EFFECT OF CROPPING SYSTEMS AND LAND MANAGEMENT PRACTICES ON RODENT POPULATION CHARACTERICTICS

BY

APIA WILBALD MASSAWE

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ABSTRACT

A Capture Mark Release (CMR) study was carried out at the Sokoine University of Agriculture, Solomon Mahlangu Campus in Morogoro, Tanzania from April 1999 to August 2001 to investigate the effect of slash and burn versus tractor ploughing on the population of rodents in agricultural fields subjected to either monocropping (maize alone) or intercropping (maize and beans). *Mastomys natalensis* was the most abundant species in the different treatments (97.8%). The spatial distribution of individuals was significantly affected by land preparation methods. The coefficient of dispersion values (based on variance-to-mean ratio calculations) indicated that before land preparation, animals were randomly distributed everywhere, but after land preparation and the consequent stages of maize growth, more animals clustered around the edges in tractor ploughed fields whereas in the slash and burn fields, animals were randomly distributed. Rodent population abundance increased in slash and burn fields during the crop growth stage in the short rainy season (*vuli*) as a result of higher recruitment of new individuals than in the tractor ploughed fields (for both mono and intercrop) ($P = 0.004$) suggesting that slash and burn fields are more attractive for colonization from the surrounding fallow fields. Tractor ploughing, slash and burn, mono and intercropping systems significantly ($p \leq 0.05$) affected the home range and movements of rodents. Home range was smaller in the tractor ploughed fields (Wald stat = 57.03; df=1; $p \leq 0.001$). Females occupied smaller home ranges than males (Wald stat=18; df =1 $p \leq 0.001$), but the reasons were not clear. Significant variations in rodent population density due to soil

types also occurred, with lowest populations in sandy clay soils ($F=(2.5)= 8.42$; $p=0.025$). These variations could be attributed to differences in the suitability of soils for burrowing. The level and distribution of crop damage in the fields indicated higher and uniform rodent damage in the slash and burn but lower and random damage occurred in tractor ploughed fields (Variance to mean ratio calculations). This suggests that seed retrieval was easier in the slash and burn fields. The current study suggests that slash and burn practice does not affect rodent population distribution in crop fields while tractor ploughing does affect rodents, probably by reducing cover and food availability or even by killing some individuals. Yet, it seems useful as a management tool when it is practiced over a large area and the surrounding fallow lands, which act as donor habitats, are cleared. Furthermore, land preparation methods should not be assumed to be adequate and effective on their own in controlling rodents but instead, they should be integrated with other strategies to reduce crop damage.

DECLARATION

I, APIA WILBALD MASSAWE, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work and neither has been submitted nor being currently submitted for a degree award in any other University.

Signature............AMassawe............

Date............10th Nov. 2003............

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DEDICATION

To Kelvin and Dennis

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LIST OF ABBREVIATIONS AND SYMBOLS

^{o}C	=	degrees celcius
ACIAR	=	Australian Centre for International Research.
Br	=	Bray
cm	=	centimetres
CMR	=	Capture Mark Release
CRD	=	Completely Randomized Design
Exch	=	Exchangeable
ha	=	hactres
K	=	Potassium
km	=	kilometers
m	=	metres
m.a.s.l.	=	metres above sea level
m.e.	=	milliequivalent
P	=	Phosphorus
P.S.D.	=	Particle size density
pH	=	hydrogen ion concentration
Ppm	=	parts per million
SO_4	=	Sulphates
Solb	=	soluble
SUA	=	Sokoine University of Agriculture

CHAPTER 1

1.0 INTRODUCTION

With the rising need for world food supplies to meet the demands of the burgeoning population, interest in augmenting agricultural production has increased rapidly in recent years (Kurian, 2000). About half the world population is actively engaged in agriculture. Yet, and despite many advances in technology, millions of people in scores of nations suffer hunger, malnutrition, and starvation. The reasons for this pathetic situation are several and complex; and one important factor is food loss to crop pests. Vertebrate pests, especially rodents, are responsible for much of this loss (Kurian, 2000). In developing countries, which are predominantly agrarian, rodent infestation poses a serious threat of not only reduced income but also widespread food shortages as well (Milan, 1990).

Rodent pests play a significant role in limiting agricultural production. They are members of the mammalian order Rodentia that consists of more than 1,700 species worldwide (Fiedler, 1994; Anderson and Jones, 1967). Africa has about 89 genera and 290 species of rodents, which fall into 14 families (Fiedler, 1994). Eastern Africa contains about 62 genera and 161 species found in 12 of the 14 rodent families. The rodent fauna is diverse in weight and size, ranging from the small African pygmy mouse (*Mus minutoides*) weighing only 5-7 grams to the South American Capybara (*Hydrochaerus hydrochaeris*), weighing 50 kg.

Next to man and through his adverted help, rodents are the most successful and abundant mammals on earth (Willan, 1992). They are highly adaptable to environmental changes, capable of surviving a wide range of environmental conditions and rapidly colonizing new ecological niches. It is this adaptability, which makes them difficult pests to manage. However, not all the 1700 rodent species are pests. About 150 species have been defined as pests at some locality to some crop at some time or another, but only 20 could be termed important (Fall, 1980)

Although most rodents live for only about one year, they are prolific breeders, multiplying rapidly under the most favorable conditions (Posamentier and Elsen, 1984). A female Norway rat (*Rattus norvegicus*) and Roof rat (*Rattus rattus*) may have up to five litters in her lifetime, with an average of 7 or 8 young in each litter. The multimammate rat (*Mastomys natalensis*) can have up to 24 young in a litter, the average being about 11. The house mouse (*Mus musculus*) and the multimammate rat (*Mastomys natalensis*) can have a new litter every four weeks (Leirs, 1994; Meehan, 1984; Brambell and Davis, 1941).

Rodents have well-developed senses of smell and touch, but poorly developed eyesight. They have excellent light sensitivity but poor acuity and are color - blind (Meehan, 1984), which is a helpful characteristic in control programs.

Rodent pests are omnivorous, an additional reason why they are successful pests. In spite of this there may be some preferences in the field if a choice is available (Meehan, 1984). Overall, rats and mice in the wild will take a balanced diet. The quantity of food may also vary. Under laboratory conditions, rodents have been observed to consume about 10% of their body weight per day (Meehan, 1984; Posamentier and Alam, 1981; Chitty, 1954). Enclosure studies indicate that under near field conditions the amount consumed or destroyed is about five times the amount eaten in the laboratory (Haque *et al*, 1980), although the proportion actually consumed is uncertain. What is certain, however, is that the actual losses caused are a multiple of their dietary requirements.

Many rodent pests are characteristically mobile and able to disperse rapidly. This allows them to move quickly into and take advantage of new areas with favorable conditions (Fiedler, 1988a). However once an individual has established a territory or home range, it will not move very far, as long as conditions remain favorable.

Rodents have some effects on human beings, they cause significant damage to agricultural crops or are involved in disease transmission. In all of Africa, about 77 species have damaged one or more crops; at least 35 species have damaged eastern Africa crops (Fiedler, 1988a,b). Cereals such as wheat, sorghum, maize and barley are particularly susceptible, but root crops, vegetables, plantation crops and stored foods may also be damaged (Fiedler, 1994).

Tanzania, like most other tropical African countries, is highly and widely populated with several genera and many species of rodents, the majority of which are Murids (true rats and mice). Of these, *Rattus rattus,* is the most common and widespread commensal species while *Mastomys natalensis* and *Arvicanthis niloticus* are some of the commonest field species in the country (Kilonzo, 1976, 1984). Whereas *R. rattus* is mostly associated with human habitats, *M. natalensis* and *A. niloticus* are semi- domestic and are found in all types of fallow and cultivated land, ranging from zero to over 2000 metres above sea level (Msangi, 1968). Several species including *Mus musculus, Lemniscomys griselda, Lemniscomys striatus, Acomys spinossisimus*, *Pelomys fallax, Otomys* spp, *Grammomys dolichurus* and *Rabdomys pumilio* are also common in many parts of the country but are less abundant (Kilonzo and Sabuni, 1992). Some examples of the most serious rodent pests in Tanzania are presented in plates 1(a)-(d).

Some rodent species have the tendency to erupt in numbers under favorable conditions, resulting in very high population densities and severe crop losses (Fiedler, 1994). Periodic rodent outbreaks affecting agricultural crops have probably occurred for centuries but have only been recorded in Eastern Africa since 1920 (Fiedler, 1988 a, b). Rodent outbreaks in Eastern Africa and other sub-Saharan regions involve the multimammate rat (*Mastomys natalensis*) and the Nile rat (*Arvicanthis niloticus*). These species are mostly responsible for crop damage (Fiedler, 1994).

Despite extensive studies (see e.g. in Buckle and Smith, 1994; Prakash, 1988) on rodent control techniques and many rodent control programs around the world, rodents still pose a recurring problem in agricultural systems of many countries (Quick, 1990; Fiedler and Fall, 1994). Surveys show that rodents are considered a major or even the number one pest, but recommendations for control are too complex (expensive and time consuming) for those who should apply them (Fiedler and Fall, 1994). Farmers however, associate large numbers of rodents with crop damage by virtual inspection of the crop in the field and the known damage characteristics (Makundi, 2001).

Rodents have not received the degree of attention given to other agricultural pests. With few exceptions, reliable information on the species involved, the extent of damage caused by them, and their economic impact are not available. The common inability to express rodent damage in economic terms is probably one of the principal reasons why control of rodent damage has been given much less attention than that caused by insects and plant diseases (Fall, 1977). Further, damage by rodents is often accepted as part of the normal scheme of things in agriculture. It is considered unavoidable and only minor attempts are made to evaluate damage, identify species or attempt control (Elias, 1988).

Contrary to what is known about insect and fungal outbreaks in crops, rodent pests are, with a very few exceptions, favoured by high degree of habitat heterogeneity and discouraged by intensively cultivated monocultures (Myllymaki, 1987). There are many examples to show that rodent problems have been alleviated, or have virtually disappeared, with the replacement of small-scale farming (habitat mosaic) by mechanically cultivated monocultures (Taylor, 1968; Myllymaki, 1979; Myllymaki, 1989). Although monocropping is said to be less attractive to rodents, it has the disadvantage that it attracts more diseases and insects that are more likely to be highly prevalent and to cause considerable damage. On the other hand, cropping mixtures may reduce the ability of pests and disease to spread (Agboola, 1981).

The type of farming practices affects the nature of the habitat, shelter and population density of rodents (Makundi *et al.,* 1999). In East Africa, a mosaic of small plots of various crops, intermingled with patches of fallow and permanent grass-land, combined with minimum land preparation and subsequent flourishing of weeds, creates favourable conditions for such opportunistic and prolific species as *M. natalensis* and results in high degree of damage (Taylor, 1968; Mwanjabe, 1993; Myllymaki, 1989).

Various studies have been carried out in Tanzania to establish the relationship between ecological parameters and rodent population dynamics. Most studies were largely conducted in areas of natural and semi-natural vegetation (Telford, 1989; Leirs, 1994; Leirs *et al.*, 1989,1990, 1993,1996; Makundi, 1995, 1999; Makundi and Kilonzo, 1994).

An understanding of the factors that influence the population dynamics of rodent pests and the way in which cropping systems differ from natural ecosystems, can provide an indication of the type of strategy that should be employed in the management of the pest. We can achieve management of rodent pests in a crop system if the techniques used not only reduce both the initial numbers infesting the crop and the rate of population growth, but also create an environment that is unfavourable for harbourage. Therefore, optimal management strategy can only be determined with reference to the ecology of the rodent pest and its interactions with the crop management components.

Little attempt has so far been made to determine interactions of rodents with the various cropping systems found in many agricultural areas under different land management practices (Yeboah and Akyeampong, 2001; Whisson, 1996). One of these interactions, for example, is the influence of agricultural practices on certain ecological characteristics of rodent populations. Other aspects of rodent ecology, which are probably affected by farming activities of which we have no scientific information include:

1. The influence of cropping systems on responses of rodent populations, such as the density, distribution, selection of nesting places and selection of feeding sites.
2. The role of land preparation methods on both rodent abundance and spatial distribution, within the cropping system complex. The question to be answered is: 'What are the consequences to the population size of enforced changes in the cropping systems and land preparation methods?'

Therefore this study was conducted to investigate the ecology of rodents in different cropping systems and to establish whether different land preparation methods and cropping systems affect population characteristics of rodents in the field.

The specific objectives of the study were:-

i) To evaluate how rodent population abundance is affected by different cropping systems and land preparation methods.

ii) To investigate the effect of land preparation methods on rodent population characteristics, especially spatial distribution, population structure (sex ratio and age structure), reproduction and movement.

iii) To assess damage and crop loss in different cropping systems (monoculture and inter-cropping) and land preparation methods (tractor ploughing and slash and burning practices).

iv) To evaluate the influence of soil types on rodent population changes and crop damage.

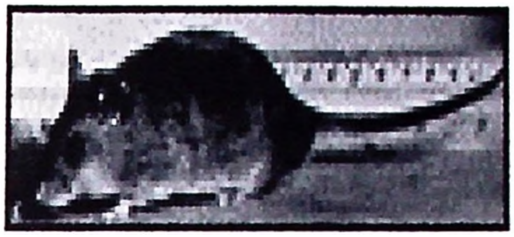


Plate 1a: Multimmamate rat (*Mastomys natalensis)*

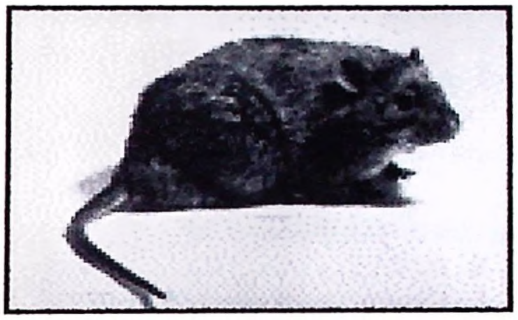


Plate 1b: Nile rat (*Arvicanthis niloticus)*

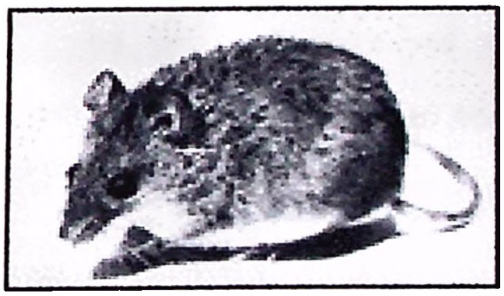


Plate 1c: House mouse (*Mus musculus)*

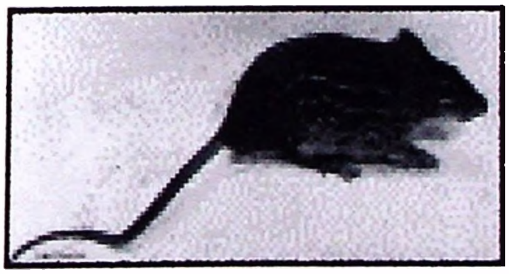


Plate 1d: Striped grass rat (*Lemniscomys* sp)

Plate 1. Some common rodent species in Tanzania

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Rodent problems around the world

Many, but different species of rodents are agricultural pests throughout the world (Caughley *et al.*, 1998). They cause damage worthy millions of dollars every year to agriculture and horticulture, forests, stored products, the food industry, public health and in factories and homes. They cause considerable losses in quality and quantity in almost all kinds of field crops and stored products (Caughley *et al.*, 1998; De Graaf, 1981). Among the household pests, rats have been found to occupy a significant position from very ancient times onwards. Rats actually evolved with human cultural and social evolution. When man lived as a nomad, rats shifted from place to place, harbouring on his luggage and eating upon his food and other holdings. The evolution of man from hunter to cultivator (agriculture) must have had an effect on the rodent world nearly as profound and far reaching as it had on his own. In many areas, some species, especially seedeaters, no longer had to search for wild plants, since cultivated crops ensured a regular and plentiful food supply (Kurian, 2000).

Today, with the sole exception of man, the most abundant mammals on earth are rodents. The success and abundance of some species of rodents can be attributed to man's activities (Hanney, 1965; Kingdon, 1972) which have made the ecological environment much more favourable than would be found in nature. After acquiring the adaptation to live with man, some species of rodents have taken advantage of human transport and trade routes and in this way spread from their ancestral habitats to new and probably better habitats (Davis, 1962; Kurian, 2000).

Rodent pests significantly damage crops before and after harvest with an estimated 20% of the world's food supply consumed or contaminated each year (Spragins, 2001). The most severe agricultural problems occur in tropical plantation crops such as sugar cane, oil palm, cocoa and coconut and also in cereals and other food crops (Elias, 1988). Surveys of the degree of rodent crop damage have been conducted and indicate substantial levels in many regions. Some examples from different geographical regions are shown in Table 1.

In Australia, Caughley *et al.* (1998) reported that the rate of rodent plague has risen in the last twenty years to one every year or two. As an example of the damage rodent plagues can cause, Australia grain industry suffered damage worth about $65 million as a result of major plague in 1993-94 in South- East Australia (Caughley *et al.*, 1998). It was also estimated that each year since 1900, mice have caused $ 13 million worth of damage to crops. Worse still, in the last 20 years, the annual damage is closer to $ 26 million (Caughley *et al.*, 1998).

In Vietnam, rats are considered the most important pre-harvest pest in the Mekong delta region (ACIAR, 1997). Some provinces have annual losses of rice production of between 10 and 25%, and it is further reported that severe damage is commonly recorded in provinces along the border of Vietnam and Cambodia (ACIAR, 1997).

Table 1. Some examples of rodent damage to crops: Pest species, geographical distribution and damage levels.

Rodent species	**Region**	**Crop**	**Damage level**
Bandicota sp	Pakistan	Cereals	20-40%
Bandicota sp	Bangladesh	Wheat	0-30%
Bandicota sp	India	Rice	5-22%
Rattus argentiventer	Southeast Asia	Rice	2-47%
Rattus tiomanicus	Malaysia	Oil palm	5%
Microtus sp	USA	Apples	6%
Microtus sp	France	Lucerne	1-22%
Microtus sp	Finland	Forestry	0.2-40%
Apodemus sp	Northwest Europe	Sugar beet	10-20%
Rattus rattus	Cyprus	Carob	Up to 20%
Hylomyscus, Praomys	West Africa	Cocoa	7-15%
Xerus sp	Kenya	Maize	10%
Mastomys natalensis	Tanzania	Food crops	Up to 50%
Rattus spp.	Caribbean and South Pacific	Coconut	5-77%
Rattus spp.	Hawaii	Sugar cane	40%
Sigmodon sp	South America	Rice	10%
Holocilus sp	South America	Sugar cane	15%

Source: Wood, B.J. (1994)

In Asia, considerable damage can be caused by rodents. While it is not possible to assess all damages, particularly those caused to structures, losses through spoilage in storage or those caused by diseases, some estimates for field crops are available. Damage assessment and opinion surveys carried out in Bangladesh show that annual losses average to about US$ 600 million (Posamentier and Engelhardt, 1990). This figure, however, appears suspiciously high. Most of these losses occur in farmers' households. In their summary of losses due to rodents in Asia, Prakash and Mathur (1988) reported over 50 species which were responsible and that most crops suffer 5% damage, but in some cases exceeding 50%. In Nepal, rodents are considered as the major pest in fields and farm houses causing 15-20% damage to crops and stored grains annually (ACIAR,1998). In the Philippines, pre-harvest damage surveys conducted in nearly 1,600 paddy-fields revealed that rodent damage is about 90% (Sanchez, *et al*, 1971 cited by Kurian, 2000). Wood (1971) estimated that rats were responsible for yield reductions of more than 60% in rice.

Some estimates of rodent damage and losses have been reported in different countries in Africa. In an outbreak of field rodents in Kenya, Taylor (1968) estimated losses of 34% in wheat. In Ethiopia, it has been estimated that rodents consume and destroy up to 20% of the cereal crops in some years (Goodyear, 1976). In Tanzania damage can be very severe in years of outbreaks. Estimates of 80 to 100% have been reported (Poulet, 1980; Mwanjabe,1993). Telford (1989) quoted 6% damage on germinating maize, while Taylor (1963) reported more than 60% loss of crop in Northern Tanzania. Fiedler (1985, 1988a) further lists damage to peanut, cassava and other root crops, sugar cane and tree saplings. Cash crops are also prone to damage by field rodents. Taylor (1976) reported revenue losses of 70% due to rodent damage in cotton in the Chunya valley, South–west of Tanzania. Makundi *et al.* (1999) reported an average of 15% losses in cereal crops in Tanzania due to rodent pests.

Recent surveys conducted in Mozambique have shown that rats have a serious impact on the livelihood and welfare of farmers and their families (New Agriculturalist, 2001). It was further reported that in rural households in Zambezia Province, rats are a constant problem because they affect crops, both in stores and in the field. They also cause damage to buildings, eating and contaminating livestock feed, killing poultry and destroying chicken eggs (New Agriculturalist, 2001).

After harvest, the actual value of losses caused by rats vary by crop, variety, year, geographical location, pest species involved, length and method of storage and climate (Gratz, 1990). The exact post harvest losses are difficult to assess (Jackson, 1977; Meehan, 1984). Some examples based on surveys are given below which indicate the huge financial losses that have been found and can generally be expected.

Surveys conducted in small warehouses in Philippines indicated losses of 40 to 120 kg of grain in each unit (Rubio and Agnon, 1981 cited by Benigno and Sanchez, 1984). Interviewing farmers in Bangladesh on rodent damage inside houses provided an estimated loss per household equivalent to US $ 29.50 for a six months period (Bruggers, 1983). This figure is supported by Mian *et al.* (1984) who found that, on average, households were each infested by 10 rats. At 10.5 million households the annual losses are estimated at US $ 620 million for the entire country in houses only. However, this figure is presumably an overestimate since it assumes that every household was infested with rats. Higher estimates were found by Krishnamurthy *et al.* (1967) in a similar study in India. In large grain stores the situation may be even worse. For example, Fratz (1977) estimated that each godown in Calcutta had, on average, a population of about 200 Bandicoot rats. At an estimated 50 gm which one rat can destroy in one night, appreciable losses will accumulate.

2.2 Rodent outbreaks in East Africa

Although serious arthropod pests sometimes occur in East Africa, rodents are by far the greatest vertebrate pest problem in agriculture and public health (Fiedler, 1994). They are responsible for substantial damage to food and cash crops and play an important role as reservoirs and carriers of zoonotic diseases. In agricultural areas, the multimammate rat (*Mastomys natalensis*) reaches population peaks during which as much as 80-100% of crops may be destroyed throughout its range in sub-Saharan Africa (Taylor, 1968; Fiedler, 1988 a&b; Leirs *et al.*, 1995). Serious outbreak of *M. natalensis* in Tanzania were recorded as early as the 1930's (Harris, 1937) and in subsequent years in various parts of the country (Mkondya, 1977; Mwanjabe, 1990). Major outbreaks occur in several regions. In areas with serious outbreaks, up to 90% of the crop may be lost and even the following crop is endangered (Posamentier and Mwanjabe, 1998). This is putting considerable hardship on small-scale farmers and social and political unrest to the Government.

A report from the Serengeti National Park in Tanzania described an outbreak of grass rats (*Arvicanthis spp*) in which the rats were so abundant that "one could hardly avoid stepping on them and many were killed by passing trucks and survivors were feeding on the dead" (Hubbard, 1972).

