and therefore a high level of labour is required to protect it from bird damage. These traditional varieties are being replaced by Serena, which is the most drought tolerant of the available varieties and is not favoured by the birds. Five years ago, this variety was not common in Nguuku, but now is grown by most farmers.

Changing eating habits are also affecting the varieties of sorghum grown. The Kwiyika Women's group said one of the reasons for the decline in Muruge and Muhuu production was that many of the old preparation methods for these varieties had been lost. This is partly because with children at school the women have many more duties and they do not have as much time for food preparation. The children also do not have as much time to learn from the parents and the girls have not learnt the methods.

Ratooning is widely practised by farmers in the two locations (Nguuku 92% and Kamuwongo 83%). The majority of these farmers, 100% in Nguuku and 73% in Kamuwongo, ratoon the local two-season sorghum varieties, Muruge and Muhuu (Table 3.6). The farmers in both locations, perceived the advantages to ratooning to be higher yields, larger grain size, the saving of seed and labour, and the crop requiring less rain and maturing earlier (Table 3.7). The two-season sorghums were also important in soil conservation and the formation of trashlines, especially between the short and long rains. Most farmers considered that there were no disadvantages to ratooning. The one farmer in Nguuku who did not ratoon had given up due to the high levels of covered kernel smut in ratooned Muruge.

Table 3.6: Number of interviewees ratooning sorghum and the varieties they ratoon

Varieties	Number of farmers		
	Nguuku (n=12)	Kamuwongo (n=18)	Both (n=30)
Muruge	11	1	12
Muhuu	3	11	14
Serena	3	4	7
Seredo	0	5	5
Kari-mtama 1	1	0	1

* Some farmers grew and ratoon more than one variety

A few farmers ratooned improved sorghum varieties (Table 3.6). In Nguuku, two and one interviewee ratooned varieties Serena and Kari-mtama 1, respectively. One farmer began to ratoon Kari-mtama 1 in 1998 during the *El Nino*, as a way to save the crop after attack by a plague of grasshoppers. She has continued with the practice, as the ratoon crop gives a more reliable and higher yield than the one season crop, it reduces the amount of seed, which needs to be saved, and the grains are larger in ratooned sorghum compared to the direct sown crop. The saving of seed is important as the seed for variety Kari-mtama 1 is hard to obtain and the variety's culinary characteristics are rated highly. However, in poor growing seasons the crop may be severely damaged by birds, as there is nothing else to eat. The other two farmers stated there were no disadvantages to ratooning Serena.

Table 3.7: Advantages and disadvantages of ratooning as given by the interviewees in Nguuku and Kamuwongo locations

	Number of farmers		
	Nguuku (n=12)	Kamuwongo (n=18)	Both (n=30)
ADVANTAGES			
Higher yield than 1st season	10	12	22
Larger grain size	4	1	5
More tiller, more heads and larger heads	1	0	1
Earlier maturing	3	1	4
Requires less rain	2	0	2
Reduces stem borer damage	3	0	3
Saves seed	1	3	4
2nd harvest	0	1	1
Soil conservation	0	1	1
DISADVANTAGES			
Birds	0	1	1
Stem borers	0	2	2
None	11	14	25

In Kamuwongo, nine of the respondents had ratooned either Serena or Seredo. Of these, four had started ratooning last year after the practice was discussed in a previous project (project DFID R6581). Unfortunately, there was severe drought during that season, so they were unable to comment on their performance. One farmer had started ratooning Serena three years ago after seeing the practice on another farm, said the practice had encouraged her to plant more sorghum, because two harvests are achieved from one land preparation and sowing. The only disadvantages to ratooning in general were stem borer damage and bird damage.

Table 3.8: Ratooning methods as practised by the farmers in Nguuku and Kamuwongo locations

Methods of ratooning	Number of farmers		
	Nguuku (n=12)	Kamuwongo (n=18)	Both
As crop reaches maturity stems are cut and staked under a tree to dry, then heads harvested. Does not remove any tillers	0	5	5
Harvests and cuts back stems at same time	1	1	2
Ratoon soon after harvest, leave approx. 4 of the youngest tillers	1	0	1
Ratoons soon after harvest	5	7	12
Ratoons just before onset of rains	2	1	3
Does not ratoon	1	3	4
No response	2	1	3

The methods of ratooning varied between the two locations (Table 3.8). In Nguuku, the most common time to ratoon sorghum was soon after harvesting (66%). Of these farmers, one thinned the number of tillers by removing the oldest and leaving the youngest four to develop. The reason given for thinning was that younger tillers are more vigorous and healthy and older tillers are usually more damaged by stem borers. One respondent used to ratooning at the onset of the rains, but changed to ratooning after harvest because it increased plant survival and reduced the damage caused by stem borers. The two respondents still ratooned at the onset of the rains also removed the tillers affected by stem borers. These tended to be the older tillers, leaving the youngest ones to develop. The reasons given were the same as the previous respondent.

In Kamuwongo, the most common ratooning practice was to ratoon soon after harvest (53%). However, unlike in Nguuku, 33% of farmers in Kamuwongo ratooned the sorghum as it reached physiological maturity and stooked the stems with the heads under a tree to dry, at which point they were harvested. The reason given was this reduced bird damage and if the plant is left to dry out before ratooning, tillering is reduced. None of the five farmers asked thinned the tillers after ratooning. Sorghum variety Muveta was not ratooned by any respondent. The reasons, given by two farmers were that it matured too early and therefore is badly attacked by birds.

The most frequently named constraint to sorghum production in both Nguuku and Kamuwongo areas was availability of cultivated land at 58% and 33% respectively (Table 3.9). The higher naming of this constraint in Nguuku location probably reflects the higher population density. In Kamuwongo, labour (28%), seed availability (18%) and availability of oxen (17%) were considered problems. Availability of oxen was a problem in Kamuwongo, because in some places the soil has a high clay component, so it can not be worked with a plough until after it has received the first rains. This means land preparation is condensed into a very short period and there is a high demand for oxen. This short period to complete land preparation and plant explains why labour is more of a constraint in Kamuwongo than in Nguuku, 29% and 8% respectively.

Availability of good seed is a problem for most crops. The main source of seed for farmers is from their own fields, personal networks and the local market. The incidence of storage pests means storage of seed for any length of time results in high levels of damage and poor germination. Several development programmes are trying to address seed supply. This is compounded by the problem of regular crop failures, which mean that it is easy for farmers to 'lose' varieties. None of the programmes address the availability of local two-season varieties. Seed availability of the two-season varieties Muruge and Muhuu is a particular problem and was cited by respondent (F5) as a constraining factor to growing these varieties. The extension officer Kavisi (Kyuso Location) confirmed that seed of these varieties was difficult to find due to the recent poor seasons. The availability has become a problem due to recent poor rains resulting in low to nil harvests.

Table 3.9: Constraints to sorghum production and pest and disease problems as identified by interviewee farmers

Constraints	Number of farmers		
	Nguuku (n=12)	Kamuwongo (n=18)	Both
Production			
None	3	2	5
Low market prices	2	0	2
Utilisation limited	1	0	1
Birds	3	2	5
Land availability	7	6	13
Seed availability	2	3	5
Age	1	0	1
Labour	1	5	6
Availability of oxen	0	3	3
Pest and diseases			
Stem borers	6	16	22
Smut	10	17	27
Aphids	4	4	8
Caterpillars	2	4	6
Birds	10	12	22
Blind heads	0	1	1
None	1	0	1

The pests and diseases cited by the respondents as problems were similar in both areas. The most commonly cited were stem borers, birds and covered kernel smut (Table 3.9). Stem borers were considered a problem by more farmers in Kamuwongo (94%) than in Nguuku (50%). This was probably related to the high water stress plants have to cope with in Kamuwongo due to the area's lower rainfall and higher temperatures. Plants under water stress are less able to compensate for the stem borer damage. Of the twelve respondents asked in Kamuwongo, all considered stem borers to be at higher levels on ratooned sorghum compared with direct sown sorghum. One farmer said that when the ratoon crop was badly attacked by stem borers the yields were low.

The high levels of stem borers and covered kernel smut on ratooned sorghum were the reasons given by a farmer for not ratooning. However, another farmer said they were only a problem in poor rains and he always planted sorghum in pure stands when ratooning, so the stem borers did not infect other crops, especially maize.

Covered kernel smut was considered a problem by 83% and 100% of farmers in Nguuku and Kamuwongo respectively. In Kamuwongo, the six respondents asked considered that covered kernel smut occurred at higher rates in the ratoon crop than direct sown. The other important pest was birds, which were considered to be more of a problem on white seeded varieties than on other varieties. The relative bird resistance of variety Serena was considered an important feature in its popularity. The increasing acreage of millet and sorghum should help initially with the bird problem, as more farmers will share the birds and this will reduce the pressure on individual crops.

1.9.2 On-farm study

The rainfall received during the long rains (March – August 2001) was particularly poor. The short rain finished early (mid-December), so the gap between the two seasons was long. The long rains began in late March and ended mid-April and were below average. This resulted in the two-season sorghum reaching maturity in only 7 of the 20 farmers participating in the on-farm observations. Six of these farmers were in Nguuku and the one in Kamuwongo location. All the farmers grew the variety Muruge.

The participating farmers planted the two-season sorghum in areas of highest moisture retention to improve yields. These areas included the base and top of the terrace embankments, and in the trashlines. Other reasons given for planting at the base of the embankments was that the embankments were not damaged during uprooting of the stumps. Other farmers planted on top of embankments to help stabilise them. The ability of two-season sorghum to aid the stabilisation of soil was an important benefit in farms without water and soil conservation systems. The sorghum was also placed on the edge of terraces so it did not impede and were not disturbed by farm activities i.e. ploughing.

The area under cultivation within each farm ranged from 0.2 to 0.5 ha. Two-season sorghum was not intra or inter-cropped in either the short or long rains. In the short rains, the farmers planted the rest of the terrace with a range of crops, including mono-crops of millet and sorghum, and inter-crops of maize with cowpea or beans or green grams. One farmer left the terrace fallow. Due to the requirements of two-season sorghum over half the farmers always planted it in the same place, even if the rest of the terrace was left fallow.

The planting distance between the planting stations differed between farmers from 45cm to 100cm. All the farmers except one planted 3-5 seeds per station. The other farmer planted 4-6 seeds per station. None of the farmers thinned. The timing of the planting was considered flexible, within the window of opportunity, with half the farmers' dry planting and the other half wet planting. The planting dates ranged from 25 October to 2 December 1999. The number and time of the weeding varied from one to three over the two-seasons. All the farmers carried the first weeding in December though the timing varied from early to late December. The second weeding was carried out by half the farmers and was completed in January. A third weeding, at the beginning of the long rains was carried out by a few farmers. In the direct sown crops, farmers weed between 2-3 times per season (Hayden and Wilson, 2000).

The crop was ratooned before the onset of the rains by 83% of the farmers, of these 60% ratooned during or soon after harvest and 40% ratooned one week before the onset of the rains. The rest of the farmers ratooned 10 days after the rains had begun. Ratooning was carried out using a panga. The stems were cut back to a range of heights: ground level, 4-6cms and 30cms, with ground level the most common. At the time of ratooning, most of the stems were still green, though over 50% of the leaves were dry. The survival of the stumps between the short and long rains was high, between 70-100%. The variation in the survival rate did not seem to relate to spacing, time of planting or dryness of the plants. Of the farmers that had successfully ratooned plants, only one failed to harvest a crop. The crop was harvested in the last week of June. The farmers' rated the crop poor to very poor. The yield achieved ranged from 0 – 75kg/ha. During this season, the direct sown crop failed on all the participating farms.

The farmers rating of the level of stem borer damage at pre-booting stage was average, but this rating increased to above average to severe by pre-harvest. The stem borer damage rating by the farmers mirrored the farmers overall opinion of the crop. Stem borer damage is considered a major disadvantage to ratooning sorghum.

1.10 DISCUSSION

Sorghum is an important component of the farming system in both Nguuku and Kamuwongo. Its main role within these systems is as a food security crop and it is in this role that the farmers are increasing production. The income generated from the marketing of surplus sorghum is minor due to the poor prices and lack of market (Wilson and Kavoi, 2001). The views expressed by the respondents during the survey on the general role of sorghum corresponded with the opinions collected during a previous survey (Hayden and Wilson, 2000). However, the previous study did not cover the practice of ratooning sorghum.

The farming systems in both Nguuku and Kamuwongo reflect the difficult conditions within which the farmers farm. They deal with these conditions by trying to spread the risk through employing different crops, varieties, planting times and off-farm generating activities. Farmers are adapting to the recent drier seasons by adopting more drought tolerant crops i.e. sorghum and millets.

The cultivation of sorghum involves the practice of both direct planting and ratooning. Presently, the practice of ratooning is mainly restricted to the local two-season varieties, Muruge and Muhuu. When farmers were asked about ratooning short duration, improved varieties the majority of farmers were unaware that it was possible. The few farmers who are ratooning the improved varieties Serena, Seredo and Kari-mtama have reported positive results. However, the advantages attributed to ratooning the two-season sorghum of higher yields, larger grains and earlier maturity need to be confirmed using a larger sample of farmers growing the ratooned improved varieties. Comments made by several respondents that the local variety Muveta was not ratooned, because it matured too early and therefore came under severe bird pressure may also hold true for the improved varieties. The improved varieties Serena, Seredo and Kari-mtama 1 all reach maturity quicker than Muveta when direct sown. The majority of farmers, when directly asked considered that there were no disadvantages to ratooning sorghum.

However, when discussing pest and disease constraints to sorghum production stem borer levels and covered kernel smut levels were higher on ratooned sorghum compared with direct planted sorghum. High levels of these pests had caused one farmer to abandon the practice of ratooning, and another farmer said "stem borers levels did occasionally reach levels where the yields were severely affected". The build up of pests on the ratooned sorghum needs to be investigated and seems to be a key question to the sustainability of ratooning improved varieties within this region.

The incidence of covered kernel smut in a crop is affected by the method of seed selection employed by the farmers in the previous season. As previously mentioned in Chapter 2, covered kernel smut is transmitted on the surface of the seed. The farming activities of harvesting and threshing cause large numbers of covered kernel smut spores to be released from the sori disseminating spores onto non-infected heads and seed. The majority of farmers in Mwingi District tend to select their seed at the homestead prior to threshing (Hayden and Wilson, 2000). The selecting of seed prior to harvesting reduces the chance of the 'clean' heads being contaminated by covered kernel smut spores from infected heads (Hayden and Wilson, 2002). The adoption of this seed selection method will reduce this problem. As respondent (F10) who had been involved in previous projects said, "smut is not a problem if you select your seed in the field".

The methods of ratooning employed by farmers varied. The majority of the respondents considered early ratooning to promote plant survival and growth of the tillers. While a few respondents thinned the number of tillers by removing tillers most badly infested with stem borers and / or the oldest to promote growth and reduce stem borer damage. Younger tillers were considered to grow more vigorously. The effects of carrying out ratooning at different times in relation to harvest and the onset of the long rains, and the thinning of tillers needs to be investigated.

Several developments in the local farming systems have recently occurred that make ratooning a more favourable option. The spread of soil and water conservation methods, particularly the building of permanent terraces, means farmers are less willing to allow animals in to fields after harvest to graze the stover as they cause serious damage to the embankments. This overcomes the problem of livestock damaging the ratooned plants and small ruminants suffering bloat from eating the young re-growth of the sorghum plants. The recent poor short and long rains have resulted in the farmers showing an increased interest in drought tolerant crops. The long rains have become so erratic that even drought tolerant direct sown crops have been failing. The problem of food security combined with the development of terraces means farmers have increased the area of 'good' land and are more willing to place sorghum on 'good' land under sorghum. The better water retention the terrace should aid survival of plants between the seasons.

1.11 MAIN CONCLUSIONS

The practice of ratooning has been traditionally used on a few local, long duration varieties within the farming systems studied. However, the practice is in decline due to the traditional varieties not coping with the increasingly dry long rains. With this farmer knowledge and experience, the adoption of this practice to new short duration varieties of sorghum will have fewer hurdles to overcome, if it is appropriate. However, the study areas are considered 'hot spots' of ratooning, outside these areas ratooning is not so widely practiced. Any further study on the suitability of ratooning should include farmers who are not presently ratooning. The study did identify several questions that need to be addressed if ratooning short duration sorghum can be recommended:

1. Suitability of the locally available short duration varieties, Serena, Seredo and Kari-mtama 1, to the practice of ratooning.
2. Effect of the practice on levels of stem borers and covered kernel smut within the crop.
3. Effect of different methods of ratooning on the level of stem borers.

Plate 3.1: Three sorghum panicles of varieties grown by farmers – local ratooned variety Muhuu (top), improved variety Seredo (left bottom) and local variety Muveta (right bottom)

Plate 3.2: Two-season sorghum growing in farmers' fields. Variety Muhuu (top) is growing along the trashline to improve soil stability. Variety Muruge (bottom) is growing in the trench in front of the embankment. Both growing methods help to increase availability of soil moisture (Long rains 2002)

COMPARISON OF SORGHUM RATOONING AND DIRECT PLANTING IN RELATION TO THE LEVEL OF COVERED KERNEL SMUT

1.12 INTRODUCTION

The available literature on factors influencing sorghum yields is based on work carried out on direct sown, short duration sorghum and little is known, in regard to tillers and their occurrence and consequences for yield. The assumption has been that tillers act the same and are in competition with the main culm (Gerik *et al*., 1990). Development of the sorghum panicle occurs concurrently with leaf expansion and may compete for substrate (Eastin, 1972). High yields are achieved under a combination of a high sink capacity and a high assimilate supply during grain-filling. The major limitation of grain yield is considered to be nutrient assimilates supply during grain filling (Maiti Rantikanta, 1995).

The systemic nature of covered kernel smut means that an infected plant in the first season will be infected in the second season. Doggett (1988) suggested that later developing tillers are more likely to express the disease than the panicle of the main culm. However, there is no information on the effect of the practice of ratooning sorghum on the incidence and severity of CKS.

A field experiment was, therefore, undertaken to provide quantitative information on the effect of CKS and stem borers on the yield of sorghum grown from crops grown over two seasons. This was achieved using crops established by direct seeding for two consecutive seasons, or from crops established from seed in the short rains (October – January) and ratooned for the second long rains season (March – July). The experiment ran from October 1999 to August 2002 and covered six cropping seasons. This enabled the experiment to be replicated three times.

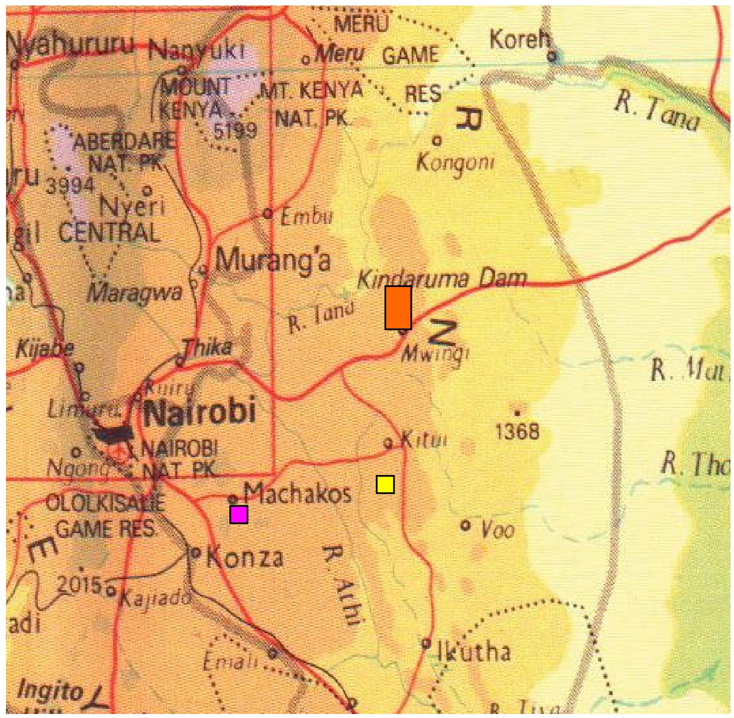


Figure 4.1: Map showing the locations of experimental sites: Katumani Research Station, Ithookwe sub-station and on-farm trial area

Source: www.onlinemaps.co.cc

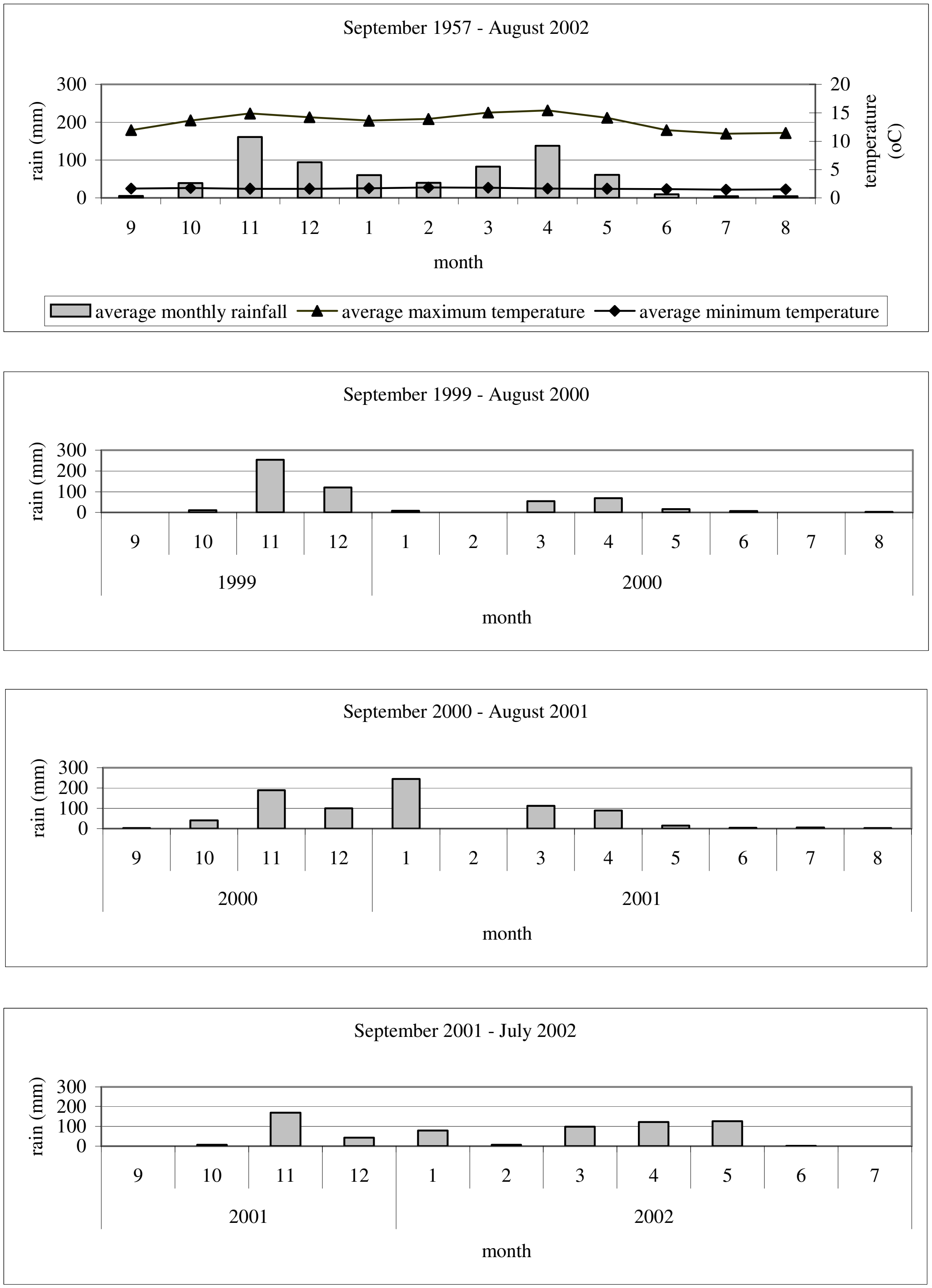


Figure 4.2: Monthly weather information for Katumani Research Station, Machokos District covering 1957 - 2002 and the three cropping cycles in which the field experiment was conducted.

1.13 MATERIALS AND METHODS

1.13.1 First cycle of field experiment (October 1999–March 2000, April–August 2000)

Location of experiment

The experiment was undertaken at KARI, Katumani Research Station, Machakos, Eastern Province of Kenya (latitude 1'35'S, longitude 37'4'E, elevation 1600m) (Figure 4.1). The site is in agro-ecological zone UM4 (upper middle 4)[1]. The rainfall pattern is bimodal and is received between March-May (long rains) and October – January (short rains). The long term average rainfall is 339mm and 359mm for the short and long rains respectively, based on 77 years of data (Figure 4.2). The minimum and maximum temperatures are 15^{o}C and 28^{o}C, with a mean of 22^{o}C. The soils are classified as oxic paleustalf chromic luvisol.

Layout of the experiment

The experiment was laid out in the design of a fully randomised complete block. There were four blocks in which each treatment was replicated once. Sorghum variety Seredo was used in all the experimental treatments. Each treatment plot measured 12 m x 3 m.

Treatment combinations

T1: (direct sown treatment nil crop i.e. no pesticide) sorghum sown and harvested in short rains (October-February) and long rains (March-July). No pesticides used.

T2: (ratooned treatment nil cropi.e no pesticide) sorghum sown in October and ratooned in February. Harvested in February and July. No pesticides used.

T3: (direct sown thiram crop) sorghum (seed treated with thiram) sown and harvested in short and long rains.

T4: (ratooned thiram crop) sorghum (seed treated with thiram) sown in October and ratooned in February. Harvested in February and July.

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[1] UM = upper midland zone: ann. Mean 18-21^{o}C, mean min 11-14^{o}C, 4 = transitional,

T5: (direct sown lamdacyhalothrin crop) sorghum sown and harvested in short and long rains. The insecticide carbofuran was applied during planting and this was replaced with the insecticide lamdacyhalothrin in the long rains. Lamdacyhalothrin was applied at approximately 2-3.5 weeks after emergence.

T6: (ratooned lamdacyhalothrin crop) sorghum sown in October and ratooned in February. Harvested February and July. The insecticide carbofuran was applied during planting and this was replaced with the chemical lamdacyhalothrin in the long rains. lamdacyhalothrin first applied at approximately 2-3.5 weeks after emergence of the direct sown crop. The ratoon crop was sprayed at the same time as the direct sown crop.

T7: (direct sown beta-cyfluthrin crop) sorghum sown in October and harvested in short and long rains. The insecticide beta-cyfluthrin first applied both seasons at growth stage 5-7 leaves (approximately 3-4 weeks after emergence).

T8: (ratooned beta-cyfluthrin crop) sorghum sown in October and ratooned in February. Harvested in February and July. The insecticide beta-cyfluthrin applied both seasons when the direct crop was at growth stage 5-7 leaves (approximately 3-4 weeks after emergence).

T9: (direct sown treatment full crop) sorghum sown in October and harvested in short rains and long rains. Seed treated with thiram. The insecticides, carbofuran, lamdacyhalothrin and beta-cyfluthrin applied in short and long rains as in above treatments.

T10: (ratooned treatment full crop) sorghum planted in October and ratooned in February. Harvested in February and July. Seed treated with thiram, carbofuran, lamdacyhalothrin and beta-cyfluthrin applied in short and long rains as in above treatments.

Preparation of seed

Smut spores were collected from infected sorghum heads at KARI sub-station Ithookwe, Kitui District in January 1999. The spores were stored in a sealed container in a laboratory cupboard until required. Sorghum seed were inoculated using CKS spores at a rate of 0.2% (0.2g per 100g) of seed in October 1999, prior to planting. The seed used to plant plots containing treatments T3, T4, T9 and T10 were also treated with a fungicide, thiram for the control of CKS.

Crop Establishment

Plots of all ten treatments were established by direct seeding on 26 October 1999. The seed was sown into holes dug with dibbers at 20cm intervals along five rows in each plot. Rows were spaced 75 cm apart. There were approximately 3 –5 seeds per hole. Two weeks after emergence seedlings were thinned to one per station giving a final stand count equivalent to 66 667 plants/ha.

Immediately after planting, an application of diammonium phosphate fertiliser (DAP) (20:20:0) was made at the rate of 20kg/ha as granular fertiliser broadcast by hand to the soil surface of each plot. Fertilisers were applied due to the relatively low fertility of the field site of the research centre. The rate applied is the KARI recommended economic rate for sorghum. The type of fertilisers used was dictated by availability.

Hand-weeding operations were undertaken when sorghum was at the seedling stage (1 – 2 weeks after emergence), two weeks later and at flowering/panicle formation to minimise competition from weeds during crop establishment

Table 4.1: Treatments used in the comparison of sorghum ratooning versus direct planting on the incidence of sorghum covered kernel smut and stem borers, KARI-Katumani, Kenya

Treatment name/ Chemical Inputs	Agronomic practice						Harvesting date (month)
	Direct sown			Ratooned			
	Treatment number	Planting date (month)	Ratooning date (month)	Treatment number	Planting date (month)	Ratooning date (month)	
NIL	**T1**	1) October 2) March	N/A	**T2**	1) October	1) March	1) February 2) August
THIRAM	**T3**	1) October 2) March	N/A	**T4**	1) October	1) March	1) February 2) August
CARBOFURAN[1]	**T5**	1) October 2) March	N/A	**T6**	1) October	1) March	1) February 2) August
BETA-CYFLUTHRIN	**T7**	1) October 2) March	N/A	**T8**	1) October	1) March	1) February 2) August
FULL Thiram+Carbofuran + Beta-cyfluthrin	**T9**	1) October 2) March	N/A	**T10**	1) October	1) March	1) February 2) August

[1] Lamdacyhalothrin was used in 2000/1 and 2001/2

Ratooning practices

The crop was ratooned immediately after harvest of the sorghum heads. The remaining stems were cut back to approximately 8 cm in height using pangas.

Re-establishment of direct sown crop (Long rains 2000)

After harvest, plots of the Treatments T1, T3, T5, T7, T9 were re-planted on 15 March 2000. The seedbeds were prepared by clearing the previous crop and turning the soil using jembes. Crop establishment and thinning were carried out as previously. All ten treatments had a top dressing of 20kg/ ha of fertiliser (23:23:0) after the first weeding and a second application of 20kg/ha of CAN (46:0:0) at booting stage.

Application of crop protection chemicals

To control CKS the chemical Murtano, active ingredients lindane and thiram, was applied to the seed of treatments T3, T4, T9 and T10 prior to planting, at the recommended rate of 1g per 700g of seed.

To control stem borers, the chemical carbofuran (5%ww) was applied at the recommended rate of 2g of granules per planting pocket during the 1999/2000 season. The chemical was placed in the planting hole with the seed before being covered with the soil to treatments T5, T6, T9 and T10. In the 2000/2001 and 2001/2002 seasons, carbofuran was replaced with lamdacyhalothrin. The insecticide lamdacyhalothrin (Trade name Karate 5EC) was applied to treatments T5, T6, T9 and T10 when the plants were at knee height (40cm). The active ingredient is lambdacyhalothrin (17.5g per litre) and was applied at the recommended rate of 300mls per hectare, with a spray volume of 120 litres per hectare, using a Hardy backpack sprayer..

To control stem borers the chemical beta-cyfluthrin (0.5g/kg) was applied at the recommended rate using the chemical company's applicator to treatments T7, T8, T9 and T10 at growth stage of 5-7 leaf stage. The decision to use these chemicals was based on their reported efficacy and availability.

Assessment of covered kernel smut

Each plot contained 150 plants. Assessments were carried out on the three inner rows to minimise errors due to the edge effects. For this same reason the first and last five plants in each row were not included in the assessments. Of the 150 plants, 15 from each row of the three inner rows i.e. a net plot of 45 plants were included in the assessments. In each row, the 15 plants were in a continuous strip. The strips were staggered diagonally across the plot so that their positions did not overlap and the whole plot was covered.

The incidence and severity of CKS was assessed at crop maturity. For incidence, the number of productive heads and the number showing CKS symptoms for each plant were assessed for 45 plants. For severity, the main heads of each plant of the 45 assessed plants were scored for the severity of CKS symptoms. Severity was assessed by visual estimation in the field. The scale used was percentage of grain in the head replaced by smut sori.

Assessment of yield

The crop was bird scared from milk stage to harvest. The yield of each plot and each of the 15 assessed plants per row was recorded separately after threshing and drying, resulting in a total of four yield figures for each plot. The grain from the net plots (45 assessed plants per plot) was combined weighed and yield data recorded. Mean 100 grain weight was assessed by randomly taking three samples of 100 sorghum grains from the grains in the total plots yields. The grains were oven dried for 48 hours, then the three samples weighed separately.

The number of productive heads per plant was recorded at harvest for each of the 15 assessed plants in the inner three rows for each plot.

1.13.2 Second cycle of field trial (October 2000 – March 2001, April – August 2001)

All the plots were first planted on 16 October 2000, but were re-planted on 8 November due to poor germination. The agronomy of the plots was similar to October 1999. After harvest of the short rain crop, plots of the Treatments 1, 3, 5, 7, 9 were re-planted on 20 April 2001 and all ten treatments had a top dressing of fertiliser (23:23:0) at 20kg ha^{-1} after the first weeding.

1.13.3 Third cycle of field trial (October 2001 – March 2002, April – August 2002)

All the plots were first planted on 16 October 2000. The agronomy of the plots was similar to October 2000. After harvest of the short rain crop, plots of the treatments T1, T3, T5, T7, and T9 were planted on 14 March 2001 and all the plots were top dressed with DAP (20:20:0) at 20kg/ha.

1.14 STATISTICAL ANALYSIS

1.14.1 First cycle of field trial (October 1999 – March 2000, April – August 2000)

The trial was designed as a random complete block design with four replicates. However, it was observed that the original blocks did not match the heterogeneity of the field and it was necessary to refine the block structure. Consequently, each block did not contain all treatments and the experiment became an unbalanced trial.

The statistical software package Genstat was used for the analysis and guidance sought from a statistician. Analysis of deviance was used to test whether differences existed among individual treatments and to make direct comparisons between the ten different individual treatments. This was done by fitting generalised linear models to overcome the unbalanced data, assuming a binomial distribution with a logit link function for the percentage. The link function provides a transformation applied before linear regression. The general model was:

$$y = constant + block\ effect + treatment$$

In the short rains, the chemical inputs were the only variate, so the general model used was:

$$y = constant + block\ effect + (agronomic\ effect)^{1} + chemical\ input$$

[1] inserted when two agronomic practices were involved

This model was modified in the long rains to account for the effect of the two different agronomic practices where applicable. The inclusion of this agronomic practice co-variate within the model enables the effect of direct sown and ratooned practices to be assessed. The order of the factors in the model was varied with the most significant factor placed first. The models were used to give predictions for the data.

The relationship between short rains data and long rain data was further investigated using simple linear regressions. Linear trendlines were plotted using the "least squares" method to calculate a straight line that best fits the equation:

$$y = m\,x + b.$$

where m is the slope and b is the intercept.

1.14.2 Second and third cycles of field trial (October 2000 – March 2001, April – August 2001 and October 2001 – March 2002, April – August 2002)

In the second and third cycles of the experiment, a new layout within the field enabled the random complete block design to match the heterogencity of the field. Consequently, each block contained all the treatments and the experiment was balanced. The percentage data were analysed using the same method as in the first cycle. However, analysis of varience (ANOVA) was used on non-percentage data, to ascertain whether differences existed among individual treatments. If the differences were insignificant the effect of the two cropping practices i.e. direct sown and ratooned, and the chemical inputs were compared. This was achieved using both one-way and two-way ANOVA. One-way ANOVA was used to identify differences between individual treatments, and two-way ANOVA to identify differences between cropping practices (direct sown or ratooned) and chemical inputs. Where results were judged significant ($p<0.05$) standard errors of difference (SED) were calculated. To examine the differences between possible pairs of means multiple comparison tests were carried out using the Tukey b test (also known as the "honestly significant difference test" or "wholly significant difference test"). The Tukey test was applied on the ranked means in order of magnitude. When there were no significant differences between a pair of means the values are grouped together by an underline. Dotted lines indicate an overlap between different groups.

The relationship between yield and CKS parameters were further investigated using simple linear regressions as in the first cycle.

1.15 RESULTS

1.15.1 First cycle of field experiment (October 1999 – March 2000, March – August 2000)

In the first season commencing October 1999, all the plots contained sorghum crops established from seed (i.e. not ratooned), therefore the data were analysed for the effectiveness of the chemical inputs against CKS.

In the second season, commencing March 2000, half the plots contained sorghum crops established from seed (i.e. not ratooned), while the other half contained sorghum crops which had been ratooned after the gathering the short rain's harvest. The poor rains received during the long rains meant that the direct seeded crop never reached maturity. The data sets were analysed for the effectiveness of the chemical inputs and differences between short rain and long rain crops.

Short rains (October 1999 – March 2000)

The incidence of CKS was significantly affected by the application of those treatments including thiram, ($p<0.001$). Treatments, treatment full (T9&T10) and thiram (T3&T4), significantly ($p<0.05$) reduced the incidence of CKS (Table 4.2). The observed incidence of CKS in treatments treatment full (T9&T10) and thiram (T3&T4) were 8.7% and 11.3% compared with treatment nil (T1&T2) of 36.8%. The application of the insecticides in treatments lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&T8) had no significant effect ($p<0.05$) on the incidence of CKS.

The effect of the treatments on severity of CKS was the same as for incidence. Severity of CKS was significantly affected by the application of these treatments including thiram ($p<0.001$). Treatments, treatment full (T9&T10) and thiram (T3&T4), significantly ($p<0.05$) reduced the severity of CKS in the panicle of the main stem (Table 4.3). The observed severity of CKS in treatments treatment full (T9&T10) and thiram (T3&T4) were 5.5% and 8.1% compared with treatment nil (T1&T2) of 27.6%.

The application of the insecticides in treatments lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&T8) had no significant effect ($p<0.05$) on the severity of CKS.

Table 4.2: The effect of seed dressings on the incidence (%) of covered kernel smut in a direct sown crop (Katumani on-station trial, short rains 1999)

Chemical inputs	Observed	Transformed data	Back-transformed data
	Incidence (%)	Prediction (s.e)	Prediction (%) (c.i.)
Nil (T1&T2)	36.8	-0.409 (0.253)	39.9 (28.8, 52.2)[2, 3]
Thiram (T3&T4)	11.3	-2.079 (0.360)	11.1 (5.8, 20.2)[1]
Lamdacyhalothrin (T5&T6)	30.9	-1.005 (0.271)	26.8 (17.7, 38.3)[2]
Beta-cyfluthrin (T7&T8)	30.2	-0.854 (0.248)	29.9 (20.8, 40.9)[2]
Full (T9&T10)	8.7	-2.520 (0.444)	7.5 (3.3, 16.1)[1]

Key [1] = significantly different ($p < 0.05$) from the treatment nil (T1&T2)
[2] = significantly different ($p < 0.05$) from treatment full (T9&T10)
[3] = significantly different ($p < 0.05$) from treatment thiram (T3&T4)

Table 4.3: The effect of seed dressings on the severity (%) of covered kernel smut (Katumani on-station trial, short rains 1999)

Chemical inputs	Observed	Transformed data	Back-transformed data
	Severity (%)	Prediction (s.e)	Prediction (%) (c.i.)
Nil (T1&T2)	27.6	-0.879 (0.218)	29.3 (21.3, 38.9)[2, 3]
Thiram (T3&T4)	8.1	-2.381 (0.328)	8.5 (4.6, 15.0)[1]
Lamdacyhalothrin (T5&T6)	21.2	-1.462 (0.242)	18.8 (12.6, 27.1)[2]
Beta-cyfluthrin (T7&T8)	20.7	-1.379 (0.221)	20.1 (14.0, 28.0)[2]
Full (T9&T10)	5.5	-3.045 (0.427)	4.6 (2.0, 9.9)[1]

Key [1] = significantly different ($p < 0.05$) from treatment nil (T1&T2)
[2] = significantly different ($p < 0.05$) from treatment full (T9&T10)
[3] = significantly different ($p < 0.05$) from treatment thiram (T3&T4)

Long rains (March – August 2000)

The treatment to control CKS involves a seed dressing and this could not be re-applied to the ratooned crop. The incidence of CKS in the ratooned crop was significantly affected by the application of those treatments including thiram, ($p<0.05$). Treatment, treatment full (T10) significantly ($p<0.05$) reduced the incidence of CKS (Table 4.4) and treatment thiram (T4) reduced the observed incidence. The observed incidence of CKS in treatments treatment full (T10) and thiram (T4) were 6.8% and 19.0% compared with treatment nil (T2) of 47.7%. The application of the insecticides in treatment lamdacyhalothrin (T6) and beta-cyfluthrin (T8) had no significant effect ($p<0.05$) on the incidence of CKS.

Table 4.4: The effect of seed dressings on the incidence of covered kernel smut in the ratooned crop (Katumani on-station trial, long rains 2000)

Chemical inputs	Observed Incidence (%)	Transformed data Prediction (s.e)	Back-transformed data Prediction (%) (ci)
Nil (T2)	47.7	-0.007 (0.389)	49.8 (31.6, 68.1)^{2}
Thiram (T4)	19.0	-1.232 (0.470)	22.6 (10.4, 42.3)
Lamdacyhalothrin (T6)	31.2	-1.092 (0.418)	25.1 (12.9, 43.2)
Beta-cyfluthrin (T8)	41.0	-0.447 (0.361)	39.0 (24.0, 56.5)^{2}
Full (T10)	6.8	-2.812 (0.687)	5.7 (1.5, 18.9)^{1}

Key ^{1} = significantly different ($p < 0.05$) from treatment nil (T2)

^{2} = significantly different ($p < 0.05$) from treatment full (T10)

The effect of the treatments on severity of CKS was the same as for incidence. Severity of CKS was significantly affected by the application of those treatments including thiram ($p<0.05$). Treatments, treatment full (T10) significantly ($p<0.05$) reduced the severity of CKS in the panicle of the main stem and thiram (T4) reduced the severity (Table 4.5). The observed severity of CKS in treatments treatment full (T10) and thiram (T4) were 4.3% and 13.6%, respectively, compared with treatment nil (T2) of 34.6%. The application of the insecticides in treatments lamdacyhalothrin (T6) and beta-cyfluthrin (T8) had no significant effect ($p<0.05$) on the severity of CKS.

Table 4.5: The effect of seed dressings on the severity of covered kernel smut on the ratooned crop (Katumani on-station trial, long rains 2000)

Chemical inputs	Observed	Transformed data	Back-transformed data
	Severity (%)	Prediction (s.e)	Prediction (%) (ci)
Nil (T2)	34.6	-0.542 (0.320)	36.8 (23.7, 52.1)[2]
Thiram (T4)	13.6	-1.754 (0.414)	14.8 (7.1, 28.0)
Lamdacyhalothrin (T6)	21.7	-1.461 (0.371)	18.8 (10.1, 32.4)
Beta-cyfluthrin (T8)	29.0	-0.897 (0.303)	29.0 (18.4, 42.5)[2]
Full (T10)	4.3	-3.287 (0.652)	3.6 (1.0, 11.8)[1]

Key [1] = significantly different ($p < 0.05$) from treatment nil (T2)

[2] = significantly different ($p < 0.05$) from treatment full (T10)

Carry-over between seasons

In the ratooned crop, the incidence of CKS was significantly ($p < 0.001$) related to the level previously found in the short rains. The relationship between the incidence of CKS in the short and long rains within the ratooned plots, was highly correlated with the trendline accounting for 79.3% of the variation in the data (Figure 4.3). The slope of the line indicates that there is a positive correlation, with levels higher in the long rains compared with the short rains. The severity of CKS in the ratooned sorghum grown as the long rain crop was significantly ($p<0.05$) related to the level previously found in the short rains. The relationship between the severity of CKS in the short and long rains within the ratooned plots, was not as strongly correlated as the incidence, with the trendline accounting for 51.9% of the variation in the data (Figure 4.4). The slope of the line indicates that there is a positive correlation, with levels higher in the long rains compared with the short rains at levels of severity below 30%.

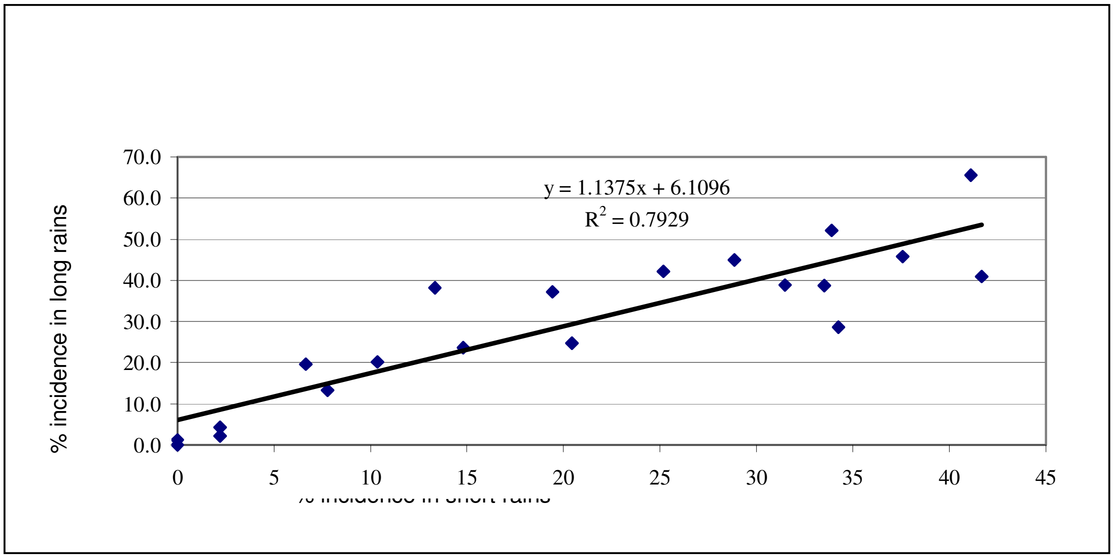


Figure 4.3: Trendline showing the relationship between the incidence of covered kernel smut in the short and long rains (first cropping cycle 1999/2000)

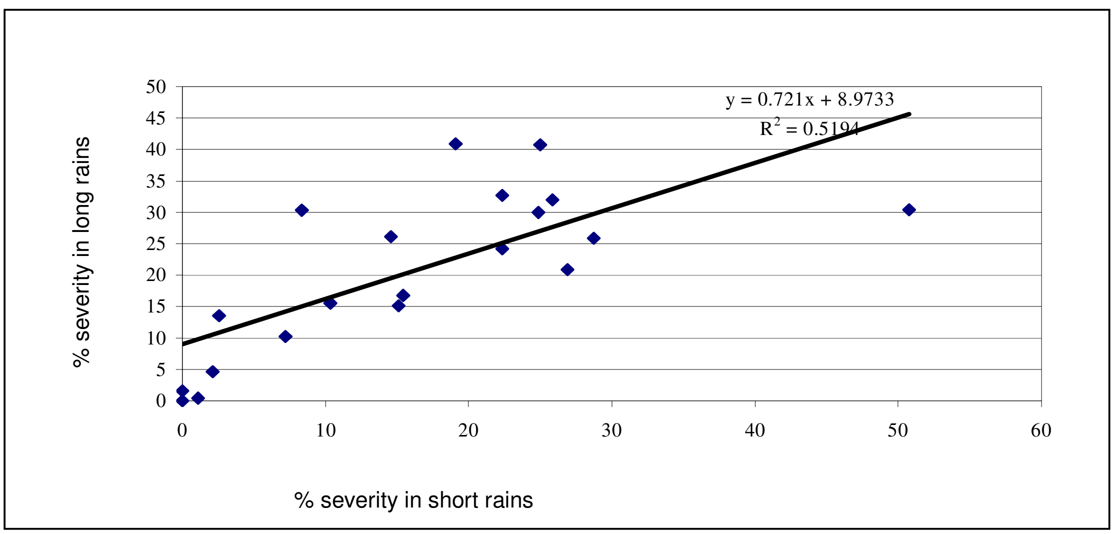


Figure 4.4: Trendline showing the relationship between the severity of covered kernel smut in the short and long rains (first cropping cycle 1999/00

Second cycle of field experiment (October 2000– March 2001, March – August 2001)

In the short rains, all the plots contained direct sown sorghum therefore the data was analysed for the effectiveness of the chemical inputs only. In the long rains, the direct sown crop failed to reach maturity, so the data was only analysed for the effectiveness of the chemical inputs. The performance of the short and long rain crops was compared.

Short rains (October 2000 – March 2001)

The observed incidence of CKS was zero in treatments including thiram, ($p<0.001$). In comparison, the observed incidence in treatment nil (T1&T2) was 42.2% (Table 4.6). The application of the insecticides in treatments lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&T8) had no significant effect ($p<0.05$) on the incidence of CKS. However, the observed incidences were lower in treatments lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&8) at 36.2% and 39.2%, respectively, compared with treatment nil (T1&T2) at 42.2%.

Table 4.6: Effect of the control treatments on the incidence of covered kernel smut in direct sown crop (short rains 2000/1)

Chemicals inputs	Observed data	Transformed data	Back transformed data
	Incidence	Prediction (s.e.)	Prediction (%) (c.i.)
Nil (T1&T2)	42.4	- 0.34 (0.149)	41.6 (34.7, 48.8)
Thiram (T3&T4)	0.0	-13.4 (33.42)	0.0
Lamdacyhalothrin (T5&T6)	36.2	- 0.61 (0.153)	35.3 (28.8, 42.4)
Beta-cyfluthrin (T7&T8)	39.2	- 0.48 (0.151)	38.3 (31.6, 45.5)
Full (T9&T10)	0.0	-13.3 (39.245)	0.0

The observed severity of CKS was zero in treatments including thiram ($p<0.001$). In comparison, the observed severity in treatment nil (T1&t2) was 30.8%. The application of the insecticides in treatments lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&T8) had no significant ($p<0.05$) effect on the severity of CKS. The observed severity under treatment lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&T8) were very similar to treatment nil at 29 and 31.8% respectively (Table 4.7).

Table 4.7: Effect of the control treatments on the severity covered kernel smut in direct sown crop (short rains 2000/1)

Chemical inputs	Observed	Transformed data	Back transformed data
	Severity	Prediction (s.e.)	Prediction (%) (c.i.)
Nil (T1&T2)	30.8	-0.87 (0.19)	29.5 (22.5, 37.7)
Thiram (T3&T4)	0.0	-13.36 (38.72)	0.0
Lamdacyhalothrin (T5&T6)	29.0	-0.96 (0.19)	27.8 (20.9, 35.9)
Beta-cyfluthrin (T7&T8)	31.8	-0.82 (0.19)	30.5 (23.4, 38.8)
Full (T9&T10)	0.0	-13.14 (45.90)	0.0

Long rains (March – August 2001)

The direct sown crop did not produce heads in the long rains due to the poor rainfall, resulting in the CKS data not being available for the direct sown treatments. The treatment to control CKS involves a seed dressing containing the chemical thiram, and this could not be re-applied to the ratooned crop. However, the incidence of CKS in the ratooned crop was significantly ($p<0.05$) affected by the application of those treatments including thiram, ($p<0.05$). Treatments, treatment full (T10) and thiram (T4) significantly ($p<0.05$) reduced the incidence of CKS (Table 4.8). The observed incidence of CKS in treatments treatment full (T10) and thiram (T4) were 0.1% and 0.8%, respectively, compared with treatment nil (T10) of 26.8%. The application of the insecticides in treatments lamdacyhalothrin (T6) and beta-cyfluthrin (T8) had no significant ($p<0.05$) effect on the incidence of CKS. However, the observed incidences were lower in treatments lamdacyhalothrin (T6) and beta-cyfluthrin (T8) at 20.8% and 14.3%, respectively, compared with treatment nil (T2) at 26.8%.

The severity of CKS was significantly affected by the application of the treatments including thiram ($p<0.001$). Treatments, treatment full (T10) and thiram (T4) significantly ($p<0.05$) reduced the severity of CKS in the panicle of the main stem (Table 4.9). The observed severity of CKS in treatments treatment full (T10) and thiram (T4) were 0.5% and 0.4% compared with treatment nil (T1&T2) of 35.2%. The application of the insecticides in treatment lamdacyhalothrin (T6) and beta-cyfluthrin

(T8) had no significant (p<0.05) effect on the severity of CKS. However, the observed severity were lower in treatments lamdacyhalothrin (T6) and beta-cyfluthrin (T8) at 32.7% and 26.5% respectively compared with treatment nil (T1&T2) at 35.2%.

Table 4.8: Effect of the control treatments on the incidence of covered kernel smut in ratooned crop (long rains 2001)

Chemical inputs	Observed	Transformed data	Back transformed data
	Incidence	Prediction (s.e.)	Prediction (%) (c.i.)
Nil (T2)	26.8	-1.01 (0.13)	26.7 (21.9, 32.0)[2, 3]
Thiram (T4)	0.8	-4.80 (0.64)	0.01 (0.2, 2.8)[1]
Lamdacyhalothrin (T6)	20.8	-1.35 (0.14)	20.6 (16.4, 25.6)[1, 2, 3]
Beta-cyfluthrin (T8)	14.3	-1.80 (0.17)	14.1 (10.7, 18.6)[1, 2, 3]
Full (T10)	0.1	-7.67 (2.63)	0.0 (0.0, 7.5)[1]

Key [1] = significantly different (p < 0.05) from treatment nil (T2)
[2] = significantly different (p < 0.05) from treatment full (T10)
[3] = significantly different (p < 0.05) from treatment thiram (T4)

Table 4.9: Effect of the control treatments on the severity covered kernel smut in ratooned crop (long rains 2001)

Chemical inputs	Observed	Transformed data	Back transformed data
	Severity	Prediction (s.e.)	Prediction (%) (c.i.)
Nil (T2)	35.2	-0.62 (0.14)	35.0 (29.1, 41.3)[2, 3]
Thiram (T4)	0.4	-5.58 (1.03)	0.0 (0, 2.8)[1]
Lamdacyhalothrin (T6)	32.7	-0.74 (0.14)	32.4 (26.7, 38.7)[1, 2, 3]
Beta-cyfluthrin (T8)	26.5	-1.04 (0.15)	26.2 (21.0, 32.2)[1, 2, 3]
Full (T10)	0.5	-5.44 (0.97)	0.0 (0.0, 2.8)[1]

Key [1] = significantly different (p < 0.05) from treatment nil (T2)
[2] = significantly different (p < 0.05) from treatment full (T10)
[3] = significantly different (p < 0.05) from treatment thiram (T4)

Carry-over between seasons

The incidence of CKS in the ratooned sorghum grown as the long rain crop was significantly (p <0.001) related to the level previously found in the short rains. The relationship between the incidence of CKS in the short and long rains within the ratooned plots, was highly correlated with the trendline accounting for 83.7% of the variation in the data (Figure 4.5). The slope of the line indicates that there was a positive correlation, with the levels lower in the long rains compared with the short rains.

The severity of CKS in the ratooned sorghum was significantly (p <0.001) related to the level previously found in the short rains. The relationship between the severity of CKS in the short and long rains within the ratooned plots was correlated with the trendline accounting for 81.4% of the variation in the data (Figure 4.6). The slope of the line indicates that there was a positive correlation, with the levels higher in the long rains compared with the short rains.