During the 1997/1998 cropping season, rodent outbreaks were reported in several regions in Tanzania and resulted in widespread crop damage as shown in Table 2. Population outbreaks of *Arvicanthis sp* and *Mastomys natalensis* around human settlements have been considered particularly problematic because these species are reservoirs for a number of diseases (Fiedler, 1988a; Gratz, 1997; Mills *et al.*, 1997; Oguge *et al.*, 1997).

Table 2. Regions and Districts affected by rodent outbreaks during 1997/1998 season in Tanzania.

Region	District	Nature of crop damage and extent region wise
Tanga region	-Muheza -Handeni -Korogwe -Pangani	- 50% of farmers replanted maize fields - 60-80% green maize cobs were damaged.
Coast region	-Bagamoyo -Kibaha	- most farmers replanted maize twice - 90% of green maize cobs were damaged
Morogoro region	-Morogoro -Ulanga -Kilosa -Kilombero	- Average of 40% of green maize cobs were damaged
Lindi	-Lindi -Nachingwea -Liwale -Kilwa -Ruangwa	- Damage was less than 5% - Only newly planted maize was affected

Source: Rodent Control Centre (1998)-unpublished report

In 2001 serious rodent outbreaks occurred in various regions of the country including Tabora, Arusha, Singida, Songea, and Mbeya. Two reports (summarized below) from Hanang and Karatu Districts in Arusha region illustrate that apart from crop losses, there could have been some serious health and social problems for people in the affected areas.

Report 1: By Charles Ole Ngereza, PST, Hanang (Nipashe Newspaper – Monday, August 20, 2001).

A child aged seven months has been attacked and killed by rats following outbreaks of these animals in Bassotu, Lanangha, Hirbadaw and Bassodesha Divisions in Hanang District.
The ward executive officer reported that rats have bitten several people, and following these attacks, some people have been forced to flee from their houses to save their lives. Some of the victims have been admitted in hospital for treatment.
The executive officer also reported that in all the affected divisions, there are many rodents and their numbers are increasing at high rate every day.
The village government in the affected ward have been asked to provide reports on the extent of damage caused by the rodents in order to assess the seriousness of the problem and report to the central government accordingly.

Report 2: By Eligius Gutta, Karatu District, and Arusha Region

Two people, all residents of Mang'ola Baraza ward in Karatu District, have been admitted at the Mission Hospital in Mang'ola due to injuries sustained after being bitten by rats on different parts of their bodies, inluding their private parts.
The Councillor of Mang'ola Baraza Ward, Mr. Andrew Ari Geffi, confirmed the incidents.
He further said that the rats are increasing in numbers everyday and no one knows where they come from and that, at the moment, they have become a threat to food crops in farms and stored produce in stores.
The Councillor also said that there are now fears that outbreaks of diseases will occur and urged the government to take drastic and immediate measures particularly to supply rodenticides to control the rats.
Report from Karatu district indicated that the species involved were Arvicanthis sp and Tatera sp.

Human plague is one of the important re-emerging zoonotic diseases threatening public health in some African, Asian and South American countries. The worsening situation of human plague in Africa is attributed to many factors including lack of established and sustainable surveillance services, large numbers of countries harbouring active foci of plague and socio-cultural as well as socio-economic factors (Kilonzo, 1999). Eastern and Southern African countries are the most affected and the magnitude of the disease in the region is substantial. Epidemics of plague have been experienced in some parts of

Tanzania. For example, the Lushoto District recorded 6599 cases of human plague and 580 deaths from 1980 to 1996 (Kilonzo *et al.*, 1997). In Singida district plague has been endemic since 1918 (Kilonzo and Komba, 1993).

2.3 Factors affecting rodent population characteristics

2.3.1 Weather

It is well known that weather influences small mammal activity and capture rate (Fall, 1968; Vickery and Bider, 1981). It is possible that small mammals change not only their rate of activity but also the habitat in which they are active under various weather conditions. Thibault (1969) reported that the woodland jumping mouse moved to drier habitat during rainfall. Drickamer and Capone (1977) suggested that differential response of white-footed mice and deer mice to weather may contribute to niche separation among these species. Kotler (1984) showed that desert rodents change microhabitats with changes in light intensity at night.

Various studies have been carried out to establish the relationship between rainfall and rodent reproduction. In Sierra Leone (Brambell and Davies, 1941) and in Transvaal (Coetzee, 1965), pregnant females were caught throughout the year, but with a peak in the latter part of the rainy season. In Natal, breeding activity peaked for most of the wet season, and declined during the dry months (Swanepoel, 1976, Bronner *et al.*, 1988). In Western Kenya, pregnant females occurred in the wet season, but not in the dry season, at the turn of the year (Delany and Roberts, 1978). Hubert and Adam (1985) showed that not only the total annual rainfall, but rather its distribution throughout the year, is important in *Mastomys* ecology. Telford (1989), Leirs *et al.* (1989) and Leirs (1994) found out that reproduction in a population of *M. natalensis* in Morogoro, Tanzania, was strongly linked to rainfall and suggested that unusual rainfall may initiate a seasonal breeding resulting in higher densities.

In South East Asia, Saunders and Giles (1977) compared the relationship between prolonged dry weather on mouse numbers and suggested that plagues of mice were preceded by draught conditions at least one year prior. Redhead (1982) proposed a triphasic model of mouse plagues from a study in the Murrumbidgee Irrigation Area (New South Wales), and demonstrated the importance of good autumn rainfall that enhanced breeding in the following spring. Singleton (1989) postulated that a mouse plague is triggered by good autumn rainfall but that a sequence of rainfall events over the next 12 months is required for its development. Mutze *et al.* (1990) developed a stochastic model based on rainfall and grain production in South Australia that accounted for 41% of the variation in plague occurrence. Cantrill (1992) developed a computer model based on a regular annual cycle in mouse abundance. He provided forecasts of mouse densities from indices of population abundance and rainfall data obtained at particular times of the year. Twigg and Kay (1994) used linear multiple regression to develop a model using microhabitat features and short term (three months) climatic variables to identify important habitat characteristics for mice.

All these observations and many others suggest that weather play an important role in regulating rodent population.

2.3.2 Predation

Predators can play an important role in species coexistence and in structuring ecological communities (Kerfoot and Sih, 1987). They may influence a community by physically removing individual prey and by affecting prey behavior (Peckarsky and Dodson, 1980; Bellman and Krasne, 1983). The influence of predators on prey behavior can have important consequences on prey population dynamics and coexistence (Holt, 1984).

It has been argued that to regulate rodent populations, predation has to be density dependent that is the consumed proportion of the prey population has to increase with increasing population size (Crawley, 1992). Some studies have shown density dependent mortality caused by predation (Beacham, 1979; Erlinge *et al.* 1983; Erlinge, 1987; Erlinge *et al.* 1988).

Anderson and Erlinge (1977) concluded that generalistic and migrating specialist predators can stabilize rodent populations, particularly during and after the decline phase in the rodent populations, but also suggested that predation is not as successful in regulating populations which are increasing or are already high.

Based on field observations and laboratory results, Ylönen (1989) suggested that predation risk from weasels caused altered breeding behaviour and thereby suppressed breeding in *Clethrionomys glareolus*. Klemola *et al.* (1997) suggested that selective predation on pregnant *Microtus* females was responsible for more males biased sex ratio. They also suggested that the altered sex ratio would lead to a lower proportion of reproducing individuals.

Koivunen *et al.* (1998) found no differences in vulnerability to avian predation between mature and immature females in the reproductive seasons. Cushing (1984), however, demonstrated that mammalian predators preferred the odour of oestrus female rodents to non-oestrus females and in the reproductive season, female voles have been reported to be more vulnerable to predation (Klemola *et al.*, 1997, Norrdahl and Korpimaki, 1998). In East Africa, the use of predators as means of rodent population regulation is not well documented. Some few studies have been carried out to explain the relationship between predators and rodent population dynamics. For example, Leirs *et al.* (1997a) showed that survival of non-reproducing *M. natalensis* is an inverse density-dependent process, an effect that would be predicted if predation is an important mortality factor. Van Gulck *et al.* (1998) observed an increase in raptor activity in areas with raptor petch poles and an increased survival of *M. natalensis* in areas excluding raptors. Also, Vibe-Petersen *et al.* (2002- unpublished data) observed that the population growth of *M. natalensis* increased faster in the absence of predators. They also observed that dispersal of rodents changed due to the effect of predation on population growth and peak population size.

2.3.3 Habitat manipulation

In practical application, habitat manipulation means managing vegetation and other characteristics of the habitat to influence food and cover. There are two approaches. One alters the carrying capacity resulting in a change in animal numbers and the other seeks to change the utilization of a crop without influencing the number of animals (Howard, 1967). However, it is also desirable to manipulate both factors for a better effect.

Central to the development of pest control program is the relationship between habitat and the life history strategy of the pest species. The life-history strategy is a complex of behaviors or traits that have evolved together and which allow an animal to maximize its ability to produce offspring (i.e. genetic fitness). High reproductive and colonization abilities are traits that allow rodents to successfully exploit the resources within habitats (Colvin, 1990).

Understanding of life-history strategies and how they change as a function of both biotic and abiotic factors, should be the starting point when evaluating and determining rodent control procedures. This is especially important when considering or implementing habitat manipulation techniques, since it has been suggested that habitat quality is the key regulating factor for rodent abundance and population growth (Davis and Jackson, 1981). In agricultural land, rodent habitat lack the checks and balances of a natural ecosystem, and are often more favourable for certain species of rodents to increase in numbers. The goal of habitat manipulation is to reduce or eliminate the ecosystem elements that enhance a pest species' success. This requires an understanding of habitat components, which favour certain population parameters of the life history of the pest species.

The limitation that habitat quality imposes on the growth and maintenance of rodent populations has been well established in studies of rodents in urban environments (Colvin, 1990). With a lower carrying capacity as a result of sanitation efforts, reproductive rates decline and populations can be markedly reduced without the use of toxicants. Preventative forms of rodent control, such as sanitation and rodent-proofing, have now become standard and widespread practices in urban environments.

Application of habitat manipulation principles to the agricultural scene generally has been given less emphasis than in urban areas. Imposing limiting factors on rodent populations is more difficult when habitats and pest populations can undergo dynamic changes seasonally (Colvin, 1990). Furthermore, when crops being grown for humans are also a key resource for rats, habitat manipulation to limit resources valuable to rats can be contradictory to maximizing crop production. These complicating factors in agricultural systems should not be used to downgrade the importance of habitat manipulation, but to emphasize the need for flexible, predictive and innovative approaches to habitat manipulation as part of rodent control strategies. In tropical regions, the dynamics of habitat growth and change, and thus rodent population dynamics, are accentuated (Colvin, 1990).

Rodent abundance has been reported to be significantly correlated with cover (Bond *et al.*, 1980). The authors also reported that "the vertical distribution of plant material, irrespective of its form or nature, is significant in rodent niche partitioning". However, they also stated that, "foliage profile appear to have low value in predicting rodent population size and specific composition".

Few studies in tropical Africa relate changes in rodent ecology and land use. Studies around lake Kivu (Rahm, 1967, cited by Jeffrey, 1977) showed different rodent compositions when primary forest was compared with secondary bush and cultivated land. Christiansen, (1966), cited by Jeffrey (1977) compared fifteen sites in the Congo including forest, villages, secondary bush and farmland. These studies and those of Delany (1971) indicate that when a forest is removed, there are extensive changes in rodent ecology.

A number of studies have examined the effect of logging and slash and burning on small mammal populations (Ahlgren, 1966; Grashwiler, 1970). Ahlgren (1966) examined small mammal population in logged and burned, logged and unburned, and unlogged – unburned areas. It was found that deer mice responded favorably to logging, but burning the logged sites resulted in greatest increase in deer mice. Redback voles (*Clethrionomys gapperi*) and chipmunks (*Eutamias minimus*) increased in the logged-unburned unit, but not in the burned unit until the third year when a variety of vegetation became available.

Gashwiler (1970) studied vegetation composition and small mammal populations in virgin forest and clear cut areas over a period of ten years. It was that found deer mice increased soon after slash and burning while Townsend's chipmunks (*Eutamias townsendii*), Oregon voles (*Microtus oregoni*) and snow shoe hares increased in the area at different periods after burning. Redback voles (*Clethrionomys occidentalis*), Douglas squirrels (*Tamiasciurus douglasii*), and flying squirrels (*Glaucomys sabrinus*) were absent from the clear cut areas.

The effect of both wildfire and prescribed burning on small rodents have been studied (Black and Hooven, 1974; Fala, 1975). Fala (1975) reported a reduction in the number of herbivorous small mammals like meadow voles for two growing seasons after a prescribed burn. Deer mice rapidly invaded the burned area within one month. Similar findings were reported by Black and Hooven (1974).

In their studies on tropical rodent species (*M. natalensis, A. niloticus, Rhabdomys pumilio and Otomys angoniensis),* Taylor and Green (1976) showed that changes in habitats within agricultural land and the effect of rain patterns, greatly influenced the local distribution of the rodents, their feeding patterns and reproductive cycle. In this study in the Kenya Highlands, it was further reported that disruption of the environment caused by harvesting and ploughing rendered arable land an unstable habitat for rodents, while the relatively small areas of uncultivated land separating fields, field edges and to a lesser extent pasture land were found to support rodents throughout the year. Further, Taylor and Green (1976) stipulated that the agricultural environment is characterized by instability due to some practices (harvesting disrupts favourable habitat of maturing cereal crop; ploughing renders the grass and stubble uninhabitable). In contrast, the cereal crop before harvest is favourable for rodent colonization.

These few examples show that in both temperate and tropical regions populations of rodents respond to changes in habitats brought about by different kinds of land management. Agricultural activities not only bring about changes in vegetation type (grass seeds, weeds, cereals crops, etc), but also affect the availability of food sources and places for harbourage, which are essential for breeding and survival of rodents.

2.4 Cropping systems and rodent management

2.4.1 Cropping systems

A cropping system is defined as the cropping patterns used on a farm and their interaction with farm resources, other farm enterprises, and available technology. Structurally, the cropping system is a physical arrangement of crops over space and time. Functionally, the cropping system is a unit which processes inputs (solar radiation, water, nutrients) to produce an output (food, fibre, etc) (Trygve, 1994).

In tropical countries the use of monoculture is practised only on large farms or estates, while the more traditional approaches to farming utilize polyculture. These polycultures include mixed cropping (no distinct row arrangement), agroforestry (trees in mixed plantation with other crops), row intercropping (one or more crops planted in rows), strip intercropping (crops grown in different strips, wide enough to permit independent cultivation), relay intercropping (two or more crops grown simultaneously for part of the life cycle of each, a second crop being planted before the harvest of the first) (Agboola, 1981). Most of the foods consumed in Africa, Tropical Asia and Latin America is produced in such systems which often more readily meet the needs of the small scale farmers than does the mono-crop.

In Tanzania, cropping systems vary greatly due to the heterogeneity of the agro-ecological conditions. However inter-cropping is the major cropping system in the whole country except for some estate crops like rice, sugarcane and sisal (Rwamugira, 1996). Inter-cropping is a very common practice in West and East Africa and also some other parts of the world (Monyo *et al.*, 1976; Okigbo and Greenland, 1976; Agboola, 1981). For example in Nigeria farmers plant maize, cassava, vegetables and cocoyams simultaneously (Okibgo and Greenland, 1976, Agboola, 1981). In South America they practise alley intercropping where maize-bean system is used (Agboola, 1981).

2.4.2 Influence of cropping systems on rodent pests

Contrary to what is known about insect and fungal outbreaks in crops, rodent pests are with few exceptions, favored by high degree of habitat heterogeneity and discouraged by intensively cultivated monocultures (Myllylimäki, 1989). Although prominent rodent problems have sometimes been considered to be due to monocultures (Herold, 1954 and Wijngarden, 1957, cited by Myllymäki, 1975), this cannot be strictly considered to be the main reason for regular rodent outbreaks in Tanzania where large-scale monocultures are lacking. In fact, in Tanzania, it has been suggested that extensive monocultures are associated with less rodent problems (Myllymäki, 1987). The nature of the cropping system in Tanzania, which is in the form of a mosaic of crop fields interspersed with fallow land produces an environment that is favorable for breeding and harborage of rodents and probably this has great influence on crop damage in adjacent cultivated fields . However, it has been suggested that when the different crops are cultivated over an extended agricultural calendar, they provide a "food continuum" encouraging the occurrence of rodent outbreaks (Makundi *et. al.*, 1999).

Lam (1980) observed that cropping patterns play an important role in the buildup of rodent pest populations in rice growing areas. He found that, changing from a single-cropping pattern to double cropping affected the reproductive potential of rice field rats, *Rattus argentiventer*. In the single-cropped area the reproductive activity was unimodal (i.e. one breeding season during the year) but it was bimodal (i.e. two breeding seasons during the year) in the double-cropped areas. Breeding was greatly influenced by the phenology of the rice crop. The shift from a single-crop to double-crop paterrn enabled rats to breed at least twice a year, thus giving the reproductive potential of the rat population a tremendous boost. This probably led to an increase in the level of rat infestations as well as cases of severe rat depredation in some rice farms. In South East Asia, the increase in intensity of cropping, that is a change from one crop per year to 2-3 rice crops per year, has greatly exacerbated the rodent pest problems (Singleton and Petch, 1994).

Leirs *et al.* (1997b) studied the population dynamics of *M. natalensis* in a small-scale maize field-fallow land mosaic in Tanzania. The seasonal evolution of rodent presence was the same in both habitat types and it was not affected by agricultural activities in the fields. About one week after planting, there was a slight increase of rodent captures in the maize fields, but this disappeared after a few days. Radio-telemetry indicated that many individuals were active in the maize field as well as in the fallow land. These observations suggest that part of their food supply may be available in crop field while another part can only be found in the fallow land. Studies by Taylor and Green (1976) in the Kenyan Highlands showed that when there were no cereal crops in the fields, rodents depended on weed seeds and the leaves and stems of dicotyledonous plants, but as soon as the cereals became available, they formed a major part of the diet of *A. niloticus*, *M. natalensis*, *Rhabdomys pumilio* and *Otomys angoniensis*.

Brown *et al.* (1999) examined the effect of modifying habitats on farms to reduce the food supply and shelter available to mice in Australia. The results showed that managing plant growth along the edges of crops in early spring (onset of breeding of mice) reduced the number of mice by late summer. By grazing sheep on the farm immediately after harvest, reduced the amount of grain remaining on the ground thus reducing the food available for the mice.

Other studies by Huang *et al.* (1999) in China indicated that there are several factors affecting *Rattus rattoides* population density. Factors such as crop structure, vegetation stage and the height of the ditch bank in the fields directly affected the conditions of the population in the habitat.

2.5 Land management practices and rodent pest management

2.5.1 Land preparation methods

The type of cultivation can markedly influence the soil environment and affect pest survival directly or indirectly. Firstly, it can create inhospitable conditions and expose the pests to their natural enemies, and secondly it can cause physical damage during actual tillage (Stinner and House, 1990).

Whisson (1996) studied the effect of a minimum-tillage practice (green-cane harvest and trash-blanketing) and conventional practice (pre-harvest burn and intensive cultivation) on the dynamics of population of the Canefield rat (*Rattus sordidus*) in sugarcane crop of the Herbert River District, north Queensland. It was observed that *R. sordidus* population became established earlier in minimum-tillage, but breeding was reduced as a result of the suppression of 'summer grasses', which is the favoured food source of *R. sordidus* during the breeding period. Summer grasses cover was high in conventional areas, which supported population characterized by female-biased sex ratio, a high incidence of pregnancy, females in the most productive age-class, and low turnover rates, relative to the population in minimum tillage areas. Furthermore, damage to sugarcane increased once breeding had ceased and the diet of *R. sordidus* had changed from seed and non-cane vegetation to sugarcane. Experience in Pakistan showed that deep disc-furrow ploughing after the sugarcane and groundnut harvesting has given good results in reducing the population *of Nesokia indica* and thus lessening rodent problems for the next growing crop (Smythe *et al.*, 1981).

Burning of vegetation in order to destroy rodent habitats has been a common practice in East Africa (Green and Taylor, 1975). In Tanzania, many farmers burn their fields in the aftermath of the harvest or immediately before ploughing. This probably changes the habitat for a short duration, but most likely it has no detrimental effect on the future population size of rodents because burnt areas soon have new vegetation and are reinvaded rapidly by pest species from other areas. For example Green and Taylor (1975) reported an increased catch of *M. natalensis* following burning in Kenya. Presumably, more grass seeds become available on the ground after fires, which probably explains why rodents are attracted to burnt areas (Makundi *et al.*, 1999).

According to Powell (1968) small mammals increased significantly at ploughing, when bushes and other vegetation were left in the soil, and decreased where this vegetation was removed in advance compared to control areas. Shelter rather than food supply was suggested as decisive factor for the variation in densities.

Yeboah and Akyeampong (2001) studied factors influencing the distribution of the mole rat, *Cryptomys zechi* (Rodentia, Bathyergidae), in Ghana. They observed that, in areas where mole rats were found, local distribution was influenced by food availability and land preparation methods. They further noted that the highest concentration of mole rats colonies was found in farmlands where traditional hoe ploughing is used for land preparation and the lowest concentration was in farms where mechanized ploughing is used.

2.5.2 Weeding

Soil disturbance and weeding are often effective rodent management strategies when practised regularly. Regular weeding reduces cover, which deprives the rodent population of both protection from predators and food (Smythe *et al.*, 1981). Weeding in peasant farms is done manually and therefore it is limited to the cultivated land due to shortage of labour. The un-weeded and un-cultivated land remain suitable habitats for rodents from where invasion of the field crops occur.

During the dry season the species that are pests of cereals are dependent on the cover provided by weeds and grasses, to protect them from predators (mainly birds), and on the weed seeds and cereals left after harvest for food. Removal of cover deprives rodent of both protection and food (Green and Taylor, 1975).

Mwanjabe (1993) observed that weeds particularly grasses, play an important role in sustaining large populations of *M. natalensis* throughout the year in the Rukwa Valley, Southwest Tanzania. Taylor (1968) made similar observations where more rodent damage was found in unweeded grain fields. The author also observed that eliminating or reducing weeds increased rodent mortality and reduced migration into cropped areas, and thereby, reducing crop losses.

Studies on the effect of land preparation methods and cropping systems on rodent (*Mastomys natalensis*) are lacking. Such studies are important in designing Integrated pest management (IPM) and could also increase our knowledge on ecologically based rodent management in Tanzania. This is the focus of the current study.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Location of the study

The field experiments were carried out at the Sokoine University of Agriculture (SUA), Solomon Mahlangu Campus (Mazimbu Ward) in Morogoro region. The location of the study area is shown in Fig.1a. Solomon Mahlangu Campus is located at $6^0$46'S $37^0$37'E at an elevation of 480 meters above sea level (m.a.s.l.). The study area is about 15 km to the South west of SUA Main Campus. In previous years the experimental fields were under maize cultivation, but the land was left fallow for animal pasture two years before setting up the grids. The layout of the grids in the study area is shown in Fig. 1b. The dominant vegetation in the area included short grass (seasonal) dominated by jungle rice (*Echinochloa obtusiflora* and *E. stagnin),* tall grass (perennial) dominated by wild sorghum (*Sorghum arundinaceae*) and guineafowl grass (*Rottboellia cochinchinensis*).

3.2 Weather Conditions

The study area receives bimodal rainfall. The short rains occur between October and January and the long rains between March and May. Rainfall, temperature, mean radiation and total pan evaporation at Sokoine University of Agriculture (SUA) are given in Figure 2 and Appendix 1. The short rains were generally low and intermittent. The mean radiation was generally higher during the short rains than the long rains.

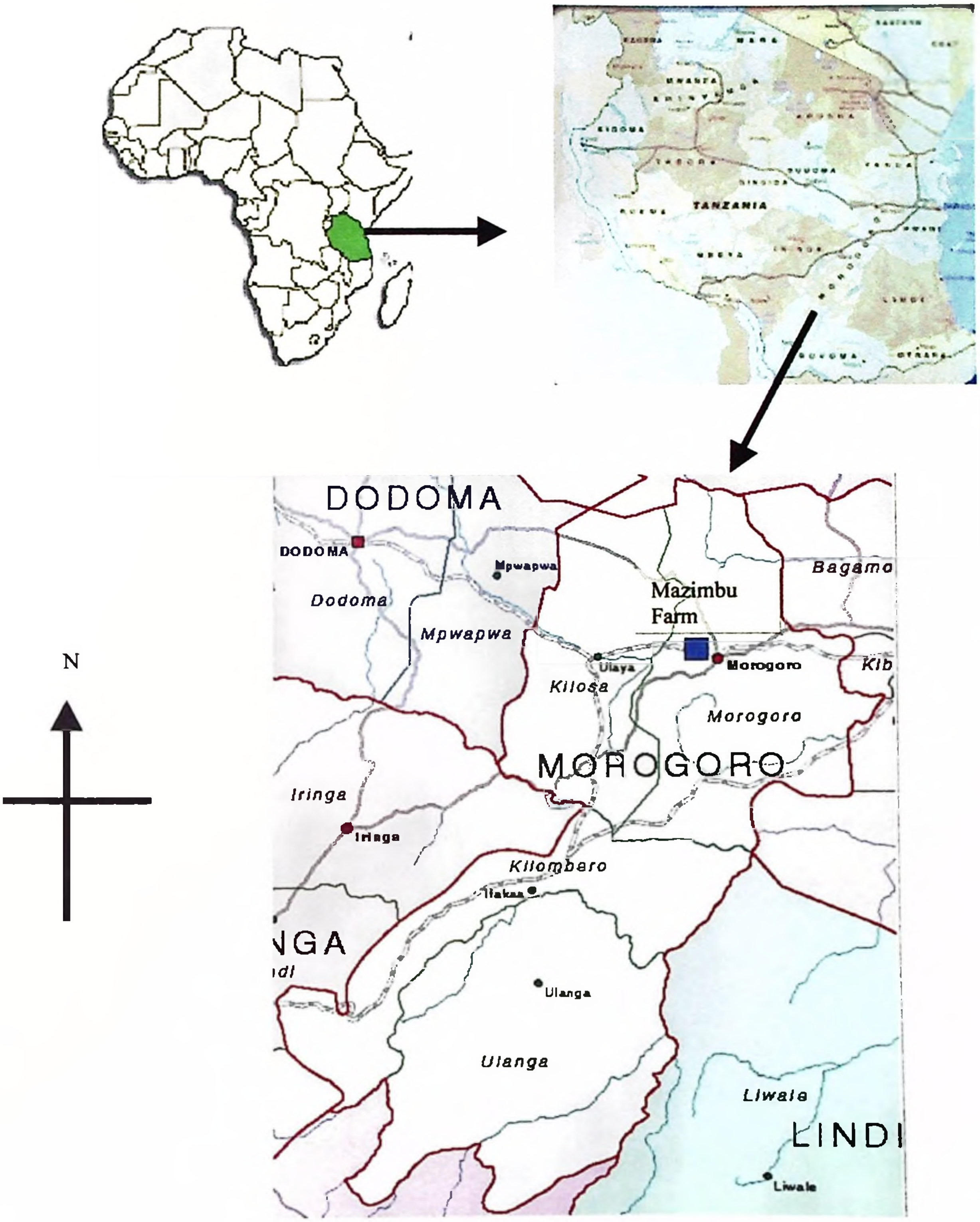


Figure 1a. Map of Africa and Tanzania and the location of the study area (Mazimbu Farm) in Morogoro region

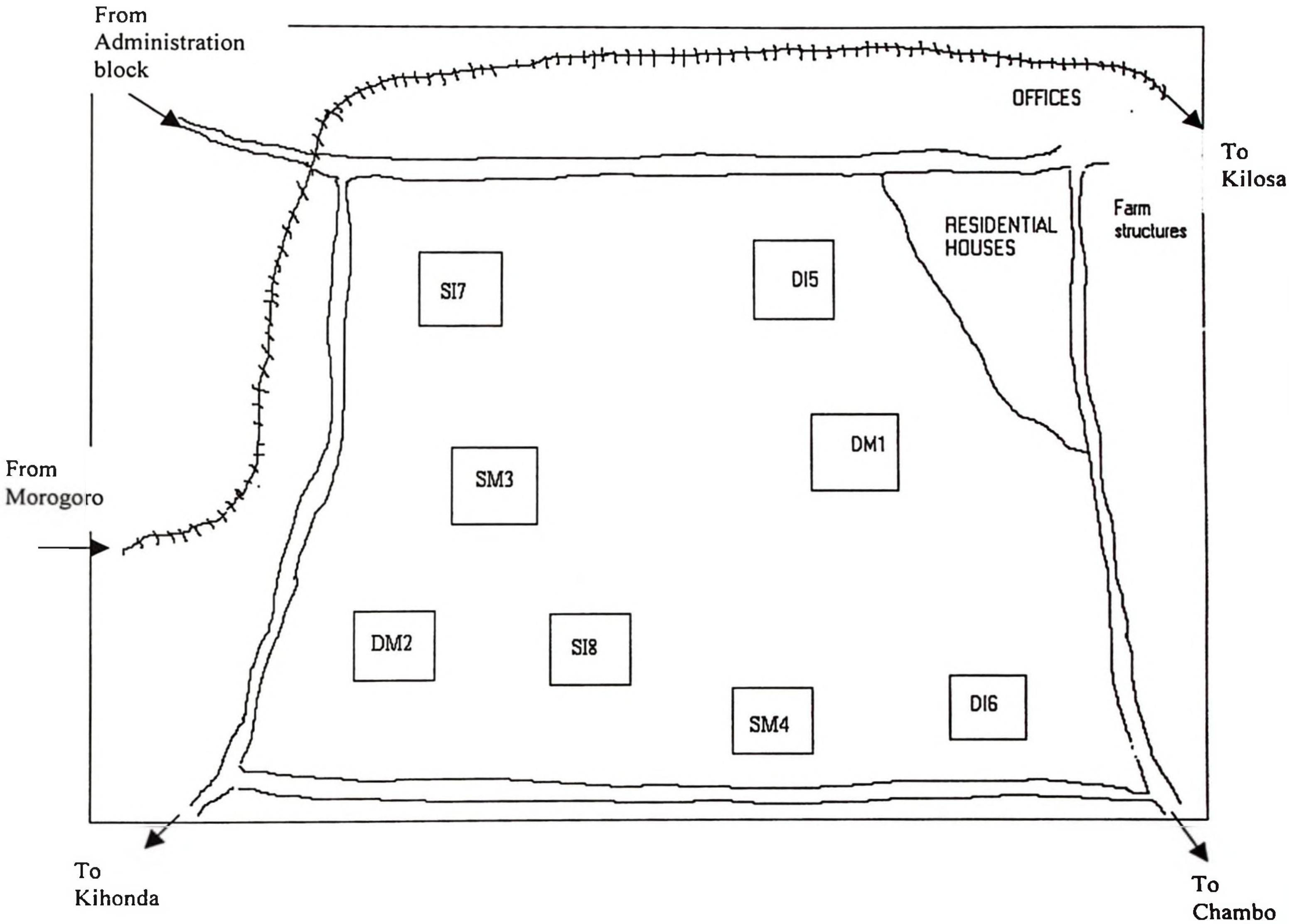


Figure 1b. Layout of Mazimbu Capture Mark Recapture Grids

DI (DI5 & DI6) = Tractor ploughed grids where maize was inter-cropped with beans;

DM (DM1 & DM2) = Tractor ploughed grids where maize was grown as monocrop;

SI (SI7 & SI8) = Slash and burn grids where maize was inter-cropped with beans

SM (SM3 & SM4) = Slash and burn grids where maize was grown as monocrop.

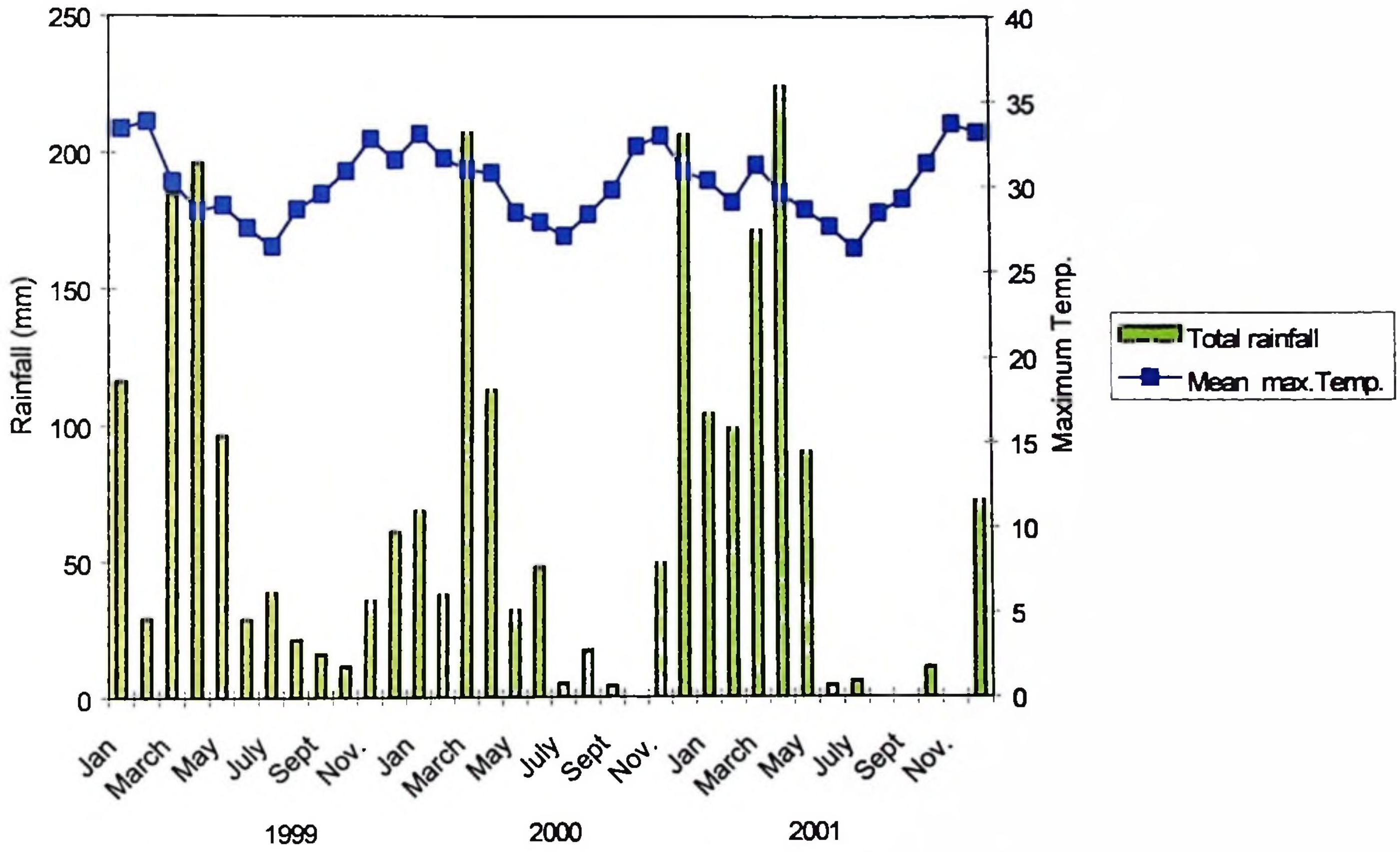


Figure 2. Monthly rainfall and mean monthly temperature in the study area (Source: Morogoro Meteorological Station, Sokoine University of Agriculture: January 1999 to December 2001.

3.3 Set up of the grids

Eight 70x70m grids were laid out for a Capture-Mark-Recapture (CMR) study (Fig. 3). These grids consisted of 7 parallel lines, 10m apart with trapping stations also 10m apart, resulting in 49 trapping stations per grid. After the initial setting and ploughing of the grids, the trapping stations were marked with labeled and numbered bricks for easy placement of the traps. The trapping stations were identified by coordinates labelled A to G, and numbered 1 to 7. The grids were separated from each other by 200-300m wide zone of fallow land.

The grids were subjected to two levels of cropping systems (mono-cropping and inter-cropping) and two levels of land preparation methods (tractor ploughing and slash and burn) in a combination. The monocrop system consisted of maize plots, and the intercrop consisted of maize and beans (Table 3). The experimental design was a Completely Randomized Design (CRD) of 2x2 factors with two replications (given the nature of the study and land availability, it was not possible to have more than two replications). The randomization of the treatments was done in relation to the topography and landscape homogeneity in the study area. Description of the different fields in the study area is presented in Table 4.

3.4 Rodent population parameters

Rodent population abundance, home range, movements and reproduction in the different treatments were determined from data collected by Capture-Mark Recapture (CMR) technique. Radio-telemetry could have been a better method to obtain additional data on survival and movements but it has the disadvantage of being expensive and time consuming if large numbers of animals were to be followed. On the other hand, removal trapping could have given more precise information on reproductive status but at the same time individual weight development, survival and movements could not be recorded. Furthermore, removal trapping creates unnatural situation where there are no local natural demographic processes.

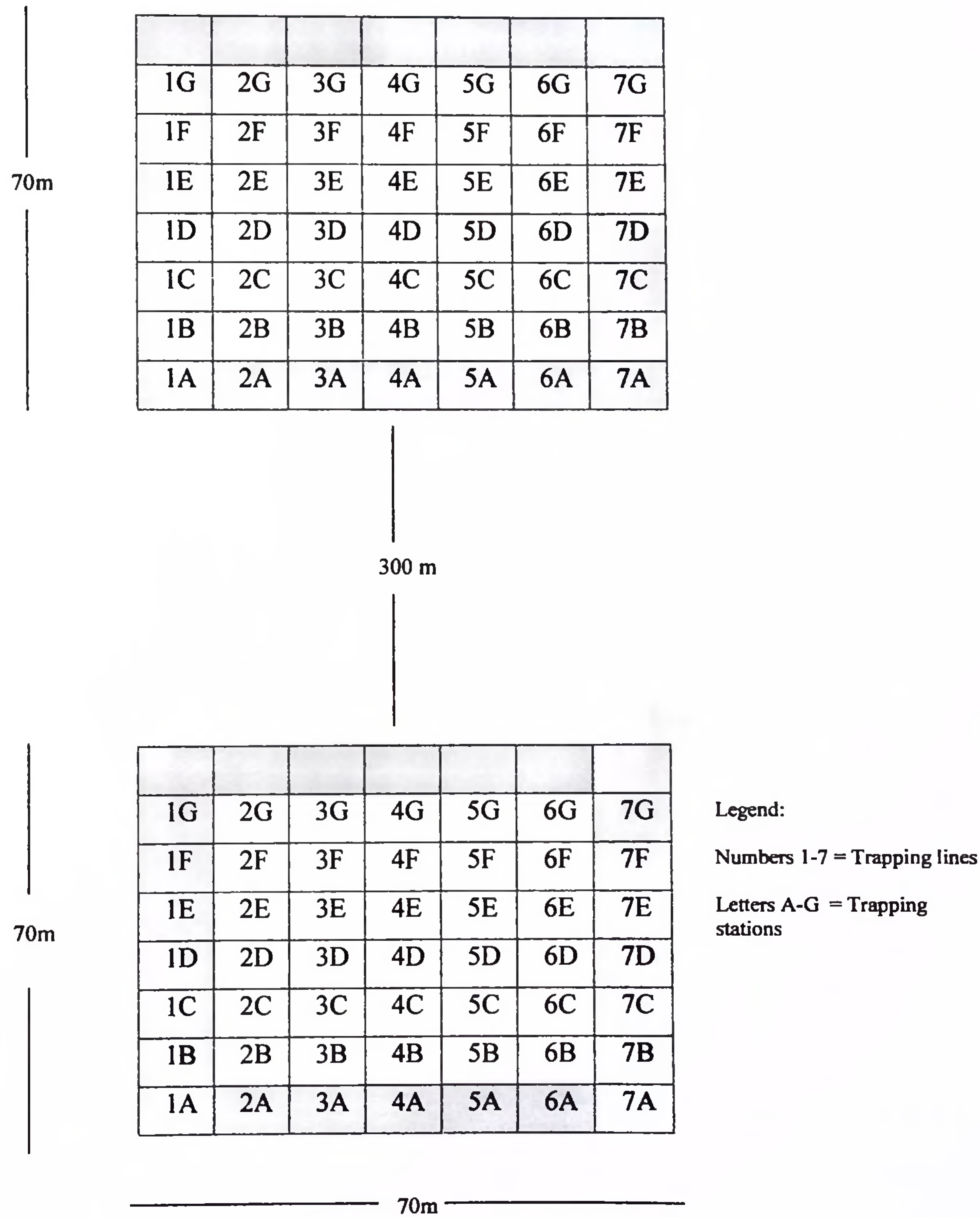


Figure 3. Layout of the Capture Mark Recapture grids.

Table 3. Number of plots within the treatment combinations.

Treatments	Tractor ploughing	Slash and burn	Total
Monocropping-maize	2	2	4
Intercropping-maize and beans	2	2	4
Total	4	4	8

Table 4: Description of treatments.

Treatment	Replication	Common weeds	Description of treatment
DM	DM1	*Trichodesma zeylanicum*, *Cyperus spp*	Tractor ploughed Mono-crop (maize)
	DM2	*Rottboellia cochinchinensis*	
SM	SM3	*Rottboellia cochinchinensis*	Slash and burn Mono-crop (maize)
	SM4	Convolvulaceae spp	
DI	DI5	Boerhavia spp	Tractor ploughed Inter-crop (maize and beans)
	DI6	*Trichodesma zeylanicum*	
SI	SI7	*Trichodesma zeylanicum*	Slash and burn
	SI8	*Trichodesma zeylanicum*	Inter-crop (maize and beans)

3.5 Land preparation methods

Ploughing was carried out by tractor using a disc plough at a depth of 30cm, which is the normal rooting depth for most annual crops. Harrowing was not done in these fields, since in most small scale farming practices, farmers do not harrow their fields. In the slash and burn fields, slashing was done by hand hoe and the weeds were left to dry for one or two days depending on the weather conditions and thereafter burnt within the fields.

3.6 Management practices

Maize was planted in a recommended spacing of: Planting lines 90cm apart, plant holes 60cm apart, and three seeds per hole to allow intercropping (Plate 2). The spacing for beans was 50cm x 10cm. Beans were sown 2-3 weeks after maize. All necessary agronomic practices such as fertilizer application and weeding were carried out. Fertilizer (TSP 20 kg P_2O_5/ha) was applied in the plots before sowing. Nitrogen was applied 3-4 weeks after sowing at a rate of 40kg N/ha (Urea was used as a source of Nitrogen). At flowering stage, the bean crop was sprayed with Thionex 35 EC at an application rate of one litre per 0.5 ha to control bean beetles.

Plate 2. Maize planting in Mazimbu fields

3.7 Trapping procedure

Capture Mark Release trapping started during the end of the long rainy season in April 1999 to July 2001. Trapping was done with live traps (Sherman LFA live traps, 7.5 x 9.0 x 23.0 cm, HB Sherman Trap Inc, Tallahassee, USA) baited with a mixture of peanut butter and maize bran. Trapping was conducted for three consecutive nights in each grid every fourth week. Additionally, trapping was conducted before and after ploughing, and after seed emergence (maize crop). The traps were checked early in the morning for the three consecutive days and captures were collected, processed and later released at the same trapping station. Before repositioning, the traps were cleaned of old bait and droppings and new bait was added.

3.8 Processing of captured animals

The captured animals were shaked gently out of the traps into a cloth bag and weighed using persola balance (Plate 3). Each new capture was marked by toe clipping and identified by a combination of individual coding of the toes (Appendix 2). The toe clips were kept in Ethanol for molecular work.

For each individual caught the following observations were recorded:

- The grid number and coordinates of the trapping station,
- Date.
- Toe clipping code.
- Sex (male or female).
- Whether the animal was marked (i.e. recaptured individuals would already have been marked).
- Body weight of each animal.
- State of maturity or reproductive status as described and illustrated in Gurnell and Flowerdew (1990) (the position of the testes and condition of the vagina and nipples were noted as indicators of current breeding, previous breeding or juvenile status).

- Males: position of testes (scrotal or abdominal)

  Epididymal gubernacula- externally visible or not.

- Females: Vagina perforated or closed.

  Visibly pregnant or not

  Nipples small or swollen due to lactation.

[Males, testes abdominal = juvenile, testes scrotal = mature; females, body weight < 20g = juvenile, body weight > 20g = adult]. Pregnancies were identified by palpation.

Other remarks (eg animal together in one trap, escaped, died) were recorded.

Plate 3. Handling of captured animal at the Mazimbu grids (A-removing an animal from the trap; B- weighing of the animal; C-repositioning of the animal)

3.9 Damage assessment

Damage assessment was carried out in all the treatments both at seedling emergence and at crop maturity. Since no rodent damage was observed during the vegetative stage of maize growth, damage assessment was not done at this stage. Systematic sampling technique was adopted from Mulungu *et al,* (2000-unpublished data).

After planting, signs of rodent damage to the sown seeds were noted. At seedling emergence, missing seedlings (three seeds were sown per hole) and those actually found cut by rats were counted. The sampling units were maize rows; five rows apart, leaving out two edge rows all round the plots. The assessor walked along maize rows across the field, counting missing seedlings at each hole or stand. Damage (D%) was calculated as:-

%D = 100d/(u+d)..[1]

Where: d is the total number of missing seedlings in the whole sample.

u is the number of undamaged seedlings.

NB: Before planting, germination test was carried out in the laboratory to check seed viability. An assumption was made that all missing seedlings were due to rodent damage.

At ear ripening stage, the ears were examined for damage by rodents on upright, leaning, and fallen maize stems. Two types of damage were assessed; namely, longitudinal and circular ear damage. Longitudinal ear damage occurred when missing kernels were along the length of the ear. In circular ear damage, missing kernels were in a ring form around the ear. Measurements taken for circular ear damage were the total length of the ear, length and circumference of damaged portion. For both types of cob damage, the proportion damaged was calculated. The damaged proportion of cobs per field was calculated from the ratio of damaged cobs to the total number of cobs per sample for the whole field.

3.10 Yield data

At maturity, maize cobs were harvested, sun dried, threshed, winnowed and yield from each treatment combination was recorded and the data were kept for further analysis.

3.11 Estimation of ground cover

In order to have a general idea about the vegetation changes occurring in the grids and the surrounding fallow land, it was necessary to estimate plant ground cover. These data were used to establish the importance of cover in rodent population dynamics in the study area. Plant cover estimation was done after every monthly capture session during the study period. In each grid, the assessor moved diagonally across the grid from point 1A to 7G and from 1G to 7A (Appendix 3). In total there were 13 points assessed for vegetation cover, which makes one quarter of the field. At each trapping station, vegetation cover higher than 5cm was included.