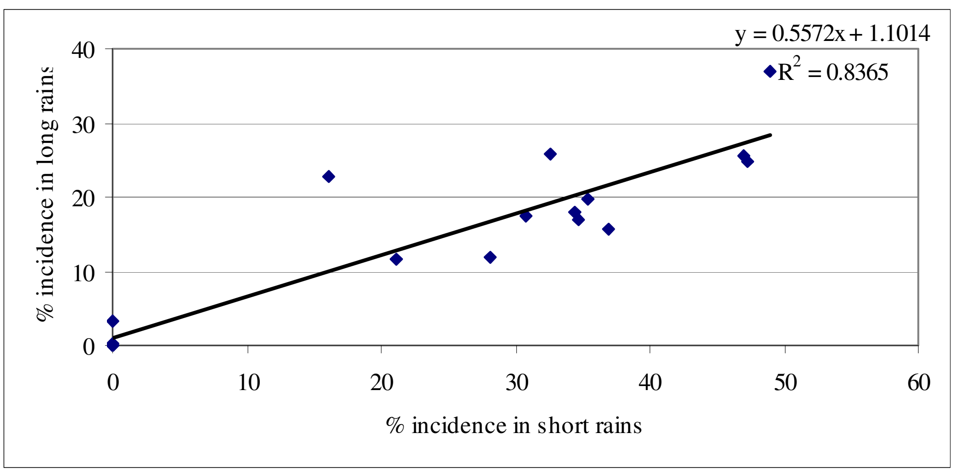


Figure 4.5: Trendline showing the relationship between the incidence of covered kernel smut in the short and long rains (second cropping cycle 2000/01)

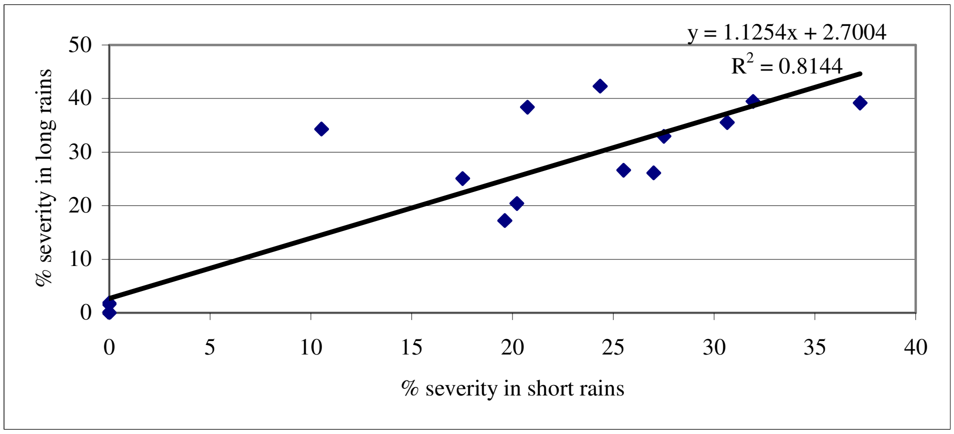


Figure 4.6: Trendline showing the relationship between the severity of covered kernel smut in the short and long rains (second cropping cycle 2000/01)

1.15.2 Third cycle of field experiment (October 2001 – March 2002, March – August 2002)

As in the previous two cropping cycles, in the short rains, all the plots contained direct sown sorghum and the data was analysed for the effectiveness of the control methods only. In the long rains, the direct sown crop reached maturity and the data was analysed for both the effect of the ratooning and the effectiveness of the treatments. The performance of the direct sown crop and ratooned crop were compared.

Short rains (October 2001 – March 2002)

The incidence of CKS was significantly ($p<0.001$) affected by the application of those treatments including thiram. Treatments, treatment full (T9&T10) and thiram (T3&T4), significantly ($p<0.05$) reduced the incidence of CKS (Table 4.10). The observed incidence of CKS in treatments treatment full (T9&T10) and thiram (T3&T4) were 6.8% and 6.2%, respectively, compared with treatment nil (T1&T2) of 35.2%. The application of the insecticides in treatments lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&T8) had no significant ($p<0.05$) effect on the incidence of CKS. The observed incidences in treatments lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&8) at 35.5% and 29.4%, respectively, were similar to treatment nil (T1&T2) at 35.2%.

Table 4.10: Effect of the control treatments on the incidence of covered kernel smut in direct sown crop (short rains 2001/2)

Chemical inputs	Observed	Transformed data	Back transformed data
	Incidence	Prediction (s.e.)	Prediction (%) (c.i.)
Nil (T1&T2)	35.2	-0.614 (0.142)	35.1 (29.1, 41.7)[2, 3]
Thiram (T3&T4)	6.2	-2.736 (0.282)	6.1 (3.6, 10.1)[1]
Lamdacyhalothrin (T5&T6)	35.6	-0.597 (0.142)	35.5 (29.4, 42.1)[2, 3]
Beta-cyfluthrin (T7&T8)	29.4	-0.882 (0.149)	29.3 (23.6, 35.7)[2, 3]
Full (T9&T10)	6.8	-2.629 (0.269)	6.7 (4.1, 10.9)[1]

Key [1] = significantly ($p < 0.05$) different from treatment nil (T1&T2)

[2] = significantly ($p < 0.05$) different from treatment full (T9&T10)

[3] = significantly ($p < 0.05$) different from treatment thiram (T3&T4)

Table 4.11: Effect of the control treatments on the severity of covered kernel smut in direct sown crop (short rains 2001/2)

Chemical inputs	Observed	Transformed data	Back transformed data
	Severity	Prediction (s.e.)	Prediction (%) (c.i.)
Nil (T1&T2)	35.8	-0.589 (0.145)	35.7 (29.5, 42.4)[2, 3]
Thiram (T3&T4)	5.8	-2.800 (0.297)	5.7 (3.3, 9.8)[1]
Lamdacyhalothrin (T5&T6)	36.0	-0.597 (0.145)	36.0 (29.7, 42.7)[2, 3]
Beta-cyfluthrin (T7&T8)	30.2	-0.842 (0.151)	30.1 (24.3, 36.7)[2, 3]
Full (T9&T10)	7.4	-2.538 (0.265)	7.3 (4.5, 11.7)[1]

Key [1] = significantly different ($p < 0.05$) from treatment nil (T1&T2)

[2] = significantly different ($p < 0.05$) from treatment full (T9&T10)

[3] = significantly different ($p < 0.05$) from treatment thiram (T3&T4)

The severity of CKS was significantly affected by the application of those treatments including thiram ($p<0.001$). Treatments, treatment full (T9&T10) and thiram (T3&T4), significantly ($p<0.05$) reduced the severity of CKS in the panicle of the main stem (Table 4.11). The observed severity of CKS in treatments treatment full (T9&T10) and thiram (T3&T4) were 7.4% and 5.8%, respectively, compared with treatment nil

(T1&T2) of 35.8%. The application of the insecticides in treatments lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&T8) had no significant ($p<0.05$) effect on the severity of CKS. The observed severity in treatments lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&8) at 36.0% and 30.2%, respectively, were similar to treatment nil (T1&T2) at 35.8%.

Long rains (March – August 2002)

Both the direct sown and ratooned crop produced heads in the long rains therefore the data was analysed for effect of the individual treatments. This enabled the performance of direct sown crop to be compared with a ratooned crop within a season. As in the previous cycles, treatments including thiram, had significantly ($p<0.05$) lower incidence of CKS than those treatments not including thiram. The range of incidence of CKS in the thiram and non-thiram treatments were 0.0-10.0 and 22.8-43.3, respectively (Table 4.12 and Figure 4.7a). The application of the insecticides had no significant ($p<0.05$) effect.

There were no significant ($p<0.05$) differences in the incidence of CKS between the direct sown and ratooned crops under any of the chemical inputs. However, ratooned treatments always had a higher incidence than the direct sown treatments. The average incidence of CKS in the ratooned and direct sown plots was 28.6 and 17.2%, respectively. The observed incidence of CKS in the direct sown crop under thiram, full, beta-cyfluthrin, lamdacyhalothrin and nil were 0.0, 0.3, 22.8, 34.6, 28.5%, respectively, compared with the ratooned crop of 10.0, 7.4, 40.1, 42.5, and 43.3, respectively. The difference in incidence between the direct sown and ratooned crop under treatments nil, thiram and full were increases of 14.8, 10 and 7.1%, respectively. These results shows the benefits of controlling CKS in a direct sown crop are carried into the ratooned crop, though the higher incidence of CKS in the ratooned treatments suggests some treated direct sown plants carry CKS infection but it is not expressed through the production of sori. The simulation of these infected plants' basal buds through ratooning gives the fungus another chance to travel with the growing meristematic tissue and spread into the differentiating floret tissue, causing developing grains to be replaced with smut sori.

Table 4.12: Effect of the control treatments on the incidence of covered kernel smut in direct sown and ratooned crops (long rains 2002)

Treatment number	Chemical inputs	Cropping practice	Observed	Transformed data Prediction (s.e.)	Back transformed Prediction (c.i)
T1	Nil	Direct sown	28.5	-0.920 (0.230)	28.5 (20.3, 38.5)[4]
T2		Ratoon	43.3	-0.271 (0.209)	43.3 (33.6, 53.5)[4]
T3	Thiram	Direct sown	0.0	-12.312 (27.372)	0.0
T4		Ratoon	10.0	-2.200 (0.345)	10.0 (5.3, 17.9)[1,2]
T5	Lamdacyhalothrin	Direct sown	34.6	-0.640 (0.218)	34.5 (25.6, 44.7)[4]
T6		Ratoon	42.5	-0.305 (0.210)	42.5 (32.8, 52.7)[4]
T7	Beta-cyfluthrin	Direct sown	22.8	-1.222 (0.247)	22.8 (15.4, 32.4)
T8		Ratoon	40.1	-0.404 (0.212)	40.0 (30.6, 50.3)[4]
T9	Full	Direct sown	0.3	5.897 (1.978)	0.3 (0.0, 11.7)[1,2]
T10		Ratoon	7.4	-2.531 (0.367)	7.3 (3.5, 14.7)[1,2]

Key [1] = significantly different ($p<0.05$) from treatment nil, direct sown (T1)

[2] = significantly different ($p<0.05$) from treatment nil treatment ratooned (T2)

[3] = significantly different ($p<0.05$) from treatment thiram, direct sown (T3)

[4] = significantly different ($p<0.05$) from treatment thiram, ratooned (T4)

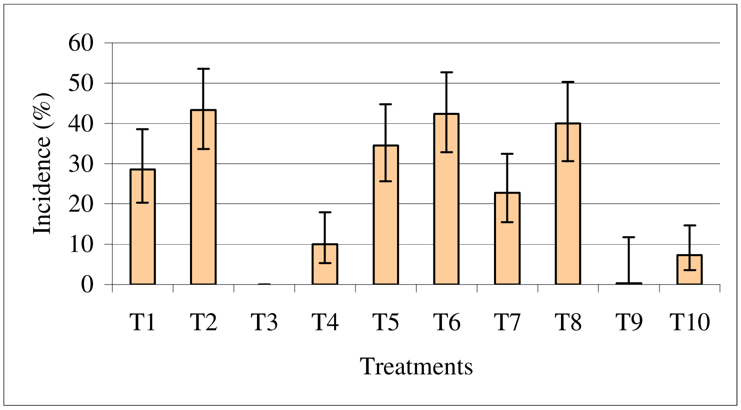


Figure 4.7a: Incidence of covered kernel smut under the ten different treatments with 95% confidence limits (long rains 2001/2)
Key:
T1: direct sown, nil application
T2: ratooned, nil application
T3: direct sown, thiram
T4: ratooned, thiram
T5: direct sown, lamdacyhalothrin
T6: ratooned, lamdacyhalothrin
T7: direct sown, beta-cyfluthrin
T8: ratooned, beta-cyfluthrin
T9: direct sown, full application
T10: ratooned, full application

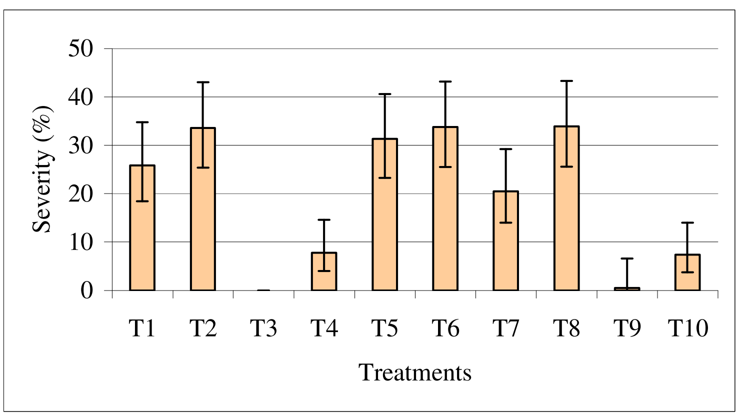


Figure 4.7b: Severity of covered kernel smut under the ten different treatments with 95% confidence limits (long rains 2001/2)
Key:
T1: direct sown, nil application
T2: ratooned, nil application
T3: direct sown, thiram
T4: ratooned, thiram
T5: direct sown, lamdacyhalothrin
T6: ratooned, lamdacyhalothrin
T7: direct sown, beta-cyfluthrin
T8: ratooned, beta-cyfluthrin
T9: direct sown, full application
T10: ratooned, full application

Table 4.13: Effect of the control treatments on the severity of covered kernel smut in direct sown and ratooned crops (long rains 2002)

Treatment number	Chemical inputs	Cropping practice	Observed	Transformed data Prediction (s.e.)	Back transformed Prediction (c.i)
T1	Nil	Direct sown	25.8	-1.057(0.219)	25.8 (18.4, 34.8)[4]
T2		Ratoon	33.7	-2.681 (0.203)	33.6 (25.4, 43.0)[4]
T3	Thiram	Direct sown	0.0	-12.312 (27.372)	0.0
T4		Ratoon	7.8	-2.470 (0.357)	7.8 (4.0, 14.6)[1,2]
T5	Lamdacyhalothrin	Direct sown	31.4	-0.786 (0.207)	31.3 (23.3, 40.6)[4]
T6		Ratoon	33.8	-0.674 (0.203)	33.8 (25.5, 43.2)[4]
T7	Beta-cyfluthrin	Direct sown	20.6	-1.354 (0.237)	20.5 (14.0, 29.2)
T8		Ratoon	33.9	-0.668 (0.203)	33.9 (25.6, 43.3)[4]
T9	Full	Direct sown	0.5	-5.259 (1.327)	0.5 (0.0, 6.6)[1,2]
T10		Ratoon	7.4	-2.531 (0.367)	7.4 (3.7, 14.0)[1,2]

Key [1] = significantly different ($p<0.05$) from treatment nil, direct sown (T1)
[2] = significantly different ($p<0.05$) from treatment nil treatment ratooned (T2)
[3] = significantly different ($p<0.05$) from treatment thiram, direct sown (T3)
[4] = significantly different ($p<0.05$) from treatment thiram, ratooned (T4)

The level of severity of CKS under the different treatments showed a similar pattern to the incidence. As in the previous cycles, treatments including thiram, had significantly ($p<0.05$) lower severity of CKS than those treatments not including thiram. The range of severity of CKS in the thiram and non-thiram treatments were 0.0-7.8% and 20.6-33.9%, respectively (Table 4.13 and Figure 4.7b). The application of the insecticides had no significant ($p<0.05$) effect.

There were no significant ($p<0.05$) differences in the severity of CKS between the direct sown and ratoooned crops under any of the different chemical inputs. However, the ratooned treatments always had a higher severity than the direct sown treatments. The average severity of CKS in the ratooned and direct sown plots was 23.3 and 15.7%, respectively. The observed severity of CKS in the direct sown crop under thiram, full, beta-cyfluthrin, nil and lamdacyhalothrin were 0.0, 0.5, 20.6, 25.8 and 31.4%, respectively, compared with the ratooned crop of 7.8, 7.4, 33.9, 33.7, and 33.8%, respectively. The difference in severity between the direct sown and ratooned crop under treatments nil, thiram and full were increases of 2.3, 7.8, and 6.9%, respectively.

Carry between seasons

The incidence of CKS in the ratooned sorghum grown as the long rain crop was significantly ($p < 0.001$) related to the level previously found in the short rains. The relationship between the incidence of CKS in the short and long rains within the ratooned plots, was highly correlated with the trendline accounting for 72.9% of the variation in the data (Figure 4.8). The slope of the line indicates that there was a positive correlation, with the levels higher in the long rains compared with the short rains.

The severity of CKS in the ratooned sorghum grown as the long rain crop was significantly ($p < 0.001$) related to the level previously found in the short rains. The relationship between the severity of CKS in the short and long rains within the ratooned plots, was correlated with the trendline accounting for 71.8% of the variation in the data (Figure 4.9). The slope of the line indicates that there was a positive correlation, with the levels slightly higher in the long rains compared with the short rains at levels below 20%.

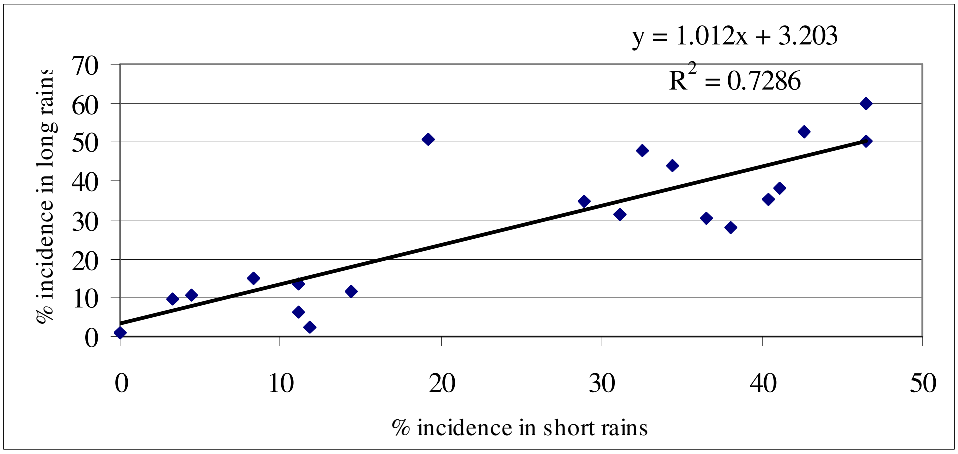


Figure 4.8: Trendline showing the relationship between the incidence of covered kernel smut in the short and long rains (third cropping cycle, 2001/02)

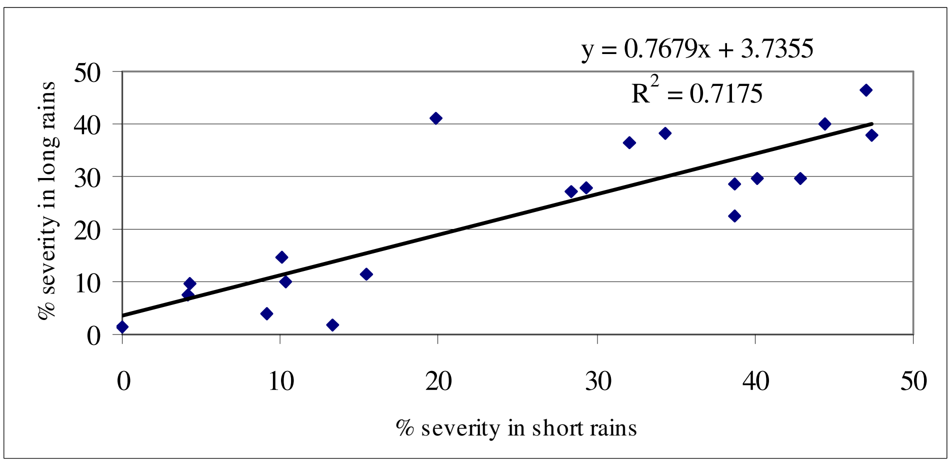


Figure 4.9: Trendline showing the relationship between severity of covered kernel smut in the short and long rains (third cropping cycle, 2001/02)

1.15.3 Effect of covered kernel smut on yield

Second cycle of field experiment (October 2000 – March 2001, March – August 2001)

The yield was measured by assessing the net plot (inner 45 plants of each plot) yield. This was to reduce edging effects. In the short rains, the chemical inputs had significantly ($p<0.05$) different yields. The highest yields were achieved in treatments that reduced CKS i.e. those including thiram, at 3.1kg (Table 4.14). These were significantly ($p<0.05$) higher than treatment nil (T1&2). Treatment nil (T1&T2) achieved a yield of 2.1kg, followed by treatment lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&T8) 2.3 and 2.7kg respectively. For treatments, thiram, full, lamdacyhalothrin, beta-cyfluthrin and nil this converts into 4305, 4305, 3750, 3194 and 2917kg/ha respectively.

An important factor in sorghum yield is the number of productive heads per plant. This can give an indication of the contribution the tillers are making to grain production. The ability of sorghum plants to tiller gives plasticity to yield as tillers can compensate when the main stem is damaged, or reduce the yield of the main head by competing for resources (Doggett, 1980). In the short rains, none of the treatments had a significant effect on the number of productive heads per plant. The highest number was recorded under treatments nil (T1&T2) and lamdacyhalothrin (T5&T6) with 2.3, followed by treatments beta-cyfluthrin (T7&T8), thiram (T3&T4) and full (T9&T10) with 2.2, 2.1 and 1.9, respectively (Table 4.15). The ranking of the treatments for number of productive heads per plant was the reverse of the ranking for yield.

In the long rains, the direct sown crop failed to produce a yield. This failure was due to a combination of factors. In the short rains, the initial planting failed to emerge and the trial had to be replanted. The lack of rain at the end of October meant the trial was not re-sown until 8th November. The good rains received in January delayed the maturing of the crop and the crop was not harvested until mid April. The long rains, direct sown crop was therefore not planted until 20th April. The total rainfall received after the planting date was 54mm.

Table 4.14: Effect of chemical inputs on sorghum yields (kg/45 assessed plants) in direct sown and ratooned crops in the short rains and long rains (2000/1 & 2001/2)

Chemical inputs	Short rains 2000/1	Long rains 2001		Short rains 2001/2	Long rains 2002	
	Direct sown	Direct sown	Ratooned	Direct sown	Direct sown	Ratooned
Nil	2.1	0	1.1	0.7	0.1	1.2
Thiram	3.1	0	1.6	1.0	0.2	1.3
Lamdacyhalothrin	2.7	0	1.2	0.8	0.1	1.0
Beta-cyfluthrin	2.3	0	0.9	0.4	0.1	1.0
Full	3.1	0	1.7	1.0	0.2	1.9
SED	0.3		0.2	0.2		0.2
All plots	2.6	0	1.3[1]	0.8	0.1	1.3[1]
SED	0.3		0.6			0.1

[1] significantly ($p<0.05$) different from the direct sown crop

Tukey b test (applied when F value from ANOVA $p<0.05$)

Comparison of individual treatments

Long rains 2002

Treatments (0.05, 10, 27) T7 T1 T5 T9 T3 T6 T8 T2 T4 T10

0.1 0.1 0.1 0.2 0.2 1.0 1.0 1.2 1.3 1.9

Comparison of chemical inputs

Short rains 2000/1

Chemical inputs (0.05, 8, 28) T1&2 T7&8 T5&6 T9&10 T3&4

2.1 2.3 2.7 3.1 3.1

Long rains 2001

Chemical inputs (0.05, 4, 12) T8 T2 T6 T4 T10

0.9 1.1 1.2 1.6 1.7

Short rains 2001/2

Chemical inputs (0.05, 8, 35) T7&8 T1&2 T5&6 T3&4 T9&10

0.4 0.7 0.8 1.0 1.0

Long rains 2002

Chemical inputs (0.05, 5, 27) T7&8 T5&6 T1&2 T3&4 T9&10

0.6 0.6 0.6 0.8 1.0

Table 4.15: Effect of chemical inputs on number of productive heads per plant (kg/45 assessed plants) in direct sown and ratooned crops in the short rains and long rains (2000/1 & 2001/2)

Chemical inputs	Short rains 2000/1	Long rains 2001		Short rains 2001/2	Long rains 2002	
	Direct sown	Direct sown	Ratooned	Direct sown	Direct sown	Ratooned
Nil	2.3	-	3.7	1.4	1.9	2.9
Thiram	2.1	-	2.4	1.8	1.3	2.4
Lamdacyhalothrin	2.3	-	3.4	1.4	1.9	2.5
Beta-cyfluthrin	2.2	-	2.4	1.1	1.9	2.2
Full	1.9	-	2.6	1.8	1.7	2.7
SED	0.2		0.3	0.2		0.3
All plots		-	2.9		1.7	2.5[1]
SED						0.1

[1] significantly (p<0.05) different from the direct sown crop

Tukey b test (applied when F value from ANOVA is significant (p<0.05) for chemical inputs or treatments

Comparison of individual treatments (Long rains 2001/2)

Treatments (0.05, 10, 27)	T3	T9	T1	T5	T7	T8	T4	T6	T10	T2
	1.3	1.7	1.9	1.9	1.9	2.2	2.4	2.5	2.7	2.9

Chemical inputs

Short rains 2000/1 none significant

Long rains 2001

Chemical inputs (0.05, 4, 12) T4 T8 T10 T6 T2

2.4 2.4 2.6 3.4 3.7

Short rains 2001/2

Chemical inputs (0.05, 5, 32) T7&8 T1&2 T5&6 T9&10 T3&4

1.1 1.4 1.4 1.8 1.8

Long rains 2002 none significant

The ratooned crop achieved an average yield of 1.3kg compared with the direct sown crop of 0kg. The application of chemical inputs significantly ($p<0.05$) affected the yield and there was significant ($p<0.05$) interaction between agronomic practice and chemical inputs. In the ratooned crop, the highest yields were achieved in treatments including thiram, with treatment full (T10) and thiram (T4) achieving yields of 1.7 and 1.6 kg respectively (Table 4.14). In comparison, treatment nil (T1&T2) achieved a yield of 1.1kg, and treatment lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&T8) 1.2 and 0.9kg respectively. Treatment full and thiram had significantly ($p<0.05$) higher yields than treatment beta-cyfluthrin (T8). For treatments full, thiram, lamdacyhalothrin, nil and beta-cyfluthrin the yield converted into 2361, 2222, 1667, 1528 and 1250 kg/ha respectively.

In the ratooned crop, the numbers of productive heads were significantly ($p<0.05$) affected by the chemical inputs. The highest number of productive heads was recorded under treatment nil (T2) with 3.7, followed by treatment lamdacyhalothrin (T6), full (T10), beta-cyfluthrin (T8), and thiram (T4) with 3.4, 2.6, 2.4, and 2.4, respectively (Table 4.15). Treatment nil (T2) had significantly ($p<0.05$) more productive heads than the treatment full (T10), beta-cyfluthrin (T8) and thiram (T4). The ranking of the treatments for number of productive heads was not similar to the ranking for yield. Treatment nil with the highest number of productive heads had one of the lowest yields and the treatment thiram, with the lowest number of productive heads per plant had the highest yield.

The relationships between CKS and yield were further investigated using correlations. In the short rains, the relationship between yield and productive heads per plant was not highly correlated, with the trendline accounting for 31% of the variation in the data. However, the slope of the trendline indicated a strong positive relationship (Figure 4.10). In the long rains, there was no correlation between these factors. This suggests that in the short rains, tillers had an accumulative effect on yield while in the long rains this was not the case.

In both the short and long rains, the relationships between incidence and severity of CKS and yield were negatively correlated (Figure 4.10). The trendlines accounted for between 24-37% of the variation in the data and the gradient of the slopes indicated a strong negative relationship. Throughout the experiment, the severity of CKS was assessed from the head of the main stem. Direct sown crops tend to have fewer heads than ratooned plants therefore in a direct sown crop the head from the main stem is a higher proportion of the yield than in ratooned plants. This may explain the steeper slope in the short rains than in the long rains.

Short rains $y=-0.031x+3.2003$ Long rains $y=-0.0144x+1.5589$

The relationship between number of productive heads per plant and incidence of CKS changed with the seasons. In the short rains, there was no correlation, but in the long rains the relationship was positive and highly correlated, with the trendline accounting for 52% of the variation in the data. This suggests that the more productive heads a plant had the higher the proportion of heads with symptoms of CKS.

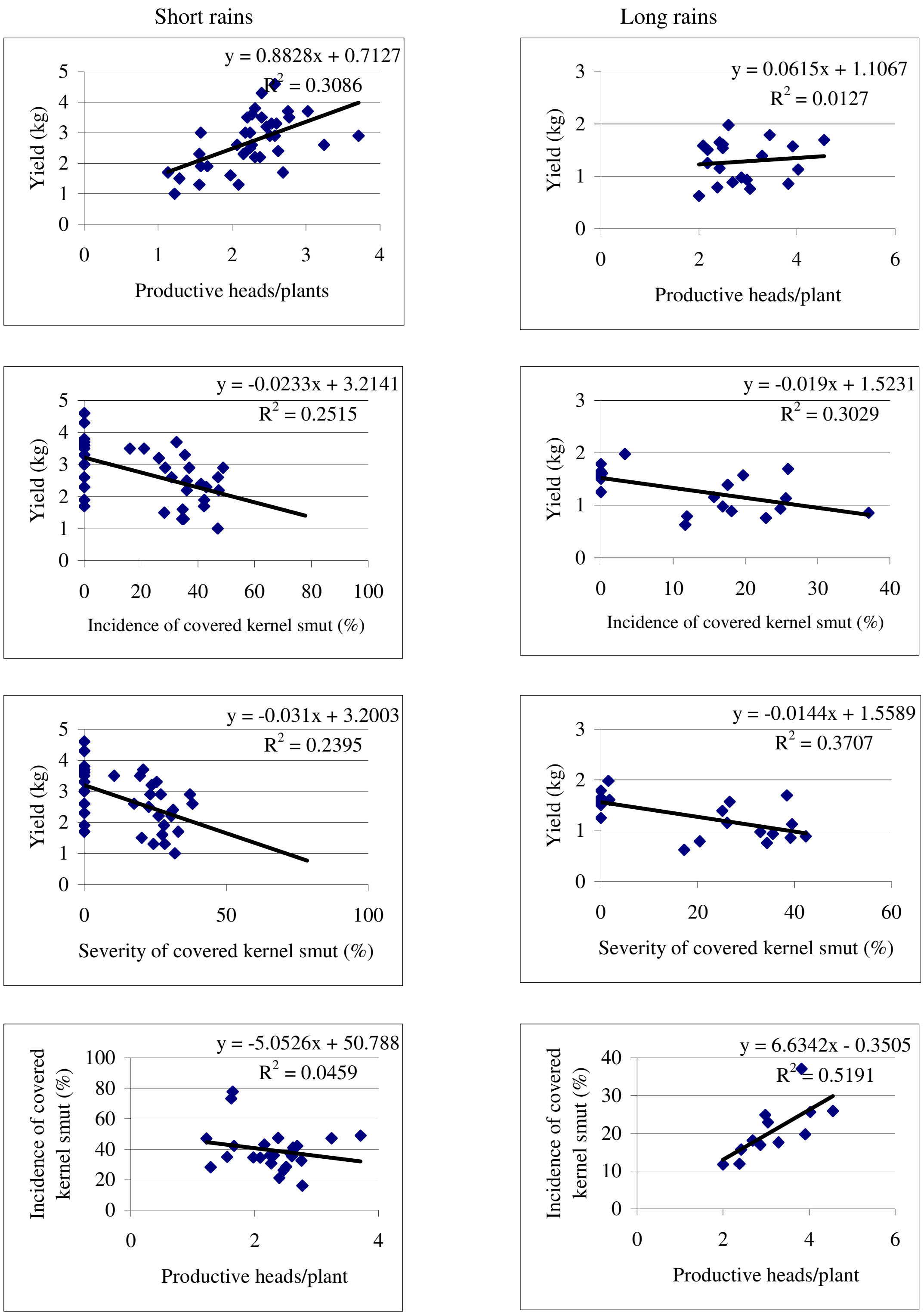


Figure 4.10: Trendlines showing the relationship between yield, productive heads/plant, incidence and severity of covered kernel smut in short and long rains ($p<0.05$) (second cropping cycle 2000/01)

Third cycle of field experiment (October 2001 – March 2002, March – August 2002)

In the short rains, the highest yields were achieved in treatments including thiram, with treatment full (T9&T10) and thiram (T3&T4) achieving yields of 1.0kg (Table 4.14). In comparison, treatment nil (T1&T2) achieved a yield of 0.7kg, and treatments lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&T8) achieved yields of 0.8 and 0.4kg respectively. The treatments containing thiram achieved significantly ($p<0.05$) higher yields than treatment beta-cyfluthrin (T7&8). For treatments, full, thiram, lamdacyhalothrin, nil and beta-cyfluthrin, this converts into 1389, 1389, 1111, 972 and 556kg/ha, respectively.

The highest number of productive heads was under treatments containing thiram with 1.8, followed by treatment nil, lamdacyhalothrin and beta-cyfluthrin with 1.4, 1.4 and 1.1 respectively (Table 4.15). The treatments containing thiram had significantly more productive heads than treatment lamdacyhalothrin. The ranking of the treatments for number of productive heads was the same as that for yield.

In the long rains, both the direct sown and ratooned crop produced heads. The data was therefore analysed so comparisons could be made between individual treatments. The yields recorded in the direct sown treatments were all significantly ($p<0.05$) lower than the yields recorded in the ratooned treatments. The ranges of yields in the direct and ratooned treatments were 0.1-0.2 and 1.0-1.9kg, respectively (Table 4.14). The average yield in direct sown and ratooned crops was 0.1 (139kg/ha) and 1.3kg (1805kg/ha) respectively. The practice of ratooning therefore resulted in an increase in yield of 1666kg/ha.

As in the previous cycles, treatments including thiram had higher yields than those treatments not including thiram (Tables 4.14). In the direct sown crop, the application of thiram (T3 or T9) did not significantly ($p<0.05$) increase the yield in comparison with treatment nil (T1). The treatments thiram (T3) and full (T9) achieved yields of 0.2kg (278kg/ha) compared to treatment nil (T1) 0.1kg (139kg/ha).

In the ratooned crop, the treatments involving thiram (T4 and T10) had higher yields than treatments not including thiram. However, only treatment full (T10) was significantly ($P<0.05$) higher than the treatments not including thiram. Treatments full (T10) and thiram (T4) achieved yields of 1.9 and 1.3kg (2639 and 1805kg/ha) compared to treatment nil (T2), with 1.2 (1667kg/ha). The difference in yield between the direct sown and ratooned crop under treatments nil, thiram and full were increases of 1.1, 1.1 and 1.7kg, respectively. This converts to 1528 and 2361kg/ha.

The number of productive heads per plant in all the direct sown treatments was lower than in the ratooned treatments. The ranges of yields in the direct and ratooned treatments were 1.3-1.9 and 2.2-2.9, respectively (Table 4.15). The average number of productive heads in direct sown and ratooned crops was 1.7 and 2.5 respectively. The practice of ratooning therefore resulted in an increase in productive heads of 0.8 per plant. This was the same trend as that for yield. The ranking of treatments for number of productive heads was not the same as that for yield. However, the treatments including thiram had significantly ($p<0.05$) higher number of productive heads under the practice of ratooning than when direct sown. This was not the case when the insecticide was individually applied.

The relationship between CKS and yield were further investigated using correlations (Figure 4.11a&b). The long rains data was split into direct-sown and ratooned plots. This was to avoid masking trends due to the different agronomic practices. The downside to this was the reduction in data points.

In the short rains, the relationship between productive heads per plant and yield was positively correlated, with the trendline accounting for 55% of the variation in the data (Figure 4.11a). This relationship was similar to that in the second cropping cycle and indicated that tillers contributed to yield in both seasons. This contribution was larger in the second cycle as shown by the linear equations:

Short rains 2000/1 $y=0.8828x+0.712$ Short rains 2001/2 $y=0.6052x-0.1144$

The higher rainfall in the second cycle compared with the third cycle probably contributed to this outcome.

In the long rains, the relationship between yield and productive heads per plant was overall positively correlated (Figure 4.11a). This though was probably an artefact of the two agronomic practices – the direct sown plots achieved lower yields and fewer productive heads than the ratooned plots. In both the direct sown and ratooned plots, there was no relationship (Figure 4.11b). This may be due to water stress during the grain filling. In both the second and third cycles, there was no relationship in ratooned plots between yield and productive heads.

In the short rains, the relationships between both incidence and severity of CKS, and yield were negatively correlated, with trendlines accounting for 32-33% of variation in the data (Figure 4.11a). This was similar to results for the second cycle, though the relationship was stonger in the third cycle. The slopes in the second cycle were steeper as showed by the equations:

	2000/1	2001/2
Incidence	$y=-0.0233x+3.2141$	$y=-0.0129x+1.071$
Severity	$y=-0.031x+3.2003$	$y=-0.013x+1.0784$

A combination of factors could have contributed to this. The ratooned plots in the second cycle had more productive heads but the tillers contributed less to the yield, resulting in the main stem contributing a higher proportion of the plant yield. Thus, in similar severity levels the reduction in yield would be greater in the second cycle. The lower contribution by the tillers to yield could be due to the higher incidence of CKS.

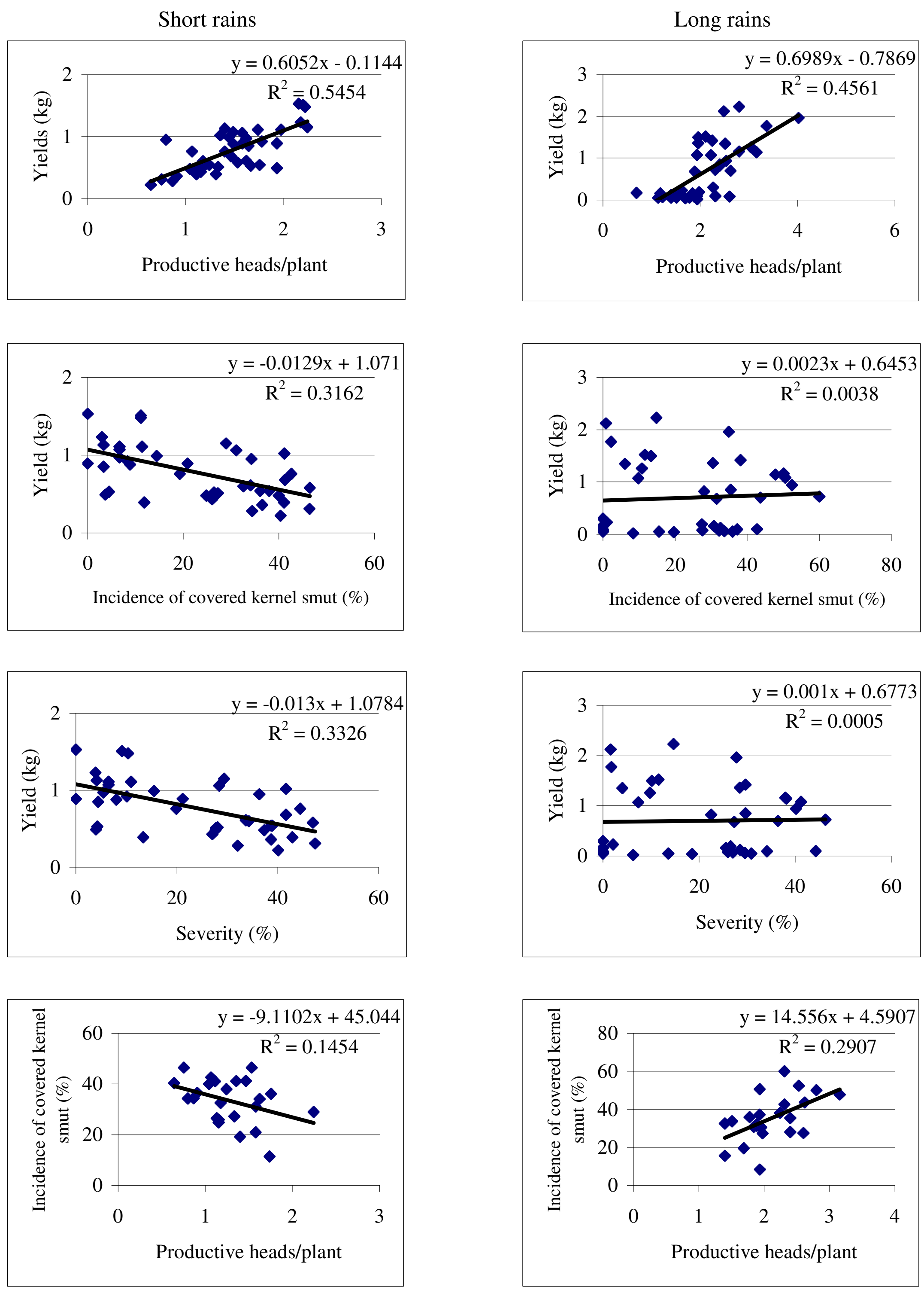


Figure 4.11a: Trendlines showing the relationships between yield, productive heads/plant, incidence and severity of covered kernel smut in short and long rains (third cropping cycle (p<0.05) (2001/02)

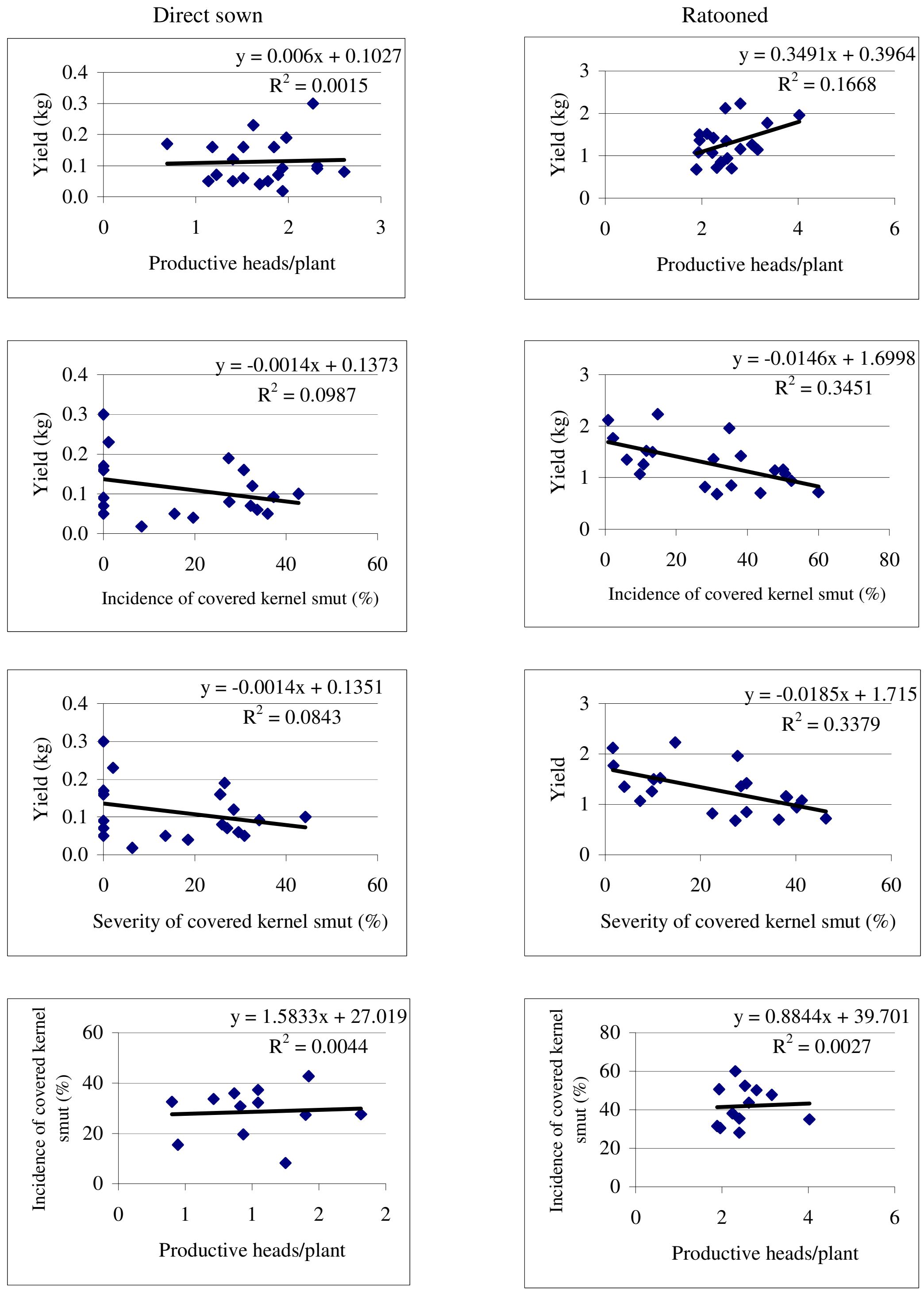


Figure 4.11b: Trendlines showing the relationship between yield, productive/plant, incidence and severity of covered kernel smut in direct sown and ratooned crops (p<0.05) (third cropping cycle 2001/02, long rains)

In the long rains, the relationships between both incidence and severity of CKS and yield were different for direct sown and ratooned plots (Figures 4.11b). In the direct sown plots, there was no correlation between these two factors. This was probable a factor of the low yield recorded in all the plots. In the ratooned plots, the relationship between both incidence and severity of CKS, and yield was negatively correlated. This was similar to the second cycle and the linear relationships are very similar as shown by the equations:

	2000/1	2001/2
Incidence	y=-0.019x+1.5231	y=-0.0146x+1.6998
Severity	y=-0.0144x+1.5589	y=-0.0185x+1.715

Though the incidence of CKS was higher in the third cycle than the second cycle the level of severity of CKS, yield and productive heads were similar for both seasons.

In the short rains, the relationship between productive heads per plant and incidence of CKS was not correlated and was similar to the second cycle (Figure 4.11a). In the long rains, the relationship between productive heads and incidence of CKS was not correlated in either the direct sown and the ratooned plots (Figure 4.11b). This was not the case in the second cycle, which was positively correlated. This may be due to the rainfall. In the third cycle, the better rainfall enabled the tillers to outpace the systemic fungus, while in the second cycle the drier weather slowed development.

1.16 DISCUSSION

The objective of this chapter was to quantify the effect of the practice of ratooning sorghum on the incidence and severity of CKS and to relate this to yield. The incidence of CKS recorded in the ratooned crop was always correlated to the levels measured in the same plots in the short rains. However, the level of incidence in the long rains was not always higher than that recorded in the short rains. This was unexpected. The generally consensus in the literature is that ratooned crop would express higher levels of CKS than in the previous season's crop (Doggett, 1988). In the first and third cropping cycles, there was an increase in the incidence of CKS between the short and long rains, as described by the slopes of the trendlines, y = 1.1375+6.1, and y = 1.012x+3.203, respectively. In the second cropping cycle, the incidence decreased, with the slope of the trendline described as y = 0.5572x+1.1014. The relationship of severity of CKS over the two seasons did not show the same pattern as incidence. The relationship was more complex. In the first and third experimental cycles, the severity in the long rain crop was higher than the short rain crop, but only at low levels. At higher levels the relationship reversed. In the second cycle, the level of severity had increased.

In second cropping cycle, the rainfall received by the crop after ratooning was poor (less than 60.9mm), and the plants would have been stressed. Under these conditions plants would have grown slower as indicated by the stem lengths at maturity being shorter than in previous long rains. The average stem length in 2001 and 2002 long rains were 85.7cm and 92cm, respectively. In slow growing plants, the systemic CKS fungus should be able to maintain its presence in the meristems easier than in faster growing plants and therefore show a higher level of smut. However, in the second cropping cycle 2000/1, the crop received a large amount of rain before the crop was ratooned, so the soil was wet, this would have enabled the plant to re-grow quickly. In the first and third seasons, the soils were relatively dry when the plants were ratooned and the plants would not have re-grown as quickly. This suggests that though the levels of CKS in a ratooned crop is highly correlated to that recorded in the previous season, the environmental factors of the seasons are important. This agrees with Doggett (1988) who proposed that interaction of weather and soil conditions affected the expression of smut by influencing the growth of the host. The interpretation of the experimental results suggests that incidence depends on the growing conditions at the initiation of the stems and during elongation, while severity is reliant on the conditions prevailing during inflorescence initiation and development.

The effect of CKS was to reduce yield, but the proportion of grain lost to CKS was not directly reflected in reduction in yield. The method of assessment for severity, where severity was assessed on the main head of each plant may have contributed to this, as this ignored the contribution of the tillers. Sorghum plants have several methods to compensate for damage. Yield compensation in the panicle can compensate for up to 20% of the floret lost (Hamilton *et al*., 1982). This is achieved by increases in grain number and size. However, this compensation does not occur when the apex florets are affected, which are often the case with CKS. Hamilton *et al*. (1982) study was undertaken by completely removing the florets, but infected florets continue to draw nutrient and photosynthetic assimilates from the plant to develop. Infected florets also reduce photosynthetic capability of the head and Fischer and Wilson, (1971b) have reported that approximately 18% of grain yield are derived from the photosynthesis in the head.

Fischer and Wilson (1971a) established that 10-12% of grain yield is derived from carbon assimilated before anthesis. These assimilates are stored in the stem, which acts as a storage vessel for carbohydrate in grain filling. The level of stem dry matter increases and decreases, as the need for carbohydrate in the panicle is either less or more than that available from photosynthesis in the leaves. Photosynthesis in the leaves can continue under dry conditions up to grain maturity. However, stored capacity can only be utilised when enough water is available to support transpiration to enable assimilates to be transported to the heads (Rattkanta Maiti, 1995). Also, poor growth and low stored assimilates from earlier growth stages can reduce the ability to contribute to yield (Borrell *et al.,* 2000). The reverse of this is that serious reduction in grain number or enhancement of photosynthesis after flowering, both of which result in a surplus to the requirements for grain filling cause late tiller growth. Tillers in unfavourable situations are in competition for light and assimilates, especially at higher plant populations (Wilson and Eastin, 1982). Tillers are considered to be less biological efficient than main stem, because their harvest index is lower (Maiti, 1995). This means that in an equal population of tillers or main stems, tillers would probably produce a lower grain yield for the same utilisation of environmental resources.

The available knowledge on CKS and the sorghum's behaviour can be used to interpret the findings from the experiment, especially the correlation plots. In the second cropping cycle, short rains, there was no relationship between productive heads per plant and incidence of CKS. This suggests that many of the tillers grew quickly and were able to outpace the systemic fungus. The late rains meant the plants were not under water stress as the tillers reached grain fill and therefore they reached their potential without affecting seriously the grain filling of the main heads. These factors resulted in a positive correlation between productive heads per plant and yield. In contrast in the long rains, there was a strong correlation between productive heads per plant and incidence of CKS. This was probably an effect of the water stress, which would have affected the later developing tillers. The water stress would have had a double effect. The growth of the tillers would have been slower thus enabling the systemic fungus to maintain its presence in the meristem. Lack of water would also, have meant the plant having insufficient resources, so partitioning fewer resources to the tillers, resulting in the tillers contributing less to the overall plant yield. This is reflected in the non-correlation between productive heads per plant and yield.

In the third cropping cycle, the rainfall received by the crop after ratooning was much better than in the previous cropping cycle. The total rainfall was 256.1 mm in 2000/01 compared with 54.1mm in 2001/02. The relatively dry start to the long rains as discussed previously would have encouraged the incidence of CKS in the ratooned crop to be higher than the short rain, direct sown crop. The occurrence of good rains in April and May meant the level of water stress that the plant was under during grain filling enabled the tillers heads to reach their potential. This is reflected in the positive correlation between yield and productive heads and the poor relationship between productive heads and incidence of CKS.

In the direct sown crop, the crop matures 2-3 weeks later than the ratooned crop. This means the grain filling took place under more severe water stress than the ratooned crop. This is reflected in the low yields and the non-contribution of the tillers to yield. The poor yields meant that errors caused in processing the grain i.e. harvest, threshing, winnowing and bagging become relatively more important in relation the yield. The poor conditions at grain filling meant that the competition between the main stem and the tillers for assimilates would be high and the tillers received a lower proportion. The relationships in regard to CKS and yield were similar to the trends shown in the other direct sown crops.

The practice of ratooning increased yields in comparison to direct sown crops. The yields achieved in the direct sown crops ranged between 0-148kg/ha, compared to the ratooned crop of 1926kg/ha. Application of the seed dressing containing the fungicide thiram to the seed prior to planting significantly reduced the incidence and severity of CKS in both the direct sown and the ratoon crop. This was reflected in the yields. In the long rains 2002, the individual application of thiram (T3) doubled the yield compared to non-application of thiram (T1), with 148kg/ha and 296kg/ha, respectively. In the ratooned crop, the effect was less dramatic; the application of thiram (T4) achieved a yield of 1919, compared to non-application (T2) of 1778kg/ha. An application of a seed dressing in the direct sown crop also protects the follow-on ratooned crop. This increases the economic benefit of using a seed dressing. This is illustrated in the Table 4.16.

Table 4.16: Effect of using a seed dressing (thiram) on the yield of direct sown and ratooned sorghum and the associated economic return (second and third cropping cycles 2000/1 and 2001/2)

	2000/1			2001/2		
	Short rains	Long rains		Short rains	Long rains	
	Direct sown	Direct sown	Ratooned	Direct sown	Direct sown	Ratooned
Yield under treatment nil (kg/ha)	3111	0	1630	1037	148	1778
Yield under thiram application (kg/ha)	4592	0	2370	1481	296	1926
Gain in yield (kg/ha)	1,482	0	740	444	148	148
Market price for extra yield (£)[1]	133.38	0	66.60	39.96	13.32	13.32
Cost of seed dressing (£/ha)[2]	0.40	0.4	0.0	0.40	0.40	0.0
Monetary gain (£)						
one season	132.98	-0.40	66.60	39.56	12.92	13.32
both seasons		132.58	199.58		52.48	52.88

Key [1] Local market price 10Ksh per kg = £0.09 (exchange rate of £1=110Ksh)

[2] based on cost of a package of Murtano in Machakos (60ksh = £0.55), that treats 7kg of seed

In the experiment, the yield losses from CKS are under represented, as grain harvested from smutted heads was included in the yield. Under farmer conditions, many farmers completely discard smutted heads, because food prepared from this grain makes the food taste moldy. Also, there is no market for grain showing signs of smut contamination (Hayden and Wilson, 2000).

The application of an insecticide had no significant effect on the incidence or severity of CKS. However, the trend of the experiment was for plots receiving an input of insecticide having lower incidence of smut than those receiving no inputs (Treatment nil). A probably explanation for this effect is that an application of insecticide reduces the pest pressure. This enables the plant to grow faster resulting in the fungus being less able to keep up with the growing point of the plant and thus less likely for the symptoms to be expressed.

Overall, the practice of ratooning had an effect on CKS and the levels recorded were related to both the level of CKS in the previous season and the environmental conditions in the growing season. In terms of inoculum, the ratooned crop would be a greater source than the direct sown crop due to the increased number of heads produced per stand. The use of an seed dressing would be highly beneficial in both the direct sown and the carry through of this control to the ratooned crop increases further the economic benefit of this input.

1.17 MAIN CONCLUSIONS

1. Ratooned sorghum produce a more reliable yield than direct sown crops in the second (long) rains
2. Application of a fungicidal seed treatment decreases the incidence and severity of covered kernel smut
3. Covered kernel smut incidence in the long rains was highly correlated with incidence in the previous short rain
4. The strong relationship between the incidence and severity of CKS in the short and long rain within the ratooned crop increases the benefit of using a fungicidal seed treatment
5. Ratooned sorghum produces a higher number of heads per plant than direct sown crops and therefore a ratooned crop infected with CKS will produce a higher level of inoculum.