At each point a qualitative estimation of ground cover (other than maize crop) was made using a scale of 1-5, in quadrat measuring 5m by 5m. The corresponding values were: 1 = no cover (< 15%); 2 = sparse cover (15-40%); 3 = moderate cover (41-65%); 4 = dense cover (66-90%); 5 = very dense cover (>90%). In the surrounding fallow land, cover estimation was done on all the four sides of the grids.

3.12 Soil properties

An investigation of the soil characteristics was carried out in the different grids to examine the possibility that the type of soil affects rodent population dynamics in the study area. Four to five soil samples (depending on vegetation type) were taken randomly from each grid. The samples were taken from a depth of 30cm. In total, 37 soil samples were taken from all the grids. The soil samples were packed in plastic bags for further laboratory processing. The physical and chemical properties of the soil samples were analyzed. Soil chemical analysis was done for agronomic purposes (ie they were not experimental parameters in the study). The physical properties included; percentage sand, percentage silt and clay. The chemical properties, which were determined included total nitrogen, extractable bray phosphorus, exchangeable potasium and water-soluble sulphate. The physical properties were analysed using the hydrometer method (Gee and Bauder, 1986). Flame photometry (Maclean, 1982) was used to determine exchangeable potasium. Exchangeable phosphorus was determined by Bray and Kurtz method (Bray and Kurtz, 1945), while total nitrogen was determined by using the Kjeldahl method

(Bremner and Mulvaney, 1982). Soil pH was determined by glass electrode method (Maclean, 1982).

3.13 Data analysis

3.13.1 Estimation of population size

Population size estimation was done for the three days capture in each month. It was assumed that three days period is too short for demographic proceses to take place in the population. Therefore estimates of population size were obtained using mark and recapture models for closed populations, and assumptions were tested by using the software program CAPTURE developed by Otis *et al.* (1978), which includes an algorithm to select the appropriate model after the hypothesis testing procedure. The conceptual basis for this selection procedure is a trade-off between precision and bias. If a simple model, such as the null model M_o in Otis *et al.* (1978), is used to estimate parameters from data that violate in any way the assumption of equal capture probability, then significant biases are introduced in parameter estimates and sampling variations will be artificially small. On the other hand, if a more complex model is used, such as M_{th} of Otis *et al.* (1978), that allows capture probability to vary with time and among individuals, biases may be reduced but the sampling variance will be greater than it should be. The selection procedure takes into account the individual goodness-of-fit tests performed for specific models on the data and the confrontation of related models (i.e. where one model is a particular case of a general one). The significant level for all these tests are combined in a standard discriminant analysis and the resulting statistic is standardized so that its value ranges from 0 to 1, 1 being the score that indicates the appropriate model (Otis *et al.*, 1978).

The basic or null model M_0 can be applied to the general case of multiple recaptures in a closed population, where all animals have equal capture probabilities, and where this probability remains constant in time. In this study, it was assumed that capture probability varied individually with sex, age, reproductive status and social status. There may also be some unrecognized sources of variation (White *et al.*, 1982) and some of them could be cropping systems and land preparation methods. This heterogeneity of capture probably could bias population estimates if the more general model of equal capture probability (Mo) was used to estimate population size. Therefore the M(h) estimator of the program CAPTURE (White *et al.*, 1978) for closed population was used. The model allows for individual variations in trapping probability. The obtained population size estimate was plotted for each treatment combination separately using Microsoft Excel program. A statistical analysis was performed to see the effect of land preparation methods and cropping systems on the rodent population abundance. Since there were some months when no animals were captured, it was not possible to look at these effects using the whole population data set. Therefore, the data for different seasons were analysed separately. Factorial ANOVA was performed using the Visual General Linear Model (GLM) of the statistical program STATISTICA. This model is an implementation of the General Linear model for analyzing responses on one or more continuous dependent variables as a function of one or more categorical or continuous independent variables. Visual general Linear Model offers a complete selection of ANOVA/MANOVA types of methods. In the current study, land preparation methods and cropping system were considered as the categorical/independent variables and population size as the dependent variable.

3.13.2 Spatial Distribution of rodents

A detailed analysis of the distribution of rodents was carried out at different stages of maize production (before land preparation, after land preparation, after seed emergence and at vegetative stage). Spatial distribution of the animals in the different fields was shown by capture maps, which showed the intensity of captures at different trapping stations. The pattern of distribution of individuals over the different trapping stations was established by determing the coefficient of dispersion (CD) by calculating the variance-to-mean ratio using the formula below:-

$$CD = \frac{s^2}{\bar{x}} = \frac{\dfrac{\sum\left(x - \bar{x}\right)^2}{n-1}}{\dfrac{\left(\sum x\right)}{n}} \quad \text{......................................} \quad [II]$$

Where: CD = Coefficient of Dispersion; S^2 = Sample variance; X = Sample unit; $\bar{x}$ = Sample mean; n = Total number of samples

These ratios indicate whether animals are aggregated, random or regular in their distribution (Kranz, 1993). The distribution was considered random when the CD values were 0.7-1.3, aggregated (clustered) when CD values were > 1.3 and regular when CD values were < 0.7 (Kratz, 1993).

Using the established maps, the percentages of animals captured at the centre grid (40*40m from line 2-6 and trapping stations B-F) were compared between treatments. Since the central grid consisted of 5x5 of the 7x7 traps of the whole grid, we expected a proportion of 25/49 if animals were evenly distributed throughout the field. Statistical analysis using Factorial ANOVA was perfomed in STATISTICA (Using the Visual General Linear Model procedures) to compare the effect of the different land preparation methods and the cropping systems on the distribution of animals.

3.13.3 Recruitment of new individuals

Recruitment of new individuals to the population in the different treatments was determined by establishing the proportions of new individuals entering the trappable population during the entire study period and at different stages of crop production (after ploughing, after seed emergence and at vegetative stage in the different seasons).

The proportion of new individuals in the population was obtained using the following formula:-

Proportion of new individuals = No. of unmarked/Total No. Captured ....[III]

The proportions of new individuals were compared between treatment combinations, using the Repeated Measure Analysis (GLM procedure in STATISTICA).

3.13.4 Sex ratio and reproduction

In this study, sex ratio is defined as the proportion of females to males in the whole population. It was hypothesized that the proportion of females to males was equal in the different treatments (ratio 1:1). The total number of captures was used in the analysis. To determine the sex ratio the following formula was adopted:

Proportion of females/males = (Number captured/ Total number of animals captured) * 100.. [IV]

The Factorial ANOVA in the Visual GLM (STATISTICA) was used to establish the effect of the different treatments on males and females in the population.

3.13.5 Reproductive conditions

In each treatment combination, the timing of reproduction was analyzed by plotting the proportion of adult females and males in reproductive condition in the population over time. Statistical analysis was performed to determine the effect of land preparation methods and cropping systems on the sexually active individuals in the population.

3.13.6 Age structure

In this study, age structure is defined as the number of individuals of each age group that are represented in the population. The idea was to see if the different land management and cropping systems affect age structure in the population. Therefore, weight was used to classify the captured animals into three weight classes (Leirs, 1992) irrespective of sex, with an assumption that nutrition status was the same. Animals with less than 25g were considered as juveniles, those with between 25g to 40g were considered as sub adults and animals with more than 40g were considered as adults irrespective of reproductive conditions. Statistical analysis was carried out using Factorial ANOVA in the Visual GLM model of the program STATISTICA, to compare the effect of the different treatments on the age structure of the population. In the current study, very few juveniles were captured, and thus they were not included in the analysis.

3.13.7 Home range and movements

Home range is defined as the area where an individual normally moves during its normal daily activities (White and Garrot, 1990). It was hypothesized that land preparation method and nature of the cropping system affected home range of an individual. The technique used for home range estimation was to define a convex polygon of corners given by the most extreme trapping locations, and the area of that polygon was calculated (Mohr, 1947; White and Garrott, 1990). To obtain a polygon at least three corners are necessary and only animals captured at least three times were included in the analysis. Figure 4 presents a schematic estimation of home range using the convex polygon method. From the figure, each of the dots indicates where the same animal was captured in different trapping sessions during the study period. If an animal was captured at point 3G on one occasion, and then at points 2E, 4F and 4E in other occasions, it was assumed that these points made a convex polygon and therefore the home range was estimated by calculating the area of this polygon. The problem with the convex polygon method is that, some animals are only captured at one point or only in one direction. But in reality we cannot assume that some animals have zero home range or they only move in one direction. Therefore, it was necessary to include a border zone of 5m width around the polygon, which is half the distance between the trapping stations. The major objective of home range estimations was to determine if individual movements differed between seasons in each treatment combination. In the course of the study, very few individuals were captured more than three times in each season which made it very difficult to meet the objectives. Therefore, in the analysis, data were pooled regardless of the cropping season. After estimating the home ranges for different individuals in the grids, statistical analysis was performed to establish whether land preparation and cropping systems affect the home range of individuals in the field.

Together with the home range estimation, rodent movement in each treatment combination was measured. The idea was to establish how rodent movements were affected by land preparation and cropping systems. To perform this analysis, the distance between the trapping points was taken and only individuals captured two or more times in each season (i.e. non-cropping season, short rain season and long rain season) were included. For individuals captured two times only, the distance between the points was taken but for more than two captures, the maximum distance was taken. Since the distances obtained were not continuous variables (i.e it can be 0, 10, 14.4, 20, 22.4, 28.3, 30, 31.6, 36.1, and 42.4m) the analysis was not done as a normal comparison of a continuous variable. This is because the traps were at fixed distances of 10 m from each other and a distance of less than 10 m between traps was not expected. Therefore, the different distances were ranked into four levels as indicated below:-

Score 1: 0-10 m; Score 2: 11-20 m; Score3: 21-30 m; Score 4: >30 m.

The home ranges were also allocated into a four point scale as follows:-

Score 1: 50-150 m^2; Score 2: 200-300 m^2; Score3: 350-450 m^2; Score 4: >450 m^2 .

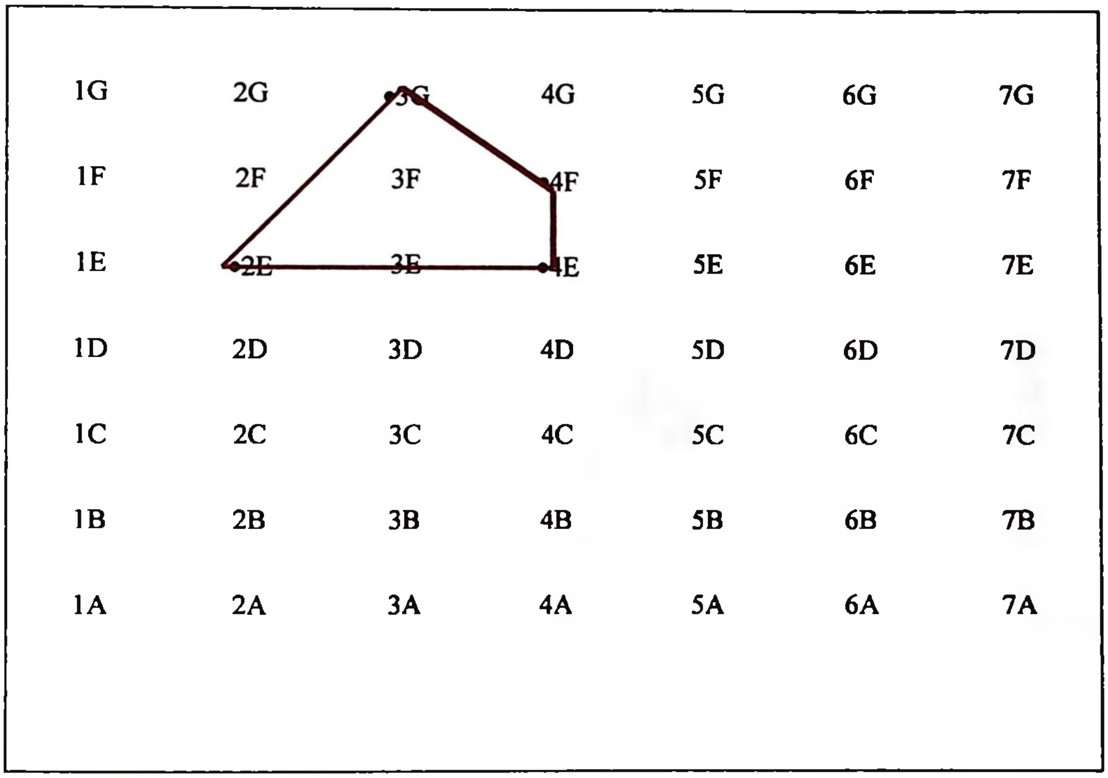


Figure 4. Schematic estimation of home range by the convex polygon technique.

The data for home range and rodent movements were modeled in STATISTICA (VGLZ- Visual generalized linear models) using the ordinal multinomial distribution and the cumulative logit as link function. The outcome is the cumulative probability expected in each level ordered in their natural order: in level 1 the analysis calculates the expected proportion in level 1. In level 2 the expected proportion in level 2 + expected proportion in level 1, in level 3 the expected proportion in level 3 + expected proportion in level 2+ expected proportion in level 1. The outcome presents intercepts (baseline probabilities) for each level (except for the last level, which always will be 100%).

3.13.8 Analysis of non-CMR data

3.13.8.1 Comparison between damage levels and damage distribution in the different systems

The main idea was to compare rodent population size and crop damage in the different treatment combinations.

Damage assessment data were obtained from an ongoing research on damage assessment (Mulungu, 2001, unpublished data). The data were handled in Microsoft Excel spreadsheet. Damage distribution was established by means of damage distribution maps, which showed the intensity of rodent damage in the fields. The pattern of distribution of damage was established by determining the coefficient of dispersion (CD) (see section 3.13.2 for details). The effects of the different treatments were tested using the Factorial ANOVA in the Visual GLM (statistical package STATISTICA). Correlation analysis was performed to establish the relationship between rodent population size and maize damage in the different cropping systems and land preparation methods (Pearson - moment product correlation). Population size and percentage damage data were log and arcsine transformed respectively, to normalize the data before the analysis.

3.13.8.2 Relationship between ground cover and rodent population size in the different treatments

The relationship between vegetation cover and rodent population size was established. A 3- dimension surface fitting method (3D- catagorised surface plots in STATISTICA) was used to show the relationship between vegetation cover and rodent population size in the different treatments. Three parameters were used in the fitting: population size, vegetation cover in the field and vegetation cover in the fallow land. Correlation analysis was performed between the different factors using Pearson–moment product correlation. Population data were log transformed to normalize them before the analysis.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Species composition in the fields

The relative proportions in the composition of the different species in the fields during the study period are presented in Table 5. *Mastomys natalensis* comprised 97.8% of the total captures whereas, *Tatera swaythlingi* accounted for only 1.6%. Few *Mus minutoides* were captured comprising less than 1% of total captures. Two individuals of *Crocidura* sp. were also captured.

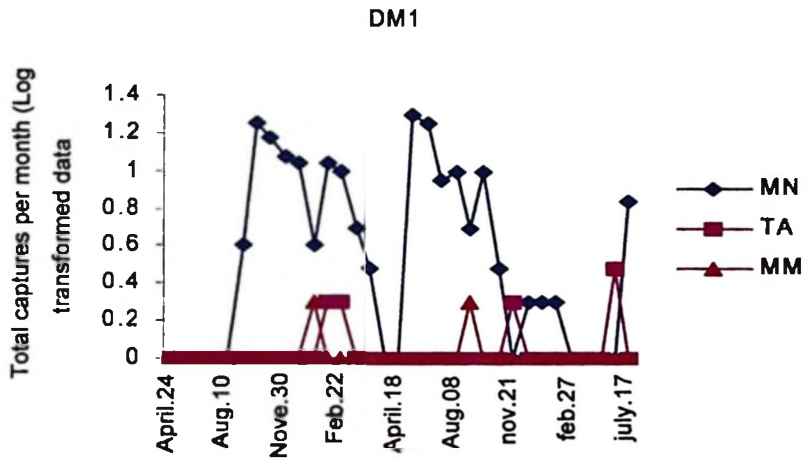
Comparing the proportion of each species, it is obvious that *M. natalensis* was the dominant species in individual fields. *Tatera swaythlingi* occurred in each treatment, but in smaller numbers.

There were no significant differences in species composition in fields subjected to the different land preparation methods and cropping systems ($P \leq 0.05$). Also, there were no interaction effects of field and time on species composition during the study period ($P \leq 0.05$). Figure 5(a – d) show the species composition over time during the study period. From the figure, *M. natalensis* were captured throughout the study period unlike the other species. Although in few numbers, *Tatera swaythlingi* were captured in those fields with loam soils (DM1, SM4, DI6 and SI7) and very few were captured in clay soils (SM3 and SI8), suggesting that this species prefers lighter soils, probably due to easiness of burrowing.

Since the resident population of *M. natalensis* as a proportion of total captures for all species in each treatment was approximately 98%, in subsequent analyses only this species was taken into account.

Table 5. Relative proportions of resident species in Mazimbu grids from April 1999 to July 2001

Species	Total captures	% Total composition
Mastomys natalensis (MN)	2812	97.8
Tatera swaythlingi (TA)	47	1.6
Mus minutoides (MM)	12	0.4
Crocidura sp (CR)	2	0.07
Missing	1	0.03



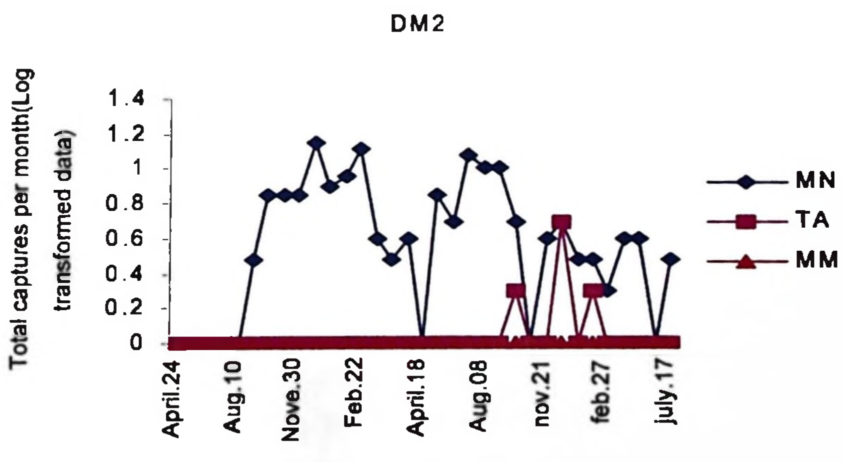
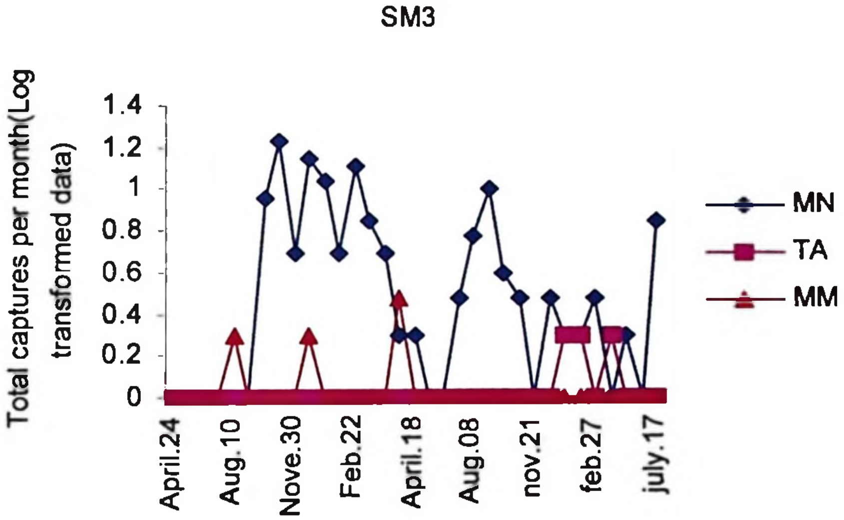


Figure 5a. Species composition over time (April 1999-July 2001) in tractor ploughed fields (monocrop) (DM1 and DM2) in Mazimbu grids (Mn= *Mastomys natalensis*; TA = *Tatera swaythlingi*; MM = *Mus minutoides*)



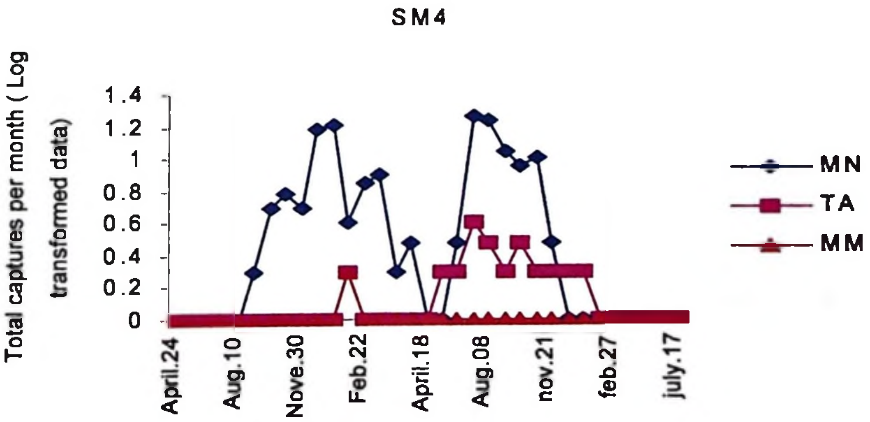


Figure 5b. Species composition over time (April 1999-July 2001) in slash and burn fields (monocrop)(SM3 and SM4) in Mazimbu grids (Mn= *Mastomys natalensis*; TA = *Tatera swaythlingi*; MM = *Mus minutoides*)

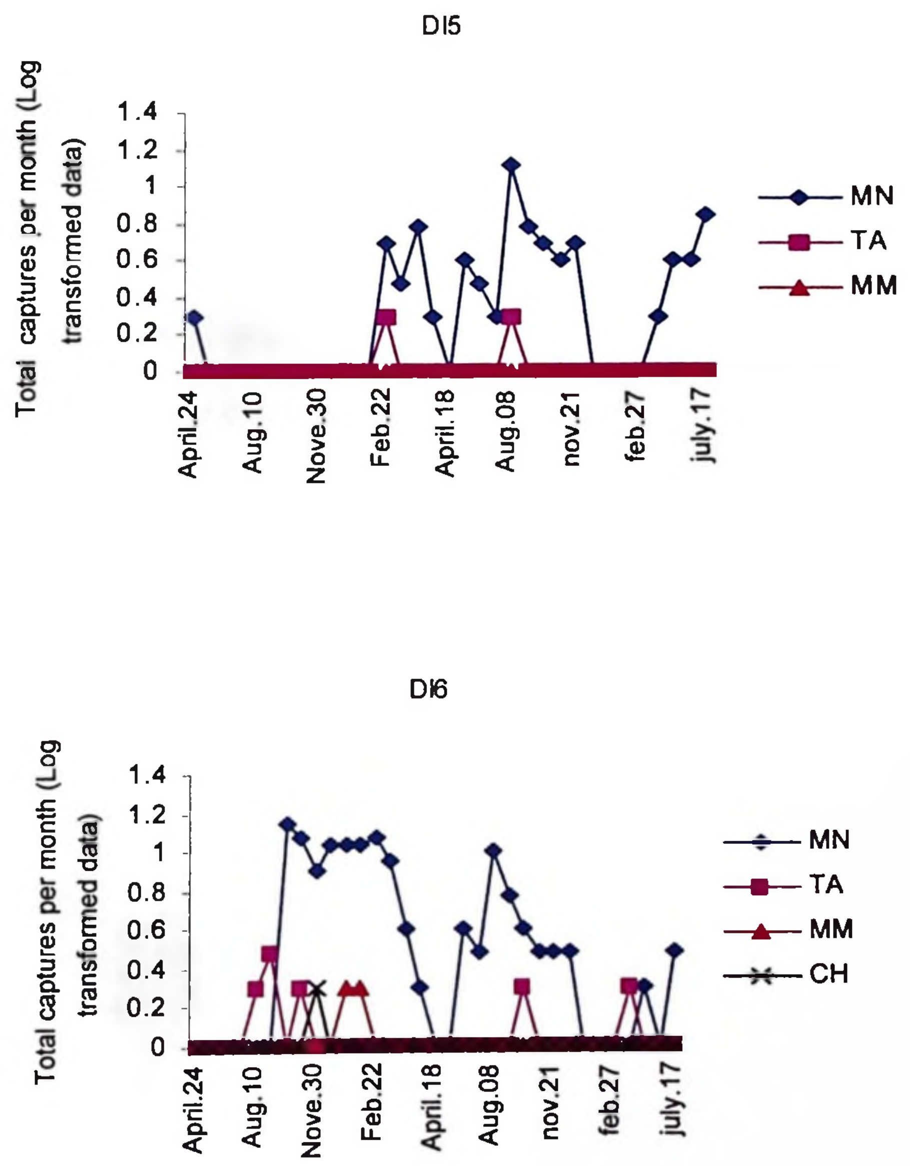
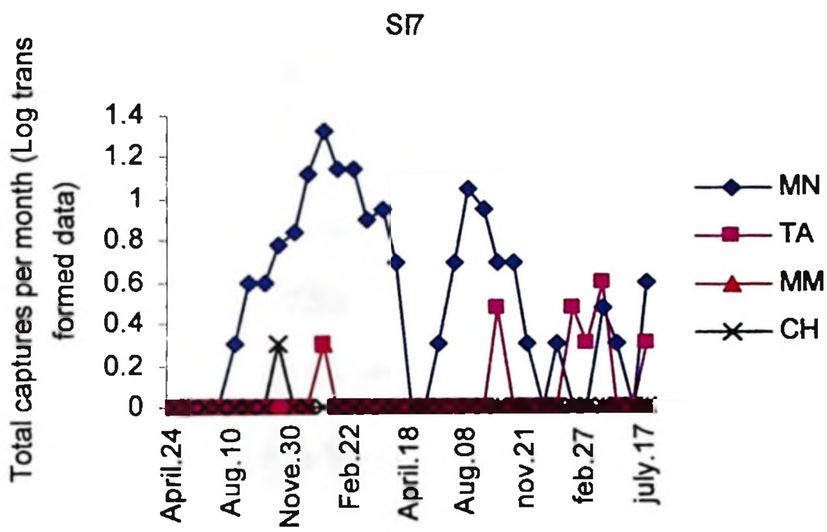


Figure 5c. Species composition over time (April 1999-July 2001) in tractor ploughed fields (intercrop)(DI5 and DI6) in Mazimbu grids (Mn= *Mastomys natalensis*; TA = *Tatera swaythlingi*; MM = *Mus minutoides*)



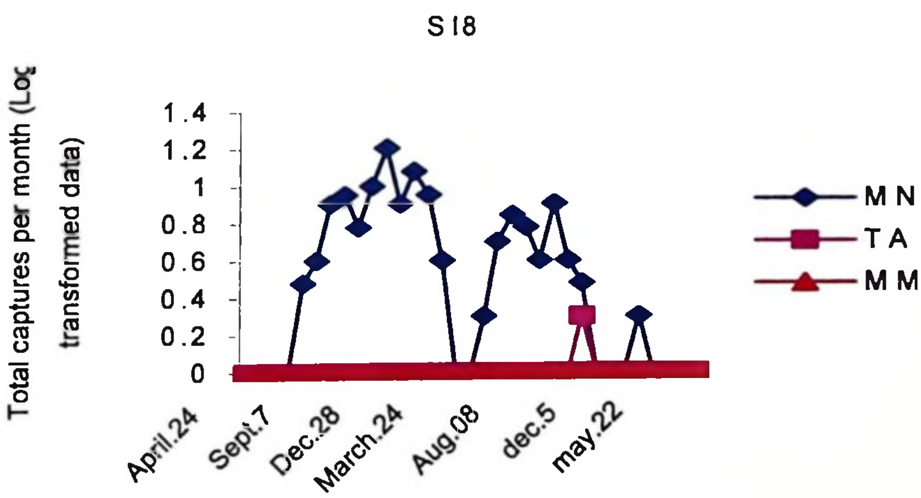


Figure 5d. Species composition over time (April 1999-July 2001) in slash and burn fields (intercrop)(SI7 and SI8) in Mazimbu grids (Mn= *Mastomys natalensis*; TA = *Tatera swaythlingi*; MM = *Mus minutoides*)

4.2 Population abundance fluctuations

Rodent population abundance for each treatment is presented in Figure 6a-d. In general, population peak was reached during the short rainy season and declined in subsequent months during the long rainy season in all the treatments. A similar pattern of population trend was observed in all the treatments throughout the study period except for the slash and burn field (SM3), during November 1999 when the population of *M. natalensis* rose from approximately 10 animals/0.5ha in October to >50 animals/0.5ha. This was attributed to a bush fire in October, resulting to immigration of animals into SM3. The rapid drop back to 10animals/0.5 in November was due to land preparation (slash and burning)

During the short rain season of 1999, trapping after land preparation (November 30), resulted to a drop in population in all the slash and burn fields. This effect was not so obvious in SM4 in which burning was incomplete due to the type of vegetation in the field (*Commelina spp* and *Convolvulacea spp* were the most abundant in this field during this period of the year). Variations in the population trend occurred between DM1 and DM2 although not significant. Population peak was reached earlier in DM1 than DM2. Differences in soil type in the two treatments could have contributed to variations in the population trends. In DM1 and DM2 the soils were sandy loam and sandy clay loam, respectively. The effect of soil type on the rodent population will be discussed later in this chapter.

An increase in population abundance in all the fields occurred after seed emergence (December 10, 1999), but this trend was much more evident in the slash and burn fields. Although very few animals were present in the fields during the long rainy season (March to May 2000) there were more animals captured in the slash and burn fields than in the tractor ploughed fields.

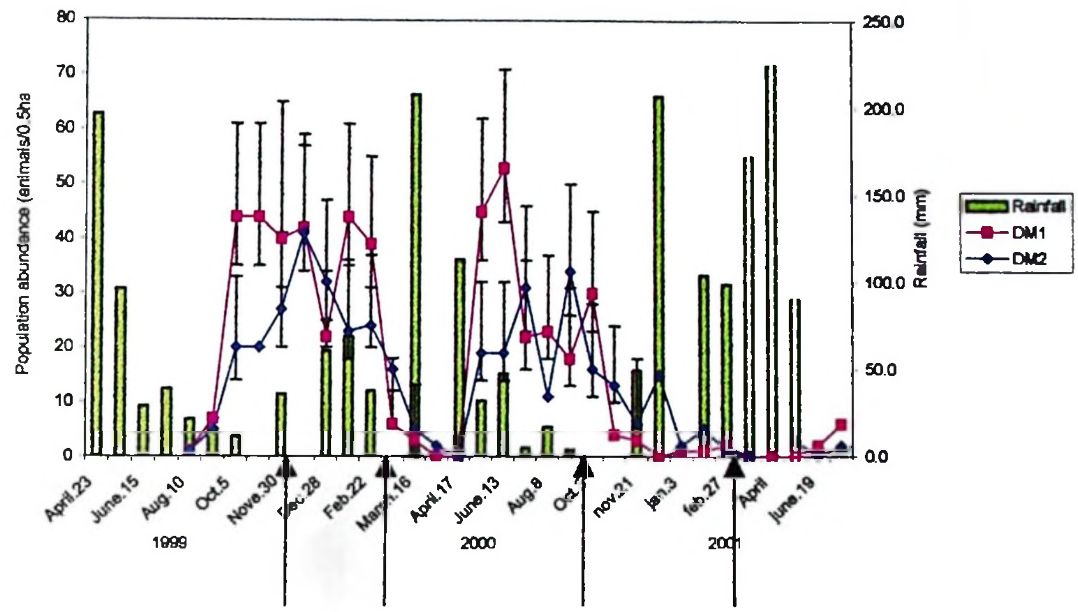


Figure 6a. Rainfall and rodent population abundance (Mh estimator of the Program Capture) in the tractor ploughed fields (mono-crop) (April 1999 -July 2001). (Arrows show the timing of land preparation)

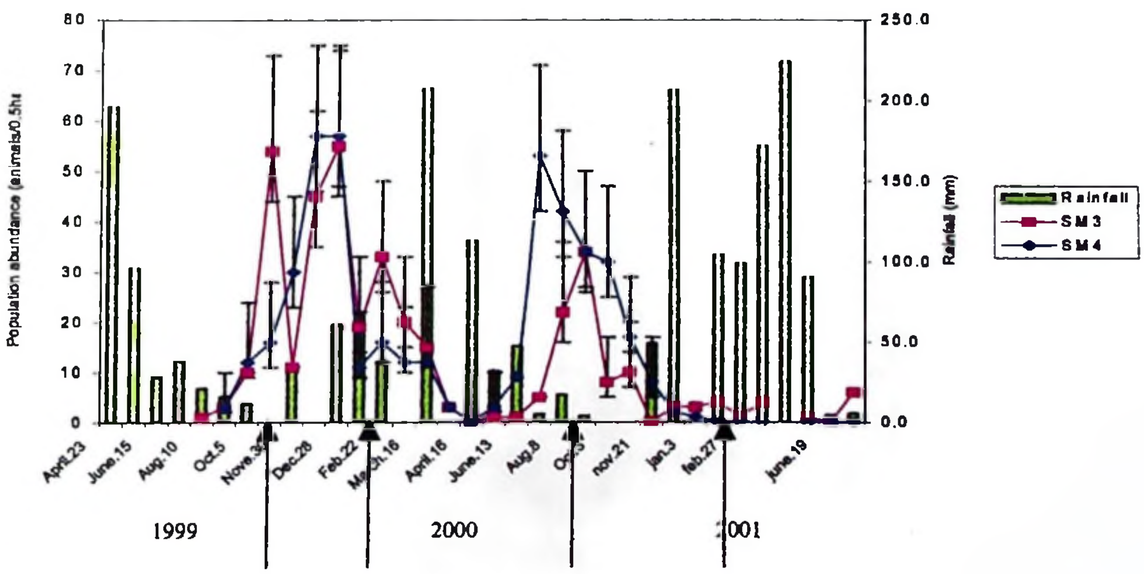


Figure 6b. Rainfall and rodent population abundance (Mh estimator of the Program Capture) in the slash and burn fields (mono-crop) (April 1999 –2001) (Arrows show the timing of land preparation)

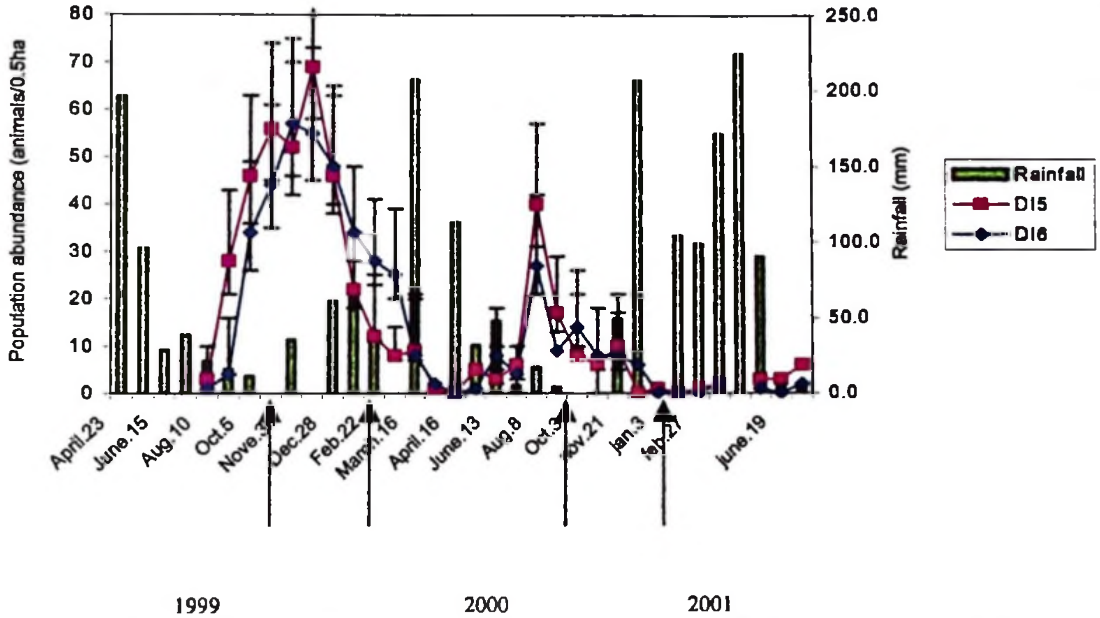


Figure 6c. Rainfall and rodent population abundance (Mh estimator of the Program Capture) in the tractor ploughed fields (inter-crop)(April 1999 - July 2001) (Arrows show the timing of land preparation)

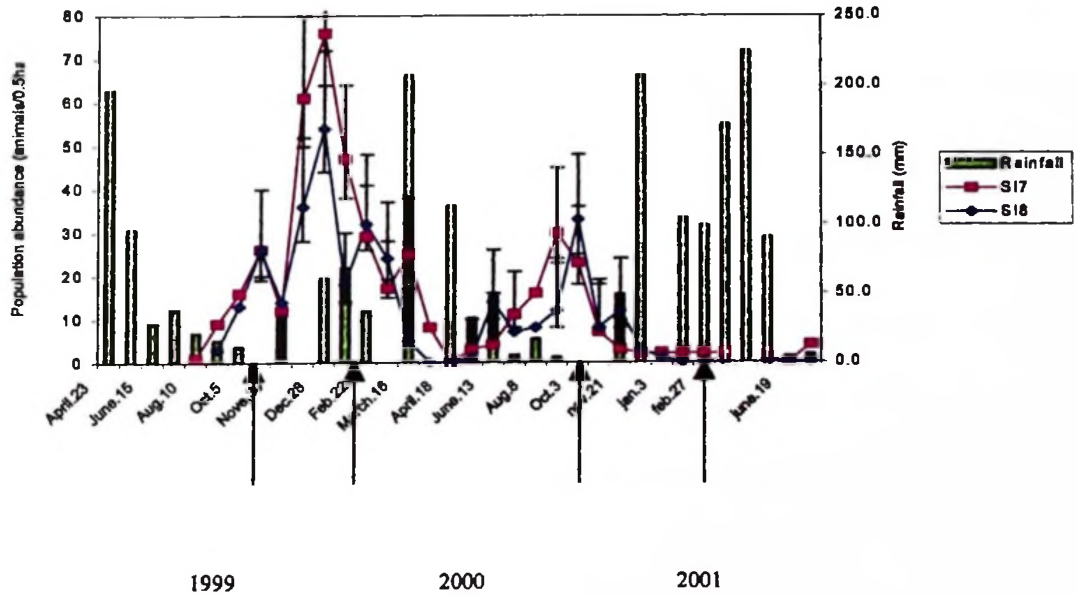


Figure 6d. Rainfall and rodent population abundance (Mh estimator of the Program Capture) in the slash and burn fields (inter-crop)(April 1999 - July 2001). (Arrows show the timing of land preparation)

Fluctuations in the population of *M. natalensis* occurred in all the fields. Highest numbers occurred in 1999-2000 but rodent populations were low in 2001. The general trend indicated that rodent populations started increasing at the onset of the dry season (June-July) and peaked in between October and December.

Data on the population abundance fluctuations of *M. natalensis* during the non- cropping season of 1999 (September – November) show that the land preparation methods had significant effect on population size ($P \leq 0.05$) with more animals captured in the tractor ploughed fields than in the slash and burn (Tukey HSD test; Mean number of animals/0.5ha: Tractor = 29.3 ± 5.19; slash and burn = 15.9 ± 4.13; $p = 0.019$). It is also evident that there were no significant differences in population abundance of *M. natalensis* in mono and inter-crop fields during the non-cropping season ($p \leq 0.05$). However, in the short rains cropping season (November, 1999 to January, 2000) rodent population abundance was significantly affected by cropping system ($p \leq 0.05$). The population was higher in the inter-crop than in the mono-crop fields (Tukey HSD test; Mean number of animals/0.5ha: Inter-crop = 43.8 ± 4.86; and mono-crop = 34.75 ± 3.81; $p=0.03$). Land preparation methods didn't have significant effect on population abundance but with time there was an interaction between land preparation methods and time ($p \leq 0.05$).

After slash and burning (November, 30, 1999) the population of animals dropped but after seed emergence (December, 10, 1999) the population increased until the maize crop was at vegetative stage (December, 28, 1999). Although the population abundance in the tractor ploughed fields was high before ploughing, the population size of trappable animals decreased after ploughing unlike in the slash and burn fields. During the long rains, significant variations between the two land preparation methods were observed with higher population size in the slash and burn fields than in the tractor ploughed fields (Tukey HSD test; $p=0.03$ Mean numbers of animals/0.5ha: 14.7 ± 2.79 and 9 ± 1.72, respectively).

Land preparation methods and cropping systems had no significant effects on rodent population peaks during the study period ($P \leq 0.05$). The population peaks differed significantly between the two years of study with the highest peak during the first year ($F\ (1,8) = 14.90$; $p \leq 0.001$). The population peaks were higher in the inter-cropped fields than in the mono cropped fields in the first year, but in the second year of the study, population peaks were higher in the mono-cropped fields ($F\ (1,8) = 6.50$; $p \leq 0.034$) (Fig.7). Therefore, population peaks were time dependent and were less affected by cropping systems.

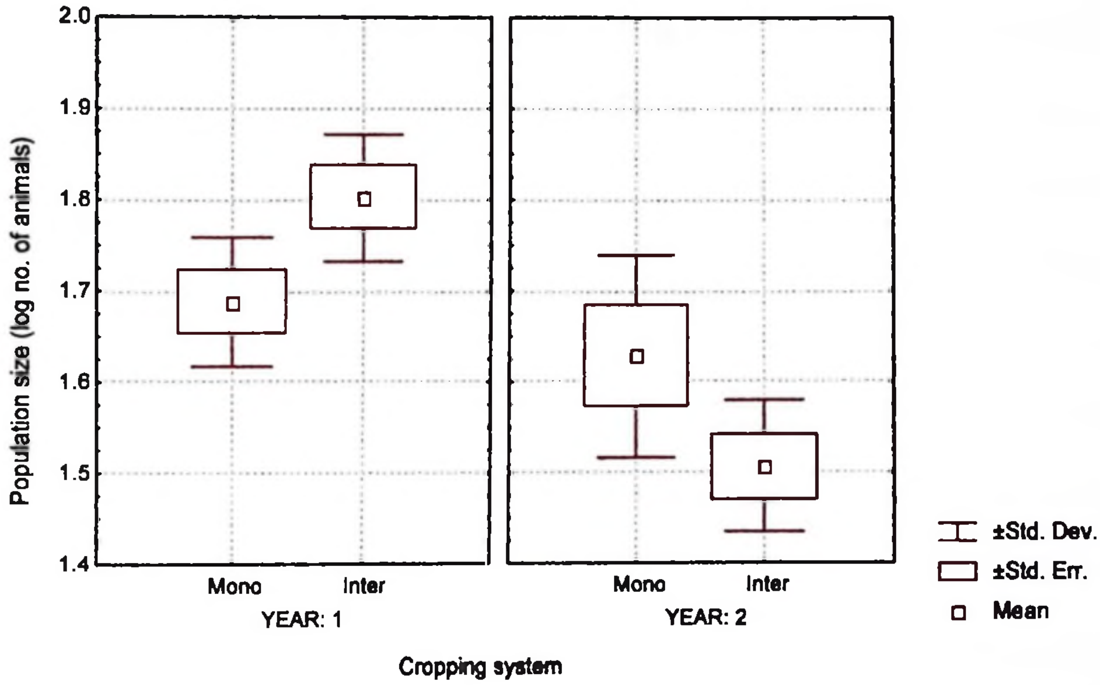


Figure 7. Actual rodent population peaks in different cropping systems during the study period ($p < 0.05$).

The immediate effect of slash and burn and tractor ploughing was a drastic drop in population size, but it increased fast in the slash and burn fields after germination of maize seedlings and emergence of weed seeds. The increased population size was probably due to recolonization from the fallow land, but this is subject to further investigations. Although the abundance of rodents increased in both types of land preparation and cropping systems later in the season, this may not be of great importance in protecting the crop because the most susceptible crop stage would have passed.

New vegetation presumably provides better nutrition for rodents and the requirements for breeding, growth and survival of young. Being an r-selected species (Leirs *et al.*, 1997a), *M. natalensis* is perhaps better adapted to colonize newly burnt Savannah land in Sub-Saharan Africa, where fires are common at the end of the dry season, and immediately after the onset of the rains. Being a generalist in feeding habits (Leirs *et al.*, 1997a), it is therefore better adapted for colonizing areas such as the slash and burn fields. This suggests that burning before the onset of rains and the subsequent sowing of seeds create favourable conditions for colonization by *M. natalensis*. It has been suggested that regenerating vegetation and availability of weed seeds on the ground create an attractive food resource for species such as *M. natalensis* (De Graaf, 1981, Makundi *et al.*, 1999).

Burning of bush and crop residues in the fields is a common practice traditionally associated with shifting cultivation systems in developing countries (Norman *et al.*, 1981). Among its advantages is the benefit in cattle raising areas where it stimulates the growth of early grasses. Also burning reduces the time required in clearing bush, an important consideration where hand labour is the sole source of power. It has been suggested that burning of plant stubble is a labour saving strategy that also helps to reduce diapausing insects and weed seeds and lowers the levels of primary disease inoculum on plants and in the soil (Moreno, 1985). Janzen (1973) also reported destruction of insects' refugia through burning. With this knowledge in mind, it is also presumed by farmers that during burning rodents are killed by the fire as is the case with the arthropod pests. However, in the current study, it was observed that after slashing and burning more rodents were attracted to the fields than in the tractor ploughed fields. Recently burned fields can be considered as disturbed habitats and therefore, the animals escape the fire by moving to unburnt areas (emigration) or remain safe in burrows in the duration of the fire.

Immediately after the slash and burn a decrease in population of *M. natalensis* in the fields occurred. Beck and Vogl (1972) suggested that some of the mortality associated with fire might have been caused by predation. Burned areas are left open and therefore, the lack of cover improves accessibility to avian and mammalian predators (Motobu, 1978). Observations in the study show that after the sprouting and emergence of weed and crop seedlings, numbers of rodents increased. This suggests that recolonization of the fields by animals which probably emigrated during the fire occurred. However, it remains to be shown how the population will respond to slash and burn over large fields, which are not interspersed with fallow land, as was the case in the current study. With slash and burn over a large area it is also possible that some animals will be killed by the fire, thus the population would be reduced. However, a reduced population size under favourable conditions could lead into compensation in fecundity resulting to the population returning to its pre-fire density or higher as has been observed after rodent poisoning (Zhang *et al.*, 1999).