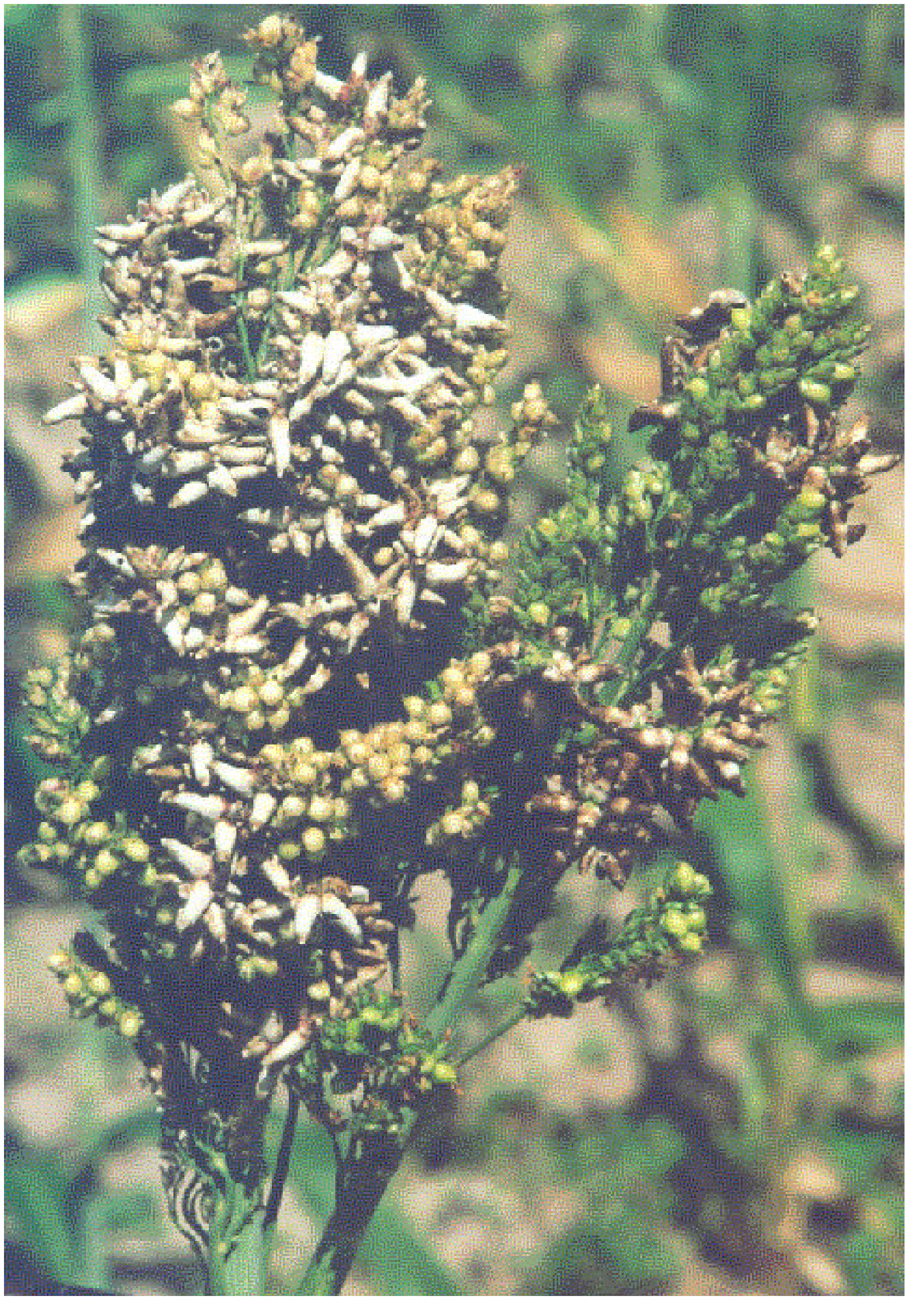


Plate 4.1: Sorghum panicle showing the symptoms of covered kernel smut. Note: The peridiums are splitting from the top of the sori.

Plate 4.2: Sorghum plants ratooned at harvest (top) and re-sprouting (bottom)

Plate 4.3: On-station trial at Katumani Research Station at the end of the long rains (July 2001). The foreground shows very poor performance of direct sown sorghum compared to the good performance achieved in the ratooned plots in tha background

COMPARISON OF SORGHUM RATOONING AND DIRECT SOWN IN RELATION TO LEVELS OF STEM BORERS

1.18 INTRODUCTION

As described in Chapter 4, a field experiment was undertaken to provide quantitative information on the effect of covered kernel smut and stem borers on the yield of sorghum grown from crops grown over two seasons. This was achieved using crops established by direct seeding for two consecutive seasons, or from crops established from seed in the short rains (October – January) and ratooned for the second long rains season (March – July). The experiment ran from October 1999 to August 2002 and covered six cropping seasons. This enabled the experiment to be repeated three times. This chapter examines the effect of sorghum ratooning on the natural levels of stem borers in the crop. The orthodox opinion on the practice of ratooning is that the green bridge produced by the practice increases pest carry-over to the next crop (Mohyuddin and Greathead, 1970, and Doggett, 1988). This carry-over enables pests to establish early within the crop. These populations then have a better opportunity to reach greater populations within the crop and act as a source of pests for other crops. However, there is no information on the effect of the practice of ratooning sorghum on the incidence of *Chilo partellus*, the main stem borer on sorghum in East Africa.

1.19 MATERIALS AND METHODS

1.19.1 First cropping cycle of field experiment (October 1999 – March 2000, April – August 2000)

The set up is the same as in Chapter 4 and the treatments are re-summarised in Table 5.1.

Table 5.1: Treatments used in the comparison of sorghum ratooning versus direct planting on the incidence of sorghum covered kernel smut and stem borers, KARI-Katumani, Kenya

Treatment name/ Chemical Inputs	Agronomic practice						Harvesting date (month)
	Direct sown			Ratooned			
	Treatment number	Planting date (month)	Ratooning date (month)	Treatment number	Planting date (month)	Ratooning date (month)	
NIL	**T1**	1) October 2) March	N/A	**T2**	1) October	1) March	1) February 2) August
THIRAM	**T3**	1) October 2) March	N/A	**T4**	1) October	1) March	1) February 2) August
CARBOFURAN[1]	**T5**	1) October 2) March	N/A	**T6**	1) October	1) March	1) February 2) August
BETA-CYFLUTHRIN	**T7**	1) October 2) March	N/A	**T8**	1) October	1) March	1) February 2) August
FULL Thiram+Carbofuran + Beta-cyfluthrin	**T9**	1) October 2) March	N/A	**T10**	1) October	1) March	1) February 2) August

[1] Lamdacyhalothrin was used in 2000/1 and 2001/2

Application of crop protection chemicals

The chemical applications were applied as an experimental device to give a range of stem borer levels and not because the farmers use them. To control stem borers the chemical carbofuran was applied at the recommended rate during the 1999/2000 season. The active ingredient is carbofuran (5% w/w carbofuran, 95% w/w inerts) and the recommended rate is 2g of granules per planting pocket. The chemical was placed in the planting hole, using the supplied shaker applicator, with the seed before being covered with the soil. Carbofuran was applied to Treatments T5, T6, T9 and T10 during planting. In the 2000/01 and 2001/02 cropping cycles, carbofuran was replaced with lamdacyhalothrin, trade name Karate 5EC. Karate 5EC contains the active ingredient lambdacyhalothrin at 17.5g per litre and was applied at the recommended rate of 300mls per hectare, with a spray volume of 120 litres per hectare, using a Hardy backpack sprayer. Prior to spraying the spray equipment was tested to check flow rate. The insecticide lamdacyhalothrin was applied to Treatments T5, T6, T9 and T10 when the plants were at knee height (40cm).

To control stem borers the chemical betacyfluthrin 0.05GR (Bayer), trade name Bulldock. Bulldock contains the active ingredient beta-cyfluthrin at 0.5g/kg and was applied at the recommendated rate of 8kg/ha, using the chemical company's applicator. The applicator released approximately 3g per stem. The insecticide betacyfluthrin was applied to Treatments T7, T8, T9 and T10 at the recommended growth stage of 5-7 leaf stage.

Stem borer assessments

Stem borer assessments were carried out at two different crop growth stages.

Assessment for stem borer damage at 5-7 leaf stage

At this stage, the number of dead hearts and the level of foliar damage were assessed on 45 randomly selected plants in each plot. The level of foliar damage caused by the young instars (1-2) feeding on the leaves is an indication of the size of the initial infestation. Larvae damaging the apical meristem when feeding cause deadhearts. This removes apical dominance and can result in tillering. The foliar damage was assessed using a modified Guthrie scale (Guthrie *et al*., 1960).

Guthrie's scale for visually scoring stem borer damage to leaves:

1 no symptoms of damage
2 few pin holes and shot holes (small holes) on a few leaves
3 several shot holes on a few (<50%) leaves
4 several (>50%) leaves with several shot holes or small lesions (<2 cm long
5 elongated lesions (>2cm) on a few (<50%) leaves
6 elongated lesions (>2cm) on several (>50%) leaves
7 several leaves with long lesions or moderate tattering
8 most leaves with long lesions or severe tattering
9 plant dying as a result of foliar damage

Assessment for stem borer damage at crop maturity

The assessments were made after harvest in the net plot on a total of 45 stems per plot. Each stem was randomly selected from one of the fifteen hills in each of the three inner rows. Each stem was split in two and the number of larvae, pupae, and length of tunnelling measured and recorded. The number of larvae is an indication of the number that is available to enter diapause, if conditions become unsuitable.

1.19.2 Second cycle of field trial (October 2000 – March 2001, April – August 2001)

All the plots were first planted on 16 October 2000, but were replanted on 8 November due to poor germination. The agronomy of the plots was similar to October 1999. After harvest of the short rain crop, plots of the Treatments T1, T3, T5, T7, T9 were re-planted on 20 April 2001 and all ten treatments had a top dressing of fertiliser (23:23:0) at 17kg per ha after the first weeding.

The number of exit holes and the length of the stem were added to the stem borer assessments. The number of exit holes per stem, is an indication of the number of moths that have emerged during the season. This assessment method probably under estimates as more than one moth can emerge from an exit hole. This is especially the case under heavy infestations, where tunnels inter-connect.

1.19.3 Third cycle of field trial (October 2001 – March 2002, April – August 2002)

All the plots were first planted on 16 October 2001. The agronomy of the plots was similar to October 1999. After harvest of the short rain crop, plots of the Treatments T1, T3, T5, T7, T9 were planted on 14 March 2001 and all the plots were top dressed with DAP (20:20:0) at 20kg/ha.

1.20 STATISTICAL ANALYSIS

1.20.1 First cycle of field trial (October 1999 – March 2000, April – August 2000)

The statistical software package Genstat was used for the analysis. Analysis of deviance was used to test whether differences existed among treatments in the proportions of stem borer damage in the plots during the two seasons. Simple correlation analysis was used to test for association between short and long rain values. The statistical methods utilised were described in Chapter 4.

1.20.2 Second and third cycles of field trial (October 2000 – August 2001, and October 2001 - August 2002, respectively)

Analysis of variance (ANOVA) was used to test whether differences existed among the individual treatments. If the differences were insignificant the effect of the two cropping practices i.e. directs sown and ratooned and the chemical inputs were compared. This was achieved using both one-way and two-way ANOVA. One-way ANOVA was used to identify differences between individual treatments, and two-way ANOVA to identify differences between the cropping practices (direct sown or ratooned) and chemical inputs. One-way ANOVA was also used to test whether difference occurred between the seasons.

Where results were judged significant ($p>0.05$), standard error of difference (SED) was calculated for comparison of means. The comparison of individual treatments was tested using Tukey b test.

The relationships between yield and stem borer parameters were further investigated using simple linear regressions. Linear trendlines were plotted using the "least squares" method to calculate a straight line that best fits the equation:

$$y = m\,x + b.$$

where *m* is the slope and *b* is the intercept.

1.21 RESULTS

1.21.1 First cycle of field experiment (October 1999 – March 2000, March – August 2000)

In the first season commencing October 1999, all the plots contained sorghum crops established from seed (i.e. not ratooned), therefore the data were analysed for the effectiveness of the stem borer control methods (beta-cyfluthrin, and carbofuran) only.

In the second season, commencing March 2000, half the plots contained sorghum crops established from seed (i.e. not ratooned), while the other half contained sorghum crops, which had been ratooned after the gathering of the short rain's harvest. The poor rains received during the long rains meant that the direct crop never reached maturity. The data sets were analysed for the effectiveness of the chemical inputs and differences between short rain and long rain crops.

Short rains (October 1999 – March 2000)

The incidence of stem borers at the 5-7 leaf stage was high in all the treatments. The incidence was not significantly ($p<0.05$) affected by the insecticides, though the incidence was lowest in those plots treated with both insecticides.

The level of foliar damage caused by stem borers at the 5-7 leaf stage was similar for all treatments, with a range of 2.2 – 2.3 (Table 5.2). The number of deadhearts was low in the plots and there was no significant ($p<0.05$) differences between the chemical inputs (Table 5.2).

Crop maturity

The level of stem borers in the mature crop was measured by the average length of tunnelling, number of larvae and pupae per stem. The treatments containing insecticides, lamdacyhalothrin or beta-cyfluthrin, had shorter tunnel length per stem than treatments containing no insecticide (Table 5.3). Treatments lamdacyhalothrin (T5&T6) and beta-cyfluthrin (T7&T8) had a tunnel length of 1.3 and 1.4cm, respectively, compared to treatments nil (T1&T2) and thiram (T3&T4) with 2.1 and 3.4cm, respectively. Treatments lamdacyhalothrin and betacyfluthrin was significantly ($p<0.05$) shorter tunnelling than treatment thiram.

The observed number of larvae per stem was low for all treatments (Table 5.2). The treatments containing insecticide beta-cyfluthrin (T7&T8) had the lowest count at 0.1. The rest of the treatments had the same count at 0.2 per stem. The ranking of the predicted values was the same order as for the length of tunnelling. None were significantly ($p<0.05$) different. The average number of pupae per stem was zero for all treatments.

Table 5.2: The effect of chemical inputs on the observed incidence of stem borer (%), foliar damage scores and deadheart (%) at crop stage 5-7 leaf, and mean number of larvae per stem at crop maturity in direct sown sorghum (short rains 1999)

Treatment number	Chemical inputs	5-7 leaf stage			Crop maturity
		Incidence of stem borers (%)[1]	Foliar damage score[*, 1]	Deadhearts (%)[1]	Larvae per stem [1]
T1&T2	Nil	95.0	2.3	3.4	0.2
T3&T4	Thiram	96.3	2.3	2.5	0.2
T5&T6	Lamdacyhalothrin	91.3	2.3	2.5	0.2
T7&T8	Beta-cyfluthrin	98.3	2.2	2.5	0.1
T9&T10	Full	83.3	2.2	3.1	0.2

Key [1] = no significant ($p<0.05$) difference between chemical inputs

* Score grade 1 = no symptoms of damage

2 = few pin holes and shot holes (small holes) on a few leaves

3 = several shot holes on a few (<50%) leaves

Table 5.3: The effect of chemical inputs on the mean stem borer tunnel length (cm) per stem in direct sown sorghum (short rains 1999)

Treatment Number	Chemical input	Observed	Transformed data	
			Prediction	s.e.
T1&T2	Nil	2.1	1.9	0.5
T3&T4	Thiram	3.4	3.8	0.5
T5&T6	Lamdacyhalothrin	1.4	1.5	0.5[1]
T7&T8	Beta-cyfluthrin	1.3	0.7	0.5[1]
T9&T10	Full	2.4	2.7	0.5

Key [1] = significantly different (p<0.05) from treatment thiram (T3&T4)

Long rains (March – August 2000)

Data was collected from both direct sown and ratooned plots up to 5-7 leaf stage and this data was analysed for both the effect of individual treatments (one-way ANOVA), and cropping practice and chemical inputs (two-way ANOVA). By crop maturity, the direct sown crop had completely dried and therefore, the data was only analysed for effect of chemical inputs. The incidence of stem borer infested plants at 5-7 leaf stage was not significantly (p<0.05) different under the individual treatments. However, the incidence of infested plants at 5-7 leaf stage was significantly (p<0.05) affected by the different agronomic practices. The direct sown crop had a lower observed incidence than the ratooned crop, with 76.4% and 85.4% respectively (Table 5.4). The application of the chemical inputs did not significantly (p<0.05) affect the incidence of stem borer ifected plants at the 5-7 leaf stage. The treatments containing the insecticide beta-cyfluthrin i.e. treatments full and beta-cyfluthrin (T9&T10 and T7&T8) had lower incidences than those not containing beta-cyfluthrin. The level of foliar damage, as measured by Guthrie's score, at 5-7 leaf stage, was not significantly (p<0.05) different under the individual treatments, the different agronomic practices or the application of the chemical inputs (Table 5.4). The direct sown and ratooned crop had almost identical scores, with 2.1 and 2.2, respectively.

The number of deadhearts was significantly (p<0.05) different under the individual treatments. The individual treatments containing an insecticide were lower than those not containing an insecticide, regardless of the cropping practice (Table 5.5a). The number of deadhearts per plot was not significantly ($p<0.05$) affected by the different agronomic practices, though the direct sown crop had a lower observed incidence than the ratooned crop, with 13.7% and 23.1%, respectively (Table 5.5b). The application of the chemical inputs did have a significantly ($p<0.05$) affect on the number of deadhearts recorded. The treatments containing insecticide (treatments lamdacyhalothrin (T5&T6), beta-cyfluthrin (T7&T8) and full (T9&T10)) had significantly ($p<0.05$) fewer deadhearts than the treatments not containing an insecticide.

Table 5.4: The effect of cropping practice and chemical inputs on the incidence of stem borer (%) and foliar damage scores at crop stage 5-7 leaf; number of larvae and pupae per stem at crop maturity in direct sown and ratooned sorghum (long rains 2000)

Chemical Inputs	5-7 leaf stage		Crop maturity	
	Incidence of stem borers[2, 3]		Larvae[3]	Pupae[3]
	Direct sown	Ratooned	Ratooned	Ratooned
Nil	83.9	89.0	0.8	0.5
Thiram	78.3	86.4	0.8	0.3
Lamdacyhalothrin	81.7	88.4	0.6	0.3
Beta-cyfluthrin	76.0	76.3	0.4	0.1
Full	62.2	87.1	0.2	0.0
All plots	76.4	85.4[1]		

Key [1] = significantly different ($p<0.05$) from direct sown crop

Crop maturity

The direct sown crop failed to reach crop maturity, so only the ratooned crop was available to assess for the level of stem borers. The level of stem borers was measured by the average length of tunnelling, number of larvae and pupae per stem. The average tunnelling length per stem was affected significantly ($p<0.05$) by the chemical inputs (Table 5.6). The shortest observed tunnelling per stem was in the plots under the combined application of lamdacyhalothrin and beta-cyfluthrin (treatment full, (T10)), with 4.9cm. This was significantly (p<0.05) shorter than treatments nil (T2), with 30.2cm.

Table 5.5a: The effect of cropping practice and chemical inputs on the mean number of dead hearts (%) under individual treatment in direct sown and ratooned sorghum (long rains 2000)

Treatment number*	Chemical Inputs	Observed	Transformed data		Back transformed	
			Pre-diction	s.e.	Pre-diction	c.i.
T1	Nil direct sown	31.7	-0.675	0.298	33.7	(22.1, 47.8)
T2	Nil ratoon	45.9	-0.418	0.322	40.0	(25.9, 55.3)
T3	Thiram direct sown	15.0	-1.284	0.433	21.7	(10.6, 39.3)
T4	Thiram ratoon	26.4	-0.852	0.305	29.9	(19.0, 43.7)
T5	Lamdacyhalothrin direct sown	5.0	-3.185	0.628	4.0	(1.2, 12.4)[1,2]
T6	Lamdacyhalothrin ratoon	10.0	-2.611	0.450	6.8	(3.0, 15.1)[1,2]
T7	Beta-cyfluthrin direct sown	15.9	-2.045	0.408	11.5	(5.5, 22.4)[2]
T8	Beta-cyfluthrin Ratoon	19.9	-1.136	0.357	24.3	(13.8, 39.3)
T9	Full direct sown	1.1	-4.235	1.196	1.4	(0.1, 13.1)[1,2]
T10	Full ratoon	13.4	-2.133	0.392	10.6	(5.2, 20.4)[1,2]

Key [1] = significantly different (p<0.05) from direct sown, treatment nil (T1)

[2] = significantly different (p<0.05) from ratooned, treatment nil (T2)

The number of larvae per stem was low at between 0.2 and 0.8 larvae per stem, and was not significantly (p<0.05) affected by the chemical inputs (Table 5.4). The plots treated with an insecticide had fewer larvae than those not treated with an insecticide i.e. treatment nil (T2) and thiram (T4). The combined application of lamdacyhalothrin and beta-cyfluthrin i.e. treatment Full (T10), had fewer larvae than the individual application of either lamdacyhalothrin (T6) or beta-cyfluthrin (T8), with 0.2, 0.6 and 0.4, respectively. The number of larvae in treatments nil (T2) and thiram (T4) were 0.8.

Table 5.5b: The effect of cropping practice and chemical inputs on the mean number of dead hearts (%) (long rains 2000)

Treatment number	Chemical inputs	Observed		Transformed data		Back transformed	
		Direct sown	Ratooned	Pre-diction	s.e.	Pre-diction	c.i.
T1&T2	Nil	31.7	45.9	-0.5	0.2	36.6	(27.4, 47.0)[3]
T3&T4	Thiram	15.0	26.4	-1.1	0.2	24.6	(16.8, 34.6)[3]
T5&T6	Lamdacyhalothrin	5.0	10.0	-2.9	0.4	5.2	(2.6, 10.1)[2]
T7&T8	Beta-cyfluthrin	15.9	19.9	-1.6	0.2	17.4	(11.5, 25.3)[2]
T9&T10	Full	1.1	13.4	-2.7	0.3	6.5	(3.4, 12.1)[2]
	All plots	13.7	23.1[1]				

Key [1] = not significantly different ($p<0.05$) from direct sown plots
[2] = significantly different ($p<0.05$) from treatment nil (T1&T2)
[3] = significantly different ($p<0.05$) from treatment full (T9&T10)

Table 5.6: The effect of chemical inputs on the mean stem borer tunnel length (cm) per stem in ratooned sorghum (long rains 2000)

Treatment number	Chemical inputs	Observed	Unbalanced data	
			Prediction	s.e
T2	Nil	30.2	29.0	3.9[2]
T4	Thiram	29.3	29.9	4.2[2]
T6	Lamdacyhalothrin	28.6	28.4	4.0[2]
T8	Beta-cyfluthrin	15.2	15.3	3.9
T10	Full	4.9	5.6	4.0[1]

Key [1] = significantly different ($p<0.05$) from treatment nil (T2)
[2] = significantly different ($p<0.05$) from treatment full (T10)

The number of pupae per stem was low at less than 0.5 (Table 5.4) and was not significantly ($p<0.05$) affected by the chemical inputs. The plots treated with an insecticide had fewer pupae than those not treated with an insecticide i.e. treatment nil (T2) and thiram (T4). The combined application of lamdacyhalothrin and beta-cyfluthrin i.e. treatment full (T10), had fewer pupae than individual application of either lamdacyhalothrin (T6) or beta-cyfluthrin (T8), with 0.0, 0.3 and 0.1, respectively. The number of pupae in treatments nil (T2) and thiram (T4) were 0.5 and 0.3, respectively. The ranking of the treatments in order of the number of pupae per stem was the same as the ranking of both number of larvae per stem and length of tunnelling per stem.

1.21.2 Second cycle of field experiment (October 2000 – March 2001, March – August 2001)

In the short rains, all the plots contained direct sown sorghum, therefore the data was analysed for the effectiveness of the chemical inputs only. In the long rains, the data was analysed for the effectiveness of the treatments, and the performance of the direct sown crop and ratooned crop were compared.

Short rains (October 2000 – March 2001)

In the short rains, the incidence of stem borer infested plants at 5-7 leaf stage was high at above 90% in all the plots. The level of foliar damage caused by the stem borers was recorded using the Guthrie scale and showed no significant ($p<0.05$) differences between the treatments (Table 5.7). The number of deadhearts recorded was not significantly ($p<0.05$) reduced by the application of insecticide and there was no trend (Table 5.7).

Crop maturity

The level of stem borer damage at crop maturity was assessed by recording the average length of tunnelling per stem in each treatment. The treatments containing beta-cyfluthrin had shorter lengths of tunnelling than treatments not containing beta-cyfluthrin, with treatment beta-cyfluthrin (T7&T8) and full (T9&T10) having lengths of 16.2 and 16.7 cm, respectively (Table 5.7). The other treatments, nil (T1&T2), lamdacyhalothrin (T5&T6) and thiram (T3&T4), had average lengths of 17.4, 18.2 and 21.1 cm respectively. None of the treatments were significantly ($p<0.05$) different from each other.

Table 5.7: Effect of chemical inputs on the stem borer damage at 5-7 leaf stage, measured by average foliar damage score per plant (Gutheris scale) and average number of deadhearts per plot; stem borer damage at crop maturity, measured by length of tunnelling per stem (cm) in direct sown crops (short rains 2000/1)

Treatment number	Chemical inputs	5-7 leaf stage		Crop maturity
		Foliar damage score	Deadhearts	Length of tunnelling
T1&T2	Nil	2.4	2.3	17.4
T3&T4	Thiram	2.3	0.8	21.1
T5&T6	Lamdacyhalothrin	2.3	0.9	18.2
T7&T8	Beta-cyfluthrin	2.2	0.5	16.2
T9&T10	Full	2.2	0.9	16.7
SED			0.7	1.8

Tukey b tests applied if F values resulting from ANOVA significant ($p<0.05$) for chemical inputs

Stem borer population

The average number of larvae per stem was low for all the treatments at less than one (Table 5.8). The treatments containing the insecticide beta-cyfluthrin (T7&T8) and T9&T10) had the lowest number of larvae at 0.4 per stem. These treatments were not significantly ($p<0.05$) different from treatments nil (T1&T2) with 0.5. The average number of pupae per stem per plot was zero for all treatments.

The average number of exit holes per stem was very similar for all treatments and the application of an insecticide had no effect (Table 5.8). The number of exit holes recorded ranged from 2.4-3.2 per stem.

The number of stem borers (larve+pupae+exit holes) per stem during the season was significantly ($p<0.05$) affected by the chemical inputs, though application of an insecticide had no effect (Table 5.8). The lowest number of stem borers was under treatments nil (T1&T2) and lamdacyhalothrin (T5&T6), with 2.9, followed by treatments beta-cyfluthrin (T7&T8), full (T9&T10) and thiram (T3&T4), with 3.0, 3.2, and 3.9, respectively. Treatments nil (T1&T2) and thiram (T3&T4) were significantly ($p<0.05$) different from each other.

Table 5.8: Effect of chemical inputs on stem borer population, measured by average number of larvae, pupae and exit holes per stem at crop maturity in direct sown crops (short rains 2000/1)

Treatment number	Chemical inputs	Larvae	Pupae	Exit holes	Stem borers
T1&T2	Nil	0.5	0	2.4	2.9
T3&T4	Thiram	0.6	0	3.2	3.9
T5&T6	Lamdacyhalothrin	0.5	0	2.5	3.0
T7&T8	Beta-cyfluthrin	0.4	0	2.5	3.0
T9&T10	Full	0.4	0	2.7	3.2
SED		0.1		0.3	0.3

Tukey b test applied if F value from ANOVA significant ($p<0.05$) for chemical inputs

Larvae

Chemical inputs (0.05, 32, 8) T7&T8 T9&T10 T1&T2 T5&T6 T3&T4

0.4 0.5 0.5 0.5 0.6

Stem borers (Larvae+pupae+exit holes)

Chemical inputs (0.05, 32, 8) T1&T2 T5&T6 T7&T8 T9&T10 T3&T4

2.9 2.9 3.0 3.2 3.9

Long rains (March – August 2001)

Stem borer damage at 5-7 leaf stage

In the long rains, the incidence of stem borer infested plants at 5-7 leaf stage was high at over 90% in all the plots. The level of foliar damage caused by the stem borers was recorded using the Guthrie scale. The foliar damage was significantly ($p<0.05$) different under the individual treatments. All the ratooned treatments had significantly higher foliar damage than the direct sown plots treated with nothing (treatment nil (T1)) (Table 5.9). The average foliar damage score in the ratooned plots was significantly higher than the direct sown plots, with 3.6 and 2.3, respectively (Table 5.9). The application of chemical inputs did not have a significant (p<0.05) affect on foliar damage.

Table 5.9: Effect of cropping practice and chemical inputs on the stem borer foliar damage at 5-7 leaf stage, measured by average damage score per plant (Gutherie scale) and average number of deadhearts per plot; stem borer damage at crop maturity, measured by average length of tunnelling per stem (cm) in direct sown and ratooned crops (long rains 2001)

Treatment number*	Chemical input	Foliar damage score**		Dead heart	Length of tunnelling
		Observed	Prediction (c.i.)		
T1	Nil direct sown	2.3	2.3 (2.0, 2.6)[3]	13.5	2.7
T2	Nil ratoon	3.8	3.8 (3.5, 4.2)[2]	36.8	12.6
T3	Thiram direct sown	2.3	2.3 (2.0, 2.6)[3]	17.0	4.0
T4	Thiram ratoon	3.4	3.4 (3.0, 3.7)[2]	36.3	11.8
T5	Lamdacyhalothrin direct sown	2.4	2.4 (2.1, 2.7)[3]	17.5	3.3
T6	Lamdacyhalothrin ratoon	3.7	3.7 (3.4, 4.1)[2]	37.3	13.6
T7	Beta-cyfluthrin direct sown	2.3	2.3 (2.0, 2.6)[3]	17.5	4.0
T8	Beta-cyfluthrin ratoon	3.7	3.7 (3.3, 4.0)[2]	36.0	13.6
T9	Full direct sown	2.3	2.3 (2.0, 2.6)[3]	17.0	4.7
T10	Full ratoon	3.6	3.6 (3.3, 4.0)[2]	35.0	12.0
SED				3.4	1.8
Direct sown		2.3		16.5	3.7
Ratooned		3.6[1]		36.3[1]	12.7[1]
SED				1.5	0.8

Key * even treatment numbers are ratooned, odd numbers are direct sown

[1] significantly (p<0.05) different from direct sown plots

[2] significantly (p<0.05) different from direct sown, treatment nil (T1)

[3] significantly (p<0.05) different from direct sown, treatment nil (T2)

Tukey b tests applied if F values resulting from ANOVA significant ($p<0.05$)

Dead hearts

Treatments (0.05, 27, 4)	T1	T3	T9	T5	T7	T10	T8	T4	T2	T6
	13.5	17.0	17.0	17.5	17.5	35.0	36.0	36.3	36.8	37.3

Length of tunnelling

Treatments (0.05, 27, 4)	T1	T5	T7	T3	T9	T4	T10	T2	T8	T6
	2.7	3.3	4.0	4.0	4.7	11.8	12.0	12.6	13.6	13.6

**Score grade

1 no symptoms of damage

2 few pin holes and shot holes (small holes) on a few leaves

3 several shot holes on a few (<50%) leaves

4 several (>50%) leaves with several shot holes or small lesions (<2 cm long)

The incidence of deadhearts was significantly ($p<0.001$) affected by the individual treatments. All the ratooned treatments had significantly ($p<0.05$) more deadhearts than the direct sown treatments (Table 5.9). The ratooned crop had significantly ($p<0.05$) more deadhearts compared to the direct sown crop, with 36.3 and 16.5 respectively. The chemical inputs did not affect the number of deadhearts and there were significant interactions between the cropping practice and chemical inputs. In the ratooned crop, the average number of deadheart in treatments ranged from 35.0 to 37.3. In the direct sown crop, the range was 13.5 to 17.5.

Stem borer damage at crop maturity

The average length of tunnelling per stem was significantly ($p<0.05$) affected by the individual treatments. All the ratooned treatments had significantly ($p<0.05$) longer tunnelling than the direct sown treatments. The direct sown crop had significantly ($p<0.05$) shorter average length of tunnelling compared to the ratooned crop, with 3.7 and 12.7cm, respectively (Table 5.9). The application of an insecticide did not reduce the length of tunnelling per stem, and there was no significant ($p<0.05$) interaction between agronomic practice and chemical inputs.

The poor rainfall in the long rains resulted in the direct sown crop drying before reaching maturity. This resulted in the stems of the ratooned crop being longer than the stems of the direct sown. The data was therefore also analysed as number per meter of stem. The average length of tunnelling per metre of stem was still lower in the direct sown compared to the ratooned crop with 7.9 and 15.7cm, respectively (Table 5.11). However, the direct sown treatments were not all significantly ($p<0.05$) lower than the ratooned treatments.

Stem borer population

The average number of larvae per stem was low at less than one per stem and there were no significant ($p<0.05$) differences between the individual treatments, or the different agronomic practices. The direct sown crop had fewer larvae compared to the ratooned crop, with 0.6 and 0.8, respectively (Table 5.10). The application of an insecticide did not reduce the number of larvae per stem and there was no significant ($p<0.05$) interaction between agronomic practice and chemical input. The number of larvae recorded in ratooned and direct sown plots ranged from 0.7-0.9 and 0.4-0.8, respectively. The average number of pupae per stem was zero for all treatments.

When the lengths of the stems were taken into account, there was still no significant ($p<0.05$) difference between the individual treatments. However, the direct sown crop had significantly ($p<0.05$) higher numbers of larvae compared to the ratooned crop, with 1.3 and 0.9, respectively (Table 5.11). This was opposite to numbers per stem. There were still no significant ($p<0.05$) interactions between agronomic practice and chemical inputs. Chemical inputs had no significant ($p<0.05$) effect on larvae per metre. In the ratooned plots, there was little difference between treatments, with a range of 0.8-1.0, and in the direct sown plots the range was 0.8-1.6 larvae per metre of stem.

The average number of exit holes per stem was significantly ($p<0.05$) higher in the ratooned plots treated with lamdacyhalothrin (T6) than the direct sown, treated with nothing (T1). The other treatments were not significantly different from each other. However, the direct sown plots had significantly ($p<0.05$) fewer holes compared to the ratooned crop, with 1.3 and 2.6, respectively (Table 5.10). The application of an insecticide did not reduce the number of exit hole per stem and there were no significant ($p<0.05$) interactions between agronomic practices and chemical inputs. In the ratooned crop, differences between the individual treatments were less than one, with recorded ranges of 2.3-3.0. In the direct sown, the range was 0.7-1.8.

Table 5.10: Effect of cropping practice and chemical inputs on the stem borer population, measured by number of larvae, pupae and exit holes per stem at crop maturity in direct sown and ratooned crops (long rains 2001)

Treatment number*	Chemical input	Larvae	Exit holes	Stem borers
T1	Nil direct sown	0.4	0.7	1.1
T2	Nil ratoon	0.7	2.3	3.0
T3	Thiram direct sown	0.7	1.6	2.4
T4	Thiram ratoon	0.7	2.6	3.2
T5	Lamdacyhalothrin direct sown	0.6	1.3	1.8
T6	Lamdacyhalothrin ratoon	0.9	3.0	3.8
T7	Beta-cyfluthrin direct sown	0.6	1.2	1.8
T8	Beta-cyfluthrin ratoon	0.8	2.7	3.4
T9	Full direct sown	0.8	1.8	2.6
T10	Full ratoon	0.8	2.4	3.1
SED		0.2	0.6	0.8
Direct sown		0.6	1.3	1.9
Ratooned		0.8	2.6[1]	3.3[1]
SED		0.2	0.3	0.3

Key [1] significantly (p<0.05) different from direct sown plots

Tukey b tests applied if F values resulting from ANOVA significant (p<0.05)

Exit holes

	T1	T7	T5	T3	T9	T2	T10	T4	T8	T6
Treatments (0.05, 27, 4)	0.7	1.2	1.3	1.6	1.8	2.3	2.4	2.6	2.7	3.0

Stem borers

	T1	T7	T5	T3	T9	T2	T10	T4	T8	T6
Treatments (0.05, 27, 4)	1.0	1.8	1.8	2.3	2.6	3.0	3.1	3.2	3.4	3.8

When the lengths of the stems were taken in to account, the number of exit holes per metre of stem were no longer significantly (p<0.05) affected by the individual treatments, different agronomic practices or chemical inputs. The direct sown had a similar number of exit holes compared to the ratooned crops, with 2.8 and 3.1 respectively (Table 5.11). There were still no significant ($p<0.05$) interactions between the agronomic practices and chemical inputs. The chemical inputs had no significant ($p<0.05$) effect on the number of exit holes per metre of stem. There was no consistent effect with the application of insecticide.

Table 5.11: Effect of cropping practice and chemical inputs on the stem borer population, measured by number of larvae, pupae and exit holes per metre of stem at crop maturity in direct sown and ratooned crops (long rains 2001)

Treatment number*,	Chemical input	Length of tunnelling[2]	Larvae[2]	Exit holes[2]	Stem borers[2]
T1	Nil direct sown	6.3	0.8	1.8	2.5
T2	Nil ratoon	14.7	0.8	2.7	3.6
T3	Thiram direct sown	8.1	1.4	3.2	4.6
T4	Thiram ratoon	14.6	0.8	3.1	3.9
T5	Lamdacyhalothrin direct sown	7.5	1.4	2.7	4.2
T6	Lamdacyhalothrin ratoon	16.3	1.0	3.5	4.5
T7	Beta-cyfluthrin direct sown	8.7	1.4	2.9	4.3
T8	Beta-cyfluthrin ratoon	16.4	1.0	3.3	4.3
T9	Full direct sown	8.8	1.6	3.5	5.0
T10	Full ratoon	14.5	0.9	2.9	3.8
SED		2.1	0.4	0.8	1.1
Direct sown		7.9	1.3	2.8	4.1
Ratooned		15.3[1]	0.9[1]	3.1	4.0
SED		0.9	0.2	0.7	0.5

Key [1] significantly ($p<0.05$) different from direct sown plots

[2] chemical inputs not significantly ($p<0.05$) different

Tukey b tests applied if F values resulting from ANOVA significant (p<0.05)

Length of tunnelling

Treatments (0.05, 27, 4)	T1	T5	T3	T7	T9	T10	T4	T2	T6	T8
	6.3	7.5	8.1	8.7	8.8	14.5	14.6	14.7	16.3	16.4

The number of stem borers (larvae+pupae+exit holes) per stem during the season was significantly (p<0.05) higher in the ratooned plots treated with lamdacyhalothrin (T6) than the direct sown, treated with nothing (T1). The other treatments were not significantly different from each other. However, the direct sown crop had significantly (p<0.05) fewer stem borers than the ratooned crop, with 1.9 and 3.3, respectively (Table 5.10). The application of an insecticide did not reduce the numbers and there was no significant (p<0.05) interaction between agronomic practice and chemical input. In the ratooned crop, there was little difference between the treatments, with a range of values from 3.0 to 3.8. In the direct sown crop, the range was 1.1 to 2.6.

When the lengths of the stems were taken in to account, there was no significant (p<0.05) difference between the individual treatments, different agronomic practices and chemical inputs. The direct sown crop had a similar number of stem borers compared to the ratooned crop, with 4.1 and 4.0, respectively (Table 5.11). There were still no significant (p<0.05) interactions between the agronomic practices and chemical inputs. The chemical inputs had no significant (p<0.05) effect on the number of stem borer per metre of stem. There was no consistent effect with the application of the insecticide. In the ratooned crop, the number of stem borers ranged from 3.6-4.5, and in the direct sown crop ranged from 2.5-5.0.

1.21.3 Third cycle of field experiment (October 2001 – March 2002, March – August 2002)

Short rains (October 2001 – March 2002)

In the short rains, the incidence of stem borer infested plants at 5-7 leaf stage was high at above 90%. The level of foliar damage caused by the stem borers was not significantly (p<0.05) different between chemical inputs, with a range of 2.9-3.4 (Table

5.12). The number of deadhearts recorded was not significantly ($p<0.05$) reduced by the application of insecticide and there was no trend (Table 5.12).

Stem borer damage at crop maturity

The level of stem borer damage at crop maturity was measured as the average length of tunnelling per stem in each treatment. The individual treatments containing an insecticide had shorter length of tunnelling than treatments without an insecticide. The insecticide containing treatments beta-cyfluthrin (T7&8), lamdacyhalothrin (T5&T6) and full (T9&T10) recorded lengths of 19.4 cm, 19.8 and 20.2, respectively. This compared to non-insecticide treatments nil (T1&T2) and thiram (T3&T4) with 23.0 and 27.7cm, respectively (Table 5.12). None of the treatments were significantly ($p<0.05$) different from each other.

Table 5.12: Effect of chemical inputs on the stem borer damage at 5-7 leaf stage, measured by average foliar damage score per plant (Gutheris scale) and average number of deadhearts per plot; stem borer damage at crop maturity, measured by length of tunnelling per stem (cm) in direct sown crops (short rains 2001/2)

Treatment number	Chemical inputs	5-7 leaf stage		Crop maturity
		Foliar damage*	Deadhearts	Length of tunnelling
T1&T2	Nil	3.2	7.0	23.0
T3&T4	Thiram	3.4	4.0	27.7
T5&T6	Lamdacyhalothrin	2.8	4.6	19.8
T7&T8	Beta-cyfluthrin	3.1	6.1	19.4
T9&T10	Full	3.0	4.4	20.2
SED			1.5	3.3

Tukey b tests applied if F values resulting from ANOVA significant ($p<0.05$)

[*] Score grade

1 no symptoms of damage

2 few pin holes and shot holes (small holes) on a few leaves

3 several shot holes on a few (<50%) leaves

4 several (>50%) leaves with several shot holes or small lesions (<2 cm long)

Stem borer population

The average number of larvae per stem was low for all the treatments (Table 5.13). The treatments containing insecticide, lamdacyhalothrin or beta-cyfluthrin (T5&T6 and T7&T8) had fewer larvae than treatments containing no insecticide, treatments nil and thiram (T1&T2 and T3&T4). Treatment full (T9&T10), which contains both beta-cyfluthrin and lamdacyhalothrin, had the least number of larvae at 0.7 per stem, followed by treatment beta-cyfluthrin (T7&T8) and lamdacyhalothrin (T5&T6) with 0.8, then treatments nil and thiram with 1.1 and 1.2, respectively. Application of both insecticides (T9&T10) had a significant ($p<0.05$) affect on the number of larvae per stem, with treatment full (T9&T10) having significantly ($p<0.05$) fewer larvae than treatment thiram (T3&T4), though not treatment nil (T1&T2). No pupae were recorded.

Table 5.13: Effect of chemical inputs on stem borer population, measured by average number of larvae, pupae and exit holes per stem at crop maturity in direct sown crops (short rains 2001/2)

Treatment number	Chemical inputs	Larvae	Pupae	Exit holes	Stem borers
T1&T2	Nil	1.1	0	1.2	2.4
T3&T4	Thiram	1.2	0	1.7	3.0
T5&T6	Lamdacyhalothrin	0.8	0	1.0	1.8
T7&T8	Beta-cyfluthrin	0.8	0	1.0	1.9
T9&T10	Full	0.7	0	1.0	1.7
	SED	0.2		0.2	0.3

Tukey b tests applied if F values resulting from ANOVA significant ($p<0.05$)

Larvae

Chemical inputs (0.05, 27, 8)	T9&T10	T7&T8	T5&T6	T1&T2	T3&T4
	0.7	0.8	0.8	1.1	1.2

Exit holes

Chemical inputs (0.05, 27, 8)	T9&T10	T5&T6	T7&T8	T1&T2	T3&T4
	1.0	1.0	1.0	1.2	1.7

Stem borers

Chemical inputs (0.05, 27, 8)	T9&T10	T5&T6	T7&T8	T1&T2	T3&T4
	1.7	1.8	1.9	2.4	3.0

The average number of exit holes per stem showed a similar pattern as the number of larvae (Table 5.13). Treatments containing an insecticide had fewer exit holes than treatments containing no insecticides, with treatments full (T9&T10), beta-cyfluthrin (T7&T8) and lamdacyhalothrin (T5&T6), recording 1.0, compared to treatments nil (T1&T2) and thiram (T3&T4) with 1.2 and 1.7, respectively. Treatments full (T9&T10), beta-cyfluthrin (T7&T8) and lamdacyhalothrin (T5&T6) had significantly ($p<0.05$) fewer than treatment nil (T1&T2).

The number of stem borer (larvae+ pupae+exit holes) per stem was significantly ($p<0.05$) affected by the treatments (Table 5.13). The treatments containing insecticide, lamdacyhalothrin or beta-cyfluthrin (T5&T6 and T7&T8) had a lower count than treatments containing no insecticide, nil and thiram (T1&T2 and T3&T4). Treatment full (T9&T10) which contains both beta-cyfluthrin and lamdacyhalothrin was the most effective and recorded the lowest count, with 1.7 per stem, followed by treatment lamdacyhalothrin, beta-cyfluthrin, nil and thiram, with 1.8, 1.9, 2.4 and 3.0, respectively. The treatments containing an insecticide had significantly ($p<0.05$) less counts than treatment thiram (T3&T4).

Long rains (March – August 2002)

In the long rains, both the direct sown and ratooned crops reached maturity, therefore data was analysed for both the effect of individual treatments (one-way ANOVA), and cropping practice and chemical inputs (two-way ANOVA). In the long rains, the incidence of stem borer infest plants at 5-7 leaf stage was high in all plots at above 90%. The level of foliar damage caused by the stem borers was significantly ($p<0.05$) different under the individual treatments. The direct sown plots treated with thiram or beta-cyfluthrin (T3, T7 and T9) had significantly lower damage than the direct sown plots treated with nothing (T1) (Table 5.14). The other individual treatments were not significantly ($p<0.5$) different from each other. The average foliar damage was significantly higher in the ratooned plots than the direct sown plots, with 4.7 and 4.2, respectively. The application of chemical inputs did not significantly ($p<0.05$) affect the foilar damage.

The incidence of deadhearts was not significantly (p<0.05) affected by the individual treatments, different cropping practice or chemical inputs (Table 5.14). The ratooned and direct sown crop had very similar number of deadhearts with 13.9 and 14.3, respectively. The chemical inputs did not affect the number of deadhearts, and there were no significant (p<0.05) interactions between agronomic practice and chemical inputs. There was no particular trend under either agronomic practice. In the ratooned crop, the average number of deadhearts in treatments ranged from 11.0 to 17.3, while in the direct sown crop, the range was 12.0 to 16.8.

Stem borer damage at crop maturity

The average tunnelling length per stem was significantly (p<0.05) different between individual treatments. The direct sown crop treated with both insecticides (treatment full (T9) had significantly (p<0.5) shorter tunnels than the direct sown crop treated with nothing (treatment nil (T1)). There were no other significant (p<0.5) differences between the other individual treatments. The length of tunnelling in the direct sown and ratooned crops was almost the same at 10.1 and 10.3cm, respectively (Table 5.14). The application of insecticides did significantly (p<0.05) affect the tunnelling length, but there were no significant (p<0.05) interactions between agronomic practice and chemical inputs. The application of an insecticide reduced the length of tunnelling per stem and the combined application of beta-cyfluthrin and lamdacyhalothrin was significantly (p<0.05) more effective than individual applications. The ranking of the treatments in both the direct sown and ratooned crops in short and long rains showed the application of insecticide reduced length of tunnelling.

The average number of larvae per stem was significantly (p<0.05) different between individual treatments. The direct sown crop treated with both insecticides (treatment full (T9)) had significantly fewer larvae than the direct sown crop treated with nothing (treatment nil (T1)). There were no other significant differences between the other treatments. However, the direct sown crop had significantly (p<0.05) more larvae than the ratooned crop, with 0.6 and 0.4, respectively (Table 5.15). The application of chemical inputs did significantly (p<0.05) affect the number of larvae per stem, but there were no significant (p<0.05) interactions between agronomic practices and chemical inputs. The application of an insecticide reduced the number of larvae and the combined application of beta-cyfluthrin and lamdacyhalothrin (T9&T10) was more effective than individual applications. The average number of pupae per stem was zero for all treatments.

Table 5.14: Effect of individual treatments on the stem borer damage at 5-7 leaf stage, measured by average foliar damage score per plant (Gutheri's scale) and average number of deadhearts per plot; average length of tunnelling per stem (cm) at crop maturity in direct sown and ratooned crops (long rains 2002)

Treatment number*	Chemical input	5-7 leaf stage			Crop maturity
		Foliar damage score[2]		Deadhearts[2]	Length of tunnelling
		Observed /predicted (c.i)			
T1	Nil direct sown	4.5	4.4 (4.1, 4.7)	14.5	15.5
T2	Nil ratoon	4.8	4.8 (4.4, 5.1)	14.5	10.5
T3	Thiram direct sown	4.1	4.1 (3.8, 4.4)[3]	12.0	12.8
T4	Thiram ratoon	4.8	4.8 (4.4, 5.1)	15.3	12.7
T5	Lamdacyhalothrin direct sown	4.3	4.3 (4.0, 4.6)	16.8	7.1
T6	Lamdacyhalothrin ratoon	4.6	4.6 (4.3, 4.9)	11.5	10.1
T7	Beta-cyfluthrin direct sown	4.0	4.0 (3.7, 4.3)[3]	13.0	9.4
T8	Beta-cyfluthrin ratoon	4.5	4.5 (4.2, 4.8)	11.0	9.4
T9	Full direct sown	4.1	4.1 (3.8, 4.4)[3]	15.3	5.8
T10	Full ratoon	4.8	4.8 (4.5, 5.2)	17.3	9.0
SED				3.4	2.6
Direct sown		4.2		13.9	10.1
Ratooned		4.7[1]		14.3	10.3
SED				1.5	1.2

Key * even treatment numbers are ratooned, odd numbers are direct sown

[1] significantly (p<0.05) different from direct sown plots

[2] chemical inputs not significantly (p<0.05) different

[3] significantly (p<0.05) different from ratooned, treatment nil (T2)

Tukey b tests applied if F values resulting from ANOVA significant ($p<0.05$)

Length of tunnelling

Treatments (0.05, 27, 4)	T9	T5	T10	T7	T8	T6	T2	T4	T3	T1
	5.8	7.1	9.0	9.4	9.4	10.1	10.5	12.7	12.8	15.5

Length of tunnelling

Chemical inputs (0.05, 27, 8)	T9&T10	T5&T6	T7&T8	T3&T4	T1&T2
	7.4	8.6	9.4	12.8	13.0

[*] Score grade

1 no symptoms of damage

2 few pin holes and shot holes (small holes) on a few leaves

3 several shot holes on a few (<50%) leaves

4 several (>50%) leaves with several shot holes or small lesions (<2 cm long)

Stem borer population

The average number of exit holes per stem was significantly ($p<0.05$) different between individual treatments. The direct sown crop treated with nothing (treatment nil (T1)) had significantly more exit holes than every treatment, except the direct sown plots treated with thiram (treatment thriam (T3)). There were no other significant differences between the other treatments. However, the direct sown crop had significantly ($p<0.05$) more exit holes than the ratooned crop, with 0.8 and 1.0 respectively (Table 5.15). The application of chemical inputs did significantly ($p<0.05$) affected the number of exit holes per stem and there were significant ($p<0.05$) interactions between agronomic practices and chemical inputs. The application of a treatment containing lamdacyhalothrin (treatment full (T9&T10 and lamdacyhalothrin (T5&T6)) significantly ($p<0.05$) reduced the number of exit holes compared to treatment nil (T1&T2). The combined application of beta-cyfluthrin and lamdacyhalothrin (T9&T10) was more effective than individual applications (T5&T6 and T7&T8).

The number of stem borers (larvae+pupae+exit holes) per stem was significantly ($p<0.05$) different between individual treatments. The direct sown plots treated with nothing (treatment nil (T1)) had significantly ($p<0.05$) more stem borers per stem than every other treatment, except the direct sown plot treated with thiram (treatment thiram (T3).

Table 5.15: Effect of cropping practice and chemical inputs on the stem borer population, measured by number of larvae, pupae and exit holes at crop maturity in direct sown and ratooned crops (long rains 2002)

Treatment number*	Chemical input	Larvae	Exit holes	Stem borers
T1	Nil direct sown	1.0	1.8	2.7
T2	Nil ratoon	0.6	0.8	1.3
T3	Thiram direct sown	0.6	1.3	1.9
T4	Thiram ratoon	0.5	1.0	1.5
T5	Lamdacyhalothrin direct sown	0.5	0.8	1.3
T6	Lamdacyhalothrin ratoon	0.2	0.6	0.9
T7	Beta-cyfluthrin direct sown	0.6	0.7	1.3
T8	Beta-cyfluthrin ratoon	0.4	0.8	1.2
T9	Full direct sown	0.3	0.6	0.9
T10	Full ratoon	0.3	0.8	1.1
SED		0.2	0.2	0.3
Direct sown		0.5	1.0	1.6
Ratooned		0.4[1]	0.8[1]	1.2[1]
SED		0.1	0.1	0.1

Key * even treatment numbers are ratooned, odd numbers are direct sown
[1] significantly ($p<0.05$) different from direct sown plots

Tukey b tests applied if F values resulting from ANOVA significant ($p<0.05$)

Larvae per stem

Treatments (0.05, 27, 4)	T6	T10	T9	T8	T4	T5	T2	T3	T7	T1
	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.6	1.0

Exit holes per stem

Treatments (0.05, 27, 4)	T9	T6	T7	T2	T5	T8	T10	T4	T3	T1
	0.6	0.6	0.7	0.8	0.8	0.8	0.8	1.0	1.3	1.8

Stem borers per stem

Treatments (0.05, 27, 4)	T9	T6	T10	T8	T7	T2	T5	T4	T3	T1
	0.8	0.9	1.1	1.2	1.3	1.3	1.3	1.5	1.9	2.7

Larvae per stem

Chemical inputs (0.05, 27, 8)	T9&T10	T5&T6	T7&T8	T3&T4	T1&T2
	0.3	0.4	0.5	0.5	0.8

Exit holes per stem

Chemical inputs (0.05, 27, 8)	T9&T10	T5&T6	T7&T8	T3&T4	T1&T2
	0.7	0.7	0.8	1.2	1.3

Stem borer per stem

Chemical inputs (0.05, 27, 8)	T9&T10	T5&T6	T7&T8	T3&T4	T1&T2
	0.9	1.1	1.2	1.7	2.0

However, the direct sown crop had significantly more stem borers per stem than the ratooned crop, with 1.6 and 1.2 respectively (Table 5.15). The application of insecticides did significantly ($p<0.05$) affect the numbers per stem, and there were significant ($p<0.05$) interactions between agronomic practices and chemical inputs. The application of an insecticide reduced the numbers and the combined application of beta-cyfluthrin and lamdacyhalothrin (T9&T10) was more effective than individual applications. Treatments full (T9&T10), beta-cyfluthrin (T7&T8) and lamdacyhalothrin (T5&T6) had significantly ($p<0.05$) fewer numbers than treatment nil (T1&T2).