Since reproduction, emigration, immigration and mortality (survival) determine population abundance, it is important to establish how the land preparation methods (tractor ploughing and slash and burn) affect these population parameters. It is obvious that in the slash and burn fields the population of rodents increased after the burn, and is probably due to immigration. However, in the tractor ploughed fields, the drop in population density could be attributed to emigration and mortality. The long-term effect is the lowering of the survival of *M. natalensis* in these fields. The importance of tractor ploughing in reducing rodent populations, particularly *M. natalensis,* is not well known by farmers in Tanzania, but it has been shown that ploughing reduces the population of some other species such as *Cricetulus triton* in cultivated fields in China (Zhang *et al.*, 1999).

4.3 Effect of land preparation methods and cropping systems on spatial distribution of rodents in the fields

Data from the short rains season of 1999 and long rains season of 2000 were used to show the effect of land preparation methods and cropping systems on spatial distribution of rodents. Figure 8 (i-iv) shows the spatial distribution of individuals over the different trapping stations during various growth stages of maize. The spatial distribution in either tractor or slash and burn fields is further illustrated in Appendix 4(i-viii). Animals were randomly distributed in all the treatments before land preparation. However, after land preparation, at seed emergence and vegetative stage, animals occurred in clusters in the tractor ploughed fields in both the short and long rain seasons, while they remained randomly distributed in the slash and burn fields. The pattern of distribution is determined by the coefficient of dispersion (CD) values obtained by calculations of the variance-to-mean ratio (Table 6a & b). The clusters in the tractor ploughed fields were situated near the field edges. The land preparation methods, cropping systems and the season significantly affected the distances where different individuals were captured from the centre of the grids. The mean distances were 27.8m and 21.6m for tractor and slash and burn fields, respectively and were significantly different (Tukey HSD test; $p < 0.001$). For the two cropping systems, the mean distances were 26.0m and 23.4m for mono and inter-cropped fields, respectively, and also varied significantly (Tukey HSD test; $p < 0.001$). In the short and long rain seasons, the distances also differed significantly (Tukey HSD test; $p = 0.041$) (25m for short rains and 23.8m for long rains).

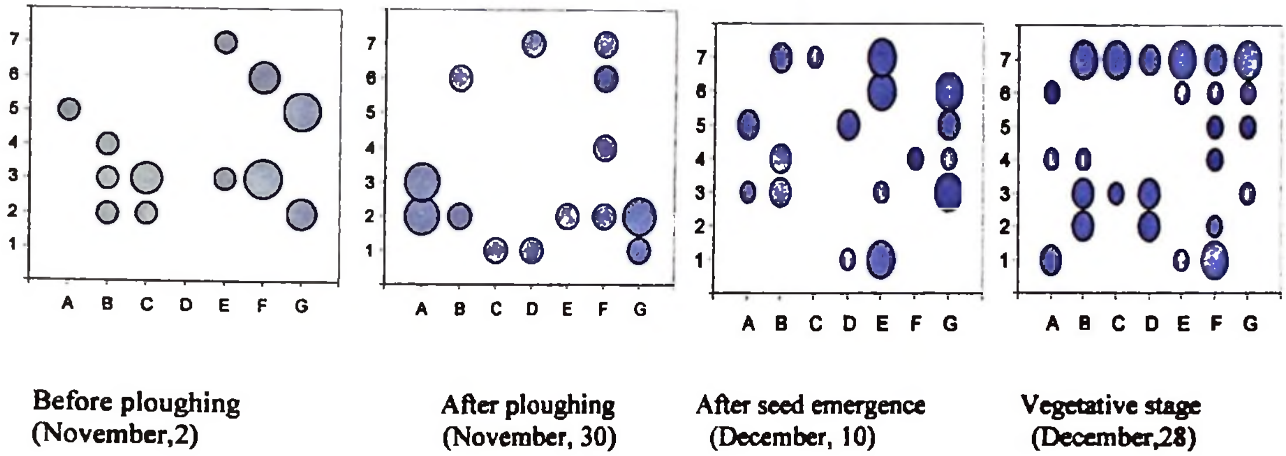


Figure 8 (i). Distribution of trapped individuals over the different trapping stations in the tractor ploughed fields (mono-crop) during the 1999 short rain season:- Dot size increases with the number of captures (1-3). Scale: Trapping stations A-G and trapping lines 1-7 are 10m apart. Lines with trapping stations were 10m apart; the field extended 5m beyond the outer trap lines; the fields were surrounded with fallow land.

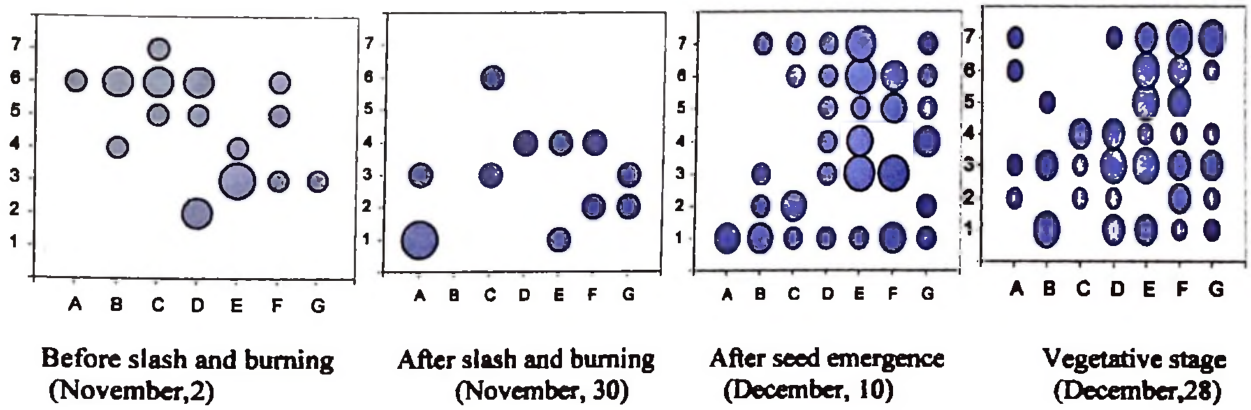
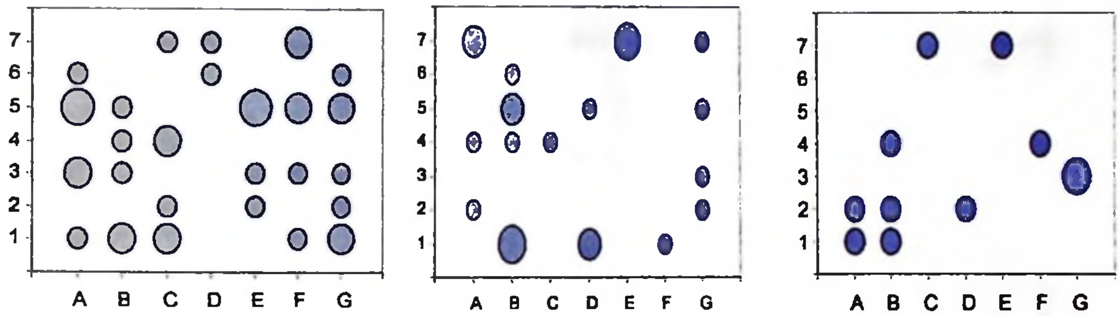
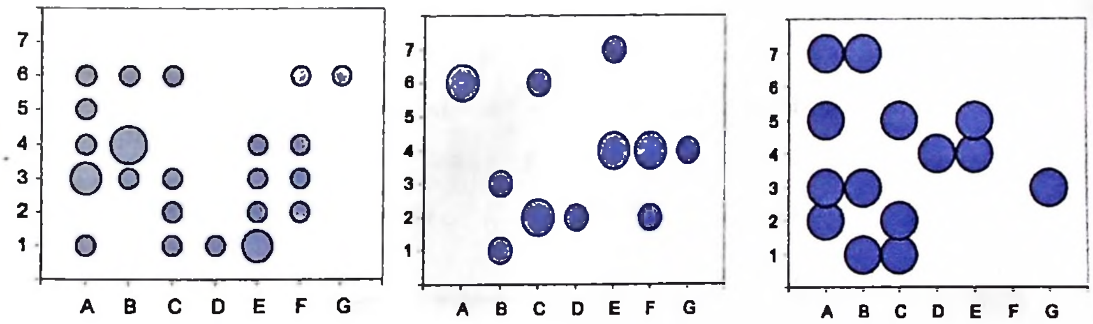


Figure 8 (ii). Distribution of trapped individuals over the different trapping stations in the slash and burn fields (mono-crop) during the 1999 short rain season:- Dot size increases with the number of captures (1-3). Scale: Trapping stations A-G and trapping lines 1-7 are 10m apart. Lines with trapping stations were 10m apart; the field extended 5m beyond the outer trap lines; the fields were surrounded with fallow land.



Before ploughing (February, 22) | After ploughing (March, 2) | After seed emergence (March, 16)

Figure 8(iii). Distribution of trapped individuals over the different trapping stations in the tractor ploughed fields (mono-crop) during the 2000 long rain season:- Dot size increases with the number of captures (1-3). Scale: Trapping stations A-G and trapping lines 1-7 are 10m apart. Lines with trapping stations were 10m apart; the field extended 5m beyond the outer trap lines; the fields were surrounded with fallow land.



Before slash and burning (February, 22) | After slash and burning (March, 2) | After seed emergence (March, 16)

Figure 8(iv). Distribution of trapped individuals over the different trapping stations in the slash and burn fields (mono-crop) during the 2000 long rain season:- Dot size increases with the number of captures (1-3). Scale: Trapping stations A-G and trapping lines 1-7 are 10m apart. Lines with trapping stations were 10m apart; the field extended 5m beyond the outer trap lines; the fields were surrounded with fallow land.

Table 6a. Coefficient of dispersion (CD) values (Variance -mean- ratio calculations) and pattern of distribution of rodents before and after land preparation and during growth of maize (1999 short rainy season).

Treatment	Before land preparation		After land preparation	
	CD	Distribution	CD	Distribution
Tractor monocrop(DM1)	0.99	Random	1.48	Clustered
Slash monocrop (SM3)	0.97	Random	1.16	Random
Tractor intercrop (DI5)	1.11	Random	1.41	Clustered
Slash intercrop (SI7)	0.94	Random	1.20	Random
	After seed emergence		At vegetative stage	
Tractor monocrop (DM1)	1.63	Clustered	1.58	Clustered
Slash monocrop (SM3)	1.12	Random	1.02	Random
Tractor intercrop (DI5)	1.41	Clustered	1.07	Random
Slash intercrop (SI7)	0.91	Random	0.89	random

Coefficient of dispersion scale: Random distribution = 0.7 - 1.3; aggregated (clustered) distribution = > 1.3; regular distribution = < 0.7

Table 6b. Coefficient of dispersion (CD) values (Variance -mean- ratio calculations) and pattern of distribution of rodents before and after land preparation and during growth of maize (2000 long rainy season).

Treatment	Before land preparation		After land preparation	
	CD	Distribution	CD	Distribution
Tractor monocrop(DM1)	1.05	Random	1.45	Clustered
Slash monocrop (SM3)	0.87	Random	1.25	Random
Tractor intercrop (DI5)	0.98	Random	1.34	Clustered
Slash intercrop (SI7)	1.53	Clustered	1.18	Random
	After seed emergence		At vegetative stage	
Tractor monocrop (DM1)	0.95	Random	*	*
Slash monocrop (SM3)	0.73	Random	*	*
Tractor intercrop (DI5)	1.42	Clustered	*	*
Slash intercrop (SI7)	1.26	Random	1.53	clustered

Coefficient of dispersion scale: Random distribution = 0.7 - 1.3; aggregated (clustered) distribution = > 1.3; regular distribution = < 0.7

* = No animals were captured in the fields (population was zero).

The concentration of the animals along the edges of the tractor ploughed grids is probably due to a combination of mortality in the ploughed grids, movement from the centre to the edges and also recolonization from the surrounding fallow land. Deep ploughing by tractor most likely reduces survival within the fields because weed seeds, which are consumed by rodents, are ploughed under while the nesting sites and burrow systems are destroyed. Direct mortality in the fields also occurs during the ploughing process. For example some animals were found cut into pieces by the plough blades while others were picked by raptors (personal observations). According to Bourne (1999), the sub-surface burrows and above ground corridors are of immediate importance to escape and to gather food both of which enhance survival. It is also presumed that survivors after ploughing escape to the fallow land. Therefore it might be possible that the animals captured at the edges of the fields are survivors trying to locate back their nesting sites. It has been reported that the local distribution of some rodent species is greatly influenced by food availability and to some extent the land preparation methods (Yeboah and Akyeampong, 2001). According to these authors, the highest concentration of mole rat (*Cryptomys zechi*) colonies were found in farmlands where traditional hoe ploughing was used for land preparation and the lowest concentration was in farms where mechanized ploughing was used for land preparation. Also, Yeboah and Akyeampong (2001) found mole rat populations to be restricted to the margins of mechanized farms and commented that such distribution could be attributed to deep ploughing. Although mole rats and the multimammate rats differ in their ecology and foraging behaviour, this example demonstrates that tractor ploughing not only disrupts the habitats of these two species adversely, but also disturbs their distribution in farmlands. This could benefit farmers if this technique for land preparation is incorporated in rodent control strategies

Within the area of our study, due to the relatively small size of the fields (0.5ha), each was considered to be essentially homogeneous with no spatial variability other than that caused by either slash and burn or ploughing. Therefore, it was expected that *M. natalensis* would be randomly distributed in the fields. However, in the tractor ploughed fields there was no homogeneity in the distribution of *M. natalensis* which implied that ploughing brought about changes in the degree of evenness of the distribution relative to the slash and burn fields.

In the current study, regeneration of the grass was faster in the slash and burn fields than in the tractor ploughed fields and led to quick re-invasion of the former. It has been reported that regenerating plants are more succulent and nutritious for rodents (Green and Taylor, 1975). Earlier studies indicated a quick decrease in the abundance of *M. natalensis* immediately after ploughing and planting, but also a sharp increase thereafter (Martin and Dickson, 1985; Leirs *et al.*, 1997). This conforms to the population trend in the slash and burn but not with the tractor ploughed fields where the spatial distribution of animals tended to be concentrated at the periphery of the fields. In case of large farms therefore, this type of distribution of rodents will lead to damage of the crops only at the edge of the fields. However, in small holder farms, which are interspersed with fallow land, deep ploughing by tractor is unlikely to reduce crop damage unless it is practiced over a large area and the surrounding fallow lands are cleared. The fallow land surrounding the small farms provide good harborage for rodents and thus the potential exists for substantial increase in rodent populations and subsequent crop damage. Earlier studies indicated that recolonization of ploughed fields by rodents occurred from the fallow land (Mercelis and Leirs, 1999).

The influence of cropping pattern on spatial distribution and population abundance of *M. natalensis* is not quite clear in the current study. However, it is plausible that there was increased activity of rodents in both types of cropping systems because the weed density increased in the fields. It is also apparent that the population density within the inter-cropped (maize and beans) fields increased, which could be attributed to increased cover. This pattern was not observed during the long rainy season because the population was already low in all the fields when the crop reached the vegetative stage. Therefore, it will be important to investigate how repeated weed control in both types of cropping systems and land preparation methods will affect the distribution pattern and population abundance of rodents and whether this could be part of an integrated approach for management of *M. natalensis*. Already, it has been reported that weeding reduces the population of rodents in the fields (Mwanjabe, 1993), but little is known on the interaction between weed density, land preparation methods and cropping patterns and the ensuing crop damage.

There have been several studies, which show for other pests, particularly insects, that certain cropping systems can be potentially advantageous for controlling them. Stoll (1988) reported that crop diversity favoured natural enemies due to multiplicity of food sources. Karel *et al.* (1980) found more pod damage by *Maruca testularis* in pure stands of cowpeas than when inter-cropped with maize. Although these examples and several others clearly show the advantages of inter-cropping to reduce pest infestation, it has not been shown experimentally how inter-cropping affects rodent pest populations in crop fields. The current study however, shows that both cropping systems and land preparation methods affected some parameters of the population dynamics of *M. natalensis* independently and jointly.

Figure 9 shows the mean percentage captures within the center 40*40m quadrat during the short rains of 1999 and long rains of 2000. Significantly more animals were captured in the centre (40*40m) grid in the slash and burn than in the tractor ploughed fields during the two cropping seasons (Tukey HSD test; Means:- Tractor =36.25%; slash and burn = 51.00%; P = 0.03). The percentage number of animals captured at the centre grid in the tractor ploughed fields was significantly different from the expected value of 51% (equivalent to the ratio of 25/49 traps at the centre) (χ^2 = 8.5; df = 1). In the slash and burn fields the centre grid had 51% of the captures, which corresponds to the expected proportion of captures for 25/49 traps. This suggests that in the slash and burn fields there were no differences in the distribution of animals between the centre and the periphery while in the tractor ploughed fields there was a tendency for more animals in the periphery than would be expected by chance. Cropping system and seasons had no significant effect on captures at the centre grid ($p < 0.05$) and there was no interaction between ploughing, cropping system and seasons on the distribution of animals.

The observed distribution in the different fields suggests that the slash and burn fields provided better protection and source of resources than the tractor ploughed fields. It could also be argued that the maize seeds provided more favourable food than weed seeds in the adjacent fallow land. This is consistent with Taylor and Green (1976) observations that when there were no cereal crops in the fields, rodents depended on weed seeds and the leaves of dicotyledonous plants, but as soon as the cereals became available, they formed a major part of the diet of *A. niloticus, M. natalensis, R. pumilio and O. angoniensis.*

In the slash and burn fields, weed regeneration was faster than in the tractor ploughed fields and therefore these fields became more attractive for *M. natalensis*, which respond quickly to changes in field conditions (Leirs *et al.,* 1997b). Most animals captured at the periphery of the fields during non-cropping season were probably from the fallow land. The significance of the fallow land close to the crop fields during the cropping season cannot be underestimated in terms of rodent abundance and crop damage that occurs. It has been suggested that the fallow patches act as refugia for rodents from where the crop is attacked (Mercelis and Leirs, 1999). Animals were found randomly distributed in the slash and burn fields suggesting that they were more attractive for rodent harborage.

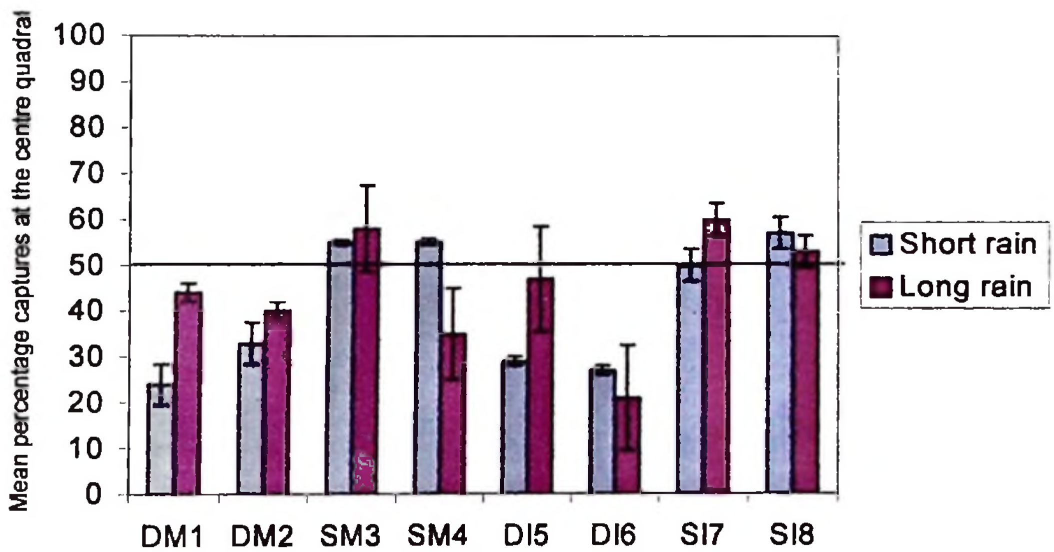


Figure 9. Mean percentage (± S.E.) captures at the center grid during the short (1999) and long rains (2000) season (the mean percentages are for the captures before land preparation, after land preparation, after seed emergence, and at vegetative stage). Abbreviations on the X-axis refer to land preparation (D= tractor ploughing; S= slash and burn) and cropping system (M= monocropping; I= intercropping). Numbers refer to different replicates. The horizontal line at 51% indicates the expected value if animals would be evenly distributed over the grid and the periphery.

4.4 Recruitment of new individuals

In the current study, it was hypothesized that variations in the recruitment of *M. natalensis* is closely associated with varying conditions created in the environment through farming practices. During the 1999 non-cropping season, land preparation methods and cropping system had no significant effects on the proportion of new individuals entering the trappable population ($P \leq 0.05$). However the proportions of new individuals differed significantly between months ($F(4,16 = 7.2991$, $p = 0.0015$). Tukey HSD test showed that there were more individuals entering the trapable population during September ($p = 0.008$), October ($p = 0.001$) and November ($p = 0.008$) than in July. This corresponded with increasing population trend.

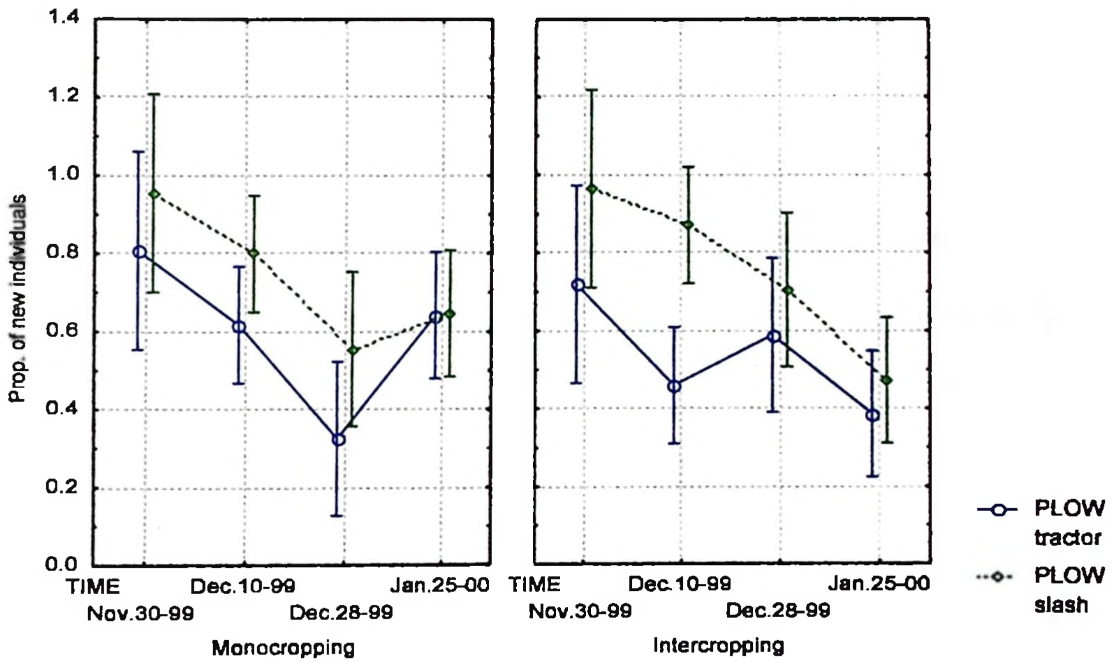
During the short rain season, there was a significant effect of ploughing and time on the proportion of new individuals entering the trappable population at different stages of maize production (Table 7). Cropping system had no significant effect on recruitment of new individuals, but the effects on recruitment were time dependent (cropping system - time interaction, $p = 0.03$). Fig. 10 and Table 7, show that before ploughing there were no significant differences in the proportion of newly recruited individuals, but after ploughing there were significant differences between the tractor and the slash and burn fields until the vegetative stage, when densities declined in all the fields. Cropping system seems to have a little effect on recruitment in the slash and burn fields. Interaction between ploughing and cropping system was not significant. During the long rain season (2000), ploughing and cropping system had no significant effect on the proportion of new individuals entering the trappable population, but show significant effects with time ($p \leq 0.05$). Few animals were captured during the short rains season in 2000 and long rains (2001), and therefore the data are not presented.