1.21.4 Effect of the practice of ratooning on the population of stem borers

During the experiment, the population of stem borers was followed through the number of exit holes, larvae and pupae found in a stem. Exit holes give an indication of the number of stem borers that successfully emerged from the stem during the season. The life span of an adult moth is short and diapausing larvae are considered the main method of survival in adverse conditions. The number of larvae gives an indication of the larvae that could enter diapause in a dry period and therefore be available in the following season. In reality, many diapusing larvae fail to reach adult moth stage due to predation. The longer the period in diapause the greater the chance of predation, especially in cut stems

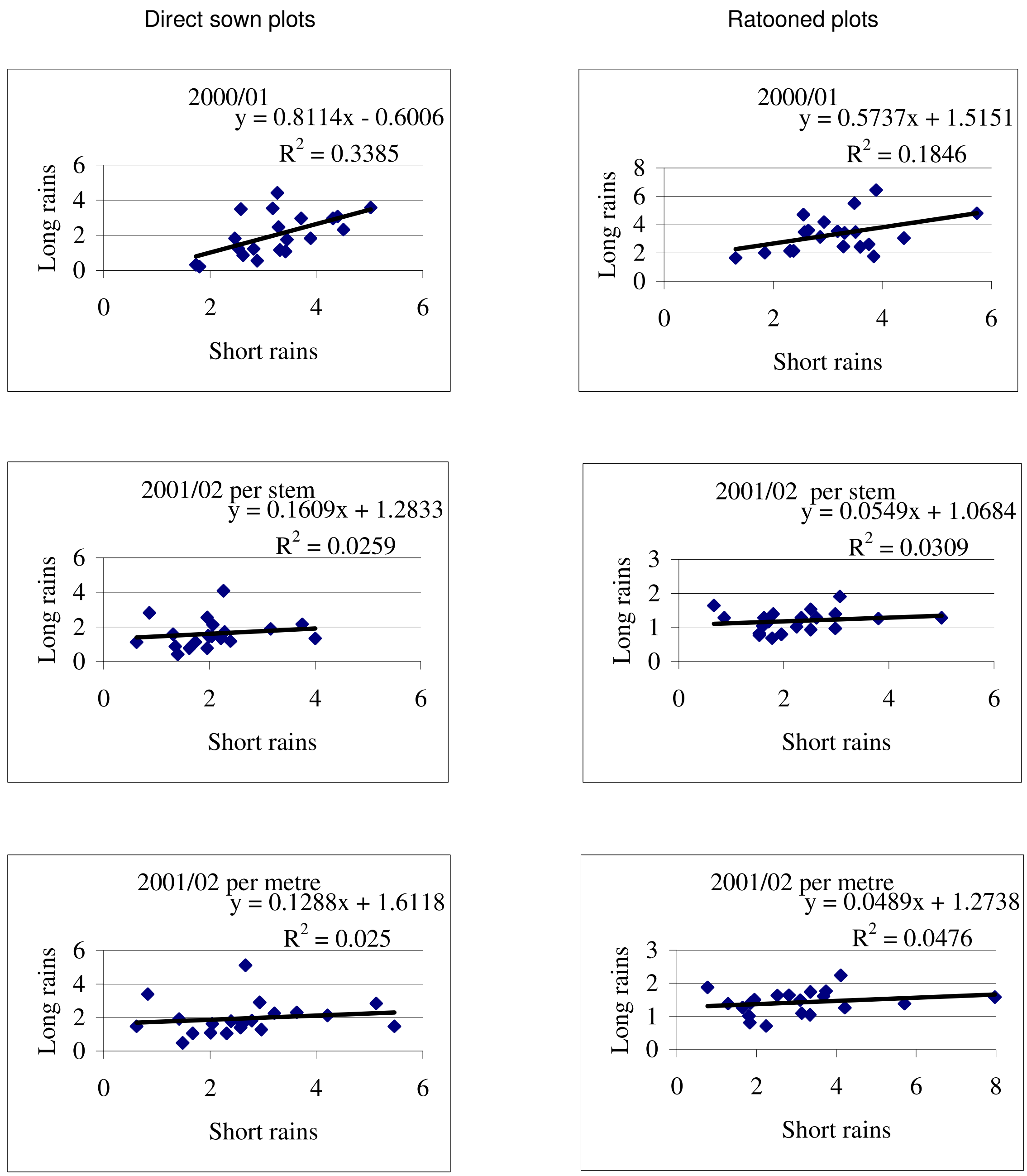


Figure 5.1: Trendlines showing the relationship between average number of larvae+pupae+exit holes per stem and metre of stem in the short and long rains for direct and ratooned crops (second and third cycles, 2000/01 and 2001/02)

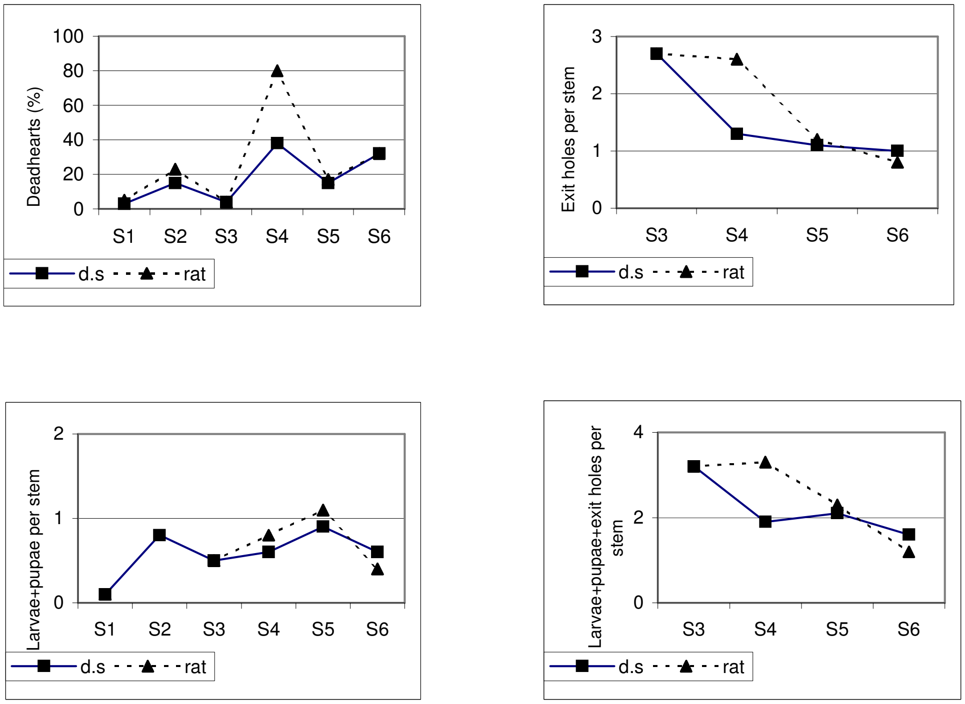


Figure 5.2: Mean plots of number of deadhearts (%) per plot, number of larvae + pupae, exit holes, and combined larvae + pupae + exit holes per stem under the agronomc practices of direct sown (d.s) and ratoon (rat) between seaons S1 (short rains 1999/00) and season 6 (long rains 2002)

* Key
S1 Short rains 1999/2000
S2 Long rains 2000
S3 Short rains 2000/01
S4 Long rains 2001
S5 Short rains 2001/02
S6 Long rains 2002

Carry-over of stem borers between the short and long rains

The relationships between the population of stem borers in the short and long rains, as measured by the number of larvae, pupae and exit holes per stem, were not strong or consistent in either the direct sown or ratooned crops (Figure 5.1). In the second cropping cycle (2000/01), the incidence of stem borers within both direct sown and ratooned plots showed weak correlation, with the trendlines accounting for 33.9% and 18.5% of the variation in the data, respectively. In both cases, the slopes of the lines indicated that the incidences were not higher in the long rains. In the third cropping cycle (2001/02), there was no correlation in the direct sown or ratooned crops.

Stem borer levels during the experiment

During the experiment, the level of stem borers was assessed over three cropping cycles i.e. six seasons. The fluctuations in the population under the different agronomic practices, ratoon and direct sown are presented using mean plots (Table 5.16 and Figure 5.2). At 5-7 leaf stage, the number of deadhearts (%) per plot in the direct sown and ratooned plots showed a similar weak pattern of peaks and troughs, with the peaks and troughs occurring in the long and short rains, respectively. This indicates the carry-over between the short and long rains was higher than that between the long and short rains.

The total number of stem borers that could emerge from a stem, as measured by the combined number of larvae, pupae and exit holes per stem, did not show a peak and trough pattern (Figure 5.2). This suggests that initial infestation is not the only factor in determining the numbers of stem borers produced per stem. Between season 3 (short rains 2000/01) to season 6 (long rains 2002), the average number of stem borers (larvae+pupae+exit holes) per stem was slightly higher in the ratooned crop compared to the direct sown crop, with 2.5 and 2.2, respectively. The average number of stem borers per stem differed significantly ($p<0.05$) between the seasons, though this is probably due to the results from season 4 (long rains 2001). There were significant ($p<0.05$) interactions between agronomic practice and seasons, however, the means plots of the different agronomic practices followed a similar trend, except in season 4 (long rains 2001), which was very dry and the direct sown crop dried before reaching maturity.

The average number of exit holes per stem followed a similar pattern to the combined number of stem borers (larvae+pupae+exit holes). This is probably due to the exit holes contributing the largest proportion to the sum of larvae, pupae and exit holes. Moth emergence over the seasons was higher in ratooned crop compared to the direct sown, with 1.8 and 1.5, respectively. The average number of exit holes per stem differed significantly ($p<0.05$) between the seasons and there were significant ($p<0.05$) interactions between agronomic practice and seasons.

The number of larvae and pupae per stem at crop maturity varied significantly ($p<0.05$) over the seasons, and showed a different pattern to the combine average of larvae+pupae+exit holes per stem. Between season 3 (short rains 2000/01) to season 6 (long rains 2002), the average number of larvae+pupae per stem was the same for the ratooned and direct sown crop, with 0.7. However, there was significant ($p<0.05$) variation between the seasons and a significant ($p<0.05$) interaction between agronomic practice and seasons. Between season 1 (short rains 1999/00) and season 6 (long rains 2002), the number of larvae under the different agronomic practices followed a similar trend. In four out five of the seasons the ratooned crop had more larvae+pupae per stem than the direct sown.

Table 5.16: Changes in stem borer numbers between season 3 (short rains 2000/01) and season 6 (long rains 2002), measured by number of larvae, pupae, and exit holes per stem in direct sown and ratooned crops

Season	Larvae+pupae		Exit holes		Stem borers (Larvae+pupae+exit holes)	
	Direct sown	Ratooned	Direct sown	Ratooned	Direct sown	Ratooned
S3	0.5	0.5	2.7	2.7	3.2	3.2
S4	0.6	0.8	1.3	2.6	1.9	3.3
S5	0.9	1.1	1.1	1.2	2.1	2.3
S6	0.6	0.4	1.0	0.8	1.6	1.2
SED		0.1		0.2		0.3
All plots	0.7	0.7	1.5	1.8	2.2	2.5
SED		0.05		0.1		0.1

Tukey b tests applied where F values resulting from ANOVA were significant ($p<0.05$) for seasons

Larvae

Seasons (0.05, 149, 4)

S6	S3	S4	S5
0.5	0.5	0.7	1.0

Exit holes

Seasons (0.05, 149, 4)

S6	S5	S4	S3
0.9	1.1	1.9	2.7

Stem borers

Seasons (0.05, 149, 4)

S6	S5	S4	S3
1.4	2.1	2.6	3.2

Comparison of stem borer populations in direct sown and ratooned crops.

Several authors (Bessin *et al.,* 1990, and van den Berg, 1997*)* have proposed that an important consideration in the management of stem borers is the number of moths produced during the season within a unit area. They called this the moth production index. The reduction of the index was considered an important factor in reducing crop damage. The practice of ratooning has been proposed by several authors, including Doggett (1988), as a practice that would increase the index. The moth production index for direct sown and ratooned crops is presented in Table 5.17. Also presented is the total number of larvae, pupae and exit holes. During experiment, the time period between the crops was small therefore the larvae carry over would have been high.

Table 5.17: An estimate of the number of exit holes and larvae per hectare in ratooned and direct sown sorghum, based on data recorded during long rains 2001 and 2002

Stem borer factors	Long rains 2001			Long rains 2002		
Agronomic practice	No. per stem	No. of productive stems[1]	No. per hectare	No. per stem	No. of productive stems	No. per hectare
Exit holes						
Direct sown	1.3	(1.5)[2]	130,001	1.0	1.7	113,334
Ratooned	2.6	2.9	502,669	0.8	2.5	133,334
Larvae						
Direct sown	0.6	(1.5)	60,000	0.5	1.7	56,667
Ratooned	0.8	2.9	154,667	0.4	2.5	66,667
Stem borers						
Direct sown	1.9	(1.5)	190,001	1.6	1.7	181,334
Ratooned	3.3	2.9	638,003	1.2	2.5	200,001

Key [1] Estimated number of plant stations per hectare: 66,667
[2] The direct sown crop failed to produce any productive heads, so the figure was estimated by taking an average of the other seasons.

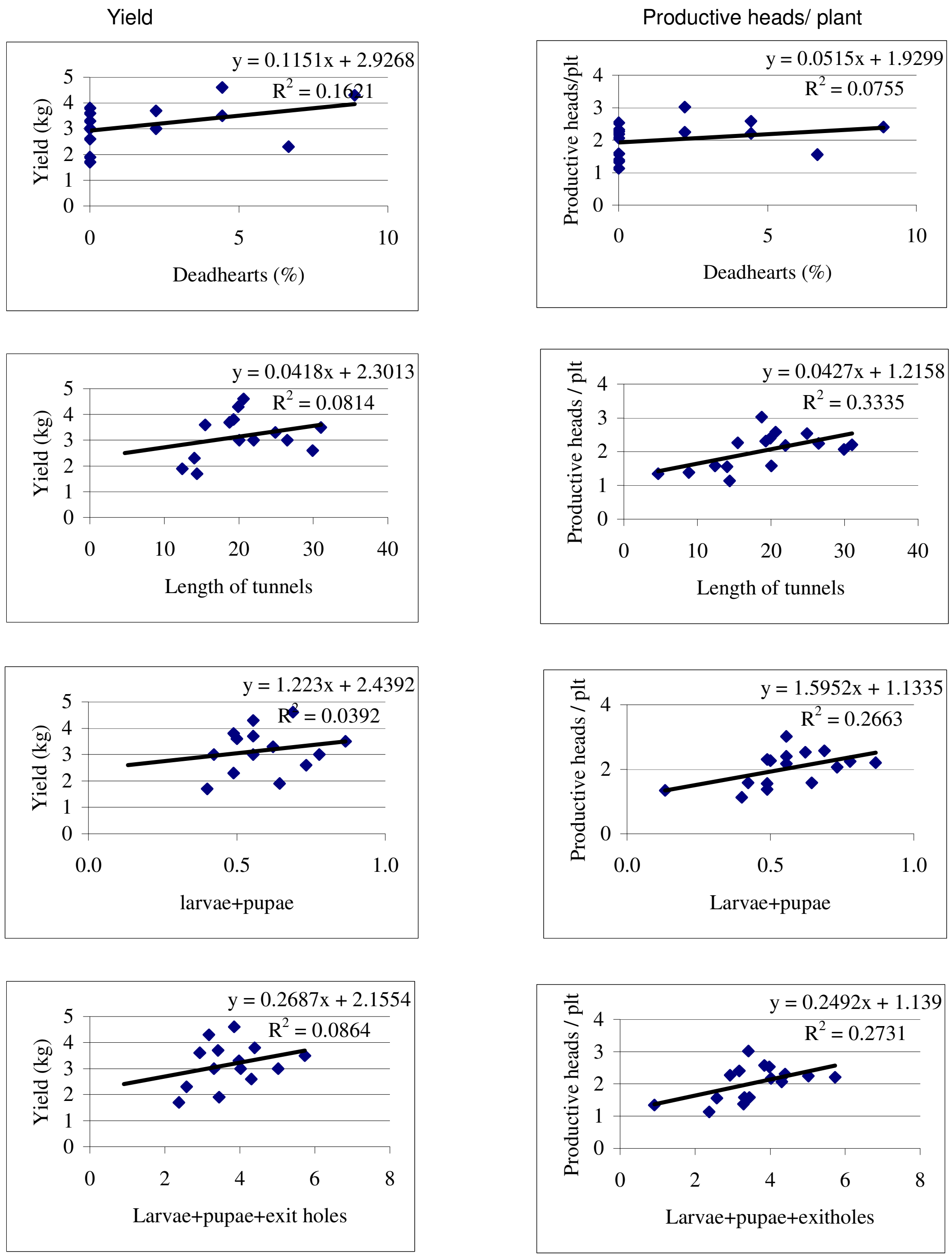


Figure 5.3: Trendlines showing the relationships between yield, productive heads /plant, deadhearts (%), Length of tunneling, number of larvae+pupae, and larvae+pupae+exit holes per stem in direct sown crop (second cropping, short rains (2000/01)

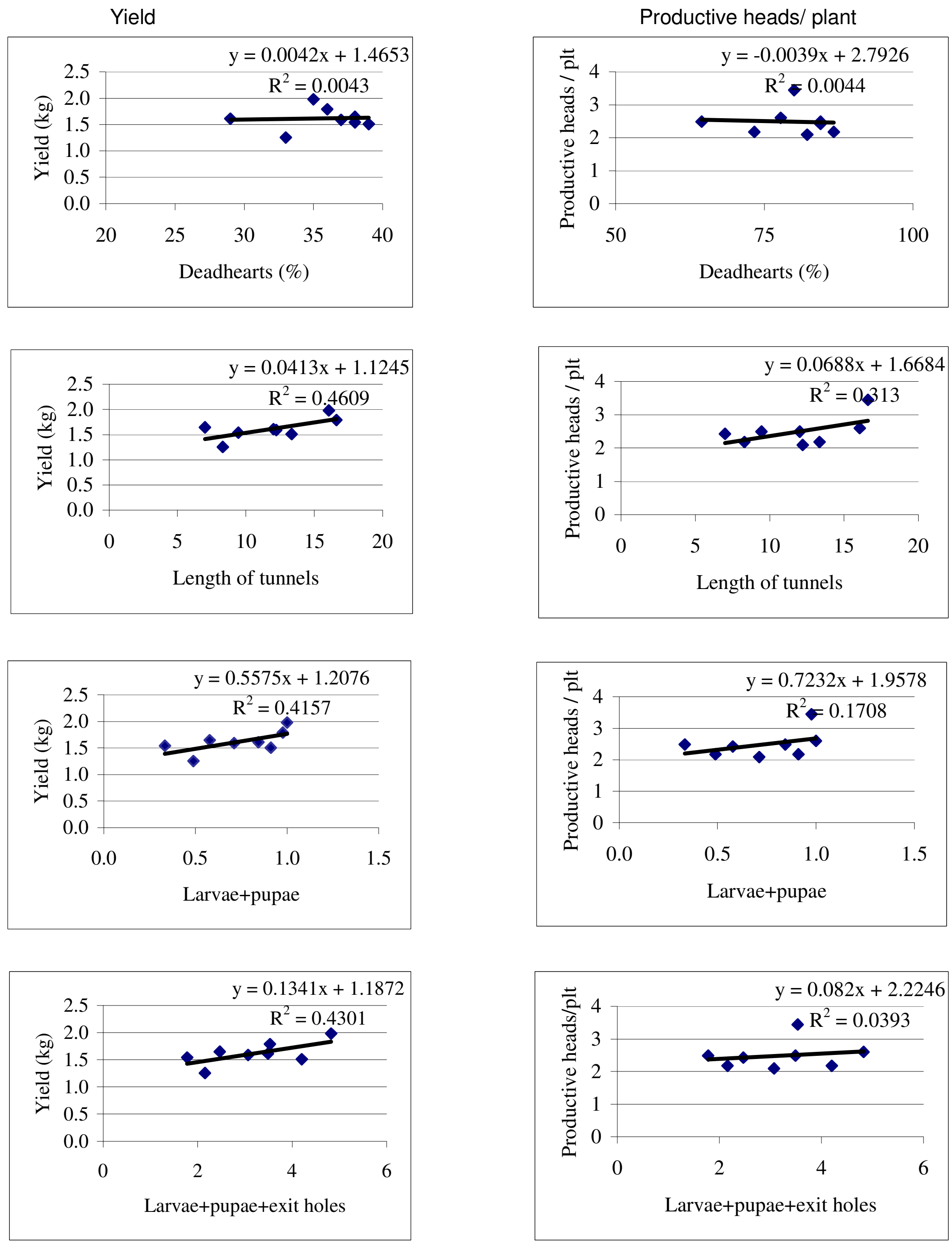


Figure 5.4: Trendlines showing the relationships between yield, productive heads /plant, deadhearts (%), length of tunneling, number of larvae+pupae, and larvae+pupae+exit holes per stem in ratooned crops (second cropping cycle, long rains 2000/01)

During the experiment, the agronomic practice of ratooning always had the most exit holes and larvae per stem varied. Moreover, the ratooned plants always produced more stems per plant than direct sown plants, and thus produced more stem borer moths/larvae per unit area (Table 5.17). The estimates are probably an under estimation, especially for ratooned plants as stem borers will also complete their life cycle in non-productive stems. The contributing effect of the tillers is illustrated in the long rains, 2002, where the ratooned crop recorded lower numbers per stem than the direct sown crop, but produced 10% more moths per unit area. Another factor to consider is the drought tolerance of the ratooned crop compared to the direct sown crop. In long rains 2001, the ratooned crop produced three times the number of stem borers than the direct sown crop. The ability of ratooned crops to perform in drought seasons may help to maintain stem borer populations, when stem borer populations would normally decline. However, over the duration of the six seasons of the experiment the number of stem borers (larvae + pupae + exit holes) recorded per stem did not show an upward trend (Table 5.16). This suggests either the stem borer population was kept in check by other factors, or the ‘extra’ stem borers migrated out of the crop area.

1.21.5 Effect of stem borers on yield

The application of chemical inputs was not always successful in reducing stem borer numbers and this made it difficult to directly relate yield losses to stem borer infestation. The yield data was presented in Table 4.27 and summarised in Table 5.18.

Second cycle of field experiment (October 2000 – March 2001, March – August 2001)

The relationship between stem borer damage / population and yield was investigated using correlation plots. The strong relationship between yield and covered kernel smut meant the correlations used only the data from the plots, where covered kernel smut was controlled i.e. treatments thiram (T3&T4) and full (T9&T10). The stem borers factors investigated for their effect on yield were number of deadhearts, length of tunnelling per stem and number of stem borers (larvae+pupae+exit holes) per stem. The interaction between stem borers and sorghum yield is complex due to the ability of plants to compensate for damage through the performance of the tillers and the relocation of assimilates. Tillers produced early in the growing season have a good chance of contributing to yield, if the environmental conditions remain favourable. However, tillers produced late in the season are unlikely to be productive and may be a drain on resources. Damage occurring early in the season, in particular deadhearts has been associated with causing tillering. The damage caused by the stem borer tunnelling is considered to affect translocation of assimilates, especially in young or thin stems i.e. peduncles, which reduces head formation and grain filling.

Table 5.18: Yields (kg/45 assessed plants) achieved during the course of the experiment under different cropping practices and chemical inputs (2000/1 & 2001/2)

Chemical inputs	Short rains 2000/1	Long rains 2001		Short rains 2001/2	Long rains 2002	
	Direct sown	Direct sown	Ratooned	Direct sown	Direct sown	Ratooned
Nil	2.1	0	1.1	0.7	0.1	1.2
Thiram	3.1	0	1.6	1.0	0.1	1.3
Lamdacyhalothrin	2.7	0	1.2	0.8	0.1	1.0
Beta-cyfluthrin	2.3	0	0.9	0.4	0.1	1.0
Full	3.1	0	1.7	1.0	0.2	1.9
SED	0.3		0.2	0.2		0.2
All plots		0	1.4[1]		0.1	1.3[1]
SED			0.6			0.1

[1] significantly ($p<0.05$) different from the direct sown crop

Tukey b test (applied when F value from ANOVA $p<0.05$)

Comparison of individual treatments

Long rains 2002

Treatments (0.05, 10, 27)	T7	T1	T5	T9	T3	T6	T8	T2	T4	T10
	0.1	0.1	0.1	0.2	0.2	1.0	1.0	1.2	1.3	1.9

Comparison of chemical inputs

Short rains 2000/1

Chemical inputs (0.05, 5, 28)	T1&2	T7&8	T5&6	T9&10	T3&4
	2.1	2.3	2.7	3.1	3.1

Long rains 2001

Chemical inputs (0.05, 5, 27)	T8	T2	T6	T4	T10
	0.9	1.1	1.2	1.6	1.7

Short rains 2001/2

Chemical inputs (0.05, 5, 32)	T7&8	T1&2	T5&6	T3&4	T9&10
	0.4	0.7	0.8	1.0	1.0

Long rains 2002

Chemical inputs (0.05, 5, 27)	T7&8	T5&6	T1&2	T3&4	T9&10
	0.6	0.6	0.6	0.8	0.1

In the short rains, none of the stem borer factors (dead hearts (%), length of tunnelling and number of stem borers per stem) were correlated to yield (Figure 5.3). The relationship between length of tunnelling or number of stem borers per stem and number of productive heads per plant showed weak correlation, with the trendlines accounting for 33.4% and 27.3% of the variation in the data (Figure 5.3). The trendlines indicated a positive relationship, but the slopes were shallow.

In the long rains, ratooned crop, the number of deadhearts per plot was not correlated to yield or number of productive heads per plant (Figure 5.4). However, the stem borer damage caused by tunnelling per stem was weakly correlated to both yield and number of productive heads per plant, with the trendline accounting for 46.1% and 31.3% of the variation in the data respectively. The trendlines indicated a positive relationship, but the slopes were shallow (Figure 5.4). The number of stem borers per stem also affected yield, but not the number of productive heads. The correlation of stem borer population per stem and yield was weak, with the trendline accounting for 43.0% of the data variation. The trendline indicated a positive relationship, but the slopes were shallow (Figure 5.4).

Third cycle of field experiment (October 2001 – March 2002, March – August 2002)

In the short rains, none of the stem borer factors were correlated to either yield or productive heads per stem (Figure 5.5). The trendlines accounted for less than 5% of the variation in the data.

In the long rains, the direct sown and ratooned crops were analysed separately. In the direct sown crop, the correlations between the factors of length of tunnelling and stem borers per stem, and either yield or productive heads were very weak. The variation in data accounted for ranged from 15 – 26% (Figure 5.6a). However, the trendlines indicated a negative relationship. This was the one season where the relationships were negative.

In the ratooned crop, dead hearts and the length of tunnelling per stem were not corelated to yield or number of productive heads, with the trendlines accounting for less than 17% (Figure 5.6b). The number of stem borer (larvae+pupae+exit holes) per stem were weakly correlated to yield; and very weakly correlated to productive heads per plant, with the trendline accounting for 43.3% and 22%, respectively.

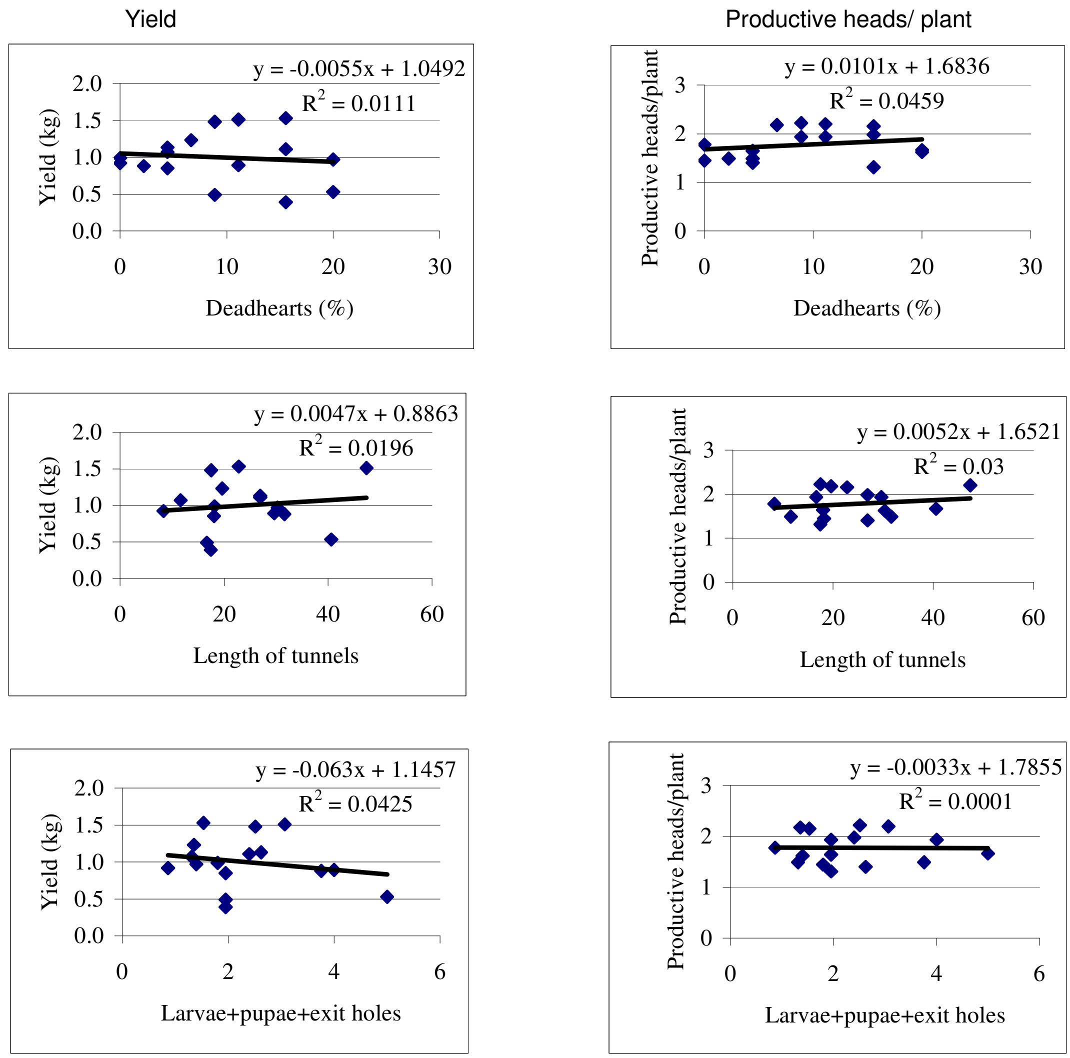


Figure 5.5: Trendlines showing the relationships between stem borer factors (deadhearts (%), length of tunnels, number of larae+pupae, and larave+pupae+exit holes per stem) and yield and productive heads per plant in direct sown crops (third cycle, short rains, 2001/02)

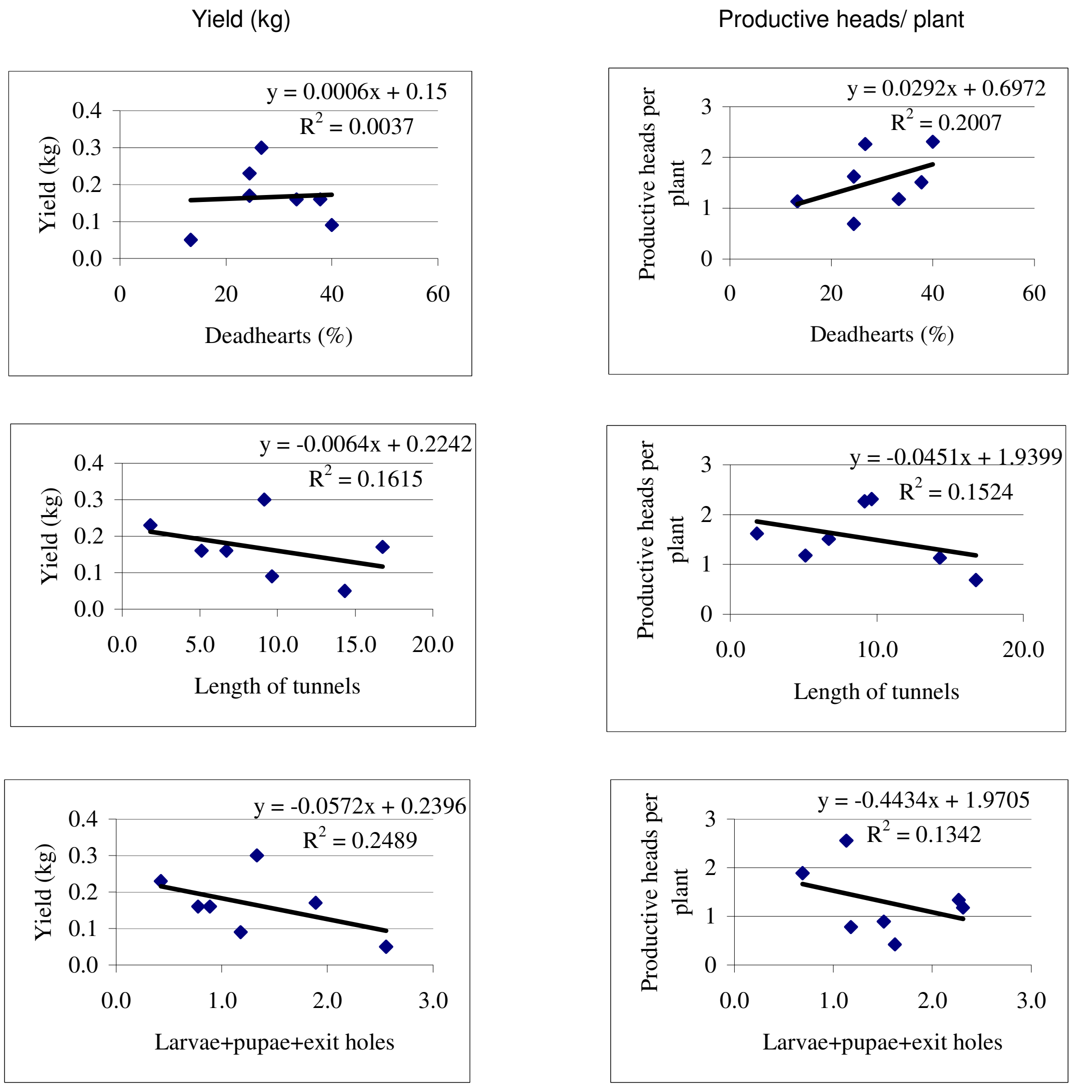


Figure 5.6a: Trendlines showing the relationships between stem borer factors (deadhearts (%), length of tunnels, number of stem borers per stem (larvae+pupae+exit holes) and yield and productive heads per plant in direct sown crops (third cycle, long rains 2001/02)

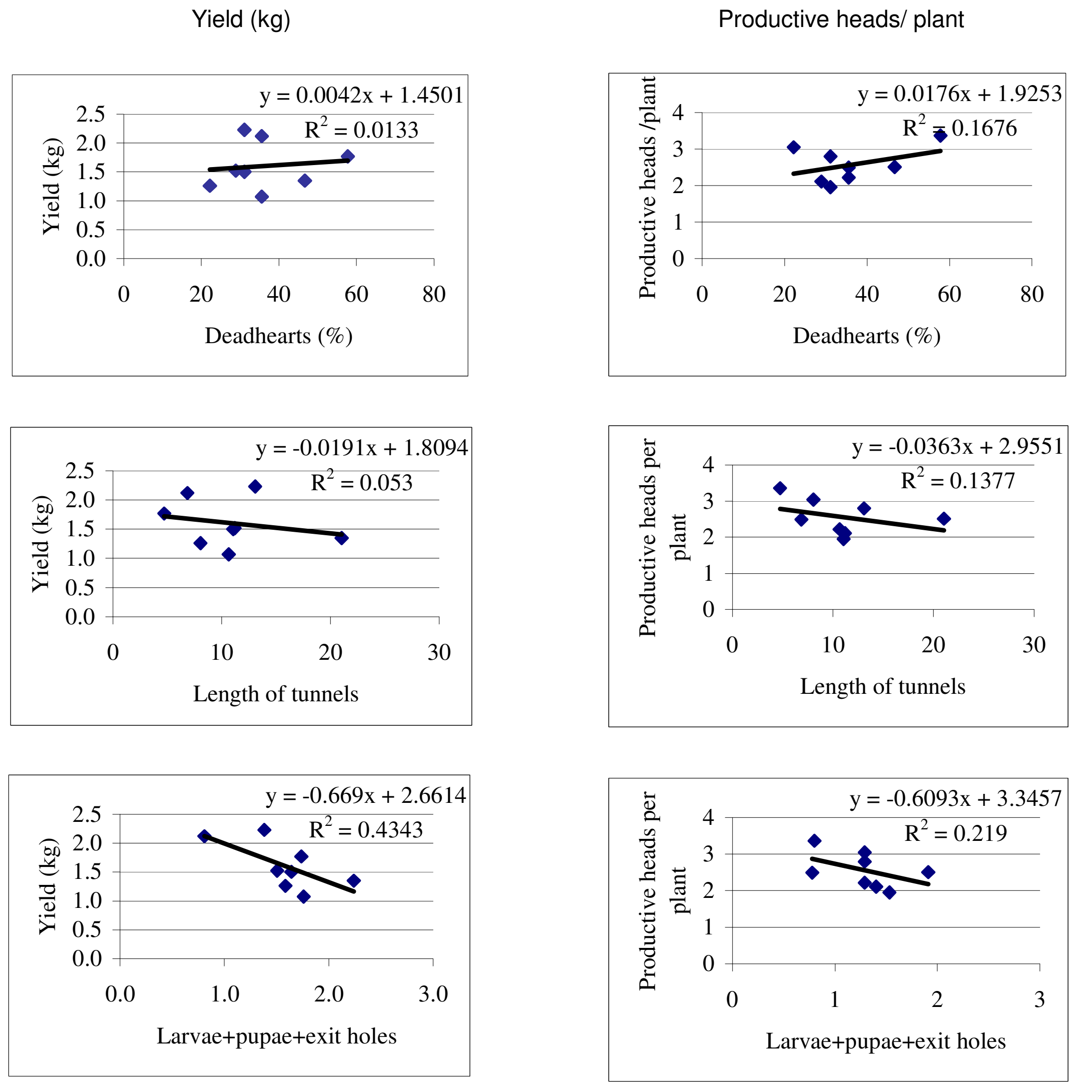


Figure 6.6b: Trendlines showing the relationships between stem borer factors (deadhearts (%), length of tunnels, number of larae+pupae, and larave+pupae+exit holes per stem) and yield and productive heads per plant in ratooned crops (third cycle, long rains 2001/02)

1.22 DISCUSSION

The objectives of this chapter were to investigate the effect of the practice of ratooning sorghum on the incidence of stem borers and relate this to yield.

Initial stem borer damage results from the external feeding by the first generation of young larvae on the young leaves, and then from internal feeding on the furled leaves within the funnel, leaving the characteristic enlongated feeding holes in the petiole. This damage is considered a poor indicator of expected grain yield, due to the ability of the plant to replace the damaged leaves (Leuscher, 1989 and Starks and Doggett, 1970). The position of the larvae in the stem after penetration is considered an important factor in yield loss. In young plants, this tunnelling can cause damage to the growing tip resulting in a deadheart. Removing the main stem dominance causes tillering and early tillering can lead to productive tillers (Taneja and Leuscher, 1985). However, tillers are less efficient in grain production than the main stem, so early damage reduces yield (Ajayi, 1998). After 25-50 days, the first generation of stem borers exits from the stem before harvest whereas larvae found in the stems at harvest have generally originated from later egg laying by the overlapping second generation of larvae. The later generations of larvae are considered to be less damaging, unless their feeding affects the peduncle elongation and the heads fails to emerge from the whorl, or the larval feeding in the peduncle damages the vascular tissue. The damage affects the translocation of assimilates and can reduce grain filling or cause chaffy heads.

1.22.1 Agronomic practice and chemical inputs

During the experiment, the agronomic practices of direct sown and ratoon cropping had a significant effect on the measured stem borer parameters. However, neither one of the cropping practices had a consistently higher level of stem borer damage than the other. The agronomic practices did interact with the performance of the chemical inputs. Generally, ratooned plants tend to be less uniform in their growth stage than direct sown plants and this makes it much harder to apply insecticides timely. The application of the insecticides generally reduced the level of tunnelling and number of larvae and exit holes per stem, though the difference was not always significant. The combined application of lamdacyhalothrin and beta-cyfluthrin tended to be more effective than individual applications, though the effect was usually non significant.

During the experiment, in both the short and long rains, the individual applications of the insecticide, lamdacyhalothrin and beta-cyfluthrin, had no significant ($p<0.05$) effect on yield compared to non-application (treatment nil). When the insecticides were used in combination with thiram the gains in yield were only slightly higher than to those of using thiram only. During the experiment, the incidence of plants infested with stem borer damage at 5-7 leaf stages was always over 50% and increased by the second and third cropping cycle to greater than 90%. The level of stem borer per stem at crop maturity was never above 3.5 per stem. In West Kenya, Seshu Reddy (1998) reported yield losses of up to 80% with 8 larvae per plant infested at 21 days after emergence, whereas at 60 days after emergence the losses were insignificant.

During the experiment, the insecticides were applied at the 5-7 leaf stage as recommended by the chemical companies. The insecticide lamdacyhalothrin was applied before the beta-cyfluthrin. Several researchers have reported the importance in the timing of the application of the insecticide. In India, Taneja and Nwanze (1989), reported the most important period to protect the sorghum crop from *C. partellus* was between 15-30 DAE. The protection was applied by the application of carbofuran granules to the furled leaf. In comparison, crops protected between 30-45 DAE suffered a 3-fold higher yield loss. In South Africa, commercial farmers are recommended in the case of early plantings and low infestations to apply the first insecticide application at flag leaf stag (van den Berg and Nur, 1998). In the case of late planting, it is recommended to apply the insecticide early at approximately 4 weeks after crop emergence, with a possible follow up application at flag leaf stage. For small holders, the recommendations change to application of a granular insecticide to the whorls of infested plants and the whorls of the adjacent plants, as soon as whorl damage symptoms are observed.

1.22.2 Carry-over between short and long rains

The incidence of stem borers recorded in the ratooned crop was not strongly correlated to the levels measured in the same plots in the short rains. An explanation for this is that in ratooned plants, the removal of the stems effectively ‘cleans’ the plant of stem borers. The new tillers are then re-infested with stem borers. The re-infestations will depend on the availability of egg laying moths and alternative hosts to carry the population until the sorghum plants produce leaves suitable for egg laying. The tillers of ratooned plants tend to be more advanced than direct sown crops and can be available to egg laying moths at a time when there is little material available. In West Africa, when the stems dry the larvae migrate to the bottom of the stem and into the root base in search of moisture (Adesiyun and Ajayi, 1980 and Kfir, 1988 & 1991). In Katumani Research Station, the stem did not dry before harvest and ratooning so this migration would not have taken place. During sampling the majority of the larvae were found in the top half of the stem, which reflects Ndemah *et al.,* (2001) report that larvae move up the stem following the nitrogen gradient. The cutting of the stems would therefore have removed the stem borers present on/in the plant. The practice of lying of the cut stems on the ground would have significantly reduced the number of larve in these stems through the impact of increase solar radiation killing the larve (Banholt *et al.* 2001), and increased predation by ants and other insects (Pats 1991).

1.22.3 Stem borer population over the duration of the experiment

Over the course of the experiment, it would be expected that there would be an underlining upward trend in the stem borer population. The experimental plot was opened to cultivation after lying fallow for several seasons, and then continuously cultivated under sorghum for six seasons. Over the duration of the experiment the number of larvae, pupae and exit holes recorded per stem did not show an upward trend, which suggests that the presence of a food source in the form of a sorghum crop was not the most important factor in determining the stem borer population.

Over the six seasons, the number of deadhearts at 5-7 leaf stage, showed a re-occurring weak pattern of peaks and troughs, with the troughs in the short rains. The length of the gap between harvest/clearing and planting probably explains this pattern. During the experiment, the gap between clearing the short rain crop and re-planting the long rain crop was a maximum of three weeks. In comparison, the gap between the clearing the long crop and planting short rain crop was a minimum of eight weeks. The cut stems were placed around the field and would have been a source of newly emerging adult moths for the next season's crop (Pats, 1998). Between the short and long rains, the short period between the placing the stems in trash lines and the start of the rains would have allowed little time for predation of the larvae and pupae. Few of the adult moths from the short rains would have survived through to the long rains. Moths have been reported to live between 2-5 days (Pats, 1991). The longer time and drier conditions between the long rains and short rains would require the larvae to enter diapause. The survival rate of the diapusing larvae would be reduced by predation and environmental conditions (Midega *et al.,* 2005 and Pat, 1996). The early productions of tillers in ratooned crops relative to direct sown plants means suitable egg laying sites are available to moths when there is little other suitable material. Several researchers have reported finding high numbers of stem borer numbers on plants when other suitable food sources are scarce (Wale, 1999 and Harris, 1990). This is probably why the number of deadhearts in ratooned plots was consistently higher than in direct sown crops.

The level of infestation at 5-7 leaf stage did not directly translate into a similar count or trend at crop maturity. During the long rains of the 2^{nd} cropping cycle (2000/01), the direct sown crop dried before reaching maturity and the stems were much shorter than the ratooned plants. When the length of the stem was taken into account the ratooned crop had significantly ($p<0.05$) more tunnelling than the direct sown crop, but significantly ($p<0.05$) less larvae and equal numbers of exit holes. The differences between the direct sown and ratooned crops can probably be explained by the late planting of the trial in the short rains combined with the late rains in January that resulted in the crop being harvested early April. This meant both the ratooning and re-planting taking place within a few days of each other in April almost a month after the long rains had started. The relative lateness of the crop probably meant that all the plants would have been highly attractive to stem borer moths at a time when the second generation of moths would of been emerging from nearby crops. The low rainfall received after April would have resulted in few of the young larvae being washed from the plants as they migrated from the leaves to the funnel of a plant. These factors probable contributed to the relative high number of stem borers compared with that recorded in the long rains 2002.

The effect of the drying of the direct sown plants would have made them less desirable to egg laying moths in the later stages of the season than the ratooned plants which were still green. Preference by *C. partellus* has been reported by several authors (Taneja and Woodhead, 1989). The drying out of the direct sown plants probably resulted in the stem borers present in the stems entering into diapause, while those in the ratooned plants continued through their life cycle, emerging as adult moths. This would result in the direct sown plants having relatively more larvae than the ratooned plants per metre of stem. The late maturing of the ratooned crop would have reduced the gap between the harvest of the long rains and the beginning of the short rains, thus improving the survival rate between seasons. This may explain the higher level of deadhearts in season 5 (third cropping cycle, short rains 2001/02).

In the long rains of the third cropping cycle (2001/02), both the direct sown and ratooned crop reached maturity and the trend in the stem borer populations were similar. The ratooned crop had significantly ($p<0.05$) fewer, larvae and exit holes than the direct sown, but no difference in tunnelling length per stem. The late rains received in January and February delaying the harvest of the crop until mid March can probably explain these trends. All the plots were either ratooned or replanted a few days after harvest, just as the long rains started. The late ratooning and almost immediate start of the rains resulted in the ratooned plants being only 1-2 weeks ahead of the direct sown plants. The late ratooning meant that the majority of the tillers would have been produced at the start of the rains and thus would not have accumulated stem borers during the dry period. The similar number of deadhearts recorded in both the ratooned and direct sown crop suggests the plants were equally desirable to the emerging moths for egg laying. During April and the beginning of May there were regular showers, which would have resulted in many of the young larvae being washed from the plants. This probably explains the lower number of stem borers recorded in this season compared to the long rains 2001. The higher density of stems in the ratooned crop compared to the direct sown crop may have had the effect of spreading the stem borer larvae load, thus resulting in fewer larvae per stem (Taneja and Woodhead, 1989).

1.22.4 Effect of stem borer population on yield

Within a particular season, the effect of stem borer damage on yield was studied using correlations. Over the course of the experiment, the relationships between these factors were not constant. As previously mentioned the plasticity of the sorghum plant, of which tillers are an important component, enables the plant to adapt to damage and environmental conditions.

Second cycle (October 2000 – August 2001)

Short rains (October 2000 – March 2001)

In the short rains of the second cropping cycle (2000/1), yield was not correlated to any of the stem borer factors. However, there were slight relationships between productive heads per plant and both length of tunnelling and number of stem borers (larvae+pupae+exit holes). The level of deadheart was low at less than 5%, so would not expect to make an impact on the average number of productive heads per plant, even under good growing conditions. The season had good rainfall, well distributed, which would enable the plant to reach maturity without suffering from serious water stress. The contribution of the productive tillers to total yield illustrates this point. The length of tunnelling per stem was relatively long at 18cm and this would have affected translocation. Tunnelling is particularly damaging when the stems are thin. Stems are thin when the plant is young, at the top of stem in the peduncle area and under drought conditions. Peduncle damage is considered particularly damaging to yield as it reduces translocation to the head. In this season, the majority of the stem borers had emerged from the stems and few were left to emerge, as shown by the number of exit holes, larvae and pupae counted. This suggests that the majority of the stem borers attacked the plant in the early half of the season. However, infestation at 5-7 leaf stage was low. Damage to the stems can trigger tillering, but these are only productive, if occurring early in the season and good condition prevail to enable the tillers to reach maturity.

Long rains (March - August 2002)

In the long rains, only the ratooned crop survived to maturity. This season had the highest level of deadhearts of the experiment. However, there was no correlation between deadhearts and either yield or productive heads. This was because deadhearts can cause tillering, but other factors decide if they are going to be productive. The end of the season was very dry with minimal rain after April. The lack of water may have resulted in a lack of resources to partition to the tillers illustrated by there being no relationship between yield and productive tillers. The length of tunnelling per stem was shorter than in the short rains, but had an effect on both yield and the number of productive heads per plant. The relationship between productive heads and length of tunnelling was similar to that in the short rains. The number of exit holes per stem was identical. The early moisture availability meant the early stages of the crop would have been similar to short rains. However, the lack of water later in the season would have affected the size of the heads and thus the yield. In the long rains, the higher number of larvae present in the stems compared to short rains suggests a higher infestation later in the season. The plants were under great stress late in the season; this meant the damage to the stems caused by the tunnelling had a proportional greater effect than in short rains. Late arriving stem borers attack the younger parts of the stem including the peduncle. Damage to the peduncle directly affects the partition of assimilates to the head.

Third cropping cycle (October 2001 – August 2002)

Short rains (October 2001 – March 2002)

In short rains of the third cropping cycle, the yields achieved were lower than in the same season in the second cropping cycle (2000/01). This reduction in yield was probably due to the season having lower total rainfall, which was less well distributed than in the short rains 2000/1. Overall, the number of larvae and exit holes per stem was lower than in the previous short rains, and the ratio of larvae to exit holes at crop maturity was 1:1.5 respectively. Therefore, the stem borer attack was more evenly spread through the season. However, the length of tunnel damage was higher than in the short rains 2000/1. None of the stem borer factors were correlated to either yield or number of productive heads per plant. The number of productive heads and yield were strongly correlated, though the number of productive heads per plant was low. The poor rains between December 2001 and February 2002 probably curtailed the development of the tillers, which were produced in response to early stem borer attack. The infestation at 5-7 leaf stage was higher than in the short rains 2000/1, but fewer productive heads were produced per plant. The relatively good late rains during grain fill would have enabled the few remaining heads to cope with the relatively low stem borer pressure and contribute to yield.

Long rains (March – August 2002)

In the long rains, both the direct sown and ratooned crop reached maturity. The difference between the agronomic practices in number of larvae and exit holes per stem and the length of tunnelling was less than one, but their relationships to yield and number of productive heads per plant were very different. In the direct sown crop, the yields achieved were very low in comparison to the yields achieved in the previous short rains and in the concurrent ratooned crop. There was no correlation between yield and productive heads per plant. The correlations between the stem borer factors and either yield or productive heads per plants were weak, but indicated a negative relationship. The low level of yield was probably due to the lack of rain in the later half of the season. The overall number of larvae and exit holes per stem was lower than all the previous seasons. The ratio of larvae to exit holes was 1:2. Therefore, the majority of the stem borer attack was in the early half of the season, at a time when there was little water stress. This enabled the tillers produced in response to the stem borer attack to develop. Overall, the direct sown crop had a higher number of productive heads than the previous short rains. However, the lack of rain at head emergence and grain fill meant the plant was under severe water stress. The damaged caused by the stem borers particularly the second generation would have affected the ability of the plant to partition assimilates and thus affect development of the heads. The stress caused by the stem borer would be proportionally more important when the plant is under water stress compared to when it is not. This could explain the negative trend between the stem borer factors at maturity and both yield and productive heads.

In the ratooned crop, the good early rains would have been more beneficial to the ratooned crop than the direct sown, due to its earlier establishment and its more advance growth compared to the direct sown crop. This shorter crop cycle and more extensive root system meant that the lack of rain in the later months would have less effect on the ratooned crop. The relatively higher yields and number of productive heads per plant than the direct sown crop show this. The good early rains and the relatively low number of larvae and exit holes per stem, explains the better relationship between deadhearts and productive heads per plant. However, the poor relationship between yield and productive heads suggests that the ratooned crop was under stress at the end of the season. This is supported by the negative correlation between number of stem borers per stem (larvae+pupae+exit holes) and both yield and productive heads per plant. The relatively stronger relationship to yield than number of productive heads suggests the stem borer damage affected the grain filling stage rather than panicle emergence or earlier.

During the experiment, the level of stem borers found in the experiment seemed to have little effect on yield, if the crop received a reasonable quantity of rainfall, well distributed through the season. However, in poor growing conditions, the extra stress caused by the stem borers seems be an important factor in yield decline. In good rains, early infestation can cause tillering, which can lead to an increase in yield. This confirms the reports by Flattery (1982) and Doggett (1988) that the inherent tillering ability of a cultivar can mask any yield reductions that may result from an attack by stem borers. During this experiment yield losses caused by stem borers were an interaction between cultivar*incidence of stem borers * stage of infestation * rain quantity and distribution. The ratooned crop had a higher level of stem borers per unit area than the direct sown crop, particularly in poor growing seasons. However, during the experiment the stem borer population did not seem to increase over the seasons. In the long rains, the number of stem borers had little correlation with the amount recorded in the previous short rain crop. The levels measured seem to be better explained by the timing of the agronomic activities i.e. planting or ratooning and the rainfall pattern.

MAIN CONCLUSIONS

1. Yield loss was an interaction between cultivar*incidence of stem borers * stage of infestation * rain quantity and distribution, but environmental conditions were the most important factor.
2. Agronomic activities i.e. planting and ratooning, affected the number of stem borers per stem.
3. Ratooned sorghum had a higher level of stem borers per unit area than direct sown crops.
4. The number of stem borers in a sorghum crop had little correlation with the numbers in the previous season's crop, indicating the reported 'green bridge' effect of ratooning maybe over emphasized within the semi-arid conditions of these experiments.
5. Over the period of six seasons there was no upward trend to the number of stem borer per stem, as measured by the of number of larvae, pupae and exit holes, suggesting that other factors than the presence of a sorghum crop have a stronger influence on the stemborer population.

Plate 5.1a: The top stem has had part of the stem removed to show larvae in-situ. The bottom stem shows four exit holes within a section of stem

Plate 5.1b: The stem is split in half to show several larvae and severe tunnelling

COMPARISON OF DIFFERENT METHODS OF RATOONING SORGHUM IN RELATION TO COVERED KERNEL SMUT AND STEM BORERS

1.23 INTRODUCTION

A field experiment was undertaken to provide quantitative information on the effect of different ratooning methods on the level of covered kernel smut and stem borers in the crop. The different ratooning methods used in the experiment were adapted from practices presently utilised by farmers on local two-season sorghums in Mwingi District. These practices were identified in a focused survey carried out in Mwingi District (October 2000) and described in Chapter 3.

1.24 MATERIALS AND METHODS

1.24.1 Location of the experiment

The experiment was undertaken at KARI-Katumani, sub-station Ithookwe. This sub-station is situated 3km southwest of Kitui Town at a latitude 1^0 35'S and longitude of 37^0 14' E. It is 1,130m above sea level. The soils are well drained, moderately to very deep, dark reddish to yellowish brown, friable to firm sandy clay, (Siderius and Muchena 1977). The site is in agro-ecological zone upper middle 4 (UM4). The rainfall pattern is bimodal and is received between end of March - May (long rains) and mid October - end of January (short rains). The long-term average yearly rainfall is 1061 mm, with 672 mm and 389 mm for the short and long rains respectively, based on 15 years of data (Figure 6.1). Jaezold and Schmidt, (1982) predicted an annual average rainfall of between 850 - 1000 mm, with a 60% reliability of 380 - 450 mm and 230 - 330 mm in the short rains and long rains respectively. The average mean temperature ranges from 19 - 21 ^oC.

The monthly weather information for Ithookwe Sub-station during the period of the experiment is presented in Figure 6.1. During the experiment, the annual rainfall was lower than the average for the last 15 years. In the 2001/02 cropping cycle, the total rainfall was 851 mm, compared with the 15 year average of 1061 mm per cropping cycle. The long rains were particularly poor, with total rainfall 300 mm compared with the 15-year average of 389mm. Compounding this was the poor distribution, with no rain after 18th April.

1.24.2 Layout of the experiment

The experiment was laid out in the design of a fully randomised complete block. This consisted of four blocks in which each treatment was replicated once. Two varieties of sorghum were used Seredo and PGRCE 216740. Each treatment plot measured 4 m x 4 m. The variety Seredo was included as it relates to the on-station and on-farm work. The variety PGRCE 216740 was included as it is available to farmers in Mwingi District and has a longer maturation period than the variety Seredo and therefore made an interesting comparison.

Treatments combinations

The experiment involved four different cropping practices applied to two sorghum varieties. The four cropping practices were:

Method 1: stems cut within a day of the crop being harvested.

Method 2: stems cut within a day of the crop being harvested, then three weeks after ratooning, the tillers per plant were reduced to four. The criteria for removing the tillers were tillers showing the most stem borer damage, and secondly, the oldest tillers.

Method 3: the stems left standing after harvest.

Method 4: fresh, direct sown sorghum

The original concept was for Method 2 to be: stems cut at harvest, then the tillers thinned to a maximum of four at the onset of rains; and Method 3 to be: stems cut at the onset of the rains. The methods were modified from the original concept due to the long rains beginning very early, resulting in there being no dry period between the harvesting of the short rain crop and the start of the long rains.

Seed preparation

Before planting, the seed was inoculated with, covered kernel smut spores at a rate of 1g per 100g of seed. The covered kernel smut spores were collected from smutted heads collected the previous season at Katumani Research Station. The spores were isolated from the infected heads using a meshed seive. The spores were mixed with the seed using a bag.

Crop establishment and management

All plots were established by direct seeding on 30 October 2001, with the rains commencing on 2nd November. The seed was sown into a pre-ploughed and harrowed bed using holes dug by dibbers at 20cm intervals along 4m rows. Each plot consisted of 5 rows spaced 75cm apart. Approximately 3-5 seeds were placed per hole. Two weeks after emergence seedlings were thinned to one per station giving a resulting plant stand equivalent to 66,667 plants per ha. The plots were spaced 1m apart from each other.

Two fertiliser applications were made at a rate of 20g per plot during the season. The first was DAP (23:23:0) during planting and the second was a top dressing of CAN (46:0:0).

Competition from weeds during crop establishment was minimised by hand weeding. This was undertaken at the seedling stage, four weeks after planting and at flowering.

No pesticides were applied during the season, but the crop was bird scared from milk stage to harvest. However, bird damage did occur during the long rains.

Crop harvest and ratooning

The crop was harvested on 28 February and the plots under treatment 1 and 2 were ratooned the next day (1 March). The plants were ratooned at a height of approximately 8cm using a panga. The direct sown plots were planted on 1 March and it rained the next day.

Crop management during the long rains

The plots were top dressed with nitrogen and phosphorus in the form of CAN (46:0:0) three weeks after ratooning the crop. The application rate was 20g per plot. The plots were weeded at two and four weeks after emergence and again at flowering. No pesticides were applied.

1.24.3 Field Assessments

All assessments were carried out on 20 plants in each of the plots, unless stated otherwise. The 20 plants were the first 10 plants from two inner rows excluding the first three plants in each row.

Assessment of covered kernel smut

The incidence and severity was assessed at crop maturity. For assessment of the incidence of covered kernel smut, the number of heads and the number showing symptoms were counted for each hill. For assessment of severity, the main head for each plant was scored for the severity of symptoms. The scale used was percentage of grain in the head replaced by smut sori.

Assessment of stem borer damage at crop maturity

The assessment of stem borer damage at crop maturity was carried out using three methods: total length of tunnelling per stem, number of chaffy heads per plant and peduncle breakage at harvest. A head was designated chaffy when it was completely blind and a peduncle was assessed by testing its strength through flexing the stem, if the peduncle broke it was recorded damaged. The stem borer damage factors chaffy heads and peduncle breakage was included as these are factors that the farmers are aware off and use to assess stem borer damage (*personal communication*, A Sutherland). The chaffy heads also directly affect yield as it means no grain is produced in the head. Peduncle breakage indicates that the stem borers have been present and may have affected translocation of assimulates to the panicle.

Assessment of stem borer population at crop maturity

Adult moth emergence during the season was assessed by counting the number of moth exit holes per stem. After splitting the stem, the number of live larvae, and pupae of all stem borer species were recorded. Species were identified in the field by experienced technicians. The total stem borer population per stem was calculated as the sum of the number of larvae, pupae and exit holes per stem.

Assessment of yield

Yield was assessed as gross plot, and the weight was recorded after the grain had been dried in the sun for several days, after threshing and willowing by hand. Average grain weight was calculated from three samples of 100 grains randomly selected from the grains harvested from each of the plots. The grains were oven dried for 48 hours, then the three samples weighed separately.

Plant stand and tiller formation

In the direct sown plots, the plant stand for each plot was counted after thinning by counting the number of plants in the two inner rows for each plot. In the ratooned plots, stump survival was assessed as the number of plants in the 1st rains that after being cut back, survived and produced re-growth within six weeks of ratooning. At this time, the number of tillers per plant was assessed.

At crop maturity, the number of tiller and the number of heads and productive heads per plant were recorded. A head was designated productive if it would be harvested. At the end of the short rains, the number of green leaves per plant were counted and separately recorded for 20 plants in each of the plots. A leaf was considered senesced when more than half the leaf area was chlorotic.

1.25 STATISTICAL ANALYSIS

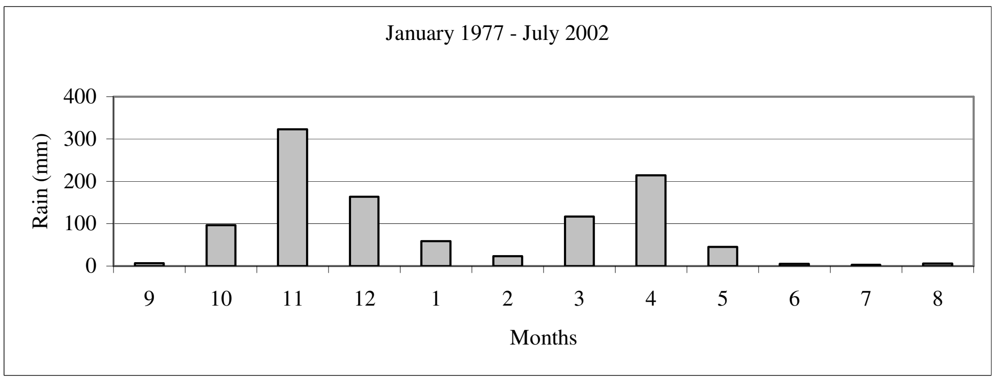
The statistical software package Genstat was used for the analysis. Analysis of Varience (ANOVA) was used to test whether differences existed among varieties and cropping practices in the level of stem borer and yield variables. One-way ANOVA was applied to the short rain data and two-way ANOVA to the long rain data to enable cropping practices and inputs to be compared. Where results were significant ($p>0.05$), standard error of difference (SED) were calculated for comparison of means. Comparisons between specific cropping methods were tested using Tukey b test.

Analysis of deviance was used to test whether differences existed among varieties and cropping practices in the percentage of covered kernel smut. Simple correlation analysis was used to test for association between short and long rain values. The statistical methods utilised were described in Chapter 4.

1.26 RESULTS

1.26.1 Short rains (October 2001 – March 2002)

In the short rains, all the plots contained sorghum crops established from seed (i.e. not ratooned, direct sown), therefore the data were analysed for the difference between the performance of the two varieties against stem borers and covered kernel smut. The rainfall data for the cropping cycle covering November 2001 – August 2002 is presented in Figure 6.1.



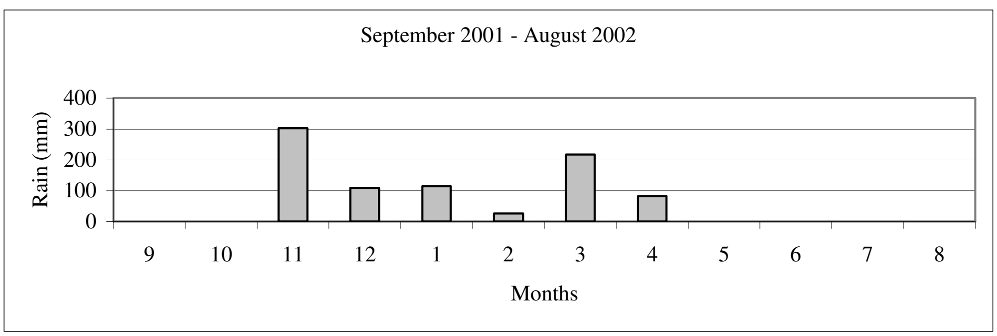


Figure 6.1: Monthly weather information for Katumani sub-station Ithookwe, Kitui District Research Station, Machokos District covering 1977 - 2002 and the cropping cycle 2001/02.

At crop maturity, the variety Seredo had significantly ($p<0.05$) more heads per plant than variety PGRCE 216740, with 1.4 and 1.2 respectively (Table 6.1). However, the number of productive heads was the same for each variety, with 1.0. A productive head was defined as a head with harvestable grain, and excluded heads in flower or in milk stage. The yield achieved by the two varieties was significantly ($p<0.05$) different. The variety PGRCE 216740 achieved a higher yield than the variety Seredo, with 2.0 and 1.7kg, respectively. For varieties PGRCE 216740 and Seredo this converts into 1333 and 1133kg per hectare.

Table 6.1: Effect of sorghum variety Seredo and PGRCE 216740, on yield, number of heads and leaf greeness at crop maturity (short rains 2001/02)

Variable	Variety		
	Seredo	PGRCE 216740	SED
Yield/plot	1.7	2.0[1]	0.2
Heads per plant	1.4	1.2[1]	0.09
Productive heads per plant	1.0	1.0	0.01
Leaf greeness at harvest	1.9	2.1	0.5

[1] significantly ($p<0.05$) different from variety Seredo

Table 6.2: Effect of sorghum varieties, Seredo and PGRCE 216740 on the incidence and severity of covered kernel smut diseases (short rains 2001/02)

Covered Kernel smut	Observed Transformed data		Back transformed data	
	Prediction (s.e)		Prediction (c.i.)	
	Seredo	PGRCE 216740	Seredo	PGRCE 216740
Incidence	8.9 -2.359 (0.306)	2.2 -3.840 (0.586)	8.6 (4.9, 14.7)	2.1 (0.7, 6.4)
Severity	4.5 -3.096 (0.313)	1.0 -4.675 (0.643)	4.3 (2.4, 7.7)	0.9 (0.3, 3.2)

Leaf greenness at crop maturity is considered an indicator of the plants ability to regenerate after harvest. This is because many improved varieties that have been bred to relocate all their energy production in the later stages of the crop cycle into the head sink to the detriment of the rest of the plant. This means that leaves, stems and roots senescence and the plant has little energy to regenerate. A leaf was considered green when less than half the leaf showed senescence. The variety PGRCE 216740 had a slightly higher number of green leaves per stem, than variety Seredo, with 2.1 and 1.9 leaves per stem, respectively (Table 6.1). The variety PGRCE 216740, however, has a longer maturity time than Seredo and the unusual rain received by the plots in February meant that the plants were under less water stress than would be expected under the normal rainfall pattern. This would have delayed senescence.

The incidence of covered kernel smut in the plots was low. The difference between the varieties was not significantly ($p<0.05$), though variety Seredo had a higher incidence than PGRCE 216740, with 8.6% and 2.1%, respectively (Table 6.2). The severity of covered kernel smut followed a similar pattern to the incidence. Variety Seredo had a higher severity than PGRCE 216740, with 4.3% and 0.9% respectively

Table 6.3: Effect of varieties Seredo and PGRCE 216740 on the stem borer damage at crop maturity, measured by average length of tunnelling (cm) per stem and per metre of tem, average number of peduncle breakages and chaffy heads per plot (short rains 2001/02)

Variable	Variety		
	Seredo	PGRCE	SED
Tunnelling per stem	36.2	30.6	4.8
Tunnelling per metre of stem	34.6	24.5	5.4
Peduncle breakage	0.2	0.2	0.1
Chaffy heads	0.05	0.04	0.02

The level of stem borer damage at crop maturity was not significantly ($p<0.05$) different in the two varieties as measured by length of tunnelling per stem, number of peduncle breakages and chaffy heads per plot (Table 6.3). Variety Seredo had longer tunnelling per stem than the variety PGRCE 216740, with 36.2 and 30.6cm, respectively. However, the variety PGRCE 216740 is a taller variety than Seredo, with average stem lengths of 138.1 and 114.8cm, respectively. When the length of stem is taken in to account, the variety Seredo still had more tunnelling per metre of stem than PGRCE 216740, with 34.6 and 24.5cm, respectively. The number of peduncle breakages per plot was minimal and identical for both varieties at 0.2. The number of chaffy heads per plot was also low, though Seredo had slightly more than variety PGRCE 216740, with 0.1 and 0.0, respectively.

Table 6.4: Effect of sorghum varieties Seredo and PGRCE 216740 216740 on stem borer population per stem and per metre of stem (short rains 2001/02)

Variable	Variety		SED
	Seredo	PGRCE	
Stem borers per stem	3.6	3.5	0.2
Stem borers per metre of stem	3.3	2.7[1]	0.3
Larvae per stem	2.0	2.0	0.2
Larvae per metre of stem	1.9	1.5[2]	0.2
Pupae per stem	0.08	0.06	0.03
Pupae per metre of stem	0.06	0.03	0.02
Exit holes per stem	1.5	1.5	0.1
Exit holes per metre of stem	1.4	1.1[2]	1.3

Key: [1] significantly ($p<0.05$) different from variety Seredo

[2] significantly ($p<0.1$) different from variety Seredo

The stem borer population during the season was calculated as the sum total of larvae, pupae and exit holes per stem. Stem borer populations in the varieties was almost identical, with variety Seredo and PGRCE 216740 having 3.6 and 3.5 stem borers per stem, respectively (Table 6.4). The number of larvae and exit holes per stem was identical for each variety, with 2.0 and 1.5, respectively. The stem borer population per metre of stem was significantly ($p<0.05$) higher in the variety Seredo than PGRCE 216740, with 3.3 and 2.7, respectively (Table 6.4).

1.26.2 Long rains (March – August 2002)

The stump survival six weeks after ratooning was above 95%. Variety Seredo had a significantly ($p<0.05$) higher survival rate than variety PGRCE 216740, with 19.9 and 18.2 per 20 plants, respectively (Table 6.5). There were significant ($p<0.1$) differences in the survival of the stumps under the different ratooning methods, but no interaction between the ratooning methods and varieties. Plants, where the stems were cut at harvest (M1) had a higher survival rate than plants, where the stems were cut at harvest and the tillers thinned (M2), with 20.0 and 18.1, respectively. At six weeks after ratooning, the number of visible tillers per plant, was significantly ($p<0.05$) higher in variety Seredo than variety PGCRE, with 5.7 and 4.5, respectively. There was no significant difference (p<0.05) between the different ratooning methods. However, the ratooning method of cutting the stem at harvest (M1) did have more tillers than the method of not cutting the stem (M3). This increased tillering is probably the effect of the apical dominance of the main stem being broken earlier. This effect was reported by Doggett (1988). The thinning of the tillers carried out three weeks after the onset of the rains removed few tillers, as the majority of the plants did not have more than four developing tillers.

Table 6.5: Effect of variety and different cropping methods on the number of stumps surviving, average number of tillers per plant at six weeks after ratooning, and at harvest per 20 plants (long rains 2002)

Method	Stump survival		Tillers at six weeks		Tillers at harvest	
	Seredo	PGRCE	Seredo	PGRCE	Seredo	PGRCE
M1: Ratoon @harvest	20.0	19.8	6.4	4.9	1.7	1.3
M2: ratoon and thinned	19.7	16.5	5.2	4.5	1.6	1.7
M3: not cut	19.4	18.3	5.6	4.1	1.5	1.5
M4: direct sown	N/A	N/A	N/A	N/A	0.5	0.6
SED		1.1		0.7		0.4
All plots	19.9	18.2[1]	5.7	4.4[1]	1.3	1.2
SED		0.6		0.4		0.2

[1] significantly (p<0.05) different from variety Seredo

Tukey b tests applied when F values resulting from ANOVA is significant (p<0.05) for ratooning methods

Stump survival

Ratooning methods (0.1, 16, 8) M1 M3 M2

20.0 18.9 18.1

Tillers at harvest

Ratooning methods (0.05, 21, 8) M2 M3 M1 M4

1.6 1.5 1.5 0.6

Table 6.6: The effect of the different varieties and cropping methods on the incidence of covered kernel smut (%) (long rains 2002)

Method	Observed		Transformed data		Back transformed	
	Seredo	PGRCE	Prediction	(s.e.)	Prediction	(c.i.)
M1: Ratoon @harvest	11.3	0.0	-2.9	(0.6)	5.4	(1.7, 15.9)[1]
M2: ratoon and thinned	13.3	3.2	-2.4	(0.5)	8.4	(3.3, 19.7)[1]
M3: not cut	9.2	6.4	-2.5	(0.5)	7.5	(2.8, 18.7)[1]
M4: direct sown	26.8	24.9	-0.6	(0.3)	36.5	(24.7, 50.7)

Key: [1] significantly (p<0.05) different from M4: direct sown

Table 6.7: The effect of the different varieties and cropping methods on the severity of covered kernel smut over the short and long rains (%)(long rains 2002)

Method	Observed		Transformed data		Back transformed	
	Seredo	PGRCE	Prediction	(s.e.)	Prediction	(c.i.)
M1: Ratoon @harvest	8.6	0.0	-3.2	(0.6)	4.0	(1.2, 12.8)[1]
M2: ratoon and thinned	10.9	3.2	-2.6	(0.5)	6.6	(2.5, 16.2)
M3: not cut	8.0	6.4	-2.6	(0.5)	6.8	(2.6, 16.4)
M4: direct sown	26.8	24.9	-1.1	(0.3)	25.2	(15.7, 37.8)

Key: [1] significantly (p<0.05) different from M4: direct sown

At crop maturity, the number of tillers per plant was not significantly ($p<0.05$) different between the varieties (Table 6.5). The direct sown plants had significantly ($p<0.05$) fewer than tillers than the ratooned plants, with 0.5 and a range of 1.5-1.6, respectively. There were no significant ($p<0.05$) differences between the different ratooning methods.

The incidence and the severity of covered kernel smut were not significantly ($p<0.05$) different between the varieties, but there were differences between the direct sown sorghum and the ratooned sorghum (Table 6.6). The direct sown sorghum had significantly ($p<0.05$) higher incidence than the ratooned sorghum, with 25.2% and a range of 4.0-6.8%, respectively. There was no difference between the different ratooning methods. In the case of severity of covered kernel smut, the direct sown sorghum had significantly ($p<0.05$) higher severity than the ratooned sorghum, with 36.5% and a range of 5.4-8.4%, respectively (Table 6.7). There was no significant ($p<0.05$) difference between the different ratooning methods

The level of stem borer damage at crop maturity was measure by the length of tunnelling per stem, number of chaffy heads and peduncle breakage per plot (Table 6.8). The length of tunnelling per stem was not significantly ($p<0.05$) different between the varieties or the different cropping methods. The direct sown sorghum (M4) had the shortest tunnels, followed by the ratooned at harvest (M1), ratooned and thinned (M2) and not cut (M3), with 18.1, 26.7, 27.8, and 28.3cm, respectively. The number of chaffy heads per plot was significantly ($p<0.05$) higher in variety Seredo than in variety PGRCE 216740 plots, with 0.8 and 0.1, respectively. There was no significant ($p<0.05$) difference between the different cropping methods. The order of the cropping methods when ranked for magnitude is the same as for tunnelling. Peduncle damage also showed a similar ranking, but the direct sown sorghum had significantly ($p<0.05$) fewer breakages than the ratoon crops where the tillers were not thinned at the onset of rains (M1 and M3) (Table 6.8). The order of the ranks of the cropping methods was similar to the order under chaffy heads and tunnelling per stem. In reverse to chaffy heads, peduncle breakages were significantly ($p<0.05$) higher in variety PGRCE 216740 than variety Seredo, with 6.1 and 5.0, respectively.

The stem borer population per stem in the varieties was similar, with varieties PGRCE 216740 and Seredo having 2.8 and 2.5 stem borers per stem, respectively (Table 6.9). However, there was a significant ($p<0.05$) difference in the number of larvae per stem. The variety PGRCE 216740 had more larvae per stem than the variety Seredo, with 0.9 and 0.6, respectively. The stem borers population in the season was not significantly ($p<0.05$) affected by the different cropping methods. The direct sown crop (M4) produced the fewest stem borers per stem, followed by ratooning methods, ratooned at harvest (M1), ratooned and thinned (M2) and not cut (M3), with 1.9, 2.7, 2.8, and 3.2, respectively. This is the same order of the cropping methods as in length of tunnelling. Taking into account the length of the stems did not change the order of rankings for the cropping method (Table 6.10)

Table 6.8: Effect of variety and cropping methods on the stem borer damage at crop maturity, measured by average length of tunnelling per stem (cm), average number of damaged peduncles and chaffy heads (long rains 2002)

Method	Length of tunnelling		Peduncle damage		Chaffy heads	
	Seredo	PGRCE	Seredo	PGRCE	Seredo	PGRCE
M1: Ratoon @harvest	26.4	26.9	8.5	5.8	0.8	0.0
M2: ratoon and thinned	23.2	32.3	3.5	8.0	0.5	0.5
M3: not cut	30.3	26.7	5.5	10.0	1.3	0.0
M4: direct sown	17.0	19.3	2.5	0.8	0.8	0.0
SED		5.2		2.6		0.5
All plots	24.2	26.3	5.0	6.1[1]	0.8	0.1[1]
SED		2.6		1.3		0.2

[1] significantly (p<0.05) different from variety Seredo

Tukey b tests applied when F values resulting from ANOVA is significant (p<0.05) for ratooning methods

Peduncle breakages

Ratooning methods (0.05, 21, 8) M3 M1 M2 M4

7.8 7.1 5.8 1.6

Table 6.9: Effect of variety and cropping methods on the stem borer population at crop maturity, measured by average number of larvae, pupae and exit holes per stem (long rains 2002)

Method	Larvae		Pupae		Exit holes		Stem borers	
	Seredo	PGRCE	Seredo	PGRCE	Seredo	PGRCE	Seredo	PGRCE
M1: Ratoon @harvest	0.5	1.1	0.1	0.0	1.8	1.9	2.4	3.0
M2: ratoon and thinned	0.6	1.0	0.1	0.1	1.8	2.0	2.4	3.1
M3: not cut	0.8	0.9	0.0	0.1	2.5	2.1	3.3	3.1
M4: direct sown	0.5	0.7	0.1	0.0	1.2	1.3	1.8	2.0
SED		0.2		0.1		0.5		0.7
All plots	0.6	0.9[1]	0.1	0.1	1.8	1.8	2.5	2.8
SED		0.1		0.03		0.3		0.3

[1] significantly ($p<0.05$) different from variety Seredo

Tukey b tests applied when F values resulting from ANOVA is significant ($p<0.05$) for ratooning methods

Exit holes per stem

Ratooning methods (0.05, 21, 8) M3 M2 M1 M4

2.3 1.9 1.8 1.2

Stem borers per stem

Ratooning methods (0.05, 21, 8) M3 M2 M1 M4

3.2 2.8 2.7 1.9

Table 6.10: Effect of variety and cropping methods on the stem borer numbers at crop maturity, measured by average number of larvae, pupae and exit holes per metre of stem (long rains 2002)

Method	Larvae		Pupae		Exit holes		Stem borer population	
	Seredo	PGRCE	Seredo	PGRCE	Seredo	PGRCE	Seredo	PGRCE
M1: Ratoon @harvest	0.6	1.1	0.1	0.0	1.9	2.1	2.5	3.2
M2: ratoon and thinned	0.8	1.0	0.1	0.1	2.5	2.1	3.4	3.3
M3: not cut	1.0	1.1	0.0	0.1	3.0	2.3	4.0	3.4
M4: direct sown	0.8	0.8	0.1	0.0	1.8	1.8	2.7	2.6
SED		0.3		0.1		0.6		0.8
All plots	0.8	1.0[1]	0.1	0.1	2.3	2.1	3.2	3.1
SED		0.1				0.3		0.4

[1] significantly ($p<0.05$) different from variety Seredo

Tukey b tests not applied as F values resulting from ANOVA is not significant ($p<0.05$) for ratooning methods

Stem borer population (0.05, 21, 8) M3 M2 M1 M4
3.7 3.3 2.8 2.6

Table 6.11: Stem borer production per hectare of crop under the varieties, Seredo and PGRCE 216740 and different cropping practices

Cropping method	Stem borer population (calculated using)			
	Productive heads[1]		Heads[1]	
	Seredo	PGRCE	Seredo	PGRCE
M1: cut @harvest	288,001	257,401	320,002	356,402
M2: cut and thinned	267,921	255,751	330,962	341,002
M3: not cut	277,421	283,651	320,102	340,382
M4: direct sown	132,001	80,000	132,001	146,667

Key

[1] formulae used in calculating stem borer population per hectare

stem borer population per hectare =

plant population[2] per hectare * stem borer population per stem * productive heads or heads per plant

[2] plant population per hectare = plant population after thinning * stump survival rate

The majority of the stem borers had emerged as adult moths before harvest, as represented by the number of exit holes compared to larvae (Table 6.9). The order of the cropping methods when ranked for magnitude was the same for both larvae and exit holes. However, the number of exit holes per stem in the direct sown crop was significantly ($p<0.05$) lower in than the ratooned methods where the stems were not cut (M3) or where the stems were thinned (M2). This was not the case in the number of larvae per stem. The number of pupae per stem was low and not significantly ($p<0.05$) affected by the different cropping methods. However, the ratoon method: stem not cut (M3) had the least number of pupae per stem and not the direct sown crop as in the other stem borer variable.

The stem borer population per hectare for the different ratooning methods is presented in Table 6.11. The formulae used to calculate the numbers is probably underestimating the population in the ratooned sorghum and overestimating the population in direct sown crop. This is because a ratooned crop usually produces more unproductive tillers then direct sown sorghum and the low survival rate of the direct sown plants is not included in the formulae. From these estimates, the ratooned crop supported more than double the stem borer population per hectare than the direct sown crop. Inclusion of non-productive heads into the equation illustrates the contribution tillers make to stem borer populations (Table 6.11).

Using the number of productive heads per plant, comparisons between the two on-station sites of Kitui and Katumani can be made. In both the direct sown sorghum and ratooned crop, the crop in Kitui supported a higher stem borer population. In the direct sown crops, Kitui and Katumani trials supported 132,001 and 181,33 stem borers per hectare, respectively, while in the ratooned crop, Kitui and Katumani trials supported 288,001 and 200,001 stem borers per hectare, respectively.

The yield per plot was low for all the plots, due to the poor rainfall received during the season. The last rain received by the trial was on 18th April 2002. The yields achieved by the varieties were not significantly ($p<0.05$) different, though variety Seredo achieved a higher yield than PGRCE 216740, with 0.7 and 0.5, respectively (Table 6.12). For varieties Seredo and PGRCE 216740, this converts into 467 and 333kg per hectare. The crop did suffer from bird damage. The bird pressure was particularly bad, because of the lack of alternative food, due to the lack of rain between April and August. The different cropping methods had a significant ($p<0.05$) effect on the yields achieved. The lack of rain at the end of the season would have most affected the later maturing crops i.e. the variety PGRCE 216740 and the direct sown crops. The ratooned crops achieved a significantly ($p<0.05$) higher yield than the direct sown crop, though there was no significant ($p<0.05$) difference between the different ratooning methods. The order of the cropping methods when ranked for magnitude was direct sown (M4), followed by stems not cut (M3), stems cut at harvest (M1) and stems cut at harvest and thinned (M2), with 0.3, 0.7, 0.7 and 0.9kg, respectively. For these cropping practices, direct sown (M4), stems not cut (M3), stems cut at harvest (M1) and stems cut at harvest and thinned (M2), this converts into a yield of 133, 400, 467 and 533kg per hectare, respectively.

Table 6.12: Effect of variety and cropping methods on the average number of heads and productive heads per plant, yield (kg) per plot and weight of 100 grains (g) (long rains 2002)

Method	Heads		Productive heads		Yield		100 grains wt	
	Seredo	PGRCE	Seredo	PGRCE	Seredo	PGRCE	Seredo	PGRCE
M1: cut @harvest	2.0	1.8	1.8	1.3	0.9	0.5	2.4	2.1
M2: cut and thinned	2.1	2.0	1.7	1.5	0.7	0.8	2.3	2.5
M3: not cut	1.5	1.8	1.3	1.5	0.7	0.6	2.4	2.5
M4: direct sown	1.1	1.1	0.9	0.6	0.3	0.1	2.1	2.1
SED		0.3		0.2		0.2		0.1
All plots	1.7	1.6	1.4	1.2[1]	0.7	0.5[1]	2.3	2.3
SED		0.2		0.1		0.1		0.1

[1] significantly (p<0.05) different from variety Seredo

Tukey b tests applied when F values resulting from ANOVA is significant (p<0.05) for ratooning methods

Heads

	M2	M1	M3	M4
Ratooning methods (0.05, 21, 8)	2.0	1.9	1.7	1.1

Productive heads

	M2	M1	M3	M4
Ratooning methods (0.05, 21, 8)	1.6	1.6	1.4	0.7

Yield

	M2	M1	M3	M4
Ratooning methods (0.05, 21, 8)	0.8	0.7	0.6	0.2

100 grain weight

	M3	M2	M1	M4
Ratooning methods (0.05, 21, 8)	2.5	2.4	2.3	2.1

The number of heads and productive heads per plant, showed the same pattern as the plot yields, with the direct sown crop (M4) having significantly (p<0.05) fewer than the ratooned crops (Table 6.12). There were no significant (p<0.05) differences between the different ratooning methods. However, the ratooning methods that involved the cutting of the stem at harvest (M1 and M2) resulted in higher numbers of heads and productive heads. This suggests that the effect of early stimulation of tillering by the early removal of the stems is carried through to crop maturity. The proportion of productive heads to heads per plant was the same for the different ratooning methods at 0.8, but the direct sown crop was lower at 0.6. Thus the stimulation of tillering by cutting the stems early not only resulted in more tillers at 5 weeks, but more of these tillers were productive. The average weight for 100 grains was identical for both varieties, but showed significant ($p<0.05$) differences between the different cropping methods (Table 6.12). The direct sown plots had the lightest grain, followed by the ratooning methods: stems cut at harvest (M1), stems cut and thinned (M2), stem not cut (M3). The ratoon methods: stems not cut (M3) and stem cut and thinned (M2) were significantly ($p<0.05$) heavier grain than the direct sown crop (M4).

1.27 DISCUSSION

Covered kernel smut

There was no difference in the levels of covered kernel smut in varieties. Doggett (1988) had suggested that the taller varieties of sorghum may suffer less severely from covered kernel smut, because the stems grows faster than short stem sorghum and the meristem is more likely to out pace the fungus. This did not happen in this experiment, as both varieties showed similar levels, though the variety PGRCE 216740 is over 20cm taller than Seredo. The lack of difference between the different ratooning methods reflects the fact that in all methods the re-growth occurred from the basal nodes. As in the Katumani on-station experiment (Chapter 4), the level of covered kernel smut in the ratooned crop was strongly correlated to the levels in the previous short rain crop. In the short rains, the incidence of covered kernel smut was low and this was carried through to the long rains. In the direct sown crop, the incidence is primary reliant on the soil conditions at seed emergence. During the long rains, the soil conditions resulted in a high infection rate. The water stress in the second half of the season would have been more severe in the later maturing direct sown crop than the ratooned crop. This would have resulted in the direct sown crop being less able to out grow the systemic fungus than the ratooned crop (Doggett, 1988).

Stem borer population

The level of stem borers in the two varieties was similar and showed no consistent preference for either one. The level of stem borer population per stem was lower in the long rains than the short rains. In the short rain crop, the 2nd generation of stem borers, as measured by live larvae in the stems, was higher than the 1st generation of stem borers, as measured by moth exit holes. The fluctuations in stem borer population may be interpreted through the rainfall pattern.

The experiment was in an area that had been previous cultivated with maize and sorghum, so there was an established population of stem borers. The heavy rain after sowing aided plant establishment and the plants would have been lush. During the season, there were several dry periods, in particularly the 14 days at the end of November-early December. This would have enabled eggs to be successfully laid, and for the early instars to feed and migrate to the funnel without being washed off (Banhof *et al.,* 2001, Kfir, 2002). The late rain in January and the lack of a gap between ratooning and start of the rains in March would have meant the larvae not entering diapause. The larvae present in the stems removed during ratooning and place in trashlines would have continued in their life cycle to emerge as moths and re-infect the sorghum plants. Death of the larvae through desiccation or predation would have been low due to the short time period. In addition, studies carried out at Katumani Research Station suggest that placing stems in trashlines reduces death by predation and desiccation compared to spreading the stems on the ground (Riches *personal communication*). Between March and mid-April, there were regular showers that would have washed eggs and migrating instars from the plants. This would have suppressed stem borer numbers. The low ratio of larvae to exit holes may be an artifact of the relatively late assessment of the crop, due to prior commitments. This would have resulted in more larvae completing their life cycle and emerging as moths before assessments were carried out. The ratooned crops had higher stem borer populations than the direct sown crop. This was probably due to the ability of the ratooned crop to better cope with the dry condition, though their larger root system. The ratooned crop would have remained greener, which would have made the plants more desirable to stem borers. Stem borer have been shown to show ovipostion preference, desirable factors include greeness (Taneja and Woodhead, 1989, Mutui, 2005 and Ndemah, 2001).

Yield

The ratooned crops out performed the direct sown crop. This performance was achieved with below average rainfall. The ratooning method showed no significant ($p<0.05$) effect on yield outcome. However, the action of cutting the stems (M1&M2) seemed to increase the number of tillers at six weeks, though less than half progressed to heading stage and the production of grain. Doggett (1980) had reported a similar occurrence in that the first tillers often do not progress and become productive. He speculated that this was due to the root system not being developed enough to support them at the beginning of their growth. Other researchers suggest the number of productive heads is reliant on the biotic conditions and when a plant is under water stress the main stem's panicle would have preference (Burrell, 2000, Maiti, 1995). At crop maturity, the plots where the stems were cut (M1&M2) had only slightly more productive heads than the plots where the stem was not cut (M3). The higher number of productive heads per plant occurred in plots that contained the higher plant density. This is the opposite of the effect reported by Escalada and Plucknett (1975), and Gerik and Neely (1987). They found that increasing plant density suppressed tiller production. Their work was under similar plant density, though the environmental conditions were dissimilar. Interestingly, the ratio of productive heads to heads (producive and unproductive heads) was the same under all the ratooning methods.

Generally, tiller panicles contribute less to yield than the main culm and can not completely compensate for low plant population. One reason given is that tillers have fewer leaves than the main culm and shading occurs, that makes them less efficient at energy production (Rantikanta Maiti, 1996). In improved sorghums, sorghum breeders have concentrated on morphological developments that rely on variations in main culm seed number and seed weight to provide yield elasticity and have discouraged tillering (Gerik and Neely, 1987). The intra-plant competition for light and resources increases with more tillers, if this competition occurs before panicle initiation the number of grain producing tillers can be reduced (Escalada and Plucknett, 1975). The panicle size and seed size can also increase and decrease under intra-plant competition (Grimes and Musick, 1960). The artificial reduction of tillers could therefore result in fewer larger heads with bigger grain. That could out perform non-thinned plants.

During the experiment, the thinning of tillers at three weeks after ratooning did not significantly effect performance compared to non-thinning. The thinned plots produced a similar number of productive heads to non-thinned, which resulted in a slightly higher yield. Generally, the number of tillers produced after ratooning by the plants was not high; therefore reducing tillers to four per plant only involved removing zero-two tillers. The selection criteria for the removal of tillers were stem borer damage, then the age, with the oldest being removed. The criteria of removing the oldest tillers were included due to the work reported by Escalada and Plucknett (1975). They reported that early tillers often did not survive. The death of early tillers has been attributed to the fact that while the parent shoot is growing and becoming established it cannot fully support the tillers without injuring itself. Milthorpe and Davidson (1966) assumed that part of the dry matter accumulating in the tiller is derived from the parent shoot and is not the product of photosynthesis of its own leaves. Therefore, reduction of early tillers may improve establishment. This may explain the slightly better performance of the thinned plots compared to the non-thinned. However, the survival rate of the thinned plot was lower than the other methods, suggesting the act of thinning may cause damage that results in death.

The act of removing stem borer damage tillers did not reduce the level of stem borer damage in the plants compared to non-thinning. The idea of removing the stem borer damage tillers would be to reduce the early stem borer population and thus reduce the 2nd generation. In this case, the removal of tillers seemed to concentrate the larvae on the remaining stems, though not significantly. The removal of badly infested tillers would probably be more effective in seasons where the gap between ratooning and the start of the long rains is longer. During these periods, green tillers are a "magnet" to surviving moths and removing this damage would reduce the green-bridge effect. Also, stem borer damage to young plants is considered more damaging than damage occurring later in the growing season (Leuschner, 1989).

The performance of the plots where the stems were not cut (M3) was not significantly different from the other ratooned plots in the yield and productive heads achieved. By not stimulating tillering by cutting the stem at harvest, fewer tillers were present at six weeks and at harvest, with fewer being productive. However, the yield was not significantly lower. The heavier weight of the grain probably helped to compensate for the fewer heads. Importantly, this performance was achieved with significantly less labour, an important consideration for farmers.

The direct sown crop, performed poorly in relation to the ratooned crop. It was more severely affected by the lack of rainfall after mid-April. The crop matured approximately two weeks after the ratooned crop and grain filling was affected by water stress. Though rainfall was below average, the lack of rain in the second half of the season is common. The role of sorghum as a food security crop within the farming system makes it important that it can perform when other crops fail.

In conclusion, the experiment indicates ratooning the locally available varieties, Seredo and PGRCE 216740 is practical and the resulting crop outperforms the direct sown crop. However, this is only one cropping cycle and further work needs to be done to confirm these findings. Under the environmental conditions presented during the season, the different ratooning methods did not perform significantly differently. Taking into account the labour inputs required for the different methods, the method where by the stems are not cut would seem to be the most efficient method.

1.28 MAIN CONCLUSION

1. The ratooned crop out performed the direct sown crop in yield.
2. There was no significant difference in crop performance, incidence of covered kernel smut and level of stem borers between the different ratooning methods.
3. The ratoon method of non- cutting of stems (M3) produced a similar yield to the method that involved cutting back stems (M1&M2) and involved less labour.
4. There was no significant difference between either the incidence of covered kernel smut, or levels of stem borers in the two sorghum varieties, Seredo and PGRCE 216740.
5. The level of stem borers was lower in the long rains than the short rains.
6. The ratooned crop supported a larger population of stem borers per unit area than the direct sown crop.

ON-FARM EVALUATION OF DIFFERENT RATOONING METHODS ON SHORT DURATION SORGHUM IN MWINGI DISTRICT

1.29 INTRODUCTION

One of the outcomes of the focused survey (Chapter 3) was that several areas needed further investigation. The on-farm investigations were set up to address the following issues:

1. The effect of the different ratooning timings on the levels of stem borers.
2. Suitability of the short duration sorghum varieties available to the farmers for the practice of ratooning.
3. Farmers' perception of ratooning short duration sorghum.

The on-farm work was undertaken to provide both quantitative and qualitative information on the practice of ratooning short duration sorghum in Mwingi District. Locally available short duration varieties were identified in the focused survey and through key informants. The varieties identified were Seredo, Kari-mtama 1, PGCRE 216740 (PGRCE) and Gadam El Hamam (Gadam). Quantitative data was collected to ascertain the effect of different ratooning methods on the performance of the crop and levels of stem borer levels. Qualitative data, including farmers' perceptions and opinions on the performance of the trials, were collected on both the different ratooning methods and local short duration varieties. The on-farm work ran from December 2000 to August 2002 and covered three cropping seasons. This enabled the trials to be replicated twice.

1.30 LOCATION OF ON-FARM WORK

On-farm trials were first set up in three locations, Kamuwongo, Kiomo and Nguuku in January 2001. The three locations were chosen because they represent three differing farming systems. The majority of the farmers in Nguuku grow several cereals (maize, sorghum and millet) including a local two-season sorghum called Muruge. The Kamuwongo location is drier than Nguuku with a higher proportion of the cereal acreage is under sorghum. The two season sorghums Muruge and Muuhu are commonly grown, probably a reflection of its isolation. In Kiomo location, the farmers grow mostly maize with a small amount of sorghum. It is considered the wettest area and the least isolated (Hayden and Wilson, 2002). The locations of the on-farm sites are shown in Figure 3.1).

1.30.1 Kiomo location

In Kiomo location, the majority of farmers plant local one-season sorghum varieties and the two season sorghums are rare. The farmers tend to plant sorghum in areas of poor drainage and low fertility, because no other crop will perform in these conditions. The systems used to inter-crop sorghum vary. These include planting one row of sorghum to two rows of cowpeas, alternate rows of sorghum with either cowpeas or maize, and as a planting mixture. Farmers try not to re-sow sorghum in the same position, because it is considered a heavy feeder and when maize follows several seasons of sorghum, the maize is badly affected by stem borers (Wilson and Kavoi, 2001).

The Kiomo location is situated approximately 9 km west of Mwingi Town. The soils are developed on quartzites and are classified as ferralo-chromic/orthic/ferric acrisols; with luvisols and ferralsols. They are moderately drained, moderately deep to very deep, dark reddish brown to dark yellowish brown, friable to firm, sandy clay to clay; in many places with topsoil of loamy sand to sandy loam (Siderius and Muchena 1977). The trial site is in agro-ecological zone lower middle 4 (LM4). Jaetzold and Schmidt, (1982) predicted an annual average rainfall of between 700 - 820 mm, with a 60% reliability of 280 - 350 mm and 150 - 200 mm in the short rains and long rains respectively. Average mean temperature ranges from 20.9 - 24^{o}C. The nearest meteorological station is at Mwingi Mission, Mwingi Town. The station is in a similar sub-zone (vs & s/vs[1]) to the trial area. Based on 23 years of data, up to 1976; the average annual rainfall was 766mm, with a 60% reliability of 569mm (Table 7.1).

1.30.2 Kamuwongo location

Kamuwongo location is situated approximately 50km north of Mwingi Town and 5 Km east of Kyuso Town. The soils are developed on quartzites and are classified as chromic Luvisols and ferralo-ferric/chromic/orthic luvisols. They are well drained,

[1] Cropping seasons vs = very short 45-54 days, s/vs = short to very short 75-84 days + = distinctive arid period between growing periods, i = intermediate rains

moderately deep to deep, dark red to yellowish red, friable to firm, sandy clay to clay; often with topsoil of loamy sand (Siderius and Muchena 1977). Jaetzold and Schmidt, (1982) predicted an annual average rainfall of between 650 - 790 mm, with a 60% reliability of 220 - 300 mm and 150 - 200 mm in the short rains and long rains respectively. Average mean temperature ranges from 23.2 - 24^{o}C. The nearest meteorological station is Kyuso District Officer's Office, Kyuso Town approximately 5 km west. The meteorological station and the trial site have the same agro-ecological zone (LM5) and sub-zone (vs + vs/s). The average annual rainfall, based on 23 years of data collected before 1976, is 1136mm, with a 60% reliability of 552mm (Table 7.1). This average is considered higher than expected due to usually wet years. The second nearest meteorological station is Ngomeni Dispensary, Ngomeni Town. This station is approximately 20Km east of the experimental site and in a drier sub-zone (i+vs or vs + i). The average annual rainfall, based on 13 years data collected before 1976, is 641mm with a 60% reliability of 446mm.

1.30.3 Nguuku location

The trial sites in Nguuku location were situated approximately 40km north of Mwingi Town at the foothills of the Mumoni Hills. The soils are developed on colluvium from various volanic rock, mainly basalts and are classified as chromic luvisols; with rhodic ferralsols and luvic/ferralic arenosols. They are well drained, very deep, yellowish red to dark reddish brown, friable, coarse loamy sand to sandy clay loam sandy, clay loam to sand clay (Siderius and Muchena 1977). The trial site is in agro-ecological zone lower middle 4 (LM4). Jaetzold and Schmidt, (1982) predicted an annual average rainfall of between 750 - 880mm, with a 60% reliability of 300 - 380 mm and 220 - 300mm in the short rains and long rains respectively. Average mean temperature ranges from 20.9 -24^{o}C. The nearest meteorological station is approximately 20 km east at Kyuso District Officer's Office, Kyuso (Table 7.1).

Table 7.1: Rainfall figures for meteorological stations Kyuso District Officers' Office, Ngomeni Dispensary, Mwingi Mission, the stations nearest the on-farm experimental locations Nguuku, Kamuwongo and Kiomo respectively

Location	Met. Office (No. of records up to 1976)	Altitude (m)	Kind of record	Ann. rainfall (mm)	Monthly rainfall (mm)											
					Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
					short rains					long rains						
Nguuku	Kyuso District Officers' Office (23 years)	747	Av. [1]	1136	1	125	357	93	46	48	139	255	67	1	0	0
			60% [2]	552	0	37	112	31	12	0	31	159	1	0	0	0
Kamuwongo	Ngomeni Dispensary (13 years)	716	Av.	641	2	37	210	85	97	13	51	122	25	0	0	0
			60%	446	0	3	111	70	3	0	32	88	3	0	0	0
Kiomo	Mwingi Mission (15 years)	1052	Av.	766	6	56	275	88	24	32	94	154	35	3	0	1
			60%	569	0	6	205	38	3	1	23	130	19	0	0	0

[1] average rainfall

[2] amount surpassed normally in 6 out of 10 years

Adapted from Jaetzold and Schmidt, 1982

1.31 APPROACH

1.31.1 First cycle of field evaluations (December 2000 – March 2001, April – July 2001)

After completion of the focused survey, it was decided to immediately start with the on-farm work to address several of the issues raised by the exercise. To enable this the trial plots were superimposed on sorghum fields already planted by the farmers. In the selected locations, the project worked through existing womens' agricultural self-help groups. These groups were selected through consultation with key informants including extension officers, and local chiefs and elders. By working through these stable groups the project integrated itself into the local area and avoided trophy participants. Trophy participants are persons, who join initiatives only to gain recognition or access to handouts, but are uninterested in contributing to the activities. Women self help groups are common in the area and tend to address specific areas i.e. agriculture, water conservation and tree production. Within these groups, the main selection criteria for participating households were a willingness to collaborate and a crop of sorghum that could be ratooned. The members of the groups were from a range of village wealth status and age groups and this was reflected in the participating farmers. However, the Katumani socio-economist said that by KARI criteria they would all be considered poor.

Layout of the trial plots

In each of the three locations (Kamuwongo, Kiomo and Nguuku), ten farmers were selected for participation in the on-farm trials. Each farmer had a site containing four plots each approximately 7x5m in size. The methods were randomly implemented on the four plots. Each farm was therefore a replicate in the trial.

The Methods tested on-farm were:

- *M1 (cut at harvest)*: (variety Seredo) stems cut at harvest and tillers are not thinned
- *M2 (thinned)*: (variety Seredo) stems cut at harvest and tillers thinned to the four youngest at on-set of rains
- *M3 (cut at onset)*: (variety Seredo) stems removed just before the on-set of the rains
- *M4 (direct sown)*: (variety Seredo) *(control)*: direct sown sorghum

Evaluation of farmer plots

The on-farm trials were monitored by a partnership between extension officers, farmers and researchers. Both the farmers and the extension officers understood the purpose of the trials. The farmer, in conjunction with the extension officers, carried out evaluation of the crops during the season. These assessments took place at 6-8 leaf stage and crop maturity. Farmers provided information on performance, stem borer damage and how and why they managed the trials. The aims of the mid-season assessments were to check the progress of the trials, keep the farmer interested in the trial and record data.

At the end of each season, data were collected through group workshops. The researchers chaired the workshops. The groups decided the location of these meetings. During the group workshops, a range of PRA techniques were utililised from farmer-led discussion groups, matrix, field assessments and brain storming. Information collected using these techniques included, treatment and variety performance: plant survival, stem borer damage, plant performance and implementation of trials. In farmer-led discussion groups, the groups choose a member to write their answers on sheets of A3 paper and these were presented to the meeting. The group work enabled farmers to discuss their experiences and draw conclusions and recommendations. In several occasions, these findings were presented to members of the groups not participating directly in the trials. This increased awareness and enabled the non-particpating farmers to understand the process and see the results and contribute ideas.

Assessment of stem borers

Assessments were made at crop maturity on a total of 15 stems per plot. Each stem was randomly selected from the four inner rows. Each stem was split in two and the number of larvae, pupae, and length of tunnelling measured and recorded. The number of larvae is an indication of the number those are available to enter diapause, if conditions become unsuitable. Experienced technical staff from KARI-Katumani carried out these assessments.

1.31.2 Second cycle of evaluations (October 2001 – February 2002, March – July 2002)

In this cycle, the research staff and farmers liaised pre-planting. This enabled the farmers to select and plant sorghum specifically for the trials. The majority of the participants continued their involvement with the on-farm trials. However, several farmers dropped out due to illness and other commitments, these were replaced in open meeting with the women groups.

The methods being tested on-farm changed to:

- ***M1** (cut at harvest):* (variety Seredo) stems cut at harvest and tillers are not thinned
- ***M2** (thinned)*: (variety Seredo) stems cut at harvest and the tillers thinned to the four youngest at on-set of rains
- ***M3** (cut at onset)*: (variety Seredo) previous season's stems removed just before the on-set of the rains
- ***M4** (direct sown)*: (variety Seredo) (control): direct sown sorghum
- ***M5** (Gadam)*: (variety Gadam El Hamam) stems cut at harvest and tillers are not thinned

M3 (cut at onset) was changed from cutting back all stems just before the onset of the rains to only removing the previous season stems. This was to take into account farmer comments from the first cycle.

M5 (Gadam): involving the variety Gadam El Hamam was added, because the farmers requested its inclusion.

During this cropping cycle, a standard layout was adopted for the methods. This was to reduce confusion and aid the discussions. The addition of the variety Gadam El Hamam, also helped with the orientation of the plots as the variety if very distinctive, with large white grains.

In the long rains, individual interviews were added to the assessments. The individual interviews were carried out at harvest time by socio-economists from KARI-Katumani. This was to provide in depth information on the performance of the trials, aid collection of yield data and triangulate the information collected during crop monitoring and end of season workshops. These interviews were carried out at the homesteads, without the local extension officer in order to make farmers feel free to give their ideas. Using interactive data collection techniques, each farmer was invited by the interviewer to show their trials. Having the trials in front of them enabled both farmer and interviewer to see and follow the course of the interview.

In the technical assessment of stem borers, the number of exit holes and length of stem was added to the data collected.

Weather data

At the Kiomo location, the extension officer, who was based within the trial area, collected the daily rainfall using a rain gauge. The officer also scored the rainfall each day using a scale of 1 - 3, with 3 being good rain, and 1 being poor. The officer identified good rain as more than 20mm a day and poor rain as less than 10mm per day. The extension officer covering the Nguuku sites also recorded daily rainfall and scored the days, but he was based in the town of Katse, 10km north of the trial sites.

In each of the sites, the participating farmers were given a sheet to record the days a rain and score the amount of rain per day on a scale of 1 – 3, with 3 being good rain, and 1 being poor days, the farmers gave a score of three to 12 days for both the short and long rains.

1.32 STATISTICAL ANALYSIS

The statistical software package Genstat was used for the analysis. Analysis of deviance was used to test whether differences existed among treatments in the proportions of stem borer damage and yield factors in the plots during the two cropping cycles. This method was utilised to deal with the unbalanced data sets and was described in Chapter 4. The data sets were unbalanced due to the loss of plots through a variety of factors, including animal grazing, accidental ploughing and misapplication of treatments. In the short rains, analysis deviance was used to test whether differences existed in the proportion of stem borer damage and yield factors in the plots at the level of site, ratooning methods. The general models used

Short rains

y= constant + (farmer)[1] + site or ratooning method

[1] inserted co-variate if improved model fit

In the long rains, the same models were fitted as in the short rains, plus site*ratooning methods. To test whether differences existed in the proportion of stem borer damage and yield factors in the ratooning methods at specific sites.

Long rains

y= constant + (farmer +site)[1] + ratooning methods

[1] inserted co-variates if improved model fit

Where the predictions from the models were the same as the observed values only one value is presented in the tables. If the predictions were different to the observed both values were presented in the tables.

1.33 RESULTS

1.33.1 First cycle of the on-farm trials (December 2000 – July 2001)

Daily rainfall data

The participants in Nguuku recorded a total of 31 days and 10 days of rain for the short and long rains respectively. Of these days, the farmers gave a score of three to 10 days in the short and and 1 day in the long rains. At the extension office in Katse town, 438 mm was recorded during the long rains (March – July 2001). This fell in 11 days and 4 days were scored as good (3).

Evaluation of trial plots

In the short rains (October 2000 – January 2001), data were collected from the superimposed trial plots. The number of heads per plot, unthreshed and threshed grain per hectare was not significantly ($p<0.05$) different between the plots or the sites. The plots in Nguuku location achieved the highest threshed grain per hectare with 1045kg, followed by Kamuwongo with 818kg. The data for Kiomo location is not available. The unthreshed yields suggest that Kiomo location had a lower yield than the other two locations (Table 7.2)

Table 7.2: Crop performance, measured by average number of heads per plot, unthreshed and threshed yield per hectare, in direct sown crops at the three locations of the on-farm trial (short rains 2000/1)

Location	Number of heads/plot[1]	Unthreshed grain/ha[1]	Threshed grain/ha[1]
	Observed	Observed	Observed
Kamuwongo	199.7	1,397	818
Nguuku	211.9	1,366	1,045
Kiomo	187.9	1,200	N/A

[1] none significantly ($p<0.05$) different

Long rains

In the long rains (March – July 2001), the extension officer covering the Kamuwongo location was unavailable to monitor the trials during the season due to family problems. The number of live stumps and heads per plot, were significantly ($p<0.05$) different between the sites. The plots in Nguuku out performed those in Kiomo in stump survival, number of heads per plot, and yield per hectare (Table 7.3, 7.4, 7.5 and 7.6). This translated into a significantly higher yield. The higher stump survival was probably due to the higher rainfall and Nguuku farmers' experience in ratooning.

In the performance of the different cropping methods, the ratooned plots outperformed the direct sown plots, with 145-188kg and 6.2kg, respectively (Table 7.6). However, in the performance of the different ratooning methods there was no significant ($p<0.05$) differences between the methods in the number of surviving stumps, heads or yield per hectare. The highest stump survival rate, at both field sites, was when the stems were cut at the onset of rains (M3), with 10,723 per hectare (Table 7.3). In the driest site, Kiomo, the difference between the methods of stems cut at onset of rains (M3) and cut at harvest (M1&M2) was greatest 8,063 and 3,818-5,686, respectively.

Table 7.3: Effect of four different ratooning methods on stump survival, measured by average number of live stumps per hectare at the three locations of the on-farm trial (long rains 2001)

Methods	Live Stumps /ha		
	Site[1]		Mean[1]
	Nguuku	Kiomo	
	Observed/ *Prediction (s.e.)*	Observed/ *Prediction (s.e.)*	
M1(cut at harvest)	12,821	3,818	7,609
M2 (thinned)	13,643	5,686	9,222
M3 (cut at onset)	13,714	8,063	10,723
M4 (direct sown)	N/A	N/A	N/A
Mean	13,393	5,856	
	12,989 (1877)	*6,037(1669)*[2]	

[1] none significantly different

[2] significantly ($p<0.05$) different from Nguuku plots

The methods with the highest number of stumps produced the highest number of heads per hectare (Table 7.4). However, these differences in the number of heads did not always translate into yield. In the wettest site, Nguuku, the plots cut at harvest (M1&M2) produced a higher yield than the plots cut at the onset of rains (M3), with 533-524 and 429, respectively. While, in the drier site, Kiomo, the plots cut at onset of rains (M3) did produce a higher yield than the plots cut at harvest (M1&M2), with 114 and 75&91 kg per ha (Table 7.6). Comparison of unthreshed and threshed yields indicates a higher wastage in the plots cut at the onset of rains (M3) compared to those cut at harvest (M1&M2) (Table 7.5 and 7.6). This suggests the heads were smaller resulting in a lower grain to chaff ratio. The removal of all the stems, even new tillers at the onset of rains (M3) delays maturation of the plants compared to the other ratooning methods. This delay results in the plots coming under greater water stress at the end of the season.