The findings show that recruitment of new individuals was greater in the slash and burn than in the tractor ploughed fields, suggesting that more favourable conditions were created by slash and burn land preparation methods. There have been some suggestions that unburnt seeds on the ground attract rodents to such fields (Makundi *et al.*, 1999). Therefore, it will be of interest to investigate this hypothesis and also the influence of germinating weed and crop seeds on recruitment of individuals and establish whether there are specific cues that attract them to the new growth.

Table 7. Analysis of variance showing the proportion of new individuals entering the trappable population in fields subjected to different treatments during the short rains season (1999).

	Df Effect	MS Effect	Df Error	MS Error	F	p-level
Cropping system	1	0.025	4	0.011	2.226	0.210
Ploughing	1	0.401	4	0.011	35.229	0.004
Time	3	0.121	12	0.006	19.539	0.000
Syst*ploughing	1	0.029	4	0.011	2.533	0.187
Syst*time	3	0.026	12	0.006	4.215	0.030
Ploughing*Time	3	0.017	12	0.006	2.788	0.086
3*Interaction	3	0.016	12	0.006	2.543	0.105

Significant at $P \leq 0.05$



Key : Nov.2-99 = Before ploughing, Nov.30-99 = after ploughing, Dec.10-99 = After seed emergence, Dec.28-99 = At vegetative stage, Jan.25-00 = At maturity stage.

Figure 10. Proportion of new individuals entering the trappable population at different time intervals during growing season of maize in the different treatments in the 1999 short rainy season ($P \leq 0.05$).

4.5 Effect of land preparation methods and cropping systems on home range and movement

The frequency distribution of home range classes (1-4 point rank) in the different fields is presented in Fig. 11. Statistical analysis using Ordinal multinomial distribution and logit as a link function (Program STATISTICA) indicates that there were significant differences in home range between males and females. Females occupied smaller home range than males (Wald Stat = 18.00; df =1; $p < 0.001$)(Table 8). From the analysis, it was also observed that significant differences occurred between the two land preparation methods (Wald sta=57.03; df=1; $p < 0.001$) and between the two cropping systems (Wald stat=4.93; df= 1; p= 0.026). The part of home range that falls within the grid was smaller in the tractor ploughed fields for both sexes although females occupied smaller home range than males (Figure 12a). There was interaction between land preparation and cropping systems on home range (Wald stat = 6.603; df = 1; $p < 0.001$). The home range of rodents was most affected in the tractor ploughed fields with mono-cropped maize than in the inter-cropped fields (Figure 12b). In the slash and burn fields there were no significant differences between the two systems.

Figure 13 shows the frequency distribution of movements of rodent in the different fields on a 4-point ranking). Statistical analysis showed that females and males differed significantly in their movements in the different treatments (Wald Stat =16.27; df = 1 and p = 0.001). In general, males were more mobile than females in all the fields. Land preparation methods, cropping system and season had no major effects on movements of rodents ($p \leq 0.05$), but there were interactions between different seasons and sex (Wald Stat = 8.08; df =3 and p = 0.02) and between land preparation methods and sex of individuals (Wald Stat =10.73; df =1 and p =0.001).

Figure 14 shows the seasonal frequency distribution of movement of rodent on a 4-point scale. There was a seasonal effect on movement between sexes during the study period. During the non- cropping and long rains males moved further than females. Very few females moved more than 20m from their centre of activity. Although the frequency distribution seems to be normal for both males and females during the short rain season, males were more mobile than females. Females were less mobile than males in the tractor ploughed fields (Fig. 15), while in the slash and burn fields movements were similar for males and females.

These findings suggest that tractor ploughing limited rodent movement and areas for foraging, but was also affected by cropping system depending on the method used for land preparation. Whereas rodents had smaller home range in the tractor ploughed fields with maize as mono-crop, in the slash and burn fields there were no differences in home range between the two cropping systems. These findings suggest that cover is an important factor contributing to home range size and movement of rodents within the crop ecosystem. The movement of females was reduced in the tractor ploughed fields, with implications that the total area for foraging was reduced. The reasons for reduced home range and rodent movements in the tractor ploughed fields were not quite clear, but it could be presumed that the deep ploughing disrupts movement of the animals due to formation of big soil clods after ploughing. These probably discourage the animals from moving up and down and consequently reduce their home range.

Theoretically, animals will forage far from the established home range when there is food scarcity and closer to home when food resources are abundant. Studies by Taitt *et al.* (1981), Ostfeld (1986) and Ims (1987) showed that access to additional food resulted in significantly smaller home ranges in adult males or reproductive females. This was not the case in this study since there was probably more food in the slash and burn fields than in the tractor ploughed fields, and yet the home range was not affected in these areas. Although males moved further than females between capture intervals, movement for females was more affected in the tractor ploughed fields. When both home range and movements are restricted to a small area it could result into reduced survival, particularly when the population is high. Smith (1996) reported that the irregularities in distribution of food and cover produce corresponding irregularities in home range and in frequency of animal visits. It is most likely that interaction between distribution of food and vegetation cover affects the home range of *M. natalensis*. It is also likely that when the food distribution is patchy in an area with minimal cover, foraging will be limited as a result of risks of exposure to predation. For example Mohr (2001) showed that there were more visits to feeding sites when cover was provided for *M. natalensis*. Although rodent dispersal was not investigated in this study, the observations from this study suggest that regular field disturbance like ploughing by tractor may force some individuals to leave their established home range.

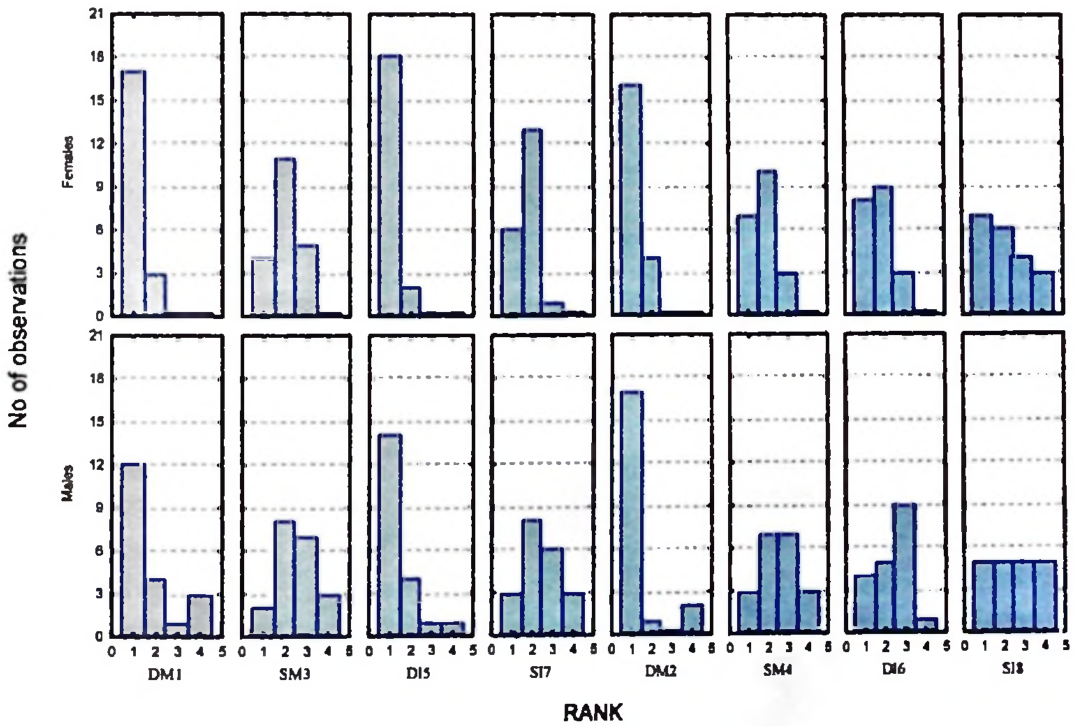


Figure 11. Frequency distribution of rodent home range classes in fields subjected to different treatments (Increase from 1-4; 1 = 50-150 m^2; 2 = 200-300 m^2; 3 = 350-450 m^2; 4 = >45 m^2).

Table 8. Analysis of variance showing the effect of the two land preparation methods and cropping systems on home range.

Effect	Df	Wald Stat	P
Intercept	3	211.80	< 0.001
Sex	1	18.00	< 0.001
Land preparation	1	57.03	< 0.001
Cropping system	1	4.93	0.026
Sex*Land preparation	1	0.06	0.800
Sex* cropping system	1	0.07	0.798
Land preparation* cropping system.	1	6.60	0.010
Sex* land preparation*cropping system	1	0.12	0.725

Significant at $P \leq 0.05$

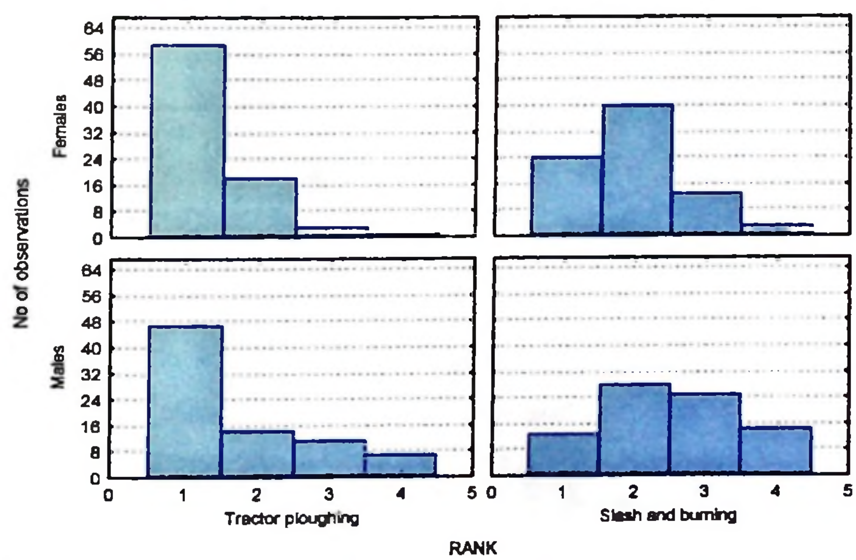


Figure 12a. Frequency distribution of rodent home range classes in relation to sex in the two land preparation methods (Increase from 1-4; 1 = 50-150 m^2; 2 = 200-300 m^2; 3 = 350-450 m^2; 4 = >450 m^2).

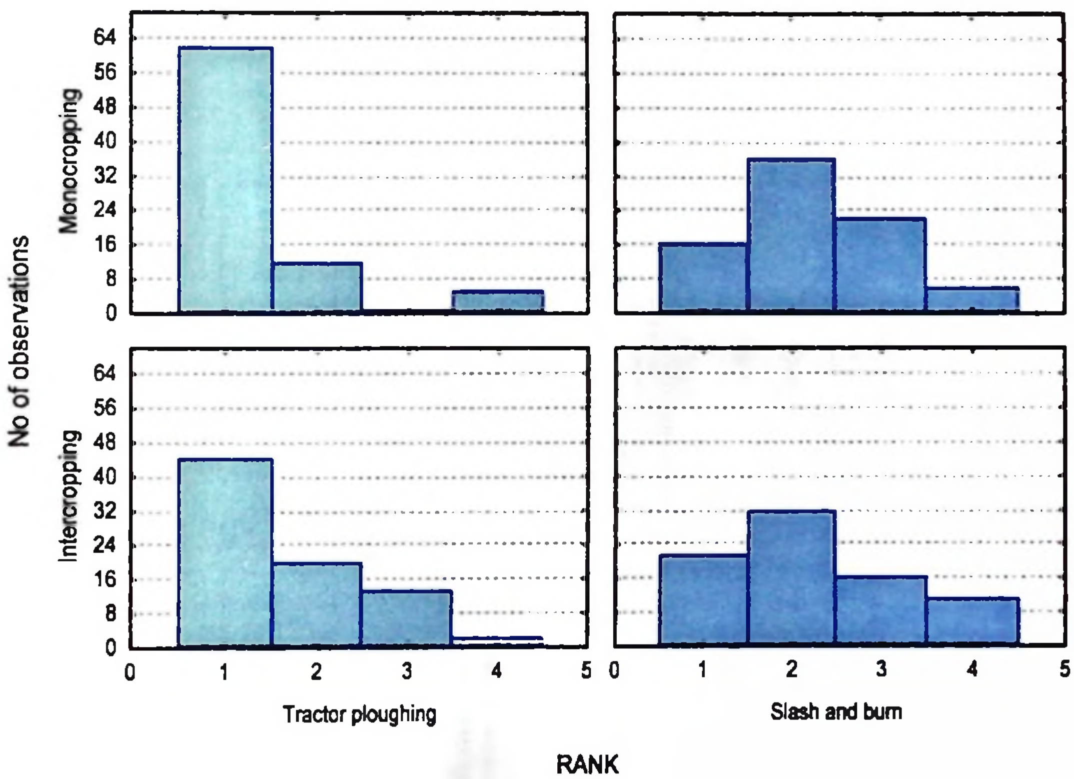


Figure 12b. Frequency distribution of rodent home range classes, showing the interaction effects of land preparation and cropping systems (Increase from 1-4; 1 = 50-150 m^2; 2 = 200-300 m^2; 3 = 350-450 m^2; 4 = >450 m^2).

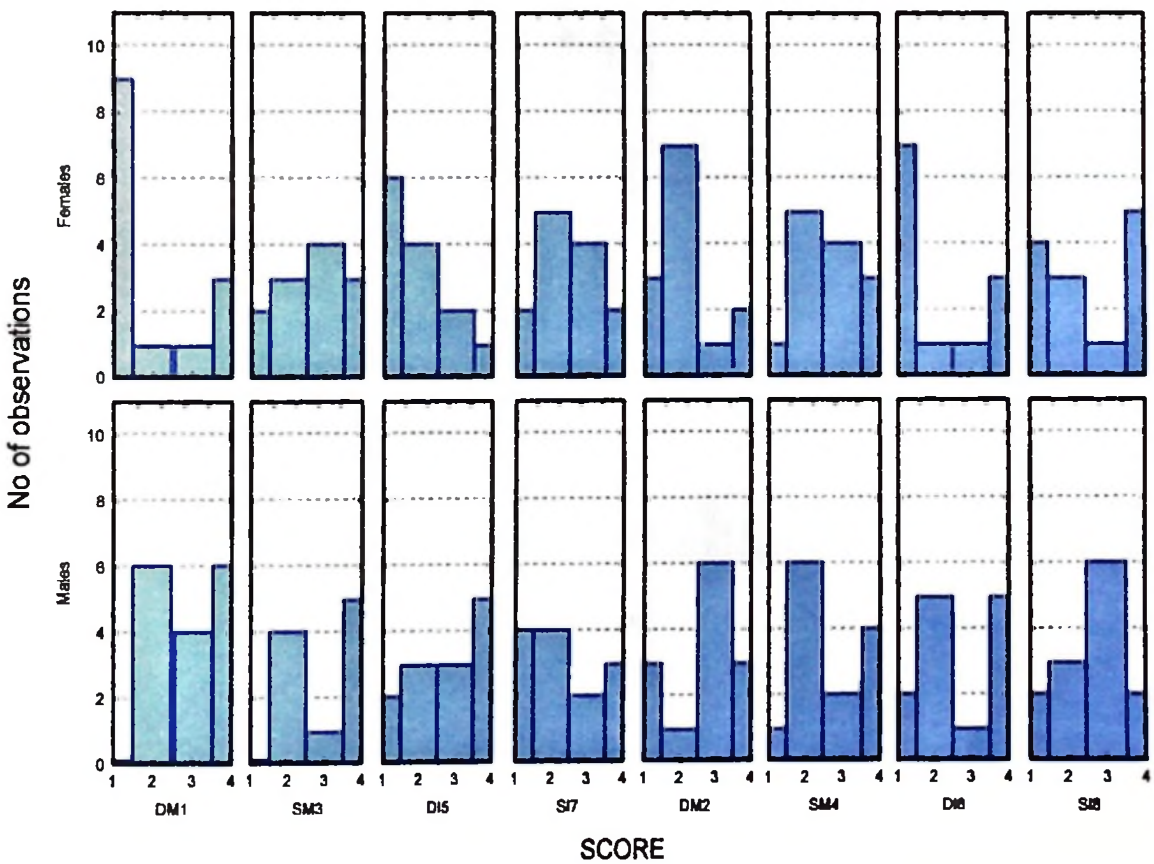


Figure 13. Frequency distribution of rodent movement during the study period (Scores 1-4 indicate increasing distances, where 1 is the shortest and 4 the longest).

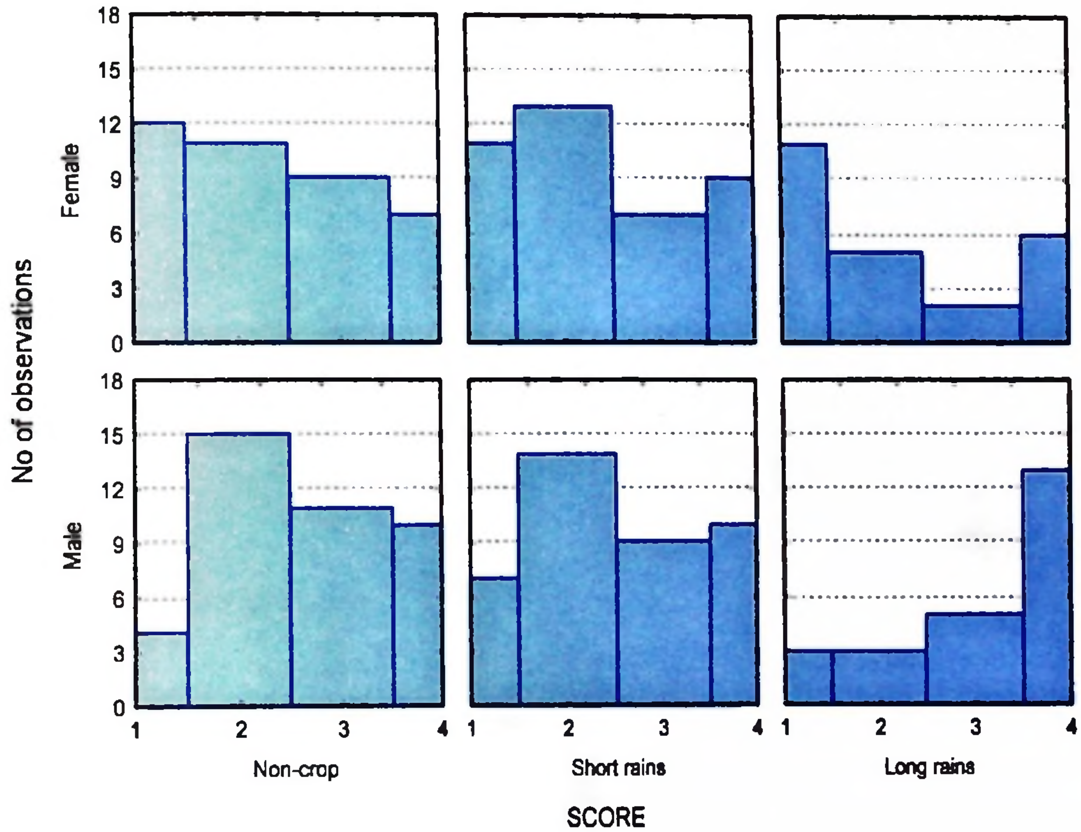


Figure 14. Frequency distribution of movement of rodents showing interaction between seasons and sex of individuals (Scores 1-4 indicate increasing distances, where 1 is the shortest and 4 the longest).

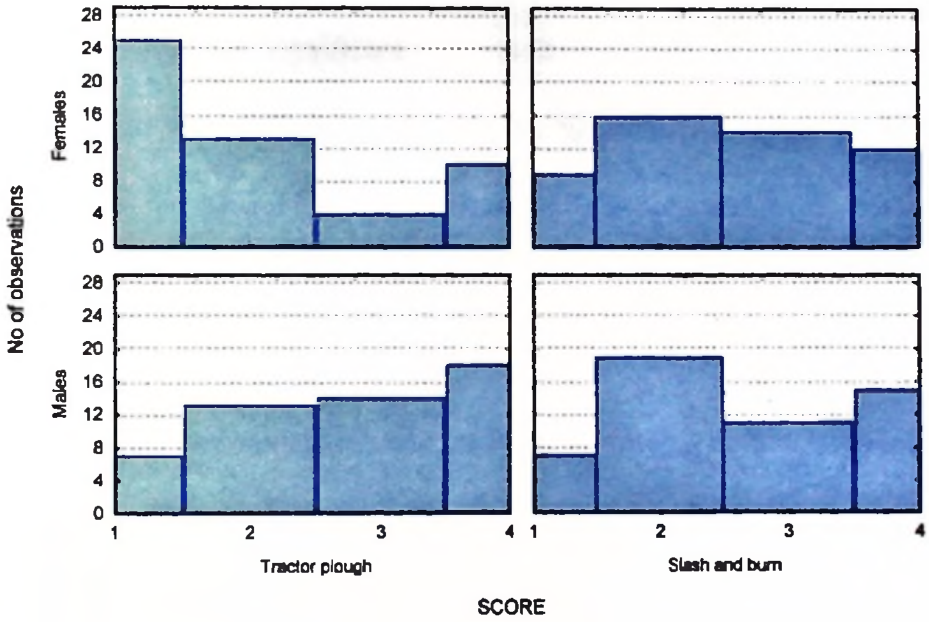


Figure 15. Frequency distribution of movement of rodents showing the interaction between land preparation methods and sex of individuals (Scores 1-4 indicate increasing distances, where 1 is the shortest and 4 the longest).

4.6 Influence of land preparation methods and cropping systems on sex ratio and reproduction

The proportions of females and males in the two cropping systems and land preparation methods are presented in Figs 16a and 16b. Both land preparation methods and cropping systems had no significant effect on the proportion of females and males in the population. However, significant changes in the proportions of both sexes occurred with time and these were influenced by cropping systems for females ($F(29,120) = 1.612$; $p = 0.039$)(Appendix 5) and land preparation methods for males in the population ($F(29,120) = 2.1352$; $p < 0.001$)(Appendix 6).