Table 7.4: Effect of four different ratooning methods on number of sorghum heads at crop maturity, measured by average number of heads per hectare at the three locations of the on-farm trial (long rains 2001)

Methods	Number of heads /ha		
	Site[1]		Mean[1]
	Nguuku	Kiomo	
	Observation/ *Prediction (s.e.)*	Observation/ *Prediction (s.e.)*	Observation
M1(cut at harvest)	24,229	1,532	8,625
	23,583 (6517)	*1,890 (4422)*[4,5]	
M2 (thinned)	26,629	2,829	10,762
	25,983 (6517)	*3,151 (4547)*[4,5]	
M3 (cut at onset)	34,171	6,000	16,061
	33,526 (6517)	*6,281 (4807)*[5]	
M4 (direct sown)	12,457	114	4,229
	11,811 (6517)	*437 (4547)*[3,4,5]	
Mean	24,371	2,507	
	23,652 (3538)	*2867 (2385)*[2]	

[1] none significantly ($p<0.05$) different

[2] significantly ($p<0.05$) different from Nguuku plots

[3] significantly ($p<0.05$) different from Nguuku plots cut at harvest (M1)

[4] significantly ($p<0.05$) different from Nguuku plots cut at harvest and thinned at onset of rains (M2)

[5] significantly ($p<0.05$) different from Nguuku plots cut at onset of rains (M3)

Table 7.5: Effect of four different ratooning methods on yield, measured by average unthreshed grain per hectare (kg) per hectare at the three locations of the on-farm trial (long rains 2001)

Methods	Unthreshed grain/ha		
	Site[1]		Mean[1]
	Nguuku	Kiomo	
	Observation/ *Prediction (s.e.)*	Observation/ *Prediction (s.e.)*	Observation/ *Prediction (s.e.)*
M1(cut at harvest)	771	75	225
	795 (85.1)[3, 4]	*71 (44.4)*	*234 (54.8)*[2]
M2 (thinned)	771	119	269
	795 (85.1)[3, 4]	*112 (45.2)*	*271(56.8)*[2]
M3 (cut at onset)	629	189	299
	652 (85.1)[3, 4]	*80 (47.7)*	*292 (59.1)*[2]
M4 (direct sown)	86	6	26
	109 (85.1)	*0 (47.7)*	*19 (59.1)*
Mean	564	97	
	587 (72.3)[1]	*90 (35.9)*	

[1] significantly ($p<0.05$) different from Kiomo

[2] significantly ($p<0.05$) different from direct sown plots (M4)

[3] significantly different from Nguuku plots direct sown (M4)

[4] significantly different from Kiomo plots cut at harvest (M1), thinned (M2), cut at onset (M3) and direct sown (M4)

Table 7.6: Effect of four different ratooning methods on yield, measured by average threshed grain per hectare (kg) per hectare at the three locations of the on-farm trial (long rains 2001)

Methods	Threshed grain/ha		
	Site[1]		Mean
	Nguuku	Kiomo	
	Observation/ *Prediction (s.e.)*	Observation/ *Prediction (s.e.)*	Observation/ *Prediction (s.e.)*
M1(cut at harvest)	533	75	139
	544 (54.6)[3, 4]	*27 (28.5)*	*146 (34.6)*[2]
M2 (thinned)	524	91	191
	534 (54.6)[3]	*87 (29.0)*[4,5]	*192 (35.9)*[2]
M3 (cut at onset)	429	114	193
	439 (54.6)[3]	*112 (30.6)*[4,5]	*188 (37.4)*[2]
M4 (direct sown)	29	5	11
	40 (54.6)[4,5]	*2 (30.6)*[4,5]	*6 (37.4)*
Mean	379	60	
	379(42.2)	*60 (23.4)*[1]	

[1] significantly ($p<0.05$) different from Nguuku

[2] significantly ($p<0.05$) different from direct sown plots (M4)

[3] significantly different from Nguuku plots direct sown (M4)

[4] significantly different from Nguuku plots cut at harvest (M1) and plot thinned (M2)

[5] significantly different from Nguuku plots cut at onset (M3)

Assessment of stem borers

In the short rains, the majority of the stem borer larvae found in the stems during assessments were *Chilo partellus.* The only other species found was *Busseola fusca*, and this was found only in Kiomo and was recorded less than two times. In the short rains, the number of live stem borers (larvae and pupae) counted in the stems and the length of tunnelling per stem was not significantly ($p<0.05$) different between the methods (Table 7.7). However, there were significant differences ($p<0.001$) between the sites (Table 7.8). The plots in Nguuku location had the highest number of larvae with 0.9 per stem, followed by Kamuwongo and Kiomo, with 0.6 and 0.3 respectively. This was mirrored in the length of tunnelling recorded per stem, Nguuku the longest followed by Kamuwongo, then Kiomo, with 16.9, 11.7 and 6.9 cm, respectively.

Table 7.7: Live stem borers and associated damage at crop maturity, measured by average number of larvae, pupae and tunnelling (cm) per stem in direct sown plots divided into the cropping methods to be implemented (short rains 2000/1)

Methods	Tunnel length[1]	Larvae[1]	Pupae[1]
(to be implemented)	Observed	Observed	Observed
M1(cut at harvest)	10.5	0.5	0
M2 (thinned)	12.2	0.6	0
M3 (cut at onset)	13.1	0.7	0
M4 (direct sown)	11.6	0.6	0

[1] none significantly ($p<0.05$) different

Table 7.8: Live stem borers and associated damage at crop maturity, measured by average number of larvae, pupae and tunnelling (cm) per stem in direct sown crops at the three locations of the on-farm trial (short rains 2000/1)

Location	Tunnel length	Larvae	Pupae
	Observed/ Prediction (s.e.)	Observation/ Prediction (s.e.)	Observed
Kamuwongo	18.2 (1.9)[1]	0.6 (0.1)	0
Nguuku	16.9 (1.9)[1]	0.9 (0.1)	0
Kiomo	6.9 (1.9)	0.3 (0.1)[2]	0

[1] significantly different ($p<0.05$) than Kiomo

[2] significantly different ($p<0.05$) than Nguuku

In the long rain crop, *Chilo partellus* was again the dominant species of stem borer. The number of live stem borers (larvae and pupae) counted in the stems was much higher than in the short rains. The level of live stem borers at crop maturity was similar in the different cropping methods, with a range of 3.2-4.0 larvae and pupae per stem (Table 7.10). There were significantly ($p<0.05$) differences between the sites (Table 7.10). The plots at Kiomo had significantly ($p<0.05$) lower numbers than those in the Nguuku and Kamuwongo sites, with 1.9, 3.7 and 4.8 per stem, respectively. This was mirrored in the length of tunnelling recorded per stem (Table 7.9). The plots in Kiomo recorded the shortest tunnelling, followed by Nguuku and Kamuwongo, with 23.5, 34.9 and

43.9cm, respectively. The length of tunnelling was significantly affected by the different cropping methods. The direct sown plots had significantly shorter tunnelling than the ratooned plots, with 24.7 and 37.5-41.7cm, respectively.

Table 7.9: Effect of four different ratooning methods on stem borer damage at crop maturity, measured by average length of tunnelling (cm) per stem at the three locations of the on-farm trial (long rains 2001)

Methods	Length of tunnelling (cm) per stem			
	Site			Mean
	Kamuwongo	Nguuku	Kiomo	
	Observed/ Prediction (s.e.)	Observed/ Prediction (s.e.)	Observed/ Prediction (s.e.)	Observed/ *Prediction* (s.e.)
M1(cut at harvest)	50.4[3] (4.3)	38.6 (4.7)	17.6 (5.7)	38.5
				38.2 (2.8)[2]
M2 (thinned)	50.3[3] (4.0)	39.5 (4.7)	30.4 (5.1)	41.7
				41.5 (2.6)[2]
M3 (cut at onset)	50.4[3] (5.1)	33.7 (4.7)	29.3 (5.1)	37.5
				39.0 (2.9)[2]
M4 (direct sown)	27.8 (4.0)	28.0 (4.7)	13.7 (5.7)	24.7
				23.9 (2.7)
Mean	43.9 (2.5)	34.9 (2.7)	23.5 (3.1)[1]	

[1] significantly ($p<0.05$) different from Kamuwongo plots

[2] significantly ($p<0.05$) different from direct sown plots (M4)

[3] significantly ($p<0.05$) different from Kamuwongo plots, direct sown (M4)

Table 7.10: Effect of four different ratooning methods on stem borer population at crop maturity, measured by average number of larvae and pupae per stem at the three locations of the on-farm trial (long rains 2001)

Methods	Live stem borers per stem			
	Site			Mean[1]
	Kamuwongo	Nguuku	Kiomo	
	Observed/ Prediction (s.e.)	Observed/ Prediction (s.e.)	Observed/ Prediction (s.e.)	Observed
M1(cut at harvest)	5.5 (0.6)	3.9 (0.6)	1.8 (0.8)[4]	4.0
M2 (thinned)	5.7 (0.6)	3.4 (0.6)	2.1 (0.7)[4]	4.0
M3 (cut at onset)	4.7 (0.7)	3.5 (0.6)	2.2 (0.7)[4]	3.5
M4 (direct sown)	3.6 (0.6)	4.0 (0.6)	1.4 (0.8)[4]	3.2
Mean	4.8 (0.3)	3.7 (0.3)	1.9 (0.4)[2, 3]	

[1] none significantly different

[2] significantly ($p<0.05$) different from Nguuku plots

[3] significantly ($p<0.05$) different from Kamuwongo plots

[4] significantly different from Kamuwongo plots cut at harvest (M1) and thinned (M2)

End of season workshops

End of season workshops were held at each of the three locations. In all three locations, the farmers thought that ratooning was a good practice. The farmers were appreciative of the ability of a ratooned crop to produce a harvest under conditions that caused direct sown crops to fail. The farmers considered the yield produced by the ratooned plots to be better than the direct sown plots and good in relation to the season. The performance of the plants in relation to early maturity, number and size of heads and the size of the grains were also considered better than the direct sown crops. Early maturity is a valued characteristic as it reduces opportunity for bird damage and enables the crop to utilise all the available soil moisture.

The lower labour input, resulting from the farmer not having to prepare the soil for planting, planting and the ease of weeding around the stumps compared with seedlings was considered a positive point. The long rains are often erratic especially at the beginning, which can result in the dry planted seed rotting in the soil. The farmers, however, have to balance this danger with the need for the crop to be able to 'capture' as much of the available water as possible. The result is farmers regularly have to re-sow crops and the later sown crops often fail to reach maturity due to water stress. This re-sowing involves a lot of work and seed at a time when farmers have a shortage of both. The level of pest damage on the ratooned crop was considered less or not significantly more than on the direct sown sorghum. The disadvantage was that in poor seasons with low rainfall, the stumps dry out and die reducing the plant population.

The Nguuku and Kamuwongo farmers identified several inputs required to produce a good ratoon crop. These inputs could be divided into two areas: 1) the production of strong plants in the first season and 2) the timing of the cutting back of the plants. To produce strong plants they identified the need for the planting site to have good retention of soil moisture. This was related to the site being flat and/or terraced to reduce run off, the incorporation of manure to increase the fertility and organic component of the soil, and tilling the soil to increase absorption and penetration of the rain. The production of strong plants was also related to low planting density and non-interrupted growth. To achieve this the farmers suggested increasing the plant spacing and planting fewer seeds per hill to avoid thinning, and weeding early to avoid competition. The second area was timing of the cutting back of the plants. They thought that stump survival would be higher if the plants were harvested as soon as possible and ratooned straight away while the stems were green.

The opinions of the Nguuku and Kamuwongo participants on the different cropping methods are presented in below:
M1 (stems cut at harvest and tillers not thinned): the farmers agreed that the advantages of this method were that the plants produced their tillers early, which resulted in early flowering, maturity and harvest. Early maturity meant that the birds did not attack the crop unlike the later maturing crops. Stem borer, also less affected the early produced tillers, than the later tillers. These factors resulted in good yields.

M2 (stems cut at harvest and thinned): The farmers from Kamuwongo and Nguuku disagreed about thinning the tillers (M2). The farmers from Kamuwongo thought thinning the tillers resulted in larger heads and a better yield than non-thinning the tillers (M1). The farmers from Nguuku thought the reverse that there were no advantages to thinning the tillers (M2), only disadvantages. The disadvantages included a lower survival rate of the stumps and the surviving plants producing fewer tillers, which when affected by stem borers resulted in a poorer yield. Time and labour was also required to thin the tillers. The Kamuwongo group considered that by reducing the number tillers there were less competition, which enabled the tillers to grow quicker and stronger. While the Nguuku group argued that if stem borers or covered kernel smut affect the remaining tillers the plant had fewer tillers to compensate for the damage.

M3 (all stems cut at onset of rains): Both groups thought, waiting to cut the stems to the onset of rains, then removing all the stems even the green tillers (M3) reduced stump survival rate and the surviving stumps did not tiller as well. The delay in ratooning delayed tiller production resulting in later flowering and harvesting and the tillers became more infested with stem borers. These factors resulted in a low yield. The farmers disliked cutting back tillers, which had already grown, as the removed tillers had utilised soil moisture, which was then unavailable to the remaining plant. Another issue was local custom that believes it is bad luck to up-root anything that has already grown. The farmers in Kamuwongo mentioned that some of the cut stems rotted, and because the ratooning height was higher tillers were produced from the cut stems and these broke off in the wind. Escalada and Plucknett (1977) reported similar breaking off of tillers when the original stems are left too long.

M4 (direct sown): In all sites the direct sown sorghum dried before it reached flowering stage and had a high level of stem borer damage. The Nguuku Group also recorded poor germination. However, the groups pointed out that in a good season direct sown sorghum germinates well, is vigorous and produces a good yield. The disadvantages are the time and labour required for land preparation, planting and the low yield if the crop is planted late or the rains are poor. In seasons with poor rainfall, levels of pests are also high and cause severe damage.

The farmer groups disagreed, which was the best ratooning method. In Nguuku, the farmers thought that cutting the stems at harvest (M1), was the best method. The reasons were that thinning tillers (M2) disturbed the stumps. Sometimes the pulling-off the tillers resulted in the whole stump coming away and removal of stems during a dry period caused some stumps to dry.

In Kamuwongo, most of the farmers (seven out of nine) thought cutting the stem at harvest and thinning at the onset of the rain (M2) was the best method. However, the thinning of the tillers had to be carried out just before the onset of the rains. The thinning enabled the stem borer affected and/or weak small tillers to be removed. The farmers thought the opinions of the farmers in Nguuku on thinning (M2) were shaped by the amount of rainfall and the timing of the thinning. Kamuwongo farmers thought that if tillers are thinned and there is a gap before the crop receives rain stumps will be weaken and therefore be less able to withstand the disturbance caused by thinning, resulting in some stumps dying after thinning. The Kamuwongo farmers also used a local tool called *kivara*, which looks like a solid, dutch hoe. This enables the farmers to select the tillers individually. The use of a panga or pulling off the tillers would require more force and could result in more damage to the stump.

The biggest concern for all the farmers was the level of plant death between the short and long rains. In Nguuku, the farmers thought for ratooning to be acceptable the survival rate would need to average 75%. If the survival rate fell below 50%, it would probably be better to plant a new crop. However, in a bad season, similar to long rains 2001, then ratooning would be better than direct sown, because they would harvest something. Under these conditions, even if more than half died it would be worth keeping, as nothing else produced a yield and the labour input was low.

In Kamuwongo and Kiomi, the farmers' thought as long as a quarter of the stumps survived it would be worth doing. Their reason for this low figure being that the stumps could be intercropped with cowpea, so little space was wasted and something was better than nothing.

1.33.2 Second cycle of the on-farm trials (October 2001 – July 2002)

Daily rainfall data

In the second cycle (October 2001 – July 2002), the Nguuku farmers recorded a total of 22 days and 19 days of rain for the short and long rains respectively. Of these days, the farmers gave a score of three (good) to 12 days in both the short and long rains. The local extension office, based in Katse town recorded a total rainfall of 434mm and 362mm for the short and long rains respectively. This fell in 28 days and 13 days for the short and long rains respectively. Of these days, the officer gave a score of three (good) to 10 days and 7 days in the short and long rains respectively.

At the Kiomo location, the extension officer recorded a total rainfall of 269mm and 310 mm for the short and long rains respectively. This fell in 20 days and 14 days for the short and long rains respectively. Of these days, the officer gave a score of three (good) to 3 days in both the short and long rains. At the Kamuwongo location, the farmers recorded a total of 16 days rain for long rains. Of these days, the farmers gave a score of three (good) to 7 days.

Evaluations of trial plots

In the short rains (October 2001 – January 2002), the plant population, number of heads, unthreshed and threshed grain per hectare were not significantly ($p<0.05$) different between the different method plots. The plots situated in Kiomo, had significantly ($p<0.05$) more plants per hectare than the other two sites (Table 7.11). However, this did not result in significantly more heads or grain, on the contrary they actually produced significantly less unthreshed and threshed grain than the other locations (Table 7.12). This was probably due to a combination of overcrowding and receiving slightly less rainfall than the other location.

Table 7.11: Crop performance, measured by average plant population and number of heads per hectare, in direct sown crops at the three locations of the on-farm trial (short rains 2001/2)

Location	Plant population/ha	Number of heads/ha
	Observed/ Prediction (s.e.)	Observed/ Prediction (s.e.)
Kamuwongo	41,529 (3829)	121,600 (7254)
Nguuku	36,594 (3829)	86,863 (7328)[1]
Kiomo	73,090 (4081)[1, 2]	80,061 (7733)[1]

[1] significantly ($p<0.05$) different from Kamuwongo

[2] significantly ($p<0.05$) different from Nguuku

Table 7.12: Crop performance, measured by unthreshed and threshed yield per hectare, in direct sown crops at the three locations of the on-farm trial (short rains 2001/2)

Location	Unthreshed grain/ha	Threshed grain/ha
	Observed/ Prediction (s.e.)	Observed/ Prediction (s.e.)
Kamuwongo	2,559 (165)	1,761 (101)
Nguuku	2,975 (165)	2,070 (113)
Kiomo	1,363 (174)[1]	908 (108)[1]

[1] significantly different from Kamuwongo

Table 7.13: Effect of four different ratooning methods on stump survival, measured by average number of live stumps per hectare at the three locations of the on-farm trial (long rains 2002)

Methods	Live Stumps /ha			
	Site			Mean[1]
	Kamuwongo	Nguuku	Kiomo	
	Observed/ Prediction (s.e.)	Observed/ Prediction (s.e.)	Observed/ Prediction (s.e.)	
M1(cut at harvest)	15,203 (3,435)	25,306 (3,602)	9,166 (4028)	17,022
M2 (thinned)	17,746 (3,797)	24,558 (3,602)	6,747 (4028)[3, 4]	17,010
M3 (cut at onset)	20,310 (3,602)	22,185 (3,602)	9,129 (4306)	18,105
M4 (direct sown)	N/A	N/A	N/A	N/A
M5 (Gadam)	6,510 (3602)[3, 4]	18,391 (3,602)	7,031 (4028)[3, 4]	10,902
Mean (s.e.)	14,879 (1,816)[2]	22,610 (1,816)	7,983 (2,063)[2]	

[1] none significantly ($p<0.05$) different

[2] significantly ($p<0.05$) different from Nguuku site

[3] significantly different from Nguuku plots under M1 (cut at harvest)

[4] significantly different from Nguuku plots under M2 (thinned)

In the long rains (March – July 2002), live stumps per hectare were significantly higher in Nguuku compared to the other sites, with 22,610 surviving stumps per hectare. This compares with Kamuwongo and Kiomo locations, with 14,879 and 7,983 (Table 7.13). The higher plant population in Nguuku translated at the end of the season into the highest number of heads and grain per hectare (Table 7.14, 7.16 and 7.17). Interestingly, the plots in Kiomo out performed in yield the plots in Kamuwongo, even with a lower plant population. This could be due to the higher temperatures and stem borer damage levels present in Kamuwongo (Table 7.21-23). The different ratooning methods had no significant ($p<0.05$) effect on stump survival. The highest stump count was when the old stems were cut back at onset of rains (M3), with 18,105 (Table 7.13). However, only at Kamuwongo site, the hottest site, did this method have the highest stump number. At Nguuku and Kiomo sites, cutting the stems at harvest (M1) had the highest survival of stumps. At Kiomo site, the driest site, the thinning of the tiller (M2) seemed to have an adverse effect on stump survival. In the wetter site, this decline in survival was not replicated.

The highest number of heads per hectare was produced by the ratooning methods with the highest stump survival, though they were no significant differences between the methods (Table 7.14). This illustrates the importance of stump survival in the practice of ratooning.

In the drier sites, Kiomo and Kamuwongo, the method of removing only the older stems at the onset of rains (M3) seemed to result in a higher ratio of heads to stumps. However, in the wetter site of Nguuku this effect was not apparent (Table 7.15). In Kamuwongo, the thinning of tillers (M2) seemed to be detrimental to the ratio of heads to stumps, with 1.5 and 1.9, respectively. The hotter conditions and low rainfall may reduce the ability of the plants to cope with the damage caused by the removal of tillers. Under the wetter conditions of Nguuku, the remaining tillers after thinning seem to be able to compensate for the thinning.

The collection of yield data depended on the farmers harvesting and threshing the plots separately. Collecting the unthreshed yields proved much easier than the threshed yields. During the threshing, grain was probably lost as farmers were inexperienced in processing such small amounts. The unthreshed yields followed a similar pattern to the number of heads and stumps (Table 7.16 and 7.17).

Table 7.14: Effect of four different ratooning methods on number of sorghum heads at crop maturity, measured by average number of heads per hectare at the three locations of the on-farm trial (long rains 2002)

Methods	Number heads per hectare			
	Site[1]			Mean[1]
	Kamuwongo	Nguuku	Kiomo	
	Observed	Observed	Observed	Observed
M1(cut at harvest)	24,500	58,891	39,532	42,588
M2 (thinned)	26,939	56,181	35,187	41,805
M3 (cut at onset)	38,321	43,826	36,841	40,245
M4 (direct sown)	38,891	30,996	25,806	32,145
M5 (Gadam)	13,250	30,085	10,852	19,665
Mean[1]	25,714	47,246	30,603	

[1] none significantly ($p<0.05$) different

Table 7.15: Effect of four different ratooning methods on number of sorghum heads per stump at crop maturity, measured by the ratio of heads per stump at the three locations of the on-farm trial (long rains 2002)

Methods[*]	Ratio of heads per stump			
	Site[1]			Mean[1]
	Kamuwongo	Nguuku	Kiomo	
	Observed	Observed	Observed	Observed
M1(cut at harvest)	1.9	2.3	2.1	2.1
M2 (thinned)	1.5	2.3	2.0	2.0
M3 (cut at onset)	2.0	2.2	2.6	2.3
M4 (direct sown)				
M5 (Gadam)	1.5	1.5	2.0	1.7
Mean[1]	1.7	2.0	2.3	

[1] none significantly different

Table 7.16: Effect of four different ratooning methods on yield, measured by average unthreshed grain per hectare (kg) per hectare at the three locations of the on-farm trial (long rains 2002)

Methods	Unthreshed grain/ha			
	Site[1]			Mean[1]
	Kamuwongo	Nguuku	Kiomo	
	Observed	Observed	Observed	Observed
M1(cut at harvest)	600	887	1,239	1,005
M2 (thinned)	429	981	1,014	965
M3 (cut at onset)	1,214	815	684	786
M4 (direct sown)	86	971	717	744
M5 (Gadam)	171	659	349	462
Mean[1]	474	857	789	

[1] none significantly different

Table 7.17: Effect of four different ratooning methods on yield, measured by average threshed grain per hectare (kg) per hectare at the three locations of the on-farm trial (long rains 2002)

Methods	Threshed grain/ha			
	Site[1]			Mean[1]
	Kamuwongo	Nguuku	Kiomo	
	Observed	Observed	Observed	Observed
M1(cut at harvest)	276	801	987	732
M2 (thinned)	352	838	880	730
M3 (cut at onset)	343	733	609	596
M4 (direct sown)	691	413	619	551
M5 (Gadam)	139	483	232	306
Mean[1]	342	654	560	

[1] none significantly different

[*] several farmers' threshed yield data was not collected

During the monitoring of the plots, farmers scored the different cropping methods for crop performance and stem borer damage at 6-8 leaf stage and crop maturity. The ratooned plots (M1, M2 & M3) at both 6-8 leaf stage and crop maturity had a higher proportion of plots scored very good and good for crop performance than the direct sown plots (M4) (Figure 7.1).

At 6-8 leaf stage, the plots where the previous season stems were cut at onset of rains (M3), had the highest proportion of plots scored good or very good for crop performance. This was followed by the plots where the stems were cut at harvest and tillers thinned at onset of rains (M2), stems cut at harvest (M1), direct sown (M4), then lastly variety Gadam El Hamam with stems cut at harvest (M5) (Figure 7.1). At crop maturity, the ratooned plots (M1, M2 and M3) had similar scores, with approximately half the plots scored very good and good. However, the plots that only the previous season's stems were cut at onset (M3) had the highest proportion of plots scored very good, but also the highest proportion of very bad plots.

The scores given by the farmers for stem borer damage did not follow the same order as a for crop performance. At 6-8 leaf stage, the direct sown crop (M4) had the highest proportion of plots scored no damage and little damage. This was followed by Gadam El Hamam (M5), previous season's stems cut at onset of rains (M3), tillers thinned (M2), and stems cut at harvest (M1). At crop maturity, the order changed and plots where the previous season's stems were cut at onset (M3), recorded the highest proportion of no damage and little damage. This was followed by tillers thinned (M2), Gadam El Hamam (M5), direct sown (M4), then cut at harvest (M1) (Figure 7.1). Stem borer damage scores for the plots with variety Gadam El Hamam (M5) were polarised into no damage and very severe damage. At both crop stages, the variety had the highest proportion of no damage and little damage plots. The performance of Gadam El Hamam compared to Seredo under the ratooning practice of cutting the stems at harvest shows the effect of variety on performance.

At 6-8 leaf stage, the two methods of assessment, scoring the plots and counting the number of dead hearts, followed the same order for the variety Seredo. However, variety Gadam El Hamam (M5) received a relatively better stem borer damage score than the number of dead hearts in the plot would indicate. When the farmers assessed for stem borer damage they factor in ability to recovery from the damage. At crop maturity, there was a divergence between scoring the plots and number of chaffy heads. For example, the farmers scored plots where the previous season's stems were cut back at onset (M3), with the least damage, but these plots had the highest number of chaffy heads.

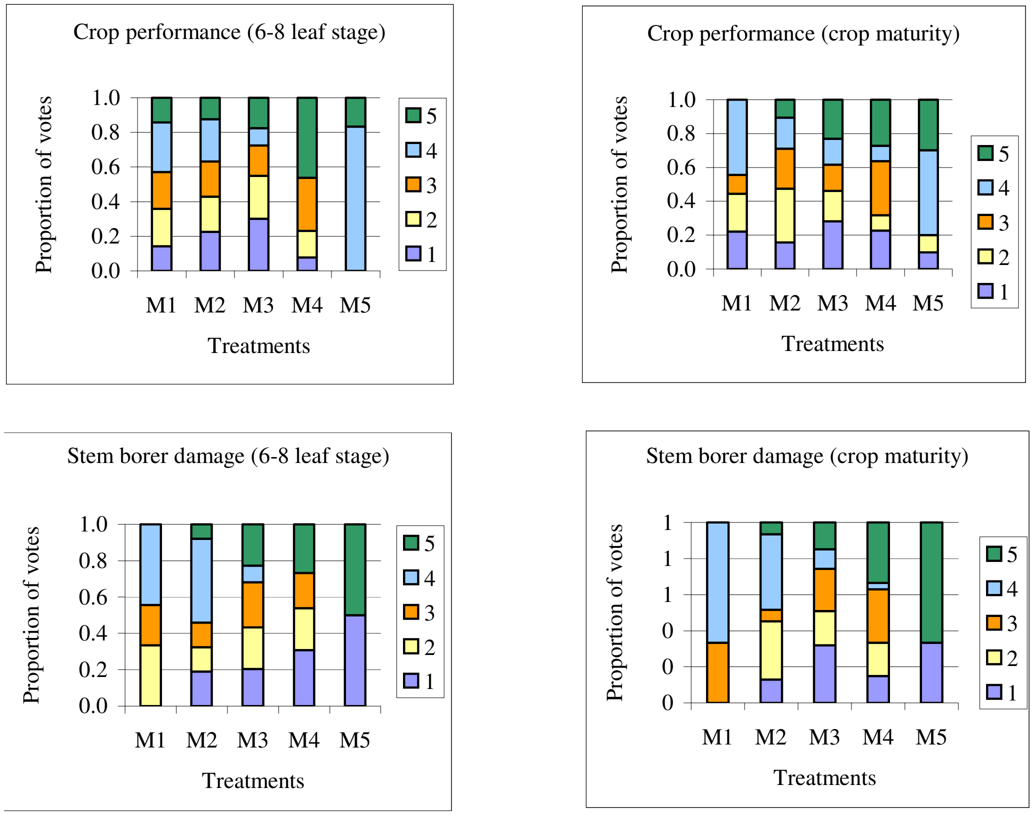


Figure 7.1: Frequency of individual farmer scores of their plots involving the different ratooning methods, presented as a proportion of the number of plots assessed, for crop performance and stem borer damage in Nguuku, Kamuwongo and Kiomo locations (long rains 2002)

Key:

Crop performance scoring:

1 very good, 2 good, 3 neither good nor bad, 4 bad, 5 very bad

Stem borer damage scoring:

1 no damage, 2 little damage, 3 moderate damage, 4 severe damage, 5 very severe damage

Treatments:

M1: (Serado) stems cut back at harvest and tillers are not thinned

M2: (Serado) stems cut at harvest and the tillers thinned to the four youngest at on-set of rains

M3: (Seredo) previous season's stems removed just before the on-set of the rains

M4: (Seredo) direct sown sorghum

M5: (Gadam El Hamam) stems cut at harvest and tillers are not thinned

Assessment of stem borers

In the short rains, the stem borer *Chilo partellus* was the only species found in the stems. The number of live stem borers (larvae+pupae) and exit holes counted in the stems, and the length of tunnelling per stem was not significantly ($p<0.05$) different between the plots (Table 7.18). However, there were significant differences ($p<0.001$) between the sites. The plots in Nguuku and Kamuwongo location had very similar number of larvae with 2.9 and 2.8 per stem, and Kiomo had the fewest with 1.4 (Table 7.19). This pattern was mirrored in the length of tunnelling recorded per stem, Nguuku and Kamuwongo had similar lengths of tunnelling, while Kiomo had less, with 49.3, 50.5 and 27.6, respectively (Table 7.19). In Kamuwongo and Nguuku location, a small number of pupae were recorded. Moth emergence as recorded through number of exit holes per stem showed the same pattern to the number of larvae per stem. The plots in Nguuku and Kamuwongo location had very similar number of exit holes and Kiomo had the fewest with 1.1, 1.2, 0.2 per stem, respectively (Table 7.20). The total number of stem borers present in the stems through the season, as measured by the combined number of larvae, pupae and exit holes per stem, in Kamuwongo, Nguuku and Kiomo were 3.8, 4.1 and 1.5, respectively.

Table 7.18: Stem borer population and associated damage, measured by average number of larvae, pupae, exit holes and tunnelling (cm) per stem in direct sown crops at the three locations of the on-farm trial (short rains 2001/2)

Location	Tunnel length[1]	Larvae[1]	Pupae[1]	Exit holes[1]	Stem borer population[1]
	Observed	Observed	Observed	Observed	Observed
M1(cut at harvest)	47.6	2.5	0.1	0.8	3.3
M2 (thinned)	40.8	2.2	0.1	0.6	2.7
M3 (cut at onset)	48.5	2.7	0.1	1.0	3.7
M4 (direct sown)	45.4	2.3	0.1	0.7	3.0
M5 (Gadam)	40.6	2.7	0.2	1.2	3.9

[1] none significantly ($p<0.05$) different

Table 7.19: Number of live stem borers and associated damage, measured by average number of larvae, and pupae per stem and length of tunnelling per stem at the three locations of the on-farm trial (short rains 2001/2)

Location	Tunnel length		Larvae		Pupae
	Observed	Observed/ Prediction (s.e.)	Observed	Prediction (s.e.)	Observed
Kamuwongo	50.5	50.5 (3.6)[1]	2.8	2.8 (0.2)[1]	0.2
Nguuku	49.3	49.3 (3.3)[1]	2.9	2.9 (0.2)[1]	0.2
Kiomo	27.6	27.6 (4.3)	1.4	1.4 (0.3)	0.0

[1] significantly ($p<0.05$) different from Kiomo

Table 7.20: Moth emergence and stem borer population, measured by average number of exit holes per stem and combined number of larvae, pupae and exit holes per stem at the three locations of the on-farm trial (short rains 2001/2)

Location	Exit holes		Stem borer population	
	Observed	Prediction (s.e.)	Observed	Prediction (s.e.)
Kamuwongo	1.2	1.2 (0.2)[1]	3.8	3.8 (0.4)[1]
Nguuku	1.1	1.1 (0.1)[1]	4.1	4.1 (0.3)[1]
Kiomo	0.2	0.2 (0.2)	1.5	1.5 (0.4)

[1] significantly ($p<0.05$) different from Kiomo

In the long rains (March – July 2002), stem borer damage was assessed through dead hearts, length of tunnelling and chaffy heads. The level of dead hearts and chaffy heads in the Kiomo plots was lower than other sites. At 6-8 leaf stage, the plots in Kamuwongo suffered significantly ($p<0.05$) higher level of dead hearts than the other sites (Table 7.21). At crop maturity, the plots in Nguuku had significantly ($p<0.05$) more chaffy heads than the other sites (Table 7.23). The Nguuku plots still outperformed the other sites in yield. Chaffy heads are caused by the stem borers' tunnelling in the peduncle and restricting the flow of assimulates to the heads.

Table 7.21: Effect of four different ratooning methods on early stemborer damage, measured by average number of deadhearts at 6-8 leaf stage at the three locations of the on-farm trial (long rains 2002)

Methods[*]	Number of deadhearts at 6-8 leaf stage			
	Site			Mean[1]
	Kamuwongo	Nguuku	Kiomo	(s.e.)
M1(cut at harvest)	12.1	2.3[5, 6, 7]	0.6[5, 6, 7]	5.0 (0.5)[3, 4]
M2 (thinned)	7.1[5]	0.9[5, 6, 7]	0.3[5, 6, 7]	2.7 (0.5)[2]
M3 (cut at onset)	10.7	2.3[5, 6, 7]	0.7[5, 6, 7]	4.4 (0.5)[3]
M4 (direct sown)	5.1[5]	0.9[5, 6, 7]	0.4[5, 6, 7]	2.0 (0.5)[2]
M5 (Gadam)	10.8[5]	2.8[5, 6, 7]	0.4[5, 6, 7]	3.5 (0.5)[3]
Mean (s.e.)[1]	10.2 (0.5)	2.1 (0.4)[1]	0.5 (0.5)[1]	

[1] significantly ($p<0.05$) different from Kamuwongo site

[2] significantly ($p<0.05$) different from cropping method M1: stems cut at harvest

[3] significantly ($p<0.05$) different from cropping method M4: direct sown

[4] significantly ($p<0.05$) different from M3: previous season's stems cut at onset of rains

[5] significantly ($p<0.05$) different from Kamuwongo plots, M1: stems cut at harvest

[6] significantly ($p<0.05$) different from Kamuwongo plots M3: previous season's stems cut at onset of rains

[7] significantly ($p<0.05$) different from Kamuwongo plots M5: Gadam

The different ratooning methods had a significant ($p<0.05$) effect on the number of dead hearts (Table 7.21). Thinning the tillers (M2) by removing the older and most badly damaged tillers reduced the number of dead heart compared to non-thinning of the tillers (M1), with 2.7 and 5.0, respectively. This was most obvious under the heaviest infestation at site of Kamuwongo. The plots that were thinned (M2) had similar levels of dead hearts as the direct sown plots, with 2.7 and 2.0, respectively. The level of dead hearts in the plots, where the previous season's stems were cut at the onset of rains (M3) had a similar or fewer stem borers than plots ratooned at harvest (M1), with 5.0 and 4.4, respectively.

Table 7.22: Effect of four different ratooning methods on stem borer damage at crop maturity, measured by average length of tunnelling (cm) per stem at the three locations of the on-farm trial (long rains 2002)

Methods	Length of tunnelling (cm) per stem			
	Site[1]			Mean[1]
	Kamuwongo	Nguuku	Kiomo	
M1(cut at harvest)	22.4	15.8	37.7	24.0
M2 (thinned)	17.3	16.8	15.1	16.7
M3 (cut at onset)	19.4	21.5	20.9	20.7
M4 (direct sown)	18.1	20.1	22.3	20.2
M5 (Gadam)	26.9	18.9	20.5	22.1
Mean[1]	20.4	18.9	24.1	

[1] none significantly (p<0.05) different

Table 7.23: Effect of four different ratooning methods on stem borer damage at crop maturity, measured by average number of chaffy heads at the three locations of the on-farm trial (long rains 2002)

Methods	Number of chaffy heads			
	Site			Mean
	Kamuwongo	Nguuku	Kiomo	(s.e.)
M1(cut at harvest)	7.0	26.4[3]	0.3	12.9 (1.4)[4]
M2 (thinned)	7.1	22.5[3]	0.3	11.5 (1.4)[4]
M3 (cut at onset)	13.6	27.3[3]	0.5	16.1 (1.5)[4]
M4 (direct sown)	4.1	5.6	0.0	3.2 (1.5)[3]
M5 (Gadam)	7.0	25.1[3]	0.6	13.1 (1.5)[4]
Mean (s.e.)	8.7 (1.3)[2]	25.3 (1.0)	0.4 (1.3)[1, 2]	

[1] significantly (p<0.05) different from Kamuwongo site

[2] significantly (p<0.05) different from Nguuku

[3] significantly (p<0.05) different from Nguuku plots under M4: direct sown

[4] significantly (p<0.05) different from M4: direct sown

At crop maturity, neither the different sites nor the crop methods had a significant effect on the length of tunnelling per stem (Table 7.22). However, the number of chaffy heads was affected by site and cropping method (Table 7.19). The direct sown plots had significantly fewer chaffy heads than the ratooned methods, with 3.2 and 11.5-16.1, respectively. The plots where the previous season's stems were cut at the onset of rains (M3) had the highest number of chaffy heads, with 16.1. At 5-7 leaf stage, the thinning of the tillers (M2) reduced the number of dead hearts in comparison to non-thinning (M1), but by crop maturity there was no longer any difference between the two methods in the average number of chaffy heads, with 11.5 and 12.9, respectively. The relationship between yield and the stem borer factors of dead hearts and chaffy heads was investigated using correlations. None of these factors was related to unthreshed or threshed yields.

In the long rain crop, *Chilo partellus* was again the dominant species of stem borer. The number of live stem borers counted in the stem was lower than in the short rains. However, the two seasons had similar number of stem borers (larvae+pupae+exit hole) per stem when the whole season is taken into account. In the long rains, there was no significant ($p<0.05$) difference in the number of larvae, pupae and exit holes per stem between the different cropping methods or sites (Table 7.24-28). Over the season, the three sites recorded similar numbers of stem borers (larvae+pupae+exit holes) per stem, with Kamuwongo, Nguuku and Kiomo recording 3.9, 3.6 and 3.7 per stem, respectively. Under the different cropping methods the stem borer per stem ranged from 3.2-4.0 per stem. The number of stem borers per stem did not seem to relate to the stem borer damage factors of dead hearts or chaffy heads.

Table 7.24: Effect of four different ratooning methods on stem borer population at crop maturity, measured by average number of larvae and pupae per stem at the three locations of the on-farm trial (long rains 2002)

Methods	Live stem borers per stem			
		Site[1]		Mean[1]
	Kamuwongo	Nguuku	Kiomo	
M1(cut at harvest)	1.1	0.9	2.6	1.4
M2 (thinned)	0.7	0.9	1.2	0.9
M3 (cut at onset)	1.0	1.0	1.5	1.0
M4 (direct sown)	1.4	1.3	1.4	1.4
M5 (Gadam)	1.9	1.3	1.4	1.5
Mean[1]	1.3	1.1	1.7	

[1] none significantly ($p<0.05$) different

Table 7.25: Effect of four different ratooning methods on stem borer population at crop maturity, measured by average number of exit holes per stem at the three locations of the on-farm trial (long rains 2002)

Methods	Exit holes per stem			
	Site[1]			Mean[1]
	Kamuwongo	Nguuku	Kiomo	
M1(cut at harvest)	3.0	2.2	2.5	2.6
M2 (thinned)	2.5	2.4	1.8	2.3
M3 (cut at onset)	2.2	2.5	2.0	2.3
M4 (direct sown)	2.2	2.6	1.7	2.2
M5 (Gadam)	3.8	2.6	1.9	2.9
Combined[1]	2.6	2.5	2.0	

[1] none significantly ($p<0.05$) different

Table 7.26: Effect of four different ratooning methods on stem borer population at crop maturity, measured by average number of stem borers (larvae+pupae+exit holes) per stem at the three locations of the on-farm trial (long rains 2002)

Methods	Stem borers (larvae+pupae+exit holes) per stem			
	Site[1]			Mean[1]
	Kamuwongo	Nguuku	Kiomo	
M1(cut at harvest)	4.1	3.2	5.1	4.0
M2 (thinned)	3.2	3.3	3.0	3.2
M3 (cut at onset)	3.3	3.5	3.5	3.4
M4 (direct sown)	3.6	4.0	3.2	3.6
M5 (Gadam)	5.7	4.0	3.3	4.4
Mean[1]	3.9	3.6	3.7	

[1] none significantly ($p<0.05$) different

Table 7.27: Effect of the different cropping methods on the stem borer population and associated damage, measured by average number of larvae, pupae, exit holes and tunnelling (cm) per stem (long rains 2002)

Methods	Tunnel length[1]	Larvae[1]	Pupae[1]	Exit holes[1]	Stem borer population[1]
	Observed	Observed	Observed	Observed	Observed
M1(cut at harvest)	24.0	1.4	0.0	2.6	4.0
M2 (thinned)	16.7	0.9	0.0	2.3	3.2
M3 (cut at onset)	20.7	1.0	0.0	2.3	3.4
M4 (direct sown)	20.2	1.4	0.0	2.2	3.6
M5 (Gadam)	22.1	1.5	0.0	2.9	4.4

[1] none significantly ($p<0.05$) different

Table 7.28: Stem borer population and associated damage, measured by average number of larvae, pupae, exit holes and tunnelling (cm) per stem, at the three locations of the on-farm trial (long rains 2002)

Methods	Tunnel length[1]	Larvae[1]	Pupae[1]	Exit holes[1]	Stem borer population[1]
	Observed	Observed	Observed	Observed	Observed
Kamuwongo	20.4	1.3	0	2.6	3.9
Nguuku	18.9	1.1	0	2.5	3.6
Kiomo	24.1	1.7	0	2.0	3.7

1 none significantly ($p<0.05$) different

End of season workshops

The farmers took into account many factors when choosing their site for the trials. The farmers agreed that the fertility of the soil and water availability were important in the choice of the site. The best soil for a ratoon crop was considered a sandy loam, as sandy soils dry too quickly and with clay soils the run-off is higher and less water is absorbed. Good fertility was identified by the previous performance of crops on the site or the historical siting of cattle boma. Soil moisture was maximised through placing the trials on flat sites, or near the embankments and trashlines to reduce run-off and increase water penetration. The areas near embankments and trashlines usually have higher soil fertility due to the build up of organic matter from decaying crop stover that is placed there by the farmers during land preparation. In Kamuwongo, when growing the two-season sorghum the cut stover is used as mulch around the sorghum stumps to conserve water. The stems are cut at a height of at least 6 inches as lower cutting heights results in the stump drying. One farmer identified a good site by the fact that vegetation stayed green during the dry period.

Several farmers took into account the previous crop and avoided areas where sorghum had been planted the previous season. The reasons given were the build up of pests and low fertility. The farmers consider sorghum to be a heavy feeder and that continuous cropping of sorghum results in reduced soil fertility. The pests they identified as increasing with continuous cropping were smuts, stem borers and soil pests i.e. chaffer grubs. In plots where sorghum had been previously planted the farmers recommended that the area be ploughed in October to expose the soil pests, especially chaffer grubs. The other consideration to the siting of the plots was the ability to protect the site from birds and livestock. Sites near the homestead were considered best for protecting against both birds and livestock, as people working at the homestead could keep an eye on them and neighbours' livestock are less likely to enter. Placing the plots near other crops e.g. millets, which require bird scaring, reduced labour inputs. Protecting the plots from livestock between the short and long rains was considered more of a problem as many farmers release their animals into the fields after harvest to feed on the stover. However, the farmers are reconsidering this practice with the spread of terracing due to the damage the livestock do to the embankments. Several farmers wanted to keep the younger goats away from the green tillers because when kids feed on them they can become ill. The leaves of sorghum contain cyanide, which is at its highest concentration when the plants/tillers are young and declines as the plant ages (Arkel, 1978). By the time the stems reach flowering cyanide levels are no longer a problem.

In all the locations, the farmers considered ratooning to be a practice applicable to their area. In Kiomo location, the general performance under reasonable rains of the direct-sown was considered better than the ratoon crop, due to the lower levels of stem borers and diseases. However, they considered ratooning to be the best practice due to the lower labour input and greater drought tolerance.

In Kiomo location, the farmers compared the performance of crops ratooned before and after the onset of the rains. This comparison was made because very few of the farmers managed to have trials that contained all the methods. Ratooning before the onset of the rains involved removing all the stems at harvest, while ratooning after the onset of the rains involved removing the previous season's stems. The farmers concluded that cutting the stems back before the onset of the rains produced the best ratoon crop. The reasons given were that plants ratooned before the rains had a higher survival rate, produced more tillers and had lower stem borer damage. The higher survival rate was contributed to the ratooned plants losing less water through transpiration. The farmers also liked ratooning before the onset of the rains as it enabled them to assess the performance of the crop and to plough the crop under and re-sow if the performance is poor. Criteria used to assess performance were stump survival rate, quality of tillers produced and level of stem borer damage. However, the farmers noted that when the crop is dry at harvest the rate of survival seemed to be higher if the stems were left standing until the onset of the rains. Ratooning at the onset of rains had the advantage of reducing stem borer damage if the badly damaged tillers are removed. The farmers concluded that when the first crop is good and the crop relatively green it is best to ratoon after harvest, but if the crop is dry it is best to cut after the onset of the rains.

In Nguuku location, the farmers concluded that ratooning at the onset of rains by removing the previous season's stems (M3) was the best practice (Table 7.29). This was because the survival rate was higher; the crop produced many tillers, and seemed to suffer less stem borer damage. The timing and relative low labour input was also considered an important issue. The farmers in Kamuwongo could not agree about the best method and concluded that they needed to continue with the experimentation.

Table 7.29: Good and bad points of the different ratooning methods as listed by the farmers from Nguuku, during the end of season meetongs (long rains 2002)

Method	Good points	Bad points
M1 (cut at harvest)	• lower labour input • early maturing/harvesting • tillers early • large head size with big seed	• low survival rate of stumps • a lot of bird damage • high level of stem borer damage
M2 (thinned)	• big heads with big seed • early maturing	• lowest survival of stumps • high level of stem borer damage • high level of bird damage • high labour input
M3 (previous season's stems cut at onset)	• higher survival rate of stumps • low stem borer damage • numerous and larger heads • vigorous tillers • heavier seed	
M4 (direct sown)	• least stem borer damage • good head size	• uses seed • attacked by birds • latest maturing • highest labour input

Key:

M1 (cut at harvest): (variety Seredo) stems cut at harvest and tillers not thinned

M2 (thinned): (variety Seredo) stems cut at harvest and tillers thinned to the four youngest at on-set of rains

M3 (cut at onset): (variety Seredo) stems from previous season removed at the on-set of the rains

M4 (direct sown): (variety Seredo) (control): direct-planted sorghum

M5 (Gadam): (variety Gadam El Hamam) stems cut at harvest and tillers not thinned

Farmer interviews

A total of 22 individual interviews were completed. All the interviewed farmers considered ratooning to be a good practice and the reasons given were similar to the group meetings. The rankings by the farmers of the performance of the different cropping methods within their plots for yield; survival rate, stem borer damage and general performance are presented in Figure 7.2. The best performing methods were identified as the methods with the highest proportion of the plots with a ranking of one or two, i.e. above average performance.

For the criteria of yield and stump survival the plots where the stems were cut back at harvest (M1) had the highest proportion of plots ranked by the farmers as the best. However, if plots ranked above average are included the plots where only the previous season's stems were cut at onset of rain (M3) are the best performing method. The ratooned plots where only the previous season's stems were cut at onset of rains (M3) also had the lowest stem borer damage and highest proportion of plots rated above average for general performance. The direct sown plots (M4) had the second highest proportion of plots ranked 1 or 2 for general performance and stem borer damage.

When the farmers were asked about their plans for next season, all the farmers were planning to plant a sorghum crop for ratooning. They considered the placing of this crop on fertile parts of the farm worthwhile as it increased the yield and therefore family food security. The most common ratooning method to be implemented by the farmers was where only the previous season's stems are cut at onset of rains (M3) with ten farmers. This was followed by cutting the stems at harvest and thinning the tillers at onset (M2), cutting the stem at harvest (M1), with eight and seven farmers, respectively. The reasons given by the farmers for choosing particular ratooning methods are listed in Table 7.30. Cutting the stems at onset of rains (M3) was particularly popular with farmers from Kamuwongo, with over half the farmers opting for it. Kamuwongo is the driest of the on-farm sites. In Kiomo, a farmer said the ratooning method would depend on the weather; if the temperatures are cool she would cut the stems at harvest (M1). However, if the temperature were high she would leave the stems standing until the onset of rains (M3). She thought plants cut back at harvest (M1) did especially well when the dry period between the rains was short.

Table 7.30: Reasons given for planning to implement specific ratooning methods in the next crop cycle (2002-3), by farmers from all three on-farm sites

Method	Reasons
M1 (cut at harvest)	• encourages early tillering and water conservation • low labour input • does especially well if the dry season is not too hot or long • easy to apply
M2 (thinned)	• produces vigorous tillers with large heads • high yielding • enable weak and badly damaged tillers to be removed
M3 (cut at onset)	• produces vigorous tillers • low stem borer damage • tillers do not dry • high survival rate • high yielding • low labour input

M1 (cut at harvest): (variety Seredo) stems cut at harvest and tillers not thinned

M2 (thinned): (variety Seredo) stems cut at harvest and tillers thinned to the four youngest at on-set of rains

M3 (cut at onset): (variety Seredo) stems from previous season removed at the on-set of the rains

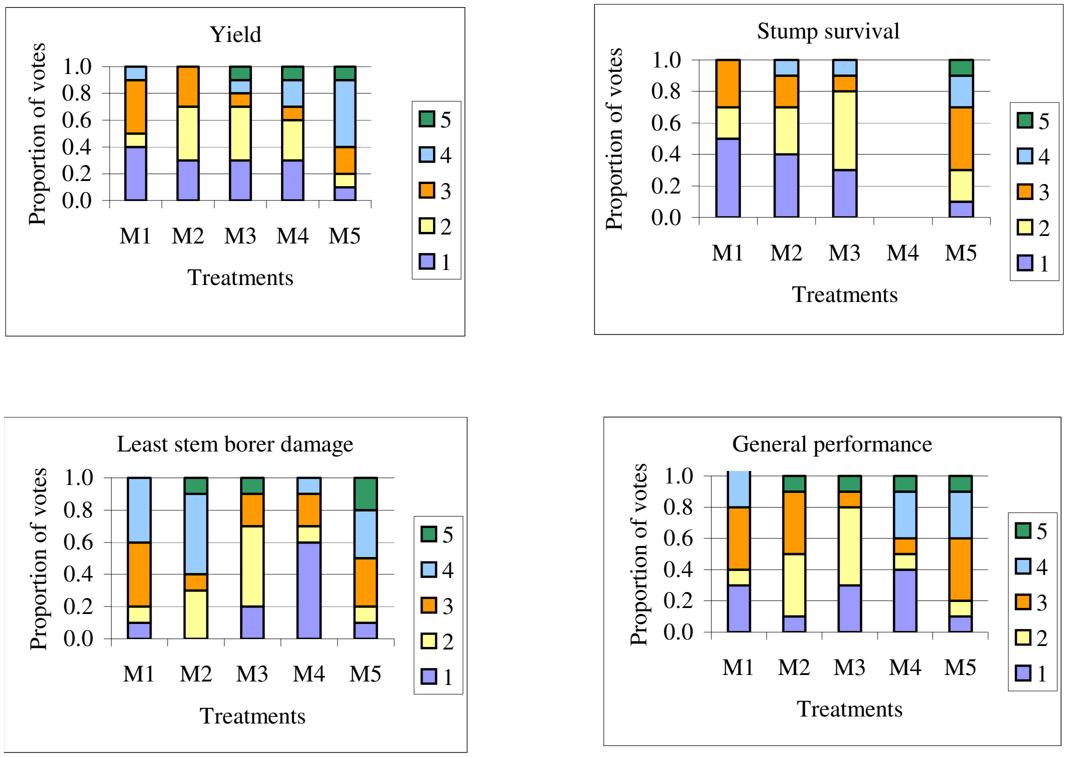


Figure 7.2: Frequency of individual farmer's rankings during the individual interviews on the different ratooning methods, presented as a proportion of the number of plots assessed, for selected criteria in the locations of Nguuku, Kamuwongo and Kiomo (long rains 2002)

Key:

Rankings:

1 best, 2 above average, 3 average 4 below average, 5 worst

Treatments:

M1: (Serado) stems cut back at harvest and tillers are not thinned

M2: (Serado) stems cut at harvest and the tillers thinned to the four youngest at on-set of rains

M3: (Seredo) previous season's stems removed just before the on-set of the rains

M4: (Seredo) direct sown sorghum

M5: (Gadam El Hamam) stems cut at harvest and tillers are not thinned

1.34 DISCUSSION

Chilo partellus was the dominant species in the three locations studied. The only other species found was *Busseola* fusca and this was only found a few times at Kiomo location in the second cropping cycle (2000/01). This confirms Songa *et al.,* (2002) who reported that *C. partellus* is the dominant species in Eastern Province, Kenya. During the four seasons monitored, Kiomo location always recorded a significantly lower stem borer damage and population. The significant difference found between the locations illustrates the variations in damage and populations that can be found in relatively close locations. In the focused survey (Chapter 4), respondents from Kamuwongo considered stem borers a greater problem than those from Nguuku. However, during the assessments of the stem borer damage and populations were similar in the two locations. The hotter conditions and often-poor rainfall in Kamuwongo may explain the greater concern for stem borers, as these conditions would exacerbate the plant stress and reduce the ability of the plant to cope with the damage caused by stem borers. Higher stem borer numbers and damage in season's of poor rainfall have been reported by many researchers including Niyibigira *et al.,* 2001, Kfir, 2002 and Mohamed *et al.,* 2004. The cause of this higher damage is considered to be due to an interaction of factors that include the plant being under water stress, thus less able to compensate for the damage caused by stem borers, less rain to wash stem borer eggs and larvae from the plant (Midega *et al.,* 2005), and few choices of plant host for the stem borer moths to lay eggs on (Mohamed *et al.,* 2004) resulting in a higher density of stem borer.

1.34.1 Direct sown crop vs. ratooned crop

Farmers considered ratooning a good practice. They were appreciative of the ability of a ratooned crop to produce a harvest under conditions that caused the direct sown crop to fail. The ratooned crop out performed the direct sown crop in both seasons (Table 7.31). The drought tolerance of the ratooned crop was considered the main benefit of ratooning, though the low labour input was also highly rated. The earlier maturity of the ratooned crop was liked and during the trial, the level of bird damage in the crop was not considered any more serious than on the direct sown sorghum.

Table 7.31: Threshed grain yield achieved in direct sown and ratooned crops in the two cropping cycles (2000/02)

Cropping Method	1st cropping cycle (2000/01)		2nd cropping cycle (2001/02)	
	Short rains	Long rains	Short rains	Long rains
Direct sown	932	26	1580	551
Ratooned	N/A	264	N/A	686

Comparisons of the direct sown crops with the ratooned crops for stem borer population per stem showed no constant trend. The direct sown crop did not always have less damage or a lower population per stem than the ratooned crop. In the second cycle, the stem borer population per stem recorded in direct sown plots (M4) was similar to the ratooned plots, though the number of dead hearts and chaffy heads was significantly less. However, farmers considered the level of stem borer damage on the ratooned crop to be less or similar to that on the direct sown crop. Farmers' knowledge of the damage caused by stem borers is good. They relate leaf feeding holes, dead hearts, stem tunnelling, non-emergence of the head and chaffy heads to stem borers. They also relate severe stem borer damage to dry seasons and plants under water stress. The level of knowledge shown by the farmers in Mwingi was similar to that of farmers on the Kenyan Coast (Banhof *et al.,* 2001)

The lower drought tolerance of the direct sown crop makes it more susceptible to the added stress caused by the stem borers and farmers are more interested in yield rather than stem borer damage *par se*. The farmers' assessments incorporated this, especially in the first cropping cycle, when background knowledge was probably used more in their conclusions than what was present in the trails. The inclusion of specific on-farm plot monitoring in the second cycle helped to overcome this. The use of both individual interviews with socio-economists and crop monitoring with researchers was incorporated to triangulate results. The individual interviews produced more extreme preferences for particular methods than the crop monitoring assessments. These interviews were carried out at/or after harvest, sometimes away from the plots and the respondents may have drawn more on background knowledge and personal preference than "reality". This and/or the recorders presenting assessments differently to the farmers may explain the slight discrepancy between the two collection systems. The calculation of the stem borer population per hectare (Table 7.32) showed the stem borer populations were higher in the ratooned crop than the direct sown crop; this higher population was due to the higher number of stems per hectare rather than a higher number of stem borers per stem. The number of stem borers per stem was similar for all treatments, however as the ratooned crop was more established and earlier than the direct sown crop it shows a greater ability to tolerant the stem borer damage.

Table 7.32: An estimate of the stem borer population per hectare of sorghum under the different agronomic and ratooning methods (long rains 2002)

Agronomic Practice	Heads/ha	Stem borers per stem			Stem borers per hectare[1]		
		Exit holes	Larvae	Stem borers	Exit holes	Larvae	Stem borers
M1(cut at harvest)	42,588	2.6	1.4	4.0	110,729	59,623	170,352
M2 (thinned)	41,805	2.3	0.9	3.2	96,152	37,625	133,776
M3 (cut at onset)	40,245	2.3	1.0	3.4	92,564	40,245	136,833
M4 (direct sown)	32,145	2.2	1.4	3.6	70,719	45,005	115,722
M5 (Gadam)	19,665	2.9	1.5	4.4	57,029	29,498	86,526

[1] Estimated from number of heads per hectare * number of stem borers per stem

Reliability of yield under severe conditions is a very important factor in crops grown for food security. Farmers require a performance under conditions where other crops fail and may prefer a lower yielding, but more reliable cropping method rather than an erratic method than may yield more under good conditions. The practice of ratooning sorghum increases food security by giving an improved yield in poor seasons. The down side is that a ratooned crop supports a larger stem borer population (Table 7.31). The farmers weighed up the pros and cons and concluded the practice of ratooning was an acceptable practice for their farms.

1.34.2 Different ratooning methods

Comparison of the different ratooning methods on variety Seredo showed no significant difference in levels of stem borers per stem. However, the results showed a trend with the plots cut back at harvest (M1) always the most damaged and with the highest stem borer population per stem. At 6-8 leaf stage, plots where the stems were cut at harvest (M1) had the highest number of dead hearts. The removal of damaged tillers (M2) reduced the number of dead hearts recorded significantly compared to non-removal (M1). At crop maturity, the plots where the tillers had been thinned (M2) still showed a reduced number of chaffy heads compared to non-thinned plots (M1), though it was not significantly ($p<0.05$) less. The cutting of stems at harvest (M1) promotes tillering (Dogget, 1988), resulting in the plants carrying the most 'green' through the dry period between the rains. The higher level of stem borers suggests that these plants are more effective as a 'green-bridge' between the rains than the other methods. The thinning of the most damaged tillers (M2) seemed to reduce this effect. Ratooning the previous season's stems at the onset of the rains (M3), would slightly delay production of the tillers and these tillers seem less affected by stem borers than the more advanced tillers produced when the plants were ratooned at harvest. The delay in cutting to onset had a similar effect as thinning the tillers. However, in the first cycle, the removal of the all stems including the new tillers at the onset of the rains (M3) resulted in the farmers reporting the crop being severely affected by stem borers. The removal of all the stems would have resulted in the tillers being younger than tillers in other plots, particularly at the beginning of the season. The young tiller may have been more desirable to the moths that were ready to lay eggs, or the damage may have been more noticeable. Wale (1999) found that the stem borer moths would lay their eggs on the younger plants in preference to old plants and whether a planting was badly infested depended on the age of the young plants at the time of the emergence of the moths. The technical assessments of stem borer levels showed no significant difference between the different ratooning methods. The results over the different sites suggest that the geographic location of the cropping site and its rainfall pattern had a stronger influence on the stem borer population and the level of damage.

Table 7.33: Threshed grain yield (kg/ha) achieved in the different ratooning methods in the two cropping cycles (2000/02)

Ratooning method	Long rains 2001	Long rains 2002
M1 (cut at harvest)	139	732
M2 (thinned)	191	730
M3 (cut at onset)	193[1]	596[2]
M4 (direct sown)	11.0	551

[1] all stems cut back at onset of rains

[2] previous season's stems cut back at onset of rains

The farmer perception of stem borer damage under the different ratooning methods was not constant. In the first cropping cycle, farmers thought the tillers produced by cutting the stem at harvest (M1) were more vigorous and showed lower stem borer damage. The thinning of tillers was thought to increase the vigor of the remaining tillers, but also reduce the ability of plants to compensate for later stem borer damage. Under the stem borer pressure in the trials, there was no evidence of stem borer damage reducing yield in thinned plots compared to non-thinned plots. In the second cropping cycle, farmers concluded that cutting the stems at harvest (M1) resulted in the highest stem borer damage and this was confirmed by all the factors used to measure stem borer populations and damage. These observations are only based on 1 or 2 crops and as previously reported in Chapter 4, stem borer populations seem to be highly influenced by the rain fall quantity and pattern. Therefore, further investigation is needed.

The farmers considered the timing of the activity of thinning the tillers to be important. They related the thinning to plant death when carried out while the plants were under stress and/or the rain is not received soon after the action. Late thinning was considered a poor option as the tillers had utilised resources and the maturity would be delayed. The farmer conclusions are similar to those reported by Escalada and Plucknett, (1975) and Milthrope and Davidson (1966). These researchers found that damage early in the season could result in plant death and the oldest tillers were less vigorous than the younger tillers and often failed to be productive. The lack of productive was explained by the new root system not being developed enough to support their growth.

The plots where only the previous season's stems were cut back at onset of rains (M3) were considered by the farmers and extension workers to have the highest plant survival rate of the different methods. Several farmers identified this method to be particularly effective when the stems at harvest were dry. The survival of plants is an important factor in the acceptability of the practice in the farming system. The labour required for bird scaring means that a 'reasonable' crop is needed to make it worthwhile. Ratooning at the onset of rains (M3) means no labour is inputted, until the farmers were sure they were going to keep the crop. However, in the season assessed, the yield achieved was not as high as when stems were cut at harvest. Despite this, the perceived higher survival rate and lack of labour input made cutting at onset (M3) the farmer choice. Leaving the stalks standing may increase the carry-over of diapausing larvae, as Pat (1996) found that significantly higher proportions of larvae and pupae survived in standing stalks compared to stalks that had been cut and layed horizontally on the ground. However, the present farmer practice is to leave the stalks standing for the livestock to feed on and the stalks will stay standing until the field is prepared for the next crop.

The farmers' opinion on the best cutting height was between 7-15cm. The problem of the tillers breaking off when the length of the stubble is left long has also been reported by Escalada and Plucknett, (1977). There are several reports that tillers are more vigorous when produced from the basal nodes and a low cutting height produces the greatest number of tillers from basal nodes (Mackenzie *et al.*, 1970; and Escalada and Plucknett, 1977). However, these researchers also reported that short stubble was more easily invaded by pathogens and completely removing the stem reduced the carbohydrate reserve available for survival and regrowth. The symptoms of charcoal rot were observed on many dead stumps, which reflects Gray *et al.,* (1991) report that *Macrophomina phaseolina* was significantly associated with non-survival of stumps. This fits the farmers' observation that a too short stubble reduced survival.

A problem with on-farm trials is the variability between sites, farms and management, which result in a wide variability in the data collected. The large effort required to run on-farm trials compared to on-station means that cost and time often decides the number of replicates. On the positive side, the "technology" is tested *in situ*, which in this study are the cropping practices. Under these conditions the farmers' opinions can be considered as important as the technical "technologies" (Pretty, 1995). By involving end users early in the assessment, non-suitable practices can be changed or adapted to farmer conditions. This can avoid resources being spent on unsuitable "technologies".

The information and experience gained during the on-farm trial was used to develop a decision tree (Figure 7.3). However, the tree is based on only 1-2 ratooned crops and needs to be tested further. The decision tree is based on two areas: 1) the production of strong plants in the first season and 2) the timing of the cutting back of the plants. To produce strong plants the site needs to retain soil moisture, which is aided by: being flat and / or terraced to reduce run off; the incorporation of manure to increase the fertility and the organic component of the soil; and tilling the soil to increase absorption and penetration of the rain. The production of strong plants also requires that the plants are not overcrowded and growth is not interrupted. This can be achieved by increasing the spacing and planting fewer seeds per hill to avoid thinning, and weeding early to avoid competition. The plants need to be harvested as soon as the plants are mature and ratooned straight away while the stems are green to increase the survival rate of the stumps during the dry period. However, if the crop is dry at harvest then cutting back the previous season's stem after the onset of the rains increases survival rate. The height of the stem after ratooning needs to be approximately 15cm. Shorter stems result in lower survival rates, while longer stems result in tillers being produced on the stem and not from the base. The thinning of weak and stem borer infested tillers was also considered to be beneficial, but labour intensive at at time when labor is in short supply. There was some debate among the farmers about the level of stump survival rate needed to be worthwhile continuing with a rationed crop. The minimum acceptable level was 50% of the stumps surviving, but the cut off point would vary depending on the rainfall.

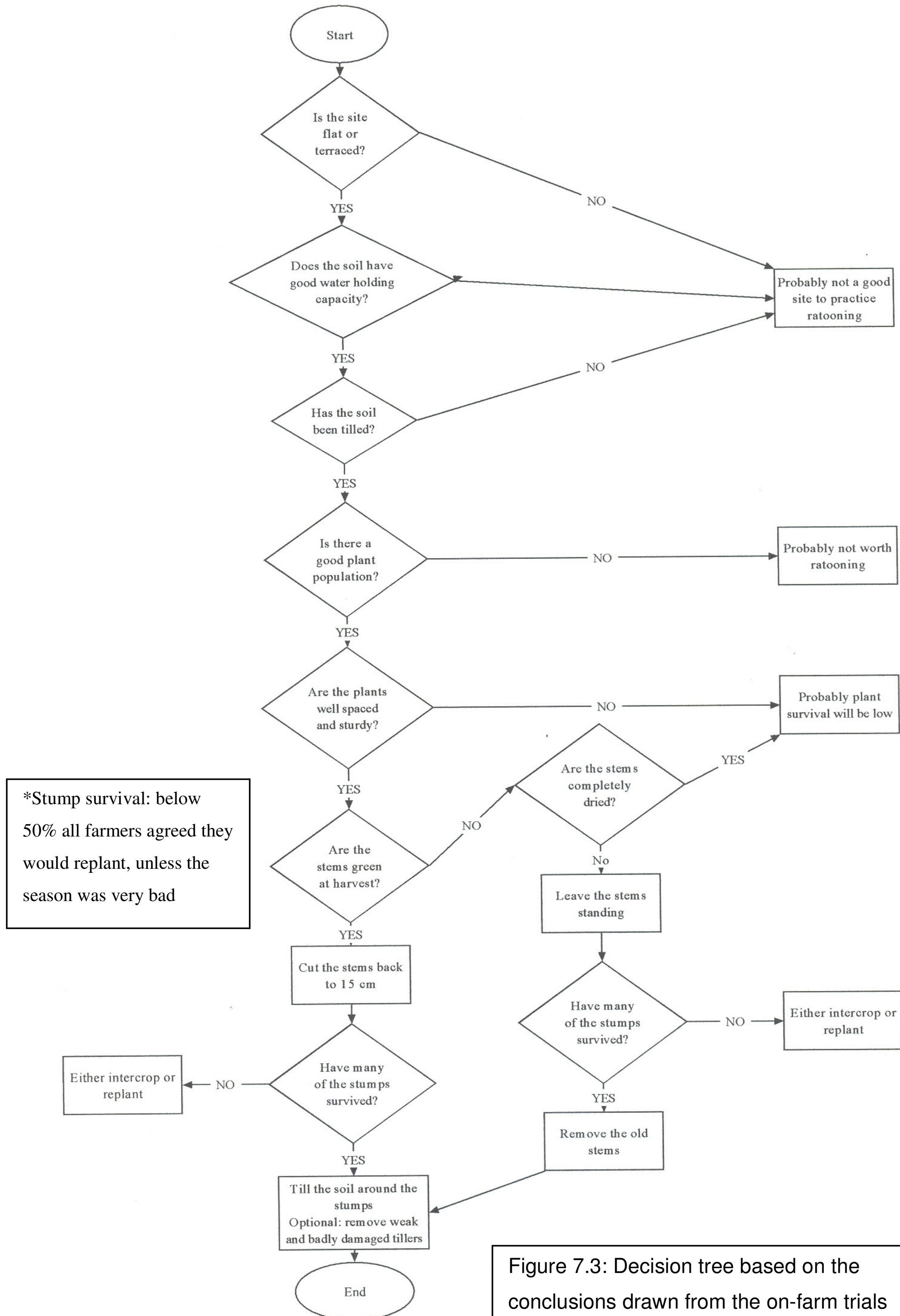


Figure 7.3: Decision tree based on the conclusions drawn from the on-farm trials

1.35 MAIN CONCLUSIONS

1. The yield of the ratooned crops outperformed the direct sown crop in both seasons.
2. Ratooned crop was more drought tolerant than the direct sown crop and produce a yield when the direct sown crop failed.
3. Cutting back the stems at harvest produced a higher yield than cutting the stems at the onset of rains.
4. Cutting the previous season's stems at the onset of rains increased plant survival when the stems were dry at harvest.
5. The preferred method for farmers was to cut the previous season's stems at the onset of rains.

Plate 7.1: KARI socio-economist interviews farmer Rosemary Musiumi. Mama Musiumi has just harvested her ratooned crop, while the direct sown crop has failed (Nguuku, August 2001)

Plate 7.2: Participating farmers discussing their on-farm trials at an end season workshop (Nguuku August 2001)

ASSESSMENT OF THE PERFORMANCE ON-FARM OF FOUR DIFFERENT SORGHUM VARIETIES UNDER THE AGRONOMIC PRACTICE OF RATOONING

The second component of the on-farm investigation was to assess locally available short duration varieties for their performance under the practice of ratooning. The varieties were identified from the focused survey and in the first cycle of the ratooning methods on-farm trials. The varieties were tested for one cropping cycle that ran from October 2001 – July 2002.

1.36 APPROACH

In each of the three locations, Kamuwongo, Kiomo and Nguuku ten farmers were selected for participation in on-farm trials. The farmers were selected from members of the self help groups. Selection was carried out by the members in an open meeting. Each farmer had a site containing four plots each a minimum of 12x7m in size. Each farm was therefore a replicate in the trial. Each farmer decided the planting order of the varieties in their plots. The plots were ratooned after harvest and the tillers not thinned (i.e. M1: cut at harvest). The varieties tested for one cropping cycle that ran from October 2001 – July 2002.

The four sorghum varieties tested on-farm were:

1. *Variety 1*: Seredo
2. *Variety 2*: Gadam El Hamam
3. *Variety 3*: Kari-mtama 1
4. *Variety 4*: PGRCE 216740

1.36.1 Data collection

The trial was completely farmer managed and they carried out the assessments during the season. Each farmer was given a data sheet and a notebook to record data. The assessments included stem borer damage, and crop performance at crop maturity, and yields. When farmers were illiterate, they received help from their children and other group members. In the pre-planting meetings, the farmers and extension officers were taken through the form and details discussed. The primary aim of the assessments was to encourage the farmers to monitor their plots and notice any differences. At the end of the season, data was collected through individual interviews and group workshops. Similar techniques were used as under the on-farm ratooning methods trial.

1.37 RESULTS AND DISCUSSION

The level of literacy in the area is low and few farmers managed to fill in the forms. This illustrates the limitations of purely farmer-managed trials. However, the use of data sheets seemed to promote a sense of involvement and equality between farmers and researchers and at the end of season meeting many of the farmers brought the uncompleted sheets.

1.37.1 Short rains (October 2001 – January 2002)

Group meetings

The opinions of the varieties as expressed by the farmers when describing their own plots are tabulated in Table 8.1. The farmers had not harvested when the meetings took place, so they were assessing pre-harvest factors. The performance descriptions used by the farmers predominantly covered germination and yield. While the level of stem borer damage and the ability of the variety to recover were the two most frequent pest descriptions. In Nguuku and Kamuwongo locations, the farmers noted that the dry planted sorghum was more affected by stem borers than the later planted sorghum, and usually the reverse is true.

In discussing the varieties at the Nguuku and Kamuwongo group meetings, the number of good and bad points used by the farmers to describe the performance of each variety in their trial was recorded. The variety Seredo had the best proportion of good to bad points of 3.6. This was followed by Kari-mtama 1 (3.3), Gadam El Hamam (2.5) and lastly PGRCE 216740 with 1.2. However, there was a wide variation between, Nguuku and Kamuwongo. In Nguuku, Gadam El Hamam (3.8) had the best proportion followed by Seredo (2.5), Kari-mtama 1 (2.4) and PGRCE 216740 (0.5). While in Kamuwongo, Seredo had the highest proportion (5.7), followed jointly by PGRCE 216740 and Kari-mtama 1 (4.7) then Gadam El Hamam (1.9).

During the farmer meetings at Nguuku and Kiomo, the participants assessed the variety plots of the host farmer. In Nguuku, the outcome was similar to their own plots, with Gadam El Hamam having the highest proportion and PGRCE 216740 the least. In Kiomo, the variety PGRCE 216740 (5.0) had the highest proportion of good to bad points, and Gadam El Hamam (1.8) the least, which was opposite to Nguuku.

All the farmers considered Gadam El Hamam to be very early maturing and drought tolerant, so it received a score of 5 (scoring system: 5 very good, 1 very bad) from all the farmers. The farmers also agreed that PGRCE 216740 took the longest to reach maturity, followed by Kari-mtama 1 and Seredo (Figure 8.1).

Yield was assessed using head size, as the crops were still in the field. In Kamuwongo and Kiomo, Gadam El Hamam received the lowest score 3, but in Nguuku, PGRCE 216740 was considered to have the smallest heads (score 3.5) (Figure 8.1). In Kiomo, however, PGRCE 216740 had the largest heads (score 5). This suggests that the performance of PGRCE 216740 varied considerably within Mwingi District. The overall performance scores suggests that the farmers considered all four varieties to be good to very good, with Seredo considered slightly better than Gadam El Hamam and Kari-mtama 1 (Figure 8.1).

One of the concerns the farmers have about the practice of ratooning is the level of stem borer damage that can result from the ratooned crop being an attractive food source between seasons and therefore attracting a high stem borer population and incurring the associated damage. The varieties were therefore assessed for stem borer tolerance. The farmers consider a sorghum variety to be tolerant to stem borer infestation when infested plants still flower and produce good filled head. The degree of tolerance is measured by the effect on the head size and grain filling under stem borer pressure; the greater the susceptibility of the variety to stem borers the greater the effect on head size and grain filling. Other factors are the number of chaffy heads, non-emergence of heads from the flag leaves, dryness of the stems and stem lodgings. The ability of a variety to recover from an early infestation i.e. deadhearts is also considered in assessing tolerance. The number of productive tillers produced measured this ability. Tillering is considered a desirable characteristic, if the tillers produced are productive.

Table 8.1: Descriptions used by the farmers in Nguuku and Kamuwongo when describing the performance of the four sorghum varieties on their farms.

Variety	Descriptions	
	Performance	Stem borers
Seredo	• fair to good • big heads • planted well • poor to good germination	• none to high stem borer infestation • moderate to good recovery from stem borer infestation through tillering
Gadam El Hamam	• fair to very good • very early maturing • poor to good germination	• none to high stem borer infestation • moderate to good recovery from stem borer infestation through tillering
PGRCE 216740	• poor to excellent performance • late maturing • productive tillers • poor to good germination • requires good land to reach maturity	• none to extensive stem borer infestation and damage • moderate to good recovery from stem borer infestation through tillering
Kari-mtama 1	• fair to good • poor to good germination • good tillers • big heads • later maturing than Seredo	• none to some stem borer infestation • good recovery from stem borer damage

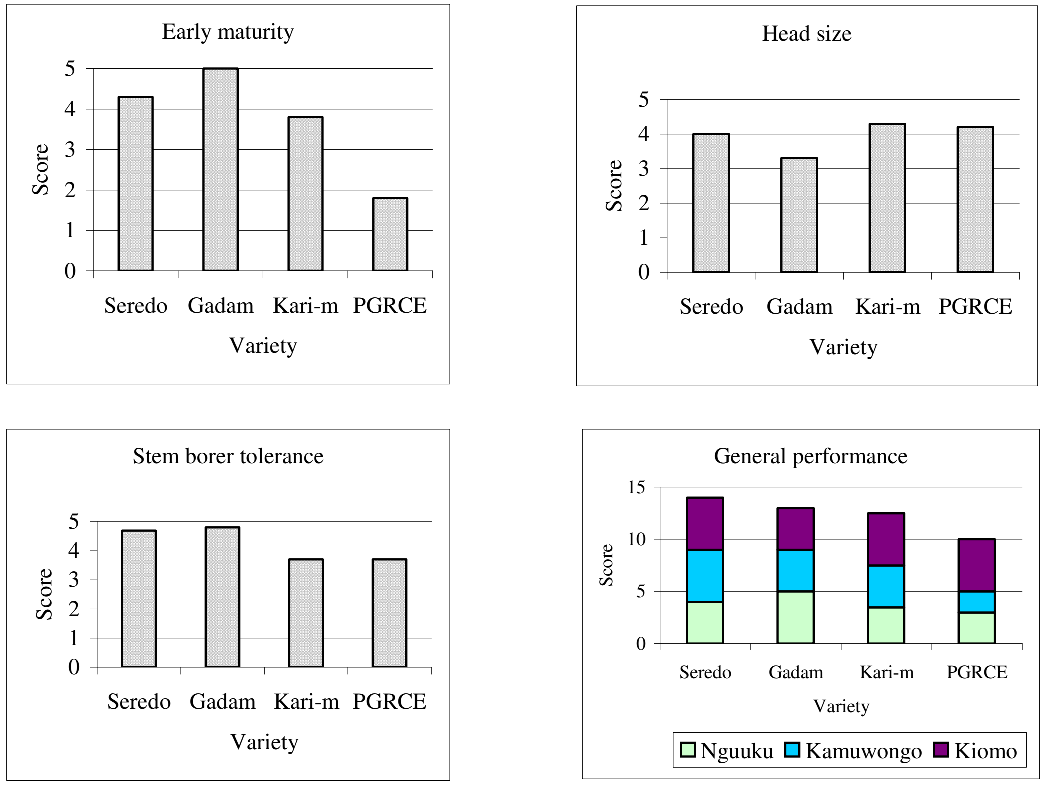


Figure 8.1: Average of the farmer group scores for the criteria the farmers identified as important in assessing a variety's performance: early maturity, head size and stem borer tolerance; and group scores from each location for general performance. Scores produced at the end of season meetings in Nguuku, Kamuwongo and Kiomo (short rains 2001/02)

Scoring system: Each variety was given a score for each criterion, with 5 very good, 4 good, 3 neither good nor bad, 2 bad, 1 very bad

In Kiomo, the level of stem borers was low; so all the varieties were scored as 5. In Nguuku and Kamuwongo, the level of stem borers were higher than in Kiomo and the farmers considered that the varieties did show different levels of tolerance. Gadam El Hamam was considered to cope best, followed by Seredo, with PGRCE 216740 and Kari-mtama 1 showing no difference (Figure 8.1). Both Gadam El Hamam and Seredo coped with early stem borer damage by producing productive tillers. This was less evident with the other two varieties.

The farmers identified several characteristics that they thought a sorghum variety required to perform well under the practice of ratooning. These were:

1. Drought tolerance

2. Strong stems
3. Stems that remain green even when the heads are mature
4. Plants that produce tillers from the stem base in the later stages of the crop cycle.

These characteristics were identified by the farmers when assessing the varieties' ability to regenerate after harvest and to survive the dry period between the end of the short rains and the beginning of the long rains. In Mwingi District, this period can last from late December to mid-March. Farmers related the ability to regenerate to the strength of the stems, greeness of the plant at crop maturity and the ability of the plants to tiller especially after harvest. This relates to Borrell and Hammer (2000) identification that whether non-senescence in sorghum is due to delayed onset or reduced rate of senescence it is very important for supporting biomass and grain yield under post-flowering drought stress. The farmers considered survival rate between the two seasons to be mainly due to drought tolerance. However, varieties that regenerate quickly i.e. start to tiller while the crop matures; tend to have a higher survival rate than varieties, which do not start to tiller until the stems are cut back.

The farmers assessed the varieties for ability to perform well under the practice of ratooning using the criteria identified by the farmers, which were named the ratoonability index. The ability to stay green was gauged by the number of green leaves and the greeness of the stems of the plants in the field. Drought tolerance was assessed by the performance of the variety during the season against rainfall, and the state of the dryness of the plants at harvest. Stem strength took into consideration the amount of lodging and the diameter of the stems. Thick stems are considered by the farmers to dry out more slowly, and retain more moisture to help the plants to produce tillers. Ability to tiller was assessed using the number of productive tillers produced as a result of deadhearts, and the production of tillers as the crop reaches maturity. This included the number of tillers produced and their development stage. For example, when assessing the plots, the tillers on Gadam El Hamam were more developed, often having several leaves, compared to the tillers on Seredo, which were mostly visible as buds at the stem base.

The variety Gadam El Hamam received the highest average scores in three of the four factors identified as important in gauging the potential performance of a variety under the agronomic practice of ratooning (Figure 8.2). Gadam El Hamam received the highest average score for drought tolerance (5.0), stem strength (4.8) and ability to tiller (4.5) and was second to PGRCE 216740 on ability to stay green. The variety Kari-mtama 1 had the lowest average scores in all the factors. Using these criteria to predict ratoonability and assuming they are of equal importance. This predicts that Gadam El Hamam (18.6) would be the best performer, followed by PGRCE 216740, Seredo and lastly Kari-mtama 1. The scores from the different locations followed a similar pattern.

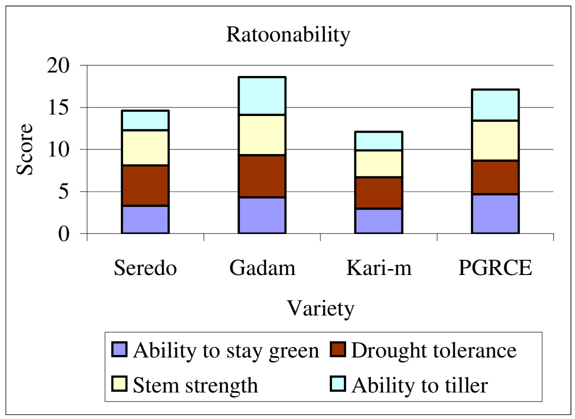


Figure 8.2: Average of the farmer group scores for criteria the farmers identified as important for predicting a variety's performance under the practice of ratoonong. Scores produced at the end of season meetings in Nguuku, Kamuwongo and Kiomo (short rains 2001/02)

Scoring system: Each variety was given a score for each criterion, with 5 very good, 4 good, 3 neither good nor bad, 2 bad, 1 very bad

When the farmers were asked to identify which varieties would ratoon well, they predicted a slightly different order to that indicated by the ratoonability criteria. Farmers in Nguuku and Kamuwongo agreed that the variety Gadam El Hamam would probably perform best, and Kari-mtama 1 the least well, but disagreed on the ranking of Seredo and PGRCE 216740. Kamuwongo farmers thought PGRCE 216740 would ratoon well, while both Seredo and Kari-mtama 1 would perform badly, though Seredo slightly less badly than Kari-mtama 1. Overall, the farmers in Kamuwongo thought the present crop would ratoon poorly, because the weather had been very hot, resulting in many of the stems drying and plants with dry stems do not usually regenerate. Of the four varieties, the stems of Seredo and Kari-mtama 1 were most dry, while PGRCE 216740 and Gadam El Hamam stems were still green. However, the Kamuwongo thought the relatively longer maturity rate of PGRCE 216740 may mean that it would not perform well during the long rains, which tend to receive less rainfall than the short rains.

In Kiomo, the farmers ranked PGRCE 216740 first and Kari-mtama 1 second. Their reasons were that stems of PGRCE 216740 were still green and the basal tiller buds were beginning to sprout. The stems of Kari-mtama 1 were also green, but tillers were not visibly, so would probably not perform as well as PGRCE 216740. The Kiomo farmers also thought Gadam El Hamam would do well, as the stems were still green and the tillers already present, but they ranked Kari-mtama 1 higher. They thought Seredo would do poorly, because the stems had dried. Overall, the farmers thought the very poor rains received in the area meant that the survival rates would be low for all varieties. From these discussions it was obvious the farmers were not giving equal weighting to the ratoonability criteria.

1.37.2 Long rains (March – July 2002)

Individual interviews

All the interviewed farmers (n=18) considered ratooning to be a good practice. The reasons given were similar to the participants in the other on-farm investigation. These included: two harvests from the same crop, assured harvest when rains were poor, early maturing, heads emerging clear of the flag leaf, higher yields, more and larger heads, lower labour input and lower bird attack.

Farmers during individual interviews ranked the performance of the different varieties in their plots for yield, survival rate, stem borer damage and general performance. The best performing varieties were: Gadam El Hamam for yield and stump survival; PGRCE 216740 for least stem borer damage; and Gadam El Hamam and Seredo for best general performance (Figure 8.3).

Group meetings

In the discussion groups, variety Gadam El Hamam received the highest proportion of votes. The reasons given for choosing Gadam El Hamam were that it produced the most productive tillers, was early maturing, high yielding, tolerant to stem borer damage, produced good looking, well filled grains, that taste good and have many utilisation options. In both Nguuku and Kamuwongo location, the farmers ranked the other varieties, 2nd Seredo, 3rd Kari-mtama 1 and 4th PGRCE 216740. In Kiomo location, the variety Seredo was voted the best performer.

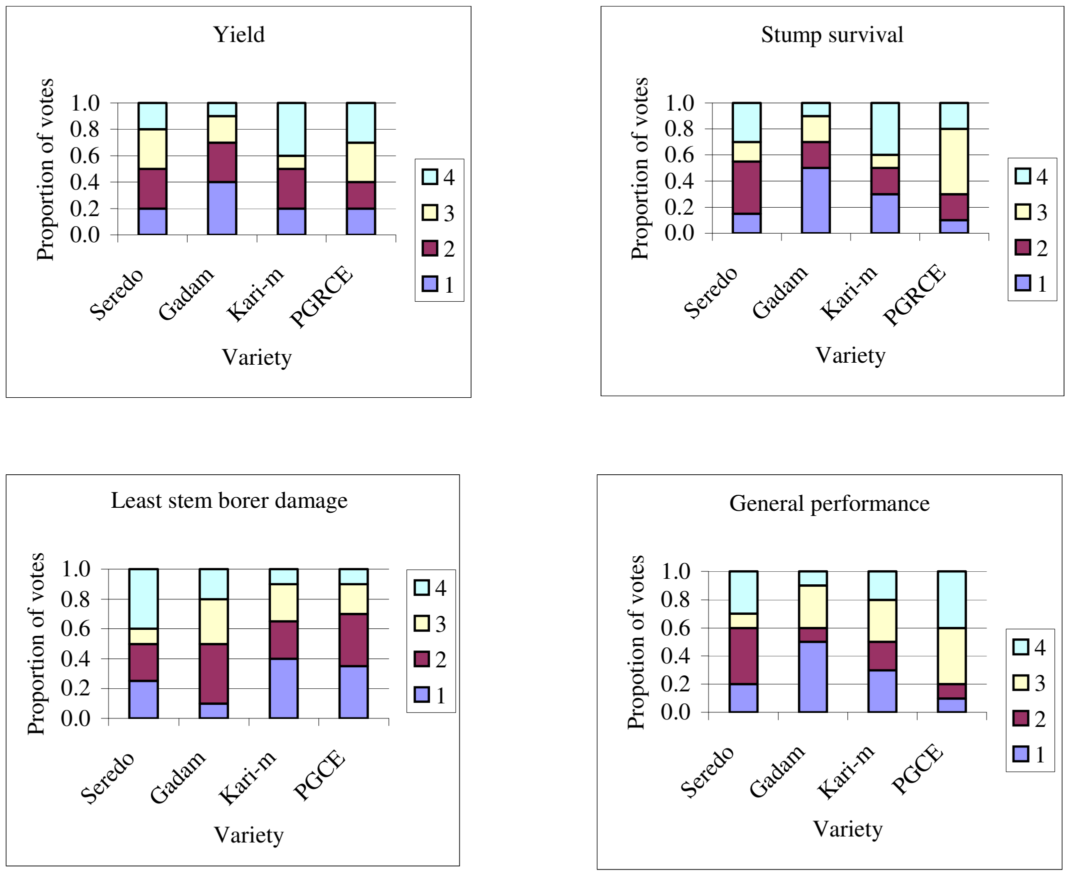


Figure 8.3: Frequency of individual farmer's (n=18) rankings during the end of season individual interviews on the different sorghum varieties, (Serado, Gadam El Hamam, Kari-mtama 1 and PGCRE 216740), presented as a proportion of the number of plots assessed for selected critieria in the locations of Nguuku, Kamuwongo and Kiomo (long rains 2002)

Key: Rankings: 1 best - 4 worst

The good performance of Gadam El Hamam was predicted by the farmers at the end of the short rains and by the ratoonability index. The variety PGRCE 216740 under performed the ratoonability index and farmers expectations due to its longer maturity rate. In Kamuwongo and Kiomo, the variety PGRCE 216740 received the second most votes for best the stump survival rate. However, by the end of the season the variety had the least votes for general performance and yield. The late maturity meant it was severely affected by water stress caused by the lack of rainfall. In comparison, the early maturing variety Gadam El Hamam combined with its ability to cope with stem borer damage meant it produced the highest yields. The farmers were surprised by the ability of variety Seredo to re-generate even when the stems were completely dry.

Farmers also identified that the site of the sorghum crop played an important part in survival. Usually sorghum is not planted on the best land as this was reserved for maize. However, the survival of the sorghum between the seasons was better on land that was flat and not sandy; therefore if they wanted to ratoon they needed to plant the sorghum on appropriate land. Some farmers had little flat land and maize was their priority for this land, others were willing and able to compromise.

The ratoonability index under the conditions of the trial was reasonably reliable in indicating the varieties that may respond to the practice of ratooning. However, the weight of the criteria in the index may vary under rainfall patterns. In a poor season, the criteria of early maturity, tillering ability and coping with stem borer damage seem particularly important. This should be further investigated.

1.38 MAIN CONCLUSIONS

1. Early maturity was more important than yield when assessing for ratoonability of a variety.
2. Gadam El Hamam was considered to be the best variety.
3. Four factors were identified by the farmers as important in a variety, if the variety is to perform well under the practice of ratooning: drought tolerance, stem strength, non-senescence and ability to produce tillers during growth stage 3.
4. The four factors identified as important to ratoonability proved effective at predicting the performance of the varieties.

Plate 8.1: Farmer Kamene Nyange assesses her trial (Nguuku, July 2001)

Plate 8.2: Participating farmers feedback their experiences with their on-farm trials with the aid of a Katumani socio-economist

Plate 8.3: Farmer Agnes Ngumbi scribes for her farmers' group as they draw their conclusions from the on-farm trials (Nguuku, July 2002)

DISCUSSION

This study developed from work carried out under project DFID R6581: An investigation into the epidemiology and control of fungal pathogens of sorghum in semi-arid systems in East Africa. Surveys by Bock *et al.* (2001) in Eastern Kenya indicated that the panicle disease covered kernel smut (*Sporisorum sorghi* Ehrenberg Link) occurred in 42% of fields surveyed, where the incidence within fields ranged from rare to 40% (Hayden and Wilson, 2000). Seed dressing was identified as a possible control measure, but lack of information, availability and cost of the chemicals were major constraints to adoption (Hayden and Wilson, 2000). Furthermore, extension officers were found to have a poor knowledge of sorghum smut and its control. Extension programmes have until recently, concentrated on maize and cash crops. The knowledge base of many of the officers was therefore poor in regards to local sorghum production. This was addressed in the present study by involving them in the activities from the beginning and incorporating them into the initial investigations into local sorghum practice in regard to the local, long duration sorghums.

The majority of sorghum seed was selected from the previous season's crop and selection was commonly carried out at the homestead (Hayden and Wilson, 2000). The practice of heaping infected heads with clean heads before selection allows spores from the contaminated heads to contaminate the clean heads. The result was that although the farmers choose the next season's seed from the clean heads, these might have been contaminated. Trials in Uganda and Tanzania showed that the incidence of smut can be halved by changing seed selection from the homestead to the field before the onset of harvest (Hayden and Wilson, 2001). However, in Mwingi District, farmers often failed to retain "clean selected" seed, because of crop failure resulting from unsuccessful establishment and/or failure to reach maturity (Hayden and Wilson, 2000). The erratic start of the long rains means that dry planted seed often rots in the soil and young seedlings dry out. Late crops often fail to reach maturity, due to water stress. The repeated sowing and crop failures combined with storage pests, which reduce the ability to store grain over long periods, results in farmers regularly running short of food and seed.

The study of the practice of ratooning on short duration sorghum began with an on-station trial at the Katumani Research Centre to investigate the effect of ratooning on the main pest *C. partellus* and the disease covered kernel smut. Running parallel to this was on-farm work to understand the implication of the practice in the local farming system. The findings from both were used to drive the direction of the study. Running both on-farm and on-station trials concurrently proved beneficial as it speeded up feedback and enabled the direction of the studies to respond to the findings.

In certain areas of Mwingi District local, long duration sorghums that are grown over two seasons are cultivated along terrace embankments and trashlines. The knowledge and experience of these farmers in growing these varieties was incorporated into the study. The knowledge gained by the extension officers during this investigation has lead them to introduce these two season sorghums to a neighbouring tribe that resides in a hilly, stoney soil area that suffers from severe soil erosion. The tribe has quickly adopted the practice of using this type of sorghum as a living terrace. In Mwingi District, several ratooning methods were employed by the farmers that varied in the time of implementation and the thinning of the tillers. The main pest and disease problems in these varieties were identified by the farmers as stem borers and covered kernel smut. The farmers identified several issues in regard to adopting the practice of ratooning short duration sorghums. The yield had to be more reliable than the direct sown crop, and to achieve this, the survival rate of plants from the short rains to the long rains had to be reasonable, and level of stem borers manageable.

Yield

The ratoon crop proved to be more reliable and higher yielding than the direct sown crop in all the on-station and on-farm trials (Table 9.1). Farmers considered ratooning to be a good practice. They were appreciative of the ability of the ratooned crop to produce a harvest under conditions that caused the direct sown crop to fail. The drought tolerance of the ratooned crop was considered the main benefit of ratooning, though the low labour input was highly rated. The earlier maturity of the ratooned crop was liked and during the trial, the level of bird damage in the crop was not considered any more serious than on the direct sown sorghum.

Table 1.5: Yield (kg/ha) achieved under ratooned and direct sown crops during the study

Site	2000/1			2001/2		
	Short rains	Long rains		Short rains	Long rains	
	Direct sown	Direct sown	Ratooned	Direct sown	Direct sown	Ratooned
Katumani Research Station (under treatment nil) (kg/ha)	3111	0	1630	1037	148	1778
Kitui Research station	-	-	-	1233	133	467
Mwingi on-farm sites	932	11	156	1580	551	686

Covered kernel smut

The effect of the practice of ratooning on CKS was studied on-station as it was considered inappropriate to hand out seed to farmers, which was known to be contaminated with CKS spores. The effect of CKS is to reduce yield. The incidence of CKS recorded in the ratooned crop was always correlated to the levels measured in the same plots in the previous short rains. The level of incidence in the long rains was higher than that recorded in the short rains in two-thirds of the crops. Several authors, Doggett (1988), and Frederiksen and Odvody (2000) have stated that ratooned crops would express higher levels of CKS than in the previous season's crop. Doggett (1988) had proposed that interactions between weather and soil conditions determine expression of smut by influencing the infection rates and growth of the host. The infection rate in a direct sown crop will depend on soil conditions at initial infection and growing conditions during the season (Bag and Agorwal, 2003). However, in the ratooned crop, the plants are already infected and expression will depend only on conditions during the season. The relationship between the ratooned crop and direct sown crop will therefore vary.

The success of seed dressing containing thiram to control CKS meant it was possible to estimate the yield losses and the monetary gain in applying a seed dressing for both direct sown crops and ratooned crops. In the direct sown plots, severity of CKS in the no-thiram applied plots ranged from 28 to 36% compared to thiram only plots of 0-8%. The yield increases ranged from 43 to 100%. In the ratooned plots, severity of CKS in the no-thiram plots ranged from 33 to 35% compared to thiram only plots of 0.4 to 8%. The yield increases ranged from 8% to 45%. The ability of seed dressing to control

CKS in both the direct sown and the follow-on ratooned crop, means the cost: benefit ratio increased. The estimated monetary returns of using a seed dressing in the two cycles were: direct sown crops £133 and £52/ha, and ratooned crop £200 and £53/ha, respectively. These figures underestimate the yield losses, as grain harvested from smutted heads was included in the yields. Under farmer conditions, many farmers completely discard badly smutted heads. Also, the grain showing CKS contamination has no market value (Hayden and Wilson, 2002).

The farmer recommendation would be to apply a seed dressing only in the short rains as the return on direct sown crop in the long rains is too risky. Work carried out in Uganda, has indicated that a seed dressing applied every third sowing combined with "clean head" selection completely controls CKS (Hayden and Wilson, 2000). The combined promotion of the two control strategies of seed dressings and "clean head" selection would reduce any potential increase in the incidence of CKS due to the practice of ratooning.

Stem borers

The effect of the practice of ratooning on the level of stem borers was studied in both on-station and on-farm trials, under natural pressure. The practices did have an effect on the stem borer damage and population. The ratooned crops did not show a consistently higher level of stem borer damage than direct sown crops, and the effect on yield was complex. Stem borers indirectly affect yield by affecting tillering, translocation of assimilates and grain filling. This means growing conditions and/or the sorghum plant's plasticity can mask stem borer damage (Ratikant Maiti, 1996; Doggett, 1988).

In the on-station trial at Katumani Research Station, the application of insecticides was not always successful in reducing stem borers numbers, and this made it difficult to estimate yield losses. The application of insecticides generally reduced the level of tunnelling and the number of exit and larvae per stem, and combined applications of the insecticides tended to be more effective than individual applications. The reduction was not usually significant. Agronomic practice interacted with the performance of the chemical inputs and the inputs were less effective on the ratooned crop. Generally, the ratooned crops tend to be less uniform than the direct sown crops and this makes it harder to apply insecticides in a timely fashion. The timing of insecticidal applications is crucial, as control measures are effective against young larvae only. Once the older larvae penetrate the stems, they are difficult to control. In addition, overlapping generations, result in re-infestations throughout the season, often rendering chemical control unsatisfactory (Kfir, 2000).

The effect of stem borers on yield was assessed using correlation plots. During the experiment, when the plants were attacked early in the season, there was often a positive relationship between numbers of deadhearts and exit holes per stem, and the number of productive heads per plant. However, the contribution of these tillers to yield was dependent on soil moisture availability at grain filling. When the plants were under water stress at grain filling, there was negative correlations between stem borer numbers and either productive heads or yield. This reflects reports by Flattery (1982) and Doggett (1988) that the inherent tillering ability of a cultivar can mask reductions that may result from attacks by stem borers. For this compensation to occur the tillers have to be produced earlier enough to reach maturity and the conditions favorable for development. Several authors have reported that the timing of the infestation is as important as the numbers (Seshu Reddy, 1987; Taneja and Nwanze, 1989, Mohamed *et al.,* 2004). Leuchner (1989) reported that the earlier tillers are formed the greater the chance that they will synchronise with the main stem and produce high yielding heads. Late tiller formation has implications for potential yield loss even without later stem borer infestation, through shading and partitioning of assimilates (Ratikanta Maiti, 1996).

The level of stem borers per stem was not correlated to the numbers recorded in the previous season, in either, direct sown or ratooned crops. Over the three cropping cycles, the total number of stem borers (combined number of larvae, pupae and exit holes) present in the each stem did not show an upward trend over the course of the experiment. The number of deadhearts showed a weak peak and trough pattern, with the peaks and troughs occurring in the long and short rains respectively. The number of stem borers per stem did not follow the same pattern as the deadhearts. This suggested that the number of deadhearts is not a good indicator of the number of moths that emerge during the season or of the number of larvae available to enter diapause at crop maturity. The varying levels of damage and population seemed to be related to an interaction between:

stem borer numbers time of infestation * establishment in the stem * soil moisture*

These factors were strongly influenced by the rainfall pattern, which Mohamed *et al.*, 2005 also reported.

During the study, the number of stem borers per stem varied under the different agronomic practices. However, the ratooned plants always produced more moths and larvae per unit area due to the ratooned plants always produced more stems than the direct sown crop (Table 9.2). Several South African authors (Bessin *et al.*, 1990; van den Berg, 1997) have proposed that the number of moths produced during a season within a unit area is an important consideration in the management of stem borers. In Eastern province there are usually two stem borer generations per season (Songa, 1999). The practice of ratooning increased the numbers of moths available to lay eggs from which the second generation will emerge. The level of soil moisture was the single most important factor in determining yield, but the ratooned sorghum crop could act as a source of moths, for other crops. Other crops may not be as tolerant to stem borer damage as sorghum. For example, maize has no tillering capacity, thus recovery from early infestations is poor and therefore more damaging to yield. However, in the drier areas where sorghum is most widely grown the rainfall in the long rains is usually insufficient for maize to be grown sucessfully, so the farmers plant only small plots, if any at all. It is during these long rains that the practice of ratooning would be expected to have the greatest impact on the stem borer population, as it acts as a green bridge between the short and long rains (Doggett, 1988).

The greater drought tolerance of the ratooned sorghum compared to direct sown crops means that it can act as a host to stem borers, when other crops have failed. Normally, the stem borer populations decline in seasons of crop failure, but this would happen less often if sorghum ratooning became a widely adopted practice. However, during the experiment the level of stems borers per stem in the long rains did not correlate to the numbers in the previous season's sorghum crop. Also, the stem borer population, as measured by deadhearts, larvae pupae and exit holes per stem did not show an upward trend over the six seasons of sorghum cropping. This suggests that factors other than the practice of ratooning and the green bridge it creates were determining the stem borer population in the sorghum crop.

Table 1.6: Moth production index under ratooned and direct sown crops during the long rains at the various trial sites (Katumani, Kitui and Mwingi District)

Sites	2000/01 Direct sown	Ratooned	2001/2 Direct sown	Ratooned
Katumani Research Station (under treatment nil) (kg/ha)	130,001	502,669	113,334	133,334
Kitui Research station	-	-	88,000	219,426
Mwingi on-farm sites	-	-	70,719	99,815

Farmer knowledge of stem borers was found to be good. Farmers match leaf-feeding holes, deadhearts, stem tunnelling and non-emergence of the heads and chaffy heads to stem borers. They also relate severe stem borer damage to dry seasons and plants under water stress. Farmers considered stem borer damage to be generally lower in the short rains than the long rains and that late planted crops were more seriously affected than early planted crops. The role of growing conditions on the losses caused by stem borers has been reported in several studies including Nwanze and Muller (1989), and Niyibigira *et al.,* (2001). Farmers thought the ratooned crops often showed more damage than the direct sown crop, but the direct sown crops were less able to cope, particularly when under water stress. Several farmers commented that maize grown near infested sorghum often becomes infested. Ogwaro (1983) reported a similar effect when maize was inter-cropped with sorghum. However, Niyibigira *et al.,* (2001) has reported no significant difference in stem borer infestations in maize and sorghum.

During the presently reported trials, the ratooned crop supported a higher number of moths per unit area than the direct sown crop (Table 9.2). The ratooned crops were therefore releasing more moths into the locality. In the short rains, direct sown sorghum is often inter-cropped with maize and millets. However, in the long rains, the lack of rains means the area of maize planted is small and the area under pearl millet increases. Pearl millet is not a good host to *C. partellus*, but the stem borer moths find it highly attractive to lay eggs, however due to the thin stems the larvae tend to be small (Adesiyun, 1983). Larvae with lower body mass have been found to produce fewer eggs as moths (Kfir, 1991).

Ratooning methods

The performance of the ratoon crop depends on the plant population in the short rains and the survival of these plants into the long rains. Significant relationships were observed between the ratoon crop performance and the locations and soil conditions. Plant survival at Katumani Research Station, the wettest site, was over 95%, but in Mwingi District, the driest site, the survival rate was much lower at a range of 30-50%. The farmers recommended increasing plant survival by siting of ratoon sorghum in areas with good fertility and soil moisture retention i.e. flat or terraced that had been tilled to increase absorption and penetration of rainwater. Enserink (1995) considered these factors important. Traditionally land that had these qualities was kept for maize and other high value crops. However, the on-going 'Food for Work' programme has involved farmers terracing their land, resulting in an increase in flat agricultural land. This combined with the recent crop failures, especially the maize crop and resulting lack of food security had changed farmers' focus and they were giving a higher priority to food security crops like sorghum.

Studies on the effect of varying the timing of the removal of the stems were investigated through on-station and on-farm trials. Enserink (1995) had previously varied the ratooning date from harvest to 3 weeks later, but had found the soil and environmental conditions masked any management practice. He recommended that it was better to ratoon as soon as possible after harvest. The promotion of tillering at harvest requires the removal of apical dominance (Doggett 1988) and the plant to have a carbohydrate reserve that can be translocated to power re-growth (Duncan *et al.* 1981). These conditions are most likely met while the plant is still green (Borrell *et al.,* 2000). The trials identified that cutting the stems at harvest promoted tillering, when the plants were green. This may have been an artifact of the greeness indicating the availability of soil moisture. The moisture availability dictates re-growth of tillers and if conditions are particularly dry, transpiration through the tillers may result in plant death. The studies also revealed that leaving the stems standing during the dry period increased plant survival, particularly when the stems were dry at harvest. In Mwingi District, most short duration sorghum shows advanced senescence at harvest. The high labour demand on the farm at harvest time often delays harvest. This combined with high temperatures and water stress means the stems can be relatively dry. The reasons for this higher survival rate could be that the dry conditions curtail the re-growth from the basal buds and leaving the stem standing protects the stem base from termites, stalk rots

(*Fusarium* spp.) and charcoal rot (*Macrophomina phaseolina*). Studies in Somalia have positively correlated ratoon failure with the incidence of *M. phaseolina* (Gray *et al.,* 1991).

The “bottom line” for farmers is a balance between yield (quantity and/or reliability) and the inputs required to achieve it. This was shown by farmers selecting the best method as leaving the ratooning until the onset of rains. This method did not produce the highest yield, but they considered the general performance the best, and particularly liked the low labour input. By leaving of plants standing until the rains, nothing was invested in the crop until a decision had been made about whether they would keep the crop or replant. In contrast, the crop ratooned at harvest required labour during a high demand period, and then the plants may still die during the dry period. This reflects Jiggins and Vodouhe (2004) observation that farmers adapt research recommendations to suit their socio-ecomonic and environmental conditions.

The effect of ratooning methods on stem borer populations was complex and interacted with the rainfall pattern. Early promotion of tillering results in the plant carrying green tillers through the dry period and these tillers are attractive to stem borers. However, this method means the crop is well established to utilise all the rainfall and generally performed well. Delaying the promotion of tillering means the tillers are younger at the start of the rains and could be at a more desirable and at a susceptible stage as the bulk of the moths emerge from the diapausing larvae. The level of damage on the different ratooning methods therefore depends on the rainfall patterns, number of stem borer moths, state of the host, and timing of the infestation. This reflects work carried out on direct sown sorghum (Niyibigira *et al.* 2001). Leaving the stalks standing until the next rain may increase the carry-over of diapausing larvae, as Pat (1996) found that significantly higher proportions of larvae and pupae survived in standing stalks compared to stalks that had been cut and layed horizontally on the ground. However, predation of the diapausing larvae will reduce the numbers (Midega *et al.,* 2005).

Available short duration varieties

Variability in the capacity of cultivars to respond to ratooning has been reported by several authors (Doggett, 1980; Duncan *et al.,* 1980). Factors identified by farmers as important for a variety to perform under ratooning were proved reliable in predicting performance. These factors were drought tolerance, early maturity, stem strength, non-senescence, and ability to produce tillers. The farmers' observations were supported by the on-farm trial results and reported research. Work by Borrell *et al.,* (2000) proved that non-senescence of sorghum, whether by delayed onset, or reduced rate of senescence is very important for supporting biomass and grain yield under post-flowering drought stress. Stem strength and non-senescence are related to the distribution of carbohydrate between the sinks. For plants to re-grow they need to draw on carbohydrate reserves. Varieties that distribute a high proportion of their carbohydrate reserves to the panicle have less to use for regeneration. Producing tillers after post-flowering is an indication that reserves are available to regenerate, though Duncan *et al.,* (1980) suggested the number of tillers at 6 weeks was also a good indicator for perenniality. Drought tolerance is important to survive the dry period between rains and to produce yield under the limited water moisture available in the long rains. Early maturity reduces the problem of water stress at grain filling. The best performing varieties, Gadam El Hamam and Seredo showed the best ability to produce tillers. Most importantly, they matured in a shorter period than the varieties Kari-mtama 1 and PGRCE 216740. The farmers identified variety Gadam El Hamam as the best. This variety had the shortest duration and had good tillering properties. Fortunately, the variety also has good culinary properties (Wilson and Kavoi, 2002).

One outcome from this study has been the recognition by researchers that the practice of ratooning sorghum may help to address the food security issues in Eastern Kenya. Sorghum breeders at several research stations are now assessing lines for ratoonability and have proposed developing breeding programmes to improve the ratoonability of short duration varieties by incorporating a higher level of non-senescence and tillering ability. Incorporating these factors will hopefully, improve the plant survival rates.

The study set out to improve food and seed security to aid the adoption of the 'clean head' seed selection and reduce the losses due to CKS. Ratooning does improve the reliability of yields and remove the problem of crop establishment in the long rains. The improved reliability reduces the length of time required to store seed and therefore diminishing the problem of storage pests. Through this study local NGO's involved in seed multiplication and distribution have adopted ratooning to reduce the amount of expensive breeder seed they have to purchase. By using ratooning, six harvests can be achieve from one purchase of breeder seed, instead of the usual three before having to replace the seed to ensure varietial purity. Farmers involved in seed production already use their good land for sorghum due to the higher price they receive for seed sorghum; therefore the adoption of ratooning has an even stronger economical basis.

The parallel running of both on-station and on-farm trials have enabled the research to evolve to fit the farmers' socio-economic and environmental conditions. It proved to be an effective way to engage farmers and communicate new ideas in an area that has low literacy rates. The methodology used was an adaption of the farmer field school methodology, which has proved effective in delivering extension messages (Ramaswami, 2004). The extent that farmers adopt the practice of ratooning will depend on their own circumstances. The sustainability of agricultural systems depends on developing technologies and practices that don't have adverse effects on environmental goods and services, are accessible to farmers and lead to improvement in food productivity (Pretty, 2006).

In conclusion, the adoption of ratooning of short duration sorghum should improve food security, but plant survival is an issue. A major factor in plant survival is the local soil and rainfall conditions, particularly soil moisture retention. The variety of sorghum is also an important factor in the success of the practice of ratooning. The present study found the varieties Gadam El Hamam and Seredo performed adequately. However, short duration varieties presently available to farmers have not been bred for ratooning. Characteristics selected for within the breeding programmes have traditional not included those that benefit for ratooning. The breeders have selected for varieties with a strong head sink, and these lines tend to senesence early (Doggett, 1988). For plants to ratoon successfully, the plants need to retain enough energy for re-growth, and readily produce tillers. Breeders need to identify varieties and lines that can perform well under ratooning.

The practice does increase the stem borer population during the season by increasing the moth production index, but under the study conditions, stem borers were not the main factor in yield outcomes, the rainfall pattern was.. In the Katumani Research Station experiment covering six seasons the stem borer population fluctuated. The population did not show an upward trend.(Figure 5.2) and there was no correlation between the number of larvae, pupae or exit holes per stem in the short rain and the long rain in either the direct sown or ratooned crops (Figure 5.1). The number of deadheart (%) per plot in the direct sown and ratooned plots showed a similar weak pattern of peaks and troughs, with the peaks and troughs, with the peaks occurring in the long rains. This indicated the carry-over between the short and long rains was higher than that between the long and short rains, but the total number of stem borers that could emerge from a stem, as measured by the combined number of larvae, pupae and exit holes per stem, did not show this peak and trough pattern. This suggests that factors other than the practice of ratooning and the green bridge it created were more strongly affecting the stem borer population in the sorghum crop.

In farmer recommendations, the conditionality of the ratooning policy should be stressed. These include:

1. The practice requires fertile soil, with good soil moisture retention.
2. Not all short duration varieties respond to the practice and they may need to experiment.
3. The ratooned crop may be damaged by stem borers and the plants may act as a source of stem borers for other crops.
4. Adoption of seed dressing or clean seed selection technique will decrease CKS in both the direct sown and following ratooned crop.
5. The timing of the cutting of stems will affect plant survival.

REFERENCES

Adlakha, K.L. and Manjal, R.L., 1963. Reaction of some varieties of *Sorghum vulgae* to *Sphacelotheca sorghi* (Link) Clint. Indian Journal of Agricultural Science 33: 8-10.

Adesiyun, A.A., 1983. Some effects of intercropping sorghum, millet and maize on infestation by lepidopterous stalk borers particularly *Busseola fusca*. Insect Science and its Application 4: 387-391.

Adesiyun, A.A., and Ajayi, O., 1980. Control of the sorghum borer, *Busseola fusca*, by partial burning of the stalks. Tropical Pest Management 26: 113-117.

Ajayi, O., 1998. Sorghum: West Africa *in* "Africa cereal stem borers:economic importance, taxonomy, natural enemies and control". A Polaszek (Ed). CABI 1998 pp530.

Alghali, A.M., 1988. Oviposition on sorghum by the stem borer *Chilo partellus* (Swinhoe) (Lepid. Pyralidae). J. Plt. Prot. Trop 5: 45-50.

Ampongo-Nyarko, K., Seshu Reddy, K.V., Nyang'or, K.A. and Saxena, K.N., 1994. Reduction of insect pest attack in sorghum and cowpea by intercropping. Ent. Exp. Appl. 70: 179-184

Arkel, van H., 1978. The ratoon yield of cold tolerant sorghums. Sorghum and Millets Development Project, Kenya, Ken/76/020 Field Document No. 7.

Bag, M.K. and Agarwal, D.K., 2003. Studies on the germination of teliospores of four smut fungi. Journal of Mycopathological Research. 41(1): 51-54.

Banhof, M.J. and Overholt, W.A., 2001. Impact of solar radiation, rainfall and cannabalism on disappearance of maize stem borers in Kenya. Insect Sci. Applic. 21(4): 40-407.

Banhof, M.J. Van Huis, Kiros, G.G., Dibogo, N. 2001. Farmers' perceptions of importance, control methods and natural enemies of maize stem borers at the Kenya Coast. Insect Sci. Applic. 21(1): 33-42.

Berger, A., 1992. Larval movement of Chilo partellus within and between plants: timing, density responses and survival. Bull.Entomol. Res. 82: 441-448.

Bernays, E.A., Woodhead, S., and Haines, L., 1985. Climbing by newly hatched larvae of spotted stalk borer *Chilo partellus* to the top of sorghum plants. Entomologia Experimentalis et Application 39: 73-79.

Bessin, R.T., Reagan, T.E. and Martin, F.A., 1990. A moth production index for evaluating sugar cane cultivars for resistance to the sugar cane borer (Lepidoptera: Pyralidae). J. Econ. Entomolgy 83: 221-225.

Bock, C., Songa, J.M.S., and Julian A.M. 2001. Survey of sorghum pests and pathogns in Eastern Kenya. Tropical Science 41: 16-22.

Borrell A.K., Hammer, G.L. and Douglas, C.L., 2000. Does maintaining green leaf in sorghum improve yield under drought? I. Leaf growth and senescence. Crop Science 40:1026-1037

Burnett, J.H., 1976. Fundamentals of Mycology (London: Edward Arnold), pp. 424-425.

Casady, A. J., 1961. Inheritance of resistance to races 1,2 and 3 of *Sphacelotheca sorghi* in sorghum. Crop Science 1(1): 63-68.

Chapman, R.F., 1982. The endocrine organs and hormones. In: The insects: structure and function. Pages 818-850. Chapman R.F., (eds). Harvard University Press. Cambridge Massachusettes. USA.

Chapman, R.F., Woodhead, S., and Bernays, E.A., 1983. Survival and dispersal of young larvae of *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) in two cultivars of sorghum. Bulletin of Entomological Research 73: 65-74.

Claflin, L.E. and Ramundo, B.A., 1996. Evaluation of all disease and insect sorghum germplasm for susceptibility to covered kernel smut. Phytopathology, 86: S63 (Abstr).

Clayton, W.D., 1961. Proposal to conserve the generic *Sorghum* Moench. (Gramineae) verus *Sorghum* Adans (gramineae), Taxon. 10(8): 242.

Crotzer, V. and Levetin, E., 1996. The aerobiological significant of smut spores in Tulsa, Oklahoma. Aerobiologia 12: 177-184

Dasgupta S. N. and Narain A., 1960. A note on physiological races *of Sphacelotheca sorghi*. Current Science 29(6): 226-227.

de Wet, J.M.J., 1978. Systematics and evolution of *Sorghum* Sec. *Sorghum* (graminaceae). American Journal of Botany, 65: 477.

Doggett H., 1980. Sorghum diseases in East Africa. Pages 33-35 *in* Sorghum Diseases a World Review: proceedings of the International Workshop on Sorghum Diseases, 11-15 Dec 1978, Hyderabad, India. Patancheru, Andhra Pradesh, 502 324, India: ICRISAT.

Doggett, H., 1965. The development of cultivated sorghums. In: Hutchinson J.B., (ed). *Essays on Crop Evolution,* Cambridge University Press, Cambridge pp50.

Doggett, H., 1988. Sorghum (2nd). Longman, Harlow pp511.

Duncan, R.R., Bockholt, A.J., Miller, F.R., 1981. Descriptive comparison of senescent and non-senescent sorghum genotypes. Agronomy Journal 73: 849-853.

Duncan, R.R., Miller, F.R., and Bockholt, A.J., 1980. Inheritance of tiller re-growth in rationed sorghum. Canadian Journal of Plant Science 60: 473-78.

Duran, R., 1969. *Ustilaginales* in the Fungi: An Advanced treatise (Vol. 4B) *In* G.C. Ainsworth, Frederick, K. Sparrow and Alfred S. Sussman (Eds.) (New York: Academic Press), pp. 281-300.

Eastin, J.D., 1972. Photosynthesis and translocation in relation to plant development *in* Sorghum in the seventies. Roa, N.G.P. and House, L.R. (Eds.). Oxford and IBH Publishing Co., New Delhi, pp 214-216.

El Halaly A. F., 1939. Studies on the control of kernel smut of sorghum. Bulletin. Ministry of Agriculture, Technical and Scientific Service, Egypt, Plant Pathology Section 233. 22pp.

Enserink, H.J., 1995. Sorghum Agronomy in West Kenya: investigations from a farming systems perspective. Royal Tropical Institute, Amsterdam, The Netherlands ISBN 90-6832-100-5.

Escalada, R.G., and Plucknett, D.L., 1975. Ratoon cropping of sorghum I. Origin, time of appearance, and fate of tillers. Agronomy Journal 67: 473-478.

Escalada, R.G., and Plucknett, D.L., 1977. Ratoon cropping of sorghum III. Effect of nitrogen and cutting height on ratoon performance. Agronomy Journal 69: 341-346.

FAO (2008) *in* www.faostat.fao.org/site

FAO and ICRISAT., 1996. The world sorghum and millet economies, facts, trends and outlook. FAO, Rome, Italy and ICRISAT., Andhra, Pradesh, India pp68

Fischer, W.G. and Holton, S.C., 1957. Biology and Control of the Smut Fungi. New Year: Ronald Press Co pp.622.

Fischer, K.S. and Wilson, G.L., 1971a. Studies of grain production in *sorghum vulgare*. I. The contributor of pre-flowering photosynthesis to grain yield. Aust. J. Agric. Res. 22 (1): 33-7. 1971.

FISCHER, K. S. and WILSON, G.L., 1971b. Studies of grain production in *sorghum vulgare*. II. Sities responsible for grain dry matter production during the post-anthesis period. Aust J. Agric. Res. 22 (1): 39-47. 1971.

Flattery, K.E., 1982. An assessment of pest damage of grain sorghum in Botswana. Experimental Agriculture 18(3): 319-328.

Frederiksen, R.A. and Odvody, G.N., 2000. Compendium of sorghum diseases. 2nd Edition APS PRESS pp 78

Frederiksen, R.A., 1982. Disease problems in sorghum *in* Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum 2-7 Nov 1981, Patancheru, A.P., India, Patancheru, A.P., India: ICRISAT.

Frowd, J. A., 1980. A world review of sorghum smuts. Pages 331-338 *in* Sorghum diseases, a world review: proceedings of the international workshop on sorghum diseases, 11-15 Dec 1978, ICRISAT, Hyderabad, India.

Gerik, T.J. and Miller, F.R., 1983. Photoperiod and temperature effects on tropically- and temperately-adapted sorghum. Field Crops Res. 9: 29-40.

Gerik, T.J. and Neely, C.L., 1987. Crop ecology, production, and management: plant density effects on main culm and tiller development of grain sorghum. Crop Science 27: 1225-1230.

Gerik, T.J., Rosenthal, W.D. and Seavey, W.F., 1990. Phenology, early growth, and yield of planted and ratoon grain sorghum. Field Crops Research, 23: 205-219.

Girling D.J., 1978. The distribution and biology of *Eldana saccharina* Walker (Lepidoptera: Pyralidae) and its relationship to other stemborers in Uganda. *Bull. Entomol. Res.* 68, 471-488.

Goldman, A., 1996. Pest and disease hazards and sustainability in African agriculture. Experimental Agriculture 32: 199-211.

Goldworthy, P.R., 1982. Sorghum and its environment. Discussant paper *in* House, L.R., Mughogho. L.K., Peacock, J.M. (eds) Sorghum in the Eighties, pp125 ICRISAT, Patancheru PO, A.P., India

Gorter G. J., 1961. Two pathogenic races of *Sphacelotheca sorghi* (Link) Clint. occurring in South Africa. South African Journal of Agricultural Science 4: 231-235.

Gray, F.A., Mihail, J.D., Lavigne, J.R. and Porter, P.M., 1991. Incidence of charcoal rot of sorghum and soil populations of *Macrophomina phaseolina* associated with sorghum and native vegetation in Somalia. Mycopathologia 114(3): 145-151.

Grimes, D., and Musick, J., 1960. Effect of plant spacing, fertility and irrigation management on grain sorghum production. Agron. J. 52: 647-650.

Gutherie. W.D., Dicke, F.F. and Neiswander, C.R., 1960. Leaf and sheath feeding resistance to the European corn borer in eight inbred lines of dent corn. Research Bulletin no. 860. Columbus, Ohio, USA:Ohio Agricultural Experiment Station. 38pp.

Hamilton, R.I., Subramanian, B.S., Reddy, M.N. and Rao, C.H., 1982. Compensation in grain yield components in a panicle of rainfed sorghum. Ann. Appl. Biolog. 101: 119-125.

Hansing, E.D. and King, C.L., 1958. Fungicide and fungicide-insecticide treatment for sorghum seed. Kansas state University Botany and Plant Pathology Circular, 13: 1-5.

Harlan, J.R. and de Wet, J.M.J., 1972. A simplified classification of cultivated sorghum. Crop Science 12: 172.

Harris, K.M., 1990. Bioecology and *Chilo* species. Insect Sci. Applic. 11: 467-477.

Hayden, N.J. and Wilson, K.S.L., 2000. Final Technical Report: an investigation into the epidemiology and control of fungal pathogens of sorghum in semi arid systems in East Africa (R6581). Natural Resources Institute, University of Greenwich, Chatham Maritime, Chatham, Kent ME4 4TB

Hayden, N.J., 2002. Final Technical Report: promotion of sustainable control of covered kernel smut of sorghum through broadening the cropping base (R7518). Natural Resources Institute, University of Greenwich, Chatham Maritime, Chatham, Kent ME4 4TB

Hsi, C.H., 1958. Environment and sorghum kernel smut. Phytopathology, 48, 22-25.

Hulluka, M. and Esele, J.P.E. 1992. Sorghum diseases in eastern Africa *in* Sorghum and millets diseases: a second world review (de Milliano, W.A.J., Frederiksen, R.A., and Dengston, G.D., eds). Patancheru, A.P. 502 324, India: International Crops Research Institute for Semi-Arid Tropics.

ICRISAT, 2008 *in* www.icrisat.org/sorghum

Ingram, W.R., 1958. The lepidopterous stalkborers associated with Graminaceae in Uganda. Bull. Entomol. Res. 49: 367-383.

Jaetzold, R., and Schmidt, H., 1982. Farm Management Handbook of Kenya. Natural conditions and farm management information. Part A, B & C. Ministry of Agriculture, Kenya, pp441.

Jiggins, J. and Vodouche, S., 2004. Participatory diagnosis of production constraints and opportunities of cotton farmers in Benin. Netherlanda J. of Agricultural Science 52: 2285-304.

Karanja, D.R., Njaimwe, A.N., Nzioki, H.Z., Kanyenji, B.M., Kooijman, M., and Mwanzau, M., 1999. Utilization of unreliable long rains through sorghum ratoon crop management in farmers, fields in Mwingi District, Eastern Kenya (unpublished). KARI-Katumani Report.

Kavoi, J.M. and Sutherland, J.A. May 2002. A working paper: Review of crop protection issues in semi-arid Eastern Kenya, in the context of sustainable livelihoods. Internal publication, Natural Resources Institute and KARI pp 43..

Kfir, R., 1988. Hibernation by the lepidopteron stalkborers *Bussseola fusca* and *Chilo partellus* on grain sorghum. Entomol. Exp. Applic. 48: 31-36

Kfir, R., 1991. Duration of diapause in the stem borers *Busseola fusca* and *Chilo partellus*. Entomol. Exp. Applic. 61: 265-279.

Kfir, R., 1993. Diapause termination in the spotted stem borer *Chilo partellus* (Lepid. Pyralidae) in the laboratory. Ann. Appl. Biolo. 123: 1-7.

Kfir, R., 1998. Maize and grain sorghum: Southern Africa *in* African Cereal Stem borers: Economic Importance, Taxonomy, Natural Enemies and Control. Edited by A. Polaszek. CABI 1998 pp530.

Kfiri R., Overholt, W.A., Khan, Z.R. and Polaszek, A., 2002. Biology and management of economically important lepidopteron cereal stem borers in Africa. Annual Review of Entomology pp 701-731.

Khaleeque, M.I.A., Alam, M., Imam-al-Haq and Ahmad M. Reaction of ten sorghum cultivars against grain smut under semi-arid conditions of Bahawalpur. Pakistan Journal of Phytopathogy, 7: 90-91.

King S. B., 1972. Major cereals in Africa, 1970 and 1971. 7th and 8th Annual reports of the AID-ARS project.

Kulkarrni, G.S., 1918. Smut of Jowar (Sorghum) in the Bombay Presidency. Agricultural Research Institute (Pulsa) Bulltin, 78, 26 pp.

Kulkarrni, G.S., 1922. Conditions influencing the distribution of grain smut (*Sphacelotheca sorghi*) of Jowar (Sorghum). Agricultural Journal of India, 17: 159-162.

Langer, R.H.M., 1963. Tillering in herbage grasses. Herb. Abstr. 33: 141-148

Leukel, R.W., 1942. New fungicides and reduced fungicide dosages for the control of kernel smut of sorghum. Phytopathology, 32:1091-93.

Leuschner, K., 1989. A review of sorghum stem borer screening procedures in International Workshop on Sorghum Stem Borers 17-20 Nov 1987, Patancheru, A.P. 502 324, India: ICRISAT

M'Ragwe, L.R. and Kanyeni, B.M., 1987. Strategies for Improvement of sorghum and millet in Kenya. In Meyonga J.M., Bezuneh, T., and Youdeowei, A. (eds.) Food Grain Production in Semi-Arid Africa. Proceedings of an International Drought Symposium, Kenyatta Conference Centre, Nairobi, Kenya, 19-3-23 May 1986. OAU/STRC-SAFGRAD, Ouagadougou, Burkina Faso pp173-190.

Mackenzie, D.H., Basinski, J.J. and Parberry, D.B., 1970. The effect of varieties, nitrogen and stubble treatments on successive cycles of grain and forage sorghums in the Ord River valley. Australian Journal of Experimental Agricultural and Animal Husbandry 10: 111-117.

Maggs, T., 1977. Some recent radiocarbon dates from eastern and southern Africa. J. Afr. Hist. 18: 161.

Malaguti, G., 2004. The studies of pathogenesis of maize, sorghum and rice smut fungi. Agronomia Tropical (Moracay) 54(4): 507-511

Mann, J.A., Kimber, C.T. and Hasted, A.M., 1983. The origin and early cultivation of sorghums in Africa. Bulletin No. 1454. College Station: Texas A&M University.

Marley, P.S., 1995. C*ynoden dactylon* - An alternative host for *Sporisorium sorghi*, the causal organism of covered kernel smut. Crop Prod. 14: 491-493.

Mathez F.C., 1972. *Chilo partellus* Swinh., *C. orichalcociliella* Strand (Lep., Crambidae) and *Sesamia calamistis* Hmps. (Lep., Noctuidae) on maize in the coast province, Kenya. *Mitt. Schweiz. Entomol. Gesellschaft* 45, 267-289.

Mathur, R. S., Swarup J., and Surendra Ram., 1964. Varietal resistance of jowar (sorghum vulgareL.) to grain smut in Uttar Pradesh, 1958-1963. Labdev. J. Sci. Technol. 2: 264-265.

Mbapila, J.C., Overholt, W.A., Kayumbo, H. Y., 2002. Comparative development and population growth of an exotic cereal stem borer *Chilo partellus* (Swinhoe) and an ecologically similar congener, *Chilo orichalcociliellus* (Strand) (Lepidoptera: Crambidae). Insect Science and its Application 22: 21-27

Mbwaga, A.M., Pande, S., de Milliano, W.A.J. and Karunakar, R.I., 1993. Diseases and parasitic weeds of sorghum in Tanzania: occurrence and incidence, 1986-1990. Crop Protection Vol. 12 May 1993

McBee, G.G., Waskom III, R.M., Miller, F.R. and Creelman, R.A., 1983. Effect of senescence and non-senescence on carbohydrates in sorghum during late kernel maturity stages. Crop Science 23: 372-376.

McKnight, T., 1966. Studies on the fungus *Sphacelotheca sorghi* (Link) Clint. 1. Effects of the position of inoculum and stage of development of the germinating seed on infection. Queensland Journal of Agricultural and Animal Sciences 23:605-607.

Melcher, L. E., 1933. Physiological specialisation of *Sphacelotheca cruenta* (Kuhn) Potter. Journal of Agricultural Research, 47: 339-342.

Melchers L.E. and Hansing, E.D., 1943. The effects of sorghum kernel smuts on the development of the host. Journal of Agricultural Research 66: 145-65.

Melchers, L.E. and Hansing, E.D., 1938. The influence of environmental conditions at planting time on sorghum kernel smut infection. American Journal of Botany 25: 17-28.

Midega, C.A.O., Ogol, C.K.P.O. and Overholt, W.A., 2005. Life tables, key factors and density relations of natural populations of the spotted maize stemborer, *Chilo partellus* (Lepidoptera: Crambidae), under different cropping systems at the Kenyan coast. International Journal of Tropical Insect Science 25(2)

Midega, C. A. O., Ogol, C. K. P. O. and Overholt., W. A., 2005. Effect of Agroecosystem diversification through agroforestry and intercropping on activity of natural enemies of maize stem borers at the Kenyan coast. International Journal of Tropical Insect Science 24: 280-286.

Milthorpe, F., and Davidson, J., 1966. Physiological aspects of regrowth in grasses. *in* Miltrope, F., and Ivius, J.D. (eds.) The growth of cereals and grasses. Easter School in Agr. Sci. Proc. 12th (Univ. Nottingham, 1965) p. 241-255.

Minja, E.M., 1990. Management of *Chilo spp*. infesting cereals in East Africa. Insect Sci. and its applic. 11(4-5): 489-499.

Mohamed, H.M., Khan, Z.R., Overholt, W.A., and Elizabeth, D.K., 2004. Behaviour and biology of *Chilo partellus* (lepidoptera: Pyralidae) on maize and wild graminaceous plants. International Journal of Tropical Insect Science 24: 287-297.

Mohyuddin, A.I. and Greathead, D.J., 1970. An annotated list of the parasites of graminaceous stem borers in East Africa, with a discussion of their potential in biological control. Entomophaga 15(3): 241-274.

Munkacsi, A.B., Stoxen, S., May, G., 2007. Domestication of maize, sorghum and sugarcane did not drive divergence of their smut pathogens. Evolution 62(2): 388-403

Mughogho, L.K., 1982. Strategies for sorghum disease control *in* Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum 2-7 Nov 1981, Patancheru, A.P., India, Patancheru, A.P., India: ICRISAT.

Murty, B.R., and Govil, J.N., 1967. Description of 70 groups in genus sorghum based on a modified Snowden's classification. Indian J. Genet. 27: 75-91.

Mutui, J.J., Ngi-Song, A.J., Schulthess, F., Mueke, J.M. and Setamum, M., 2005. Location of stem borer pupae in various host plants and implications for the performance of natural enemies with emphasis on the pupal parasitoid *Xathopimpla stemmator* (Hymenoplera Ichneumonidae). Int. J. Trop. Insect Sci. 25 (1): 12-18.

Ndemah, R., Schulthess, F., Poehling, M., and Borgemeister, C., 2001. Spatial dynamics of lepidopterous pests on *Zea mays*(L.) and *Pennisetum purpureum* (Moench) in the first zone of Cameroon and their implications for sampling schemes. J. Applied Entomology 125: 507-514.

Nesbitt, B.F., Beevor, P.S., Hall, D.R., Lester, R., Davies, J.C., and Seshu Reddy, K.V., 1979. Components of the female sex pheromone of the spotted stalk-borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae): identification and preliminary field trials. Journal of Chemical Ecology 5: 153-16.

Neupane, F.P., Coppel, H.C. and Chapman, R.K., 1985. Bionomics of the maize borer, *Chilo partellus* (Swinhoe), in Nepal. Insect Sci. and Applic. 6: 547-553.

Niyibigira, E.L., Abdallah, Z.S., Overholt, W.A., Lada, V.Y. and Van Huis, A., 2001. Distribution and abundance in maize and sorghum of lepidopterous stem borers and associated indigenous parasitoids in Zanibar. Insect Sci. Applic. 21(4): 335-346.

Norman M.J.T., Pearson C.J., and Searle, P.G.E., 1984. Sorghum *in* The Ecology of Tropical Crops. 1995. Cambridge University Press New York

Nwanze, K.F. and Miller, R.A.E., 1989. Management options for sorghum stem borers for farmers in the Semi-arid tropics, *in* International Workshop on sorghum stem borers, 17-20 November 1987 ICRISAT.

Nye, I.W.B., 1960. The insect pests of graminaceous crops in East Africa. Colonial Research Study No. 31. Her Majesty's Stationary Office, London 48pp.

Nzioki, H.S., Claflin, L.E., and Ramundo, B.A., 2000. Evaluation of screening protocols to determine genetic variability of grain sorghum germplasm to *Sporisorium sorghi* under field and glasshouse conditions. International Journal of Pest Management 46(2): 91-96.

Nzioki, H.S., Claflin, L.E., Bramel, P.J., and Ramundo, B.A. 2000. Inheritance of resistance to *Sporisorium sorghi* in sorghum. International Sorghum and Millet Newsletter Journal 42: 47-50.

Ochieng, R.S., Onyango, F.O. and Bungu, M.D.O., 1985. Improvement of techniques for mass culture of *Chilo partellus* (Swinhoe). Insect Sci. applic. 6: 425-428.

Ogwaro, K. 1979. 1983. Intensity levels of stem borers in maize and sorghum and the effect on yield under different cropping patterns. Insect Sci. applic. 4(1-2): 32-37.

Oizumi, H. 1977. Role of organic reserves upon the re-growth of forage plants: I. Elongation of tiller buds of sorghum (*Sorghum bicolor* Moench) plants after cutting as influenced by levels of organic reserves. Technical Bulletin of Faculty of Horticulture, Chiba University, Japan 25:55-62

Oleinik, A.A. 2002. Sources of reistance to *Sphacelotheca sorghi*. Selektsiya, agrotekhnika-i-eknonomika proizvodstua sorgo sbornik nauchnykh-trudov 1989: 119-124

Oloo G.W. 1989. The role of local natural enemies in population dynamics of *Chilo partellus* (Swinh.) (Pyralidae) under subsistence farming systems in Kenya. Insect Sci. Applic. 10: 243-251.

Omer, E.H. and Frederiksen, R.A., 1992. Sorghum smuts, *in* Sorghum and Millet Diseases: A Second World Review. Proceedings of International Workshop on Sorghum and Millet Diseases, Harare, Zimbabwe, March 1988, pp. 245-338.

Pady, S.M. and Kramer, C.L., 1960. Kansas Aeromycology. VII. Smuts. Phytopathology, 50, 332-334.

Pats, P., 1991. Activity of *Chilo partellus* (Lepidoptera: Pyralidae): eclosion, mating and oviposition time. Bull. Ent. Res. 81: 93-96.

Pats, P., 1996. Management of crop residues to reduce the aestivating population of stem borers in maize. Int. J. Pest management 42: 151-156.

Paul, C.L., 1990. Sorghum Agronomy. ICRISAT/LASIP. ICRISAT, Patancheru, A.P. 502 324, India

Peacock, J.M. and Wilson, G.L., 1984. Sorghum *in*: Goldsworth, P.R., and Fischer, N.M., (eds) The Physiology of Tropical Field Crops. John Wiley, London, pp249-279.

Perez, J.M., Hernandez, M., Rodriguez Pipenbring, M., and M. Minter, D.W. (2002) IMI Description of Fungi and Bacteria, sheet 1527. CAB

Plucknett, D.L., and Young, O.R., 1963. Hawaii Farm Science. 12: 4-6.

Plucknett, D.L., Evenson, J.P., and Sanford, W.G., 1970. Ratoon cropping. Advances in Agronomy 22: 285-330

Pretty, J.N. 1995. Regenerating agriculture: policies and practice for sustainability and self-reliance. Earthscan Publications Limited, London.

Pretty, J.N., Guijt, I., Scoones, I., and Thompson, J. 1995. A trainer's guide for participatory learning and action. IIED Participatory Methodology Series, IIED, London.

Pretty, J., Noble, A.D., Bossio, D., Dixon, J., Hine, R.E., Penning de Vries, F.W.T. and Morison, J.I.L., 2006. Resource-conserving agriculture increases yields in developing countries. Environmental Science and Technology 40(4): 1114-1119

Purseglove, J.W., 1972. Tropical Crops: monocotyledons. Harlow, Longman, pp 670.

Ramaswami, D.R., 2004. Farmer field school as a platform for delivering extension messages. Agri. Research and Extension Network Newsletter 49, January.

Ramakrishnan, T.S., 1963. Diseases of millets. New Delhi, India: Indian Council of Agricultural Research.

Ranganathaiah, K.G. and Govindu, H.C., 1970. Reaction of some sorghum varieties to grain smut (*Sphacelotheca sorghi* (Link) Clint. Indian Journal of Agricultural Science 40:298-301.

Ranganathaiah, K.G., 1969. Cultural characteristics of physiological forms of *Sphacelotheca sorghi*. Mysore Journal of Agricultural Science 3: 471-472.

Ratikanta Maiti, 1996. Sorghum Science. Science publishers, Inc. NH 03766, USA.

Reed, G.M. and Faris, J.A., 1924a. Influence of environmental factors on the infection of sorghums and oats by smuts. Experiments with covered kernel smuts of sorghum. American Journal of Botany, 11: 518-534.

Reed, G.M. and Faris, J.A., 1924b. Influence of environmental factors on the infection of sorghums and oats by smuts. Experiments with covered kernel smuts of sorghum. American Journal of Botany, 11, 579-599.

Revington, J., 1986. This borer spreads rapidly through crops of maize and sorghum on The Hignveld but it can be controlled. Farmer's Weekly, 24 Oct 1986.

Rodenhiser, H., 1934. Studies on the possible origin of physiological forms of *Sphacelotheca sorghi* and *S. cruenta*. Journal of Agricultural Research 49(12): 1069-1086.

Rodenhiser, H.A., 1932. Heterothallism and hybridization in *Sphacelotheca sorghi* and *S. cruenta*. Journal of Agricultural Research, 49, 1069-1086.

Rutto, J.K., 1982. The status of sorghum improvement in Kenya *in* Gebrekdan, B., (ed.) Proceedings of the Regional Workshop on Sorghum Improvement in Eastern Africa, 17-21 October, 1982, Nazreth & debre zeit, Ethiopia 1982, EARSAM, Nairobi.

Scheltes, P., 1978. Ecological and physiological aspects of aestivation-diapause in the larvae of two pyralid stalk borers of maize in Kenya. Wageningen, Netherlands: Landbourwhogeschool 110pp.

Selvaraj, J.C., 1980. Sorghum smuts *in* Sorghum diseases, A World Review: Proceedings of the International Workshop on sorghum diseases, 11-15 December 1978, Hyderabad, India. pp 351-365.

Seshu Reddy, K.V., 1983. Studies on the stemborer complex of sorghum in Kenya. Insect Sci. and its Applic. 4, 3-10.

Seshu Reddy, K.V., 1985. Integrated approach to the control of sorghum stem borers. Proc. Int. Sorghum Entomol., Workshop, Tex., 1984, pp205-15. Patancheru, India: ICRISAT.

Seshu Reddy, K.V., 1987. Sorghum stem borers in eastern Africa *in* International Workshop on Sorghum Stem Borers 17-20 Nov 1987, Patancheru, A.P. 502 324, India: ICRISAT

Seshu Reddy, K.V., 1998. Maize and sorghum: East Africa *in* African Cereal Stem Borers: Economic Importance, Taxonomy, Natural Enemies and Control. Wallingford, UK: CABI 150pp Ed. Polaszek, A.

Shankara, P. and Ramalingam, A., 1988. Wind-tunnel estimation of fungi colonizing sorghum seed from field to storage. Proc. Indian Acad. Sci. (Plant Sci.) vol. 98 No. 6, pp 501-505.

Shenoi, M.M. and Ramalingam, A., 1976. Aerial dissemination of grain smut of sorghum (*Sphacelotheca sorghi* (Link) Clint.). Proc. Indian Natn. Sci. Acad., vol. 42, part B, No4&5, pp194-204.

Siderius, W. and Muchena, F.N. 1977. Soils and environmental conditions of Agricultural Research Stations in Kenya. Miscellaneous Soil paper No. M5. 36 – Ithookwe. Ministry of agriculture – NARL, Kenya Soil Survey pp 97-100

Singh, P.P. and Yadav, H.R., 1966. Varietal resistance to jowar (S*orghum vulgare* L.) to grain smut in Uttar Pradesh, 1964 and 1965. Labdev. J. Sci. Technol. 4:148-149.

Sithole, S.Z., 1987. Maize insect pests in Zimbabwe. Toward insect resistant maize for the third world. Proc. Int. Symp. Methodol. Developing Host Plant Resistance

Maize Insects, Mexico. Pp 286-88. Mexico City: Centro Int. Majoramiento Maiz y Trigo.

Sithole, S.Z., 1990. Status and control of the stem borer *Chilo partellus* Swinhoe (lep. Pyralidae) in southern Africa. Insect Sci. and its Applic. 11, 481-488.

Sithole, S.Z., 1994. Distribution and economic importance of sorghum stem borers in Zimbabwe. PhD thesis, University of Zimbabwe, Harare, Zimbabwe.

Snowden, J.D., 1936. The cultivated races of Sorghum. Adlard & Son, London, UK

Songa, J.M., 1999. Distribution, importance and management of stem borers (Lepidoptera) in maize production systems of semi-arid eastern Kenya with emphasis on biological control. PhD Thesis. Kenyatta Univ., Nairobi. pp251.

Songa, J.M., Overholt, W.A., R.O.Okello and Mueke, J.M., 2002. Regional distribution of Lepidopteran stemborers and their parasitoids among wild grasses in the semi-arid eastern Kenya. *African Journal of Crop Science* 10(2): 183-194.

Sreeramulu, T. and Vittal, B.P.R., 1972. Spore dispersal of sugar cane smut (*Ustilago scitaminea*). Trans. Br. Mycol. Soc., 58, 301-312.

Sreeramulu, T., 1962. Aerial dissemination of barley loose smut (*Ustilago nuda*). Trans. Br. Mycol. Soc., 45, 373-383.

Starks, K.J., 1969. Some cereal crop insects in East Africa. Kampala, Uganda: East African Agriculture and Forestry Research Organisation, Serere Research Station.

Starks, K.J., and Doggett, H., 1970. Resistance to a spotted stem borer in sorghum and maize. Journal of Economic Entomology 63:1790-1795.

Sundram, N.V., 1972. Plant Pathology. *In*: Improvement and production of maize, sorghum and millet. Rome: FAO.

Tabo, R., Olabongi, O.G., Ajay, O., Flower, D.J. 2002. Effect of plant population on the growth and yield of sorghum varieties grown on vertisol. African Crop Science 10(1): 31-38

Taneja, S.L., and Leuschner, K., 1985. Methods of rearing, infestation, and evaluation for *Chilo partellus* resistance in sorghum. Pages 175-188 *in* Proceedings of the Internatioal Sorghum Entomology Workshop, 15-21 July 1984, College Station, Texas, USA. Patancheru, A.P. 502 324 India: ICRISAT

Taneja, S.L., and Nwanze, K.F., 1989. Assessment of yield loss of sorghum and pearl millet due to stem borer damage. Pages 95-104 *in* International Workshop on Sorghum Stem, 17-20 November 1987, ICRISAT Centre, Patancheru, A.P. 502 324, India: ICRISAT.

Taneja, S.L., and Woodhead, S., 1989. Mechanisms of stem borer resistance in sorghum. Pages 137-143 *in* International Workshop on Sorghum Stem, 17-20 November 1987, ICRISAT Centre, Patancheru, A.P. 502 324, India: ICRISAT.

Tarr, S.A.J., 1962. Diseases of sorghum, sudan grass and broom corn. Kew (Surrey), England: Commonwealth Mycological Institute, 380 pp.

Tisale, W.H., Melchers, J.E. and Clemmer, H.J., 1927. Strains of kernel smut of sorghum, *Sphacelotheca sorghi* and *S. cruenta*. Journal of Agricultural Research 34: 825-838.

Unnithan, G.C. and Paye, S.O. 1991. Mating, longevity, fecundity and egg fertility of *Chilo partellus* (Lepid: Pyralidae): effects of delayed or successive matings and their revelance to pheromonal control methods. Environ. Entomol. 20: 150-155.

Usua, E.J., 1974. Observations on the physiology of diapause and non-diapause larvae of *Busseola fusca* (Fuller) (Lep: Noctuidae). Bulletin of Entomological Research 63:513-518.

Vaheedudin S., 1951. Two new physiologic races of *Sphacelotheca sorghi*. Indian Phytopathology 3:162-164.

Van den Berg J., and Nur A.F., 1998. Chemical control *in* African Cereal Stem Borers; economic importance, taxonomy, natural enemies and control ed. A. Polaszek. CABI, Wallingford, UK pp530

Van den Berg J., van Rensburg, G.D.J. and van der Westhuizen, M.C., 1997. Economic threshold levels for *Chilo partellus* (Lep.: Pyralidae) control on resistant and susceptible sorghum plants. Bulletin of Entomological Research 87, 89-93.

Van Hamburg, H., 1980. The grain sorghum stalk borer, *Chilo partellus* (Swinhoe)(Lepidoptra: Pyralidae): survival and location of larvae at different infestation levels in plants of different ages. Journal of the Entomological Society of South Africa 43(1): 71-76.

Van Rensberg, J.B.J., Walters, M.C., and Giliomee, J.H., 1987. Ecology of the maize stalk borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae). Bulletin of Entomological Research 77: 255-269.

Van Rensburg, G.D.J., and Malan, E.M., 1982. Control of sorghum pests and phytotoxic effect of carbofuran on five hybrids of grain sorghum. Phytophylactica 14:159-163.

Van Rensburg, J.B.J., 1980. The use of granular formulation of insecticides for the control of insect pests in grain sorghum. Proceedings of the Congress of the Entomlogical Society of Southern Africa 3:52-53.

Van Rensburg, J.B.J., and van den Berg, J., 1992. Infestation patterns of stalk borers *Busseola fusca* (Fuller) (Lep.:Noctuidae) and *Chilo partellus* (Swinhoe) (Lep.:Pyralidae). Journal of the Entomological Society of Southern Africa 55, 197-212.

Vanderlip, R.L. and Reeves, H.E., 1972. Growth stages of sorghum, *Sorghum bicolor* L. Moench. Agron. J. 54:13-16.

Vanky, K., 1987. *Illustrated genera of Smut Fungi* (New York: Gustav Fischer verlag) pp. 106-107.

Wale, M., 1999. Population dynamics of the stem borers *Chilo partellus* (Swinhoe), *Busseola fusca* (Fuller) and *Sesamia calamistis* attacking sorghum in Central Ethiopia. Insect Sci. Applic. 19(2/3): 149-156.

Wallace, G.B. and Wallace, M.M., 1953. Pamphlet No53, Tanganyika, Department of Agriculture, Tanganyika.

Wendorf, F., Close, A.E., Schild, R., Wasylikowa, K., Housely, R.A., Harlan, J.R. and Krolik, H., 1992. Saharn Exploitation of Plants 8,000 years B.P. Nature 359:721-724.

Williams, T.E., 1966. Root activity of perennial grass swards *in* Root growth. Whittington, W.J., (eds.) Plenum Press, N.Y.

Wilson, G.L., and Eastin, J.D., 1982. The plant and its environment. In Sorghum in the eighties: Proceedings of the International Symposium on Sorghum, 2-7 November 1981. Patancheru, India. ICRISAT, Patancheru, AP 502324, India.

Wilson, K.S.L. and Kavoi, J., May 2001. NRI Report 2612: Current production practices and constraints to sorghum production in Nguuku and Kamuwongo Locations, Mwingi District, Kenya (October 2000).

Wilson, K.S.L. and Kavoi, J., August 2001. NRI Report 2697: KARI/NRI project on sorghum ratooning in Mwingi District on-farm trials – August 2001: End of season farmer meetings (July 2001).

Zartman, R.E., Woyewodzic, R.T., 1979. Root distribution patterns of two hybrid grain sorghums under field conditions. Agronomy Journal 71: 325-328.

APPENDIX 1: CHAPTER 3: SORGHUM RATOONING IN LOCAL FARMING SYSTEMS, MWINGI DISTRICT, EASTERN KENYA

The baseline data was collected in two locations from 28 farmers and triangulated with two womens' groups. The locations, Nguuku and Kamuwongo were selected as they are considered "hotspots" for the cultivation of the two-season sorghums. The focused survey was carried out in October – November 2000.

Checklist used for focused survey

1. Enterprise patterns
2. Crops and varieties grown
3. Recent changes in crop patterns
    - Increasing and decreasing crops, and new crops
4. Decision making on:
    - What crops to grow and where
    - Land preparation
    - Timing of planting and crop mixtures
5. Sorghum production
    - Varieties grown
    - Factors leading to changes in production level
    - Proportion of cultivated land under sorghum
    - Yield (bags)
6. If ratooning:
    - Varieties ratooned
    - Pros and cons
    - Methods used to ratoon
7. Seed
    - Who selects the seed
    - When is seed selected
    - Has this practice changed recently
    - Is the seed treated for storage
8. Sorghum constraints
    - Factors which stop the planting of more sorghum and decrease yields
    - Main pest and disease problems
9. Sorghum history
    - Have the varieties of sorghum grown changed
    - Have the methods of cultivation changed
    - What were the reasons for the changes

Farmers' interviewed in the focused PRA from Nguuku and Kamuwongo Location

No.	Name of farmer	Location	Village	Sex	Age
1	Kanyaa Muthui	Nguuku		F	
2	Ngali Musyimi	Nguuku		F	Y
3	Tabitha Mwilu / Mwende Muandikwa	Nguuku	Monbebi	F	Y
4	Kavola Mwenewa / Muli Kavola / Peter Mwanzi / Luis Musyia	Nguuku	Kyanika	M & F	O & Y
5	Muisyo Kimwele	Nguuku	Kakuyu	M	M
6	Rosemary Musimi	Nguuku	Kasaki	M	M
7	Beattrice Muthani	Nguuku	Kithiani	F	M
8	Tresia Mbuli Mutambuki	Nguuku	Kithiani	F	O
9	Joyce Nguli	Nguuku	Kithiani	F	Y
10	Kasembi Mwisa	Nguuku	Kasika	F	O
11	Kwiyika Women's Group	Nguuku	Katie	F	Y - O
12	Kivonia Women's Group	Nguuku	Katie	F	Y - O
13	Kilonzo Nzioka (wife Christine)	Kamuwongo	Tii	F	Y
14	Grace Mutiui	Kamuwongo	Tii	F	M
15	Jacob (Job) Mukunzu	Kamuwongo	Itundua	F	M
16	Mutinda Mukunzu (wife Nduni)	Kamuwongo	Tulanduli	M	M
17	Mwoki Mbuli (wife Laeli)	Kamuwongo	Tii	F	M
18	Kilonzo Mulonzya	Kamuwongo	Syomurori	M	M
19	Nzambi Mwangangi	Kamuwongo	Itivanzou	F	M
20	Nduni Mwaniki	Kamuwongo	Tulanduli	F	M
21	Kiluti Kyengo	Kamuwongo	Tii	F	M
22	Kimwele Muthangya	Kamuwongo	Tii	M	O
23	Ester Munmu	Kamuwongo	Tii	F	O
24	Syombua Kiilu	Kamuwongo	Tii	F & F	O & M
25	Daniel Muthusi	Kamuwongo	Tii	M	O
26	Rose Mbiwa Kavuvi	Kamuwongo	Tii	F	M
27	Mwoki Mbuli	Kamuwongo	Tii	M	O
28	Muvengei Mwanzia	Kamuwongo	Tii	F	O
29	Muli Mwambu	Kamuwongo	Tulanduli	F	Y
30	Mutie Mwanzia	Kamuwongo	Tii	F	Y

Key: F = female, M = male, Y = young, M = middle aged, O = older aged

APPENDIX 2: CHAPTER 7: ON-FARM EVALUATION OF DIFFERENT RATOONING METHODS ON SHORT DURATION SORGHUM IN MWINGI DISTRICT

The extension officers and farmers were given data sheets to record the information for each ratooning method plot. The extension officers visited each farmer at pre-booting, booting, pre-harvest and post-harvest and helped the farmers to record their information.

Field evaluations carried by farmers and extension officers

In the first cycle the research plots were super imposed on existing sorghum fields and in the second cycle they were prepared at planting time. Data collected from each farmer's plot included:

1. Name of sorghum variety planted
2. Date of planting
3. Was manure applied yes / no
4. Plant spacing used
5. How many times the plot was weeded?
6. Date of harvest
7. How were the different ratooning methods carried out?
8. Dates the different ratooning methods were carried out
9. Number of stumps surviving per plot
10. What score would you give the level of stem borer damage (1-5*) at
    - Pre-booting
    - Booting
    - Pre-harvest
    - Post-harvest
11. What does the a) farmer and b) extension officer like and dislike about the different methods at:
    - Pre-booting
    - Booting
    - Pre-harvest
    - Post-harvest
12. Number of sorghum plants per plot at pre-harvest at pre-harvest
13. Number of harvested sorghum heads per plot
14. Number of tillers per plot at pre-harvest
15. Unthreshed yield per plot
16. Threshed yield per plot

*Score 1 = very googno damage, 2 = a little damage, 3 = average damage, 4 = above average damage, 5 = severe damage

On-farm interviews with farmers at their homestead (second cycle)

1. How were the treatments applied?
2. What score would you give each methods' performance (1-5)* on:
    - Yield
    - Survival rate
    - Stem borer attack
    - Rate of maturity
    - Evenness of maturity
    - Number of productive tillers
    - Head size
    - Labiur input
    - General performance
3. How does the labour input compare with direct planting?
4. Any suggestions to improve on the ratooning methods tested?
5. How do you feeling about growing two-season sorghum on the fertile parts of your farm?
6. Will you grow a ratoon crop next season?
    a. If yes, which variety, which ratooning method willl you use and why?
    b. If no, why?
7. What did you learn about sorghum ratooning from the trial?
8. How much earlier is the ratoon crop compared to the direct planted sorghum crop?

*Score 1 = very good, 2 = good, 3 = neither good or bad, 4 = bad, 5 = very bad

Checklist for end of season workshops

A checklist was produced before the farmer meetings, which included the following questions:

1. Is it a good or bad season to ratoon sorghum, and why?
2. What characteristics make a good ratooning crop?
3. How have the direct sown plots performed compared to the ratooned plots?
4. What characteristic are you using to compare the plots?
5. What characteristics make a good ratooning crop?
6. What score would you give each methods' performance (1-5)* on:
    - Ability to stay green
    - Drought tolerance
    - Earliness to mature
    - Stem strength
    - Head size
    - Number of heads
    - Size of grains
    - Stem borer resistance
    - Other pests
    - Ability to tiller
    - Overall performance.
7. Does how you carry out the ratooning make a difference to the crop?
8. What are the good and bad characteristics of each method?

9. Which method is best and why?
10. Can the ratooning methods be improved?
11. Will you grow a ratoon crop next season? If yes, what varieties and what method of ratooning will you use?

*Score 1 = very good, 2 = good, 3 = neither good or bad, 4 = bad, 5 = very bad

List of Farmers with on-farm trial plost: first cycle (2000-1) and second cycle 2001-2)

No.	Name of farmer	Location	1st cycle 2000-1	2nd cycle 2001-2
1	Ndanavi Maithya	Nguuku	Y	
2	Theresiah Maluki	Nguuku	Y	
3	Mary Kamwoki	Nguuku	Y	
4	Agnes Kisai	Nguuku	Y	Y
5	Martha Nzoka	Nguuku	Y	Y
6	Naomi Maluki	Nguuku	Y	
7	Ndunge Mwema	Nguuku	Y	Y
8	Mwende Kalonzo	Nguuku	Y	Y
9	Rosemary Musymi	Nguuku	Y	
10	Mbuli Mulonzi	Nguuku	Y	
11	Agnes Kithumbi	Nguuku	Y	
12	Kamene Mukiti	Nguuku		Y
13	Lena Makumbi	Nguuku		Y
14	Lucia Musiyasya	Nguuku		Y
15	Kasyoka Muthengi	Nguuku		Y
16	Esther Muliwa	Nguuku		Y
17	Rhoda Mati	Nguuku		Y
18	Makaa Musya	Kiomo	Y	Y
19	Simon Mutunga Nzivu	Kiomo	Y	Y
20	Munyithya Musyoka	Kiomo	Y	Y
21	Mitambo Mulumbi	Kiomo	Y	Y
22	Mutio Musembi	Kiomo	Y	Y
23	John Musyaka	Kiomo	Y	Y
24	Katui Mwangangi	Kiomo	Y	Y
25	Ngeu Musembi	Kiomo	Y	Y

26	Kiluti Wakaka	Kiomo	Y	Y
27	Mutuao Mutambuki	Kiomo	Y	Y
28	Synthi Mbaluka	Kamuwongo	Y	Y
29	Christine Kilonzo	Kamuwongo	Y	Y
30	Grace Muthui	Kamuwongo	Y	Y
31	Mumbe Mwendwa	Kamuwongo	Y	Y
32	Syombua Kiilu	Kamuwongo	Y	Y
33	Mutua Usili	Kamuwongo	Y	Y
34	Kathini Mailu	Kamuwongo	Y	Y
35	Mawia Musyimi	Kamuwongo	Y	Y
36	Daniel Muthusi	Kamuwongo	Y	Y

APPENDIX 3: CHAPTER 8: ASSESSMENT OF THE PERFORMANCE ON-FARM OF FOUR DIFFERENT SORGHUM VARIETIES UNDER THE AGRONOMIC PRACTICE OF RATOONING

Field evaluations (Short rains October 2001 - January 2002, Long rains March - July 2002)

At the start of the short and long rains, each farmer was given a data-sheet and a notebook to record data. The purpose was to encourage the farmers to feel their opinions were as important as the researchers, who also carried notebooks, and to encourage farmers to monitor their plots and notice any differences. The data sheet contained the following questions for each variety:

Short rains

1. Date of planting
2. Was manure applied yes / no
3. How would you score the plant population in the plot? 1-5*
4. How many times was the plot weeded?
5. Date of harvest
6. Date the crop was ratooned
7. How would you score the variety's ability to tolerate stem borer damage? 1-5*
8. How would you score the variety's drought tolerance? 1-5*
9. How would you score the variety's yield? 1-5*
10. What are the variety's good points?
11. What are the variety's bad points?

*Score 1 = very good, 2 = good, 3 = average, 4 = poor, 5 = very poor

Long rains

1. How would you score the variety's stump survival? 1-5*
2. How would you score the variety's ability to tolerate stem borer damage? 1-5*
3. How would you score the variety's drought tolerance? 1-5*
4. How would you score the variety's yield? 1-5*
5. Date the crop was harvested
6. What are the variety's good points?
7. What are the variety's bad points?

Checklist for end of season workshops

A checklist was produced before the farmer meetings, which included the following questions:

1. How have the varieties performed?
2. What characteristics make a good ratooning variety?
3. What are the good and bad characteristics of each variety?
4. Score the varieties for:
    - Ability to stay green
    - Drought tolerance
    - Earliness to mature
    - Stem strength
    - Head size
    - Stem borer resistance
    - Other pests
    - Ability to tiller
    - Overall performance.
5. Will the variety ratoon well, and why?
6. Which variety do you think will ratoon best and rank the varieties?
7. What factors did you take into account in choosing the site for the trial and why?
8. Where is sorghum normally grown on the farm, and why?
9. Is it a good or bad season to ratoon sorghum, and why?
10. Will you grow a ratoon crop next season? If yes which varieties?

For questions 3-6, the farmers had their own discussion groups and the secretary of the group wrote their answers on sheets of paper. In Nguuku, the farmers were split into two groups. Group 1: contain the farmers participating in the trials, and Group 2: contained the farmers who were members of the farmer group, but did not have a trial on their farm. The conclusions of the group discussions were presented to the meeting. The other questions were discussed with the whole group.

List of participants in the three workshops

Kamuwongo Location

	Farmer's name	Sex	Age	Education level
1	Kivau Kasovo	F	65	none
2	Kathini Mailo	F	50	none
3	Syombua Kiru	F	55	none
4	Kithumba Kiivya	F	33	std 7
5	Kalekye Mutua	F	35	std 7
6	Christine Kilonzo	F	38	std 7
7	Rose Katonyo	F	38	std 3
8	Grace Muthui	F	40	form 3
9	Mutua Isili	M	60	std 5

Nguuku Location

	Farmer's name	Sex	Age	Education level
1	Meli Kasyoki	F	49	std 3
2	Muli Mati	F	52	none
3	Mbuli Mwinzi	F	49	adult edu
4	Beth Eric	F	31	std 8
5	Kamene Syengo	F	49	std 1
6	Rose Mwangangi	F	38	adult edu
7	Mwende Kilonzo	F	44	std 7
8	Dorcus Muthengi	F	27	std 9
9	Kamene Nyange	F	37	std 7
10	Kathini Mutemi	F	37	std 2
11	Katui Maithya	F	53	none
12	Mbua Maithya	F	53	std 6
13	Syanthi Kithome	F	48	adult
14	Beatrice Muthami	F	42	std 7
15	Nguno Munyoki	F	37	std 8
16	Mbuli Mulonzya	F	44	std 5
17	Mary Kamwaki	F	35	std 3
18	Rosemary Musuimi	F	51	form 4
19	Kalekye Nguli	F	31	form 4
20	Esther Ngu	F	55	adult
21	Monicah Mutiso	F	29	std 6
22	Martha Nzoka	F	61	none
23	Paul Muthengi	M	43	std 6
24	Ndunge Muema	F	28	std 8
25	Agnes Simeon	F	61	std 2
26	Serah Musili	F	63	std 8
27	Kimala Kathambula	F	60	none
28	Jemimah Moses	F	57	none
29	Agnes Ngumbi	F	65	P3 (teacher)

Kiomo Location

	Farmer's name	Sex	Age	Education level
1	Mitambo Mulumbi	F	50	none
2	Kakingi Mutio	F	42	std 5
3	Nzangi Musyoka	F	25	std 8
4	Katui Mwangangi	F	48	none
5	Mutuo Mutambuki	F	48	none
6	Makaa Musya	M	39	none
7	Kiluti Kaka	F	53	none
8	Munyithya Musyoka	F	43	std 7
9	Vata Mutunga	F	48	std 6
10	Nzilani Mulonzya	F	45	std 8