The proportions of sexually active individuals (males with scrotal testis, females with perforated vigina, lactating or pregnant) are presented in Figs. 17 a-d. The highest proportion of sexually active males occurred between November and March. Statistical analysis was performed to test the effect of land preparation methods and cropping systems on distribution of sexually active male population. The time of trapping, land preparation methods and cropping systems were considered as predictor variables, while the proportion of males with scrotal testis was the dependent variable. The analysis showed that there was an interaction between land preparation methods and trapping time on the distribution of sexually active males during the months with highest percentage of males with scrotal testis ($F(8,36) = 3.73$; $p \leq 0.004$). From August to early November 1999, land preparation methods had a significant effect on the distribution of males with scrotal testis in the population ($p \leq 0.05$) with more sexually active males occurring in the tractor ploughed fields (Tukey HSD test: ($F(1,16) = 5.15$; $p < 0.037$). Trapping after ploughing and after seed emergence indicated that more males with scrotal testis occurred in the tractor ploughed fields. When the maize crop was at the vegetative stage and beans were already established in the fields, the proportion of males with scrotal testis was higher in the slash and burn fields. However, when there was no crop in the field more sexually active males were found in the tractor ploughed fields. At the onset of the long rainy season, (February), more sexually active males with scrotal testis were found in the slash and burn fields than in the tractor ploughed fields.

The distribution of females with perforated vagina was also significantly influenced by the land preparation methods ($p \leq 0.05$), and was higher in the slash and burn fields than in the tractor ploughed fields (Tukey LSD test; $F(1,32) = 11.199$; $p < 0.001$). Land preparation methods also affected the distribution of reproductively active females with time (Tukey LSD test: $F(8,36) = 2.93$; $p = 0.017$). During the short rainy season, the proportion of females with perforated vagina was higher in the slash and burn fields, particularly when the bean crop was established and maize was at its vegetative stage. An interaction between land preparation methods and cropping system on the distribution of sexually active females in the population was found ($F(1,12) = 5.279$, $p = 0.040$).

The influence of land preparation and cropping systems on the distribution of the different sexes (sex ratio) and reproduction of *M. natalensis* is not quite clear. In some months during the study period there were significantly more reproductive individuals present in the slash and burn than in tractor ploughed grids. There are two plausible explanations. One is that individuals in breeding condition were attracted to these fields and secondly the conditions within these fields were more conducive for breeding probably as a result of more food availability when maize was at its vegetative stage. In the slash and burn fields weed regeneration was faster than in the tractor ploughed fields. The weed seeds were probably an important food source for the onset and continuation of breeding.

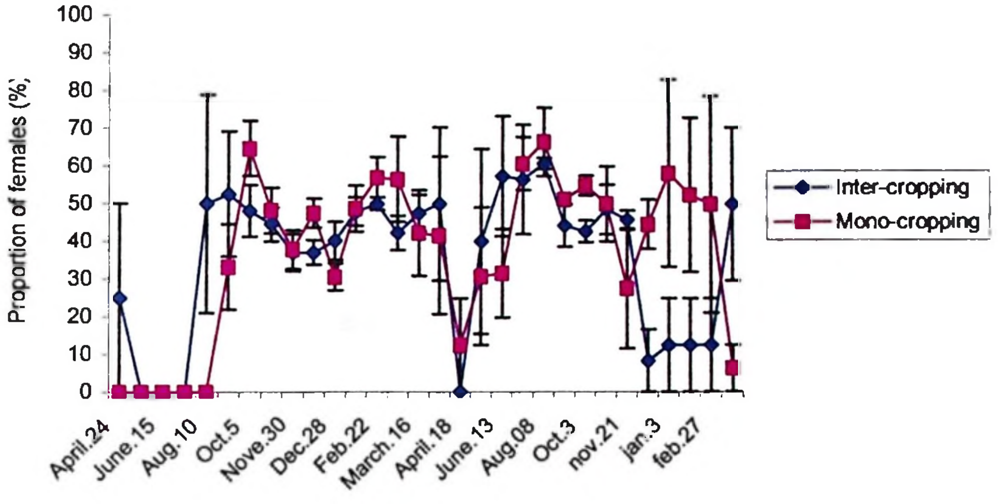


Figure 16a. Proportion of females in fields subjected to intercropping and monocropping.

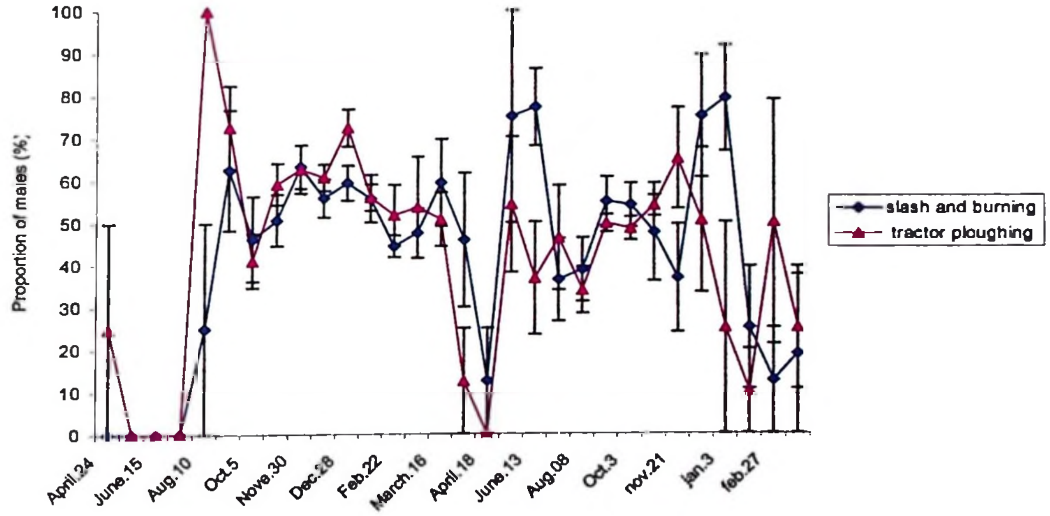


Figure 16b. Proportion of males in fields subjected to slash and burn and tractor ploughing.

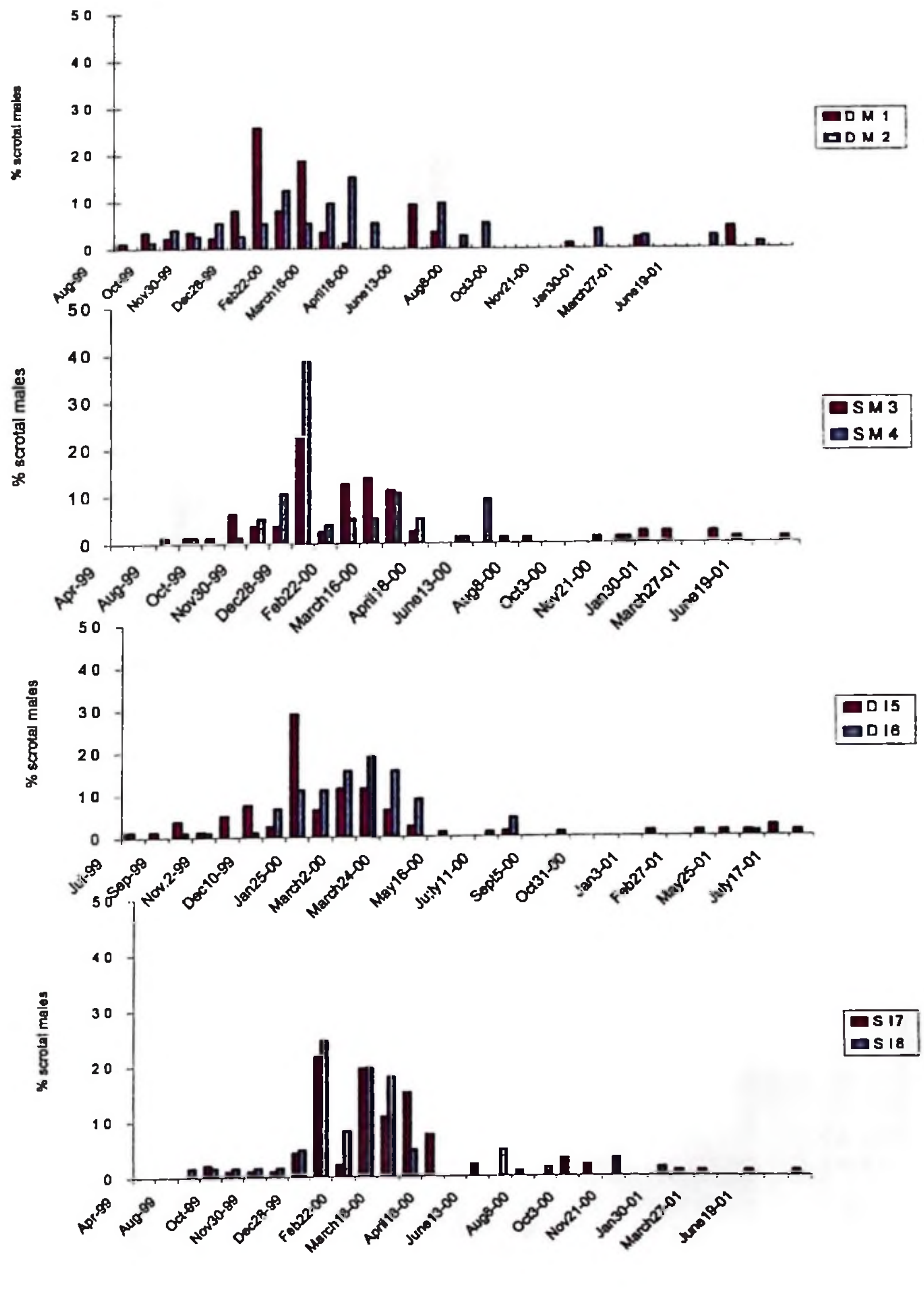


Figure 17a. Distribution of sexually active males of *M. natalensis* in fields subjected to different treatments.

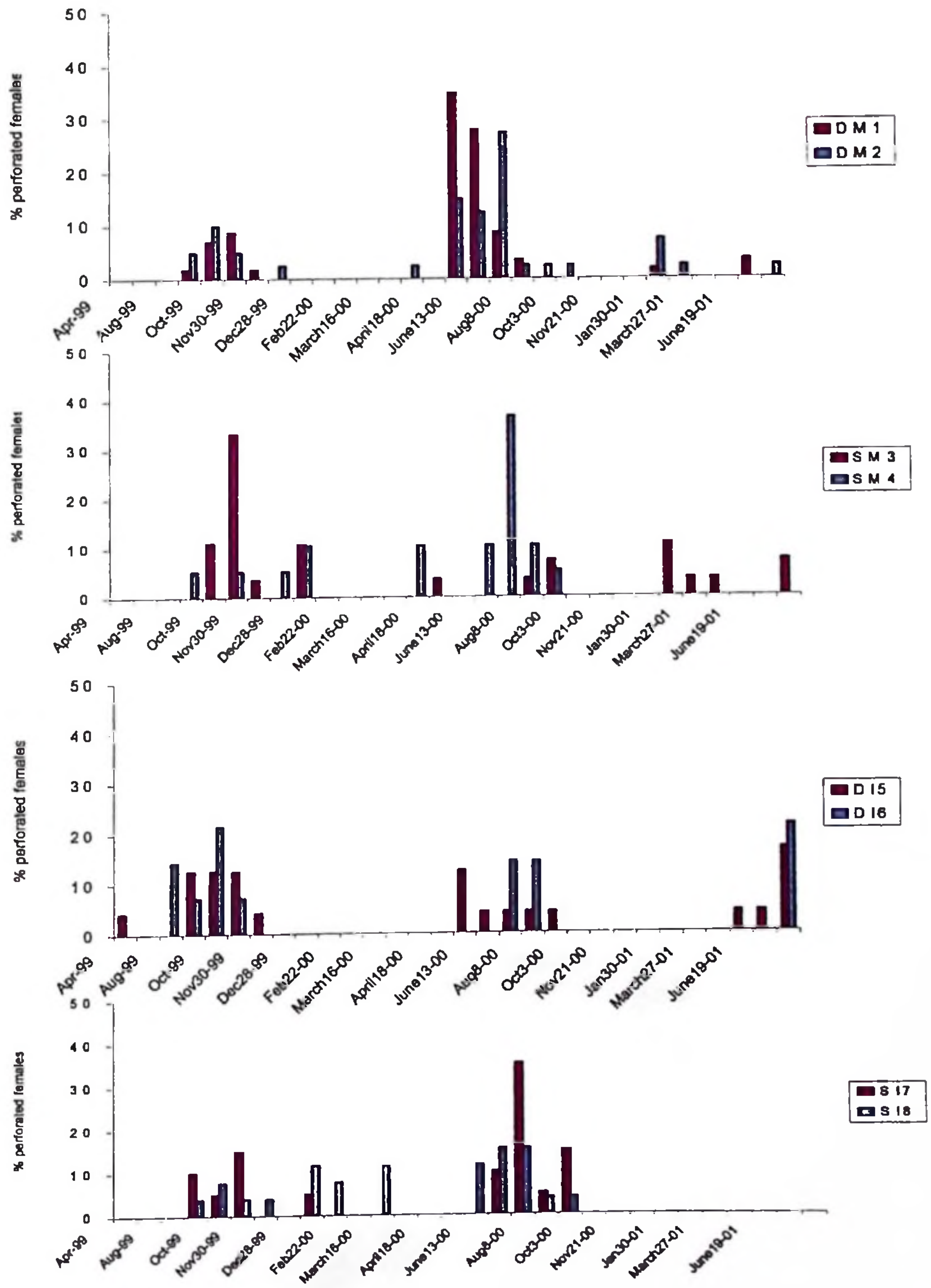


Figure 17b. Distribution of females with perforated vagina in fields subjected to different treatments.

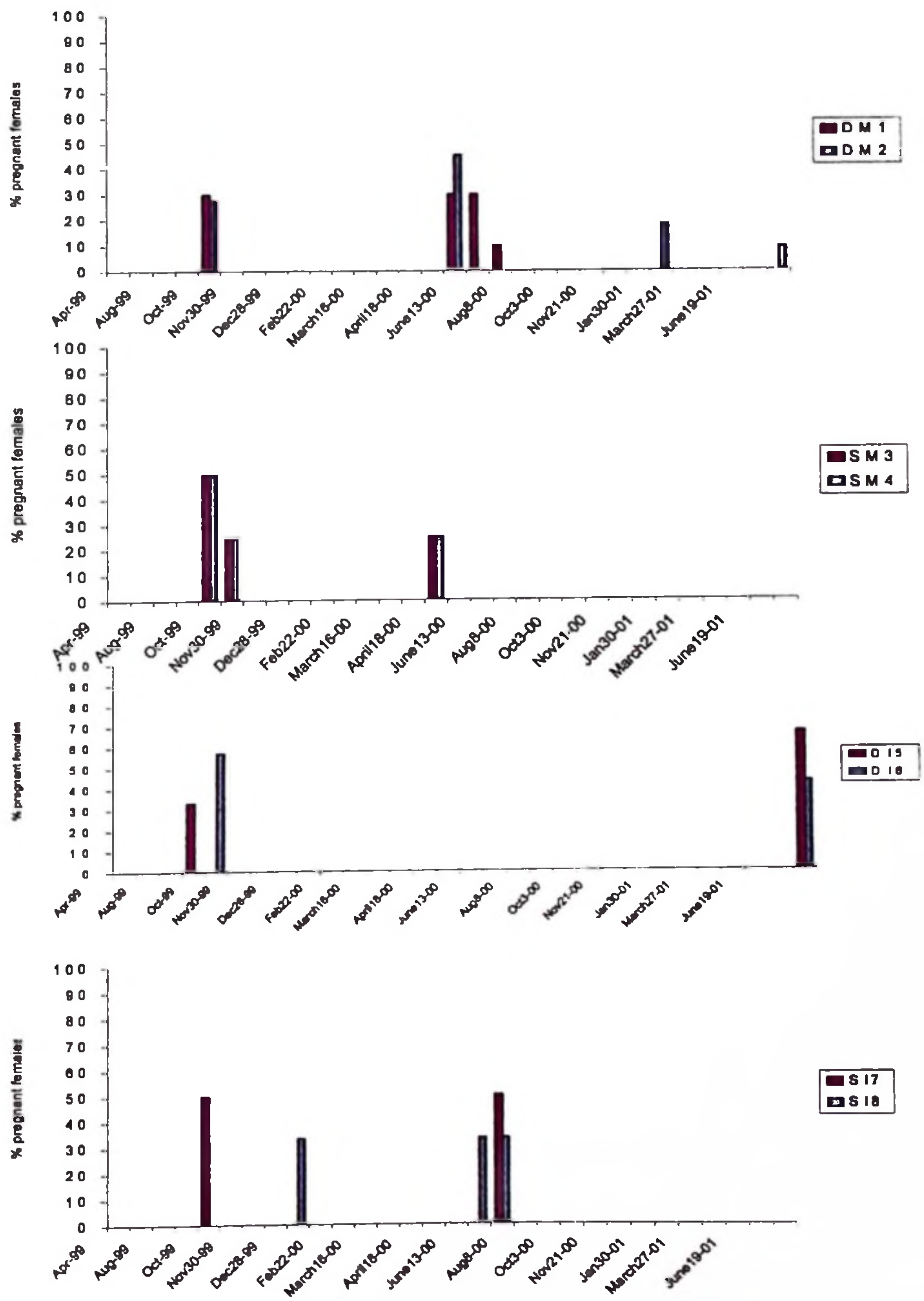


Figure 17c. Distribution of pregnant females in fields subjected to different treatments.

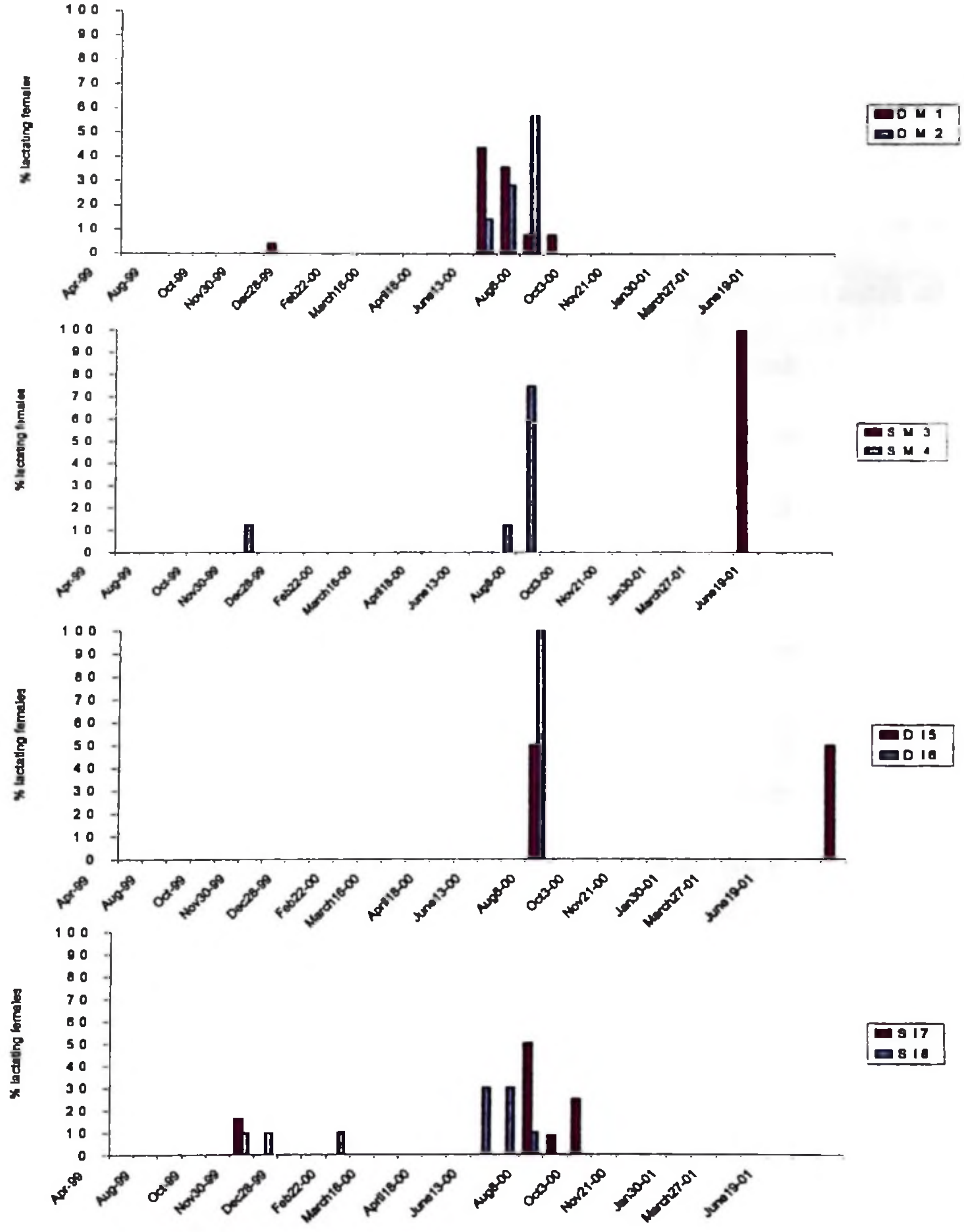


Figure 17d. Distribution of lactating females in fields subjected to different treatments.

4.7 Age structure in tractor ploughed, slash and burn, monocrop and intercrop fields.

To determine the age structure of the population, weight was used to classify the animals into three classes as adults, sub-adults and juveniles. Statistical analysis of the data indicated that the distribution of adults in the population differed significantly between intercropped and monocropped fields ($F(1,124) = 4.3498$, $p = 0.039$), with more adults in the mono-crop than in the inter-crop fields (Tukey LSD test). Slash and burn and tractor ploughing didn't have significant effect on the proportion of adults in the population. However, land preparation methods significantly affected the age structure with time ($F(30,124) = 2.0840$, $p < 0.001$). In October 1999, more adults were found in the tractor ploughed fields than in the slash and burn fields, but immediately after ploughing (November 30,1999) more adults occurred in the slash and burn fields (Figure 18). After seed emergence (December 10, 1999) adults were fewer in the tractor ploughed than in the slash and burn fields but the differences were not significant. However, later in the season, (January 2000 to March 2000) there were significantly more adults in the slash and burn fields than in the tractor ploughed fields. During the long rainy season (2000), the mean number of adults was significantly higher in the tractor ploughed fields immediately after seed emergence (March) and remained significantly higher in these fields for the rest of the season (June 2000). After harvest (July 2000 to September 2000), there were no significant variations in the distribution of adults between the tractor ploughed and slash and burn fields. The higher number of adults in the population in the slash and burn fields than in the tractor ploughed fields suggests that more adults were attracted to these fields after the fire. Probably more weed seeds become available for rodents as a result of the slash and burn.

There were significant differences in the distribution of sub-adults between tractor ploughed and slash and burn fields and mono and inter-crop systems ($F\ (1,124) = 13.167$, $p < 0.001$ and $F(1,124) = 8.3734$, $p < 0.001$ respectively). Interaction occurred between land preparation methods and cropping systems ($F(30,124) = 3.9081$, $p = 0.001$). Land preparation methods affected distribution of sub-adults with time (Figure 19). The distribution of sub-adults in the population differed significantly during June – October 1999. After seed emergence (December, 10) sub-adults numbers were significantly higher in the tractor ploughed fields than in the slash and burn fields. During the vegetative stage of the maize crop (December, 1999 – March, 2000) significant differences occurred with more sub-adults in the slash and burn fields than in the tractor ploughed fields. During the onset of the dry season (July – August), the sub-adults population was high in the slash and burn fields.

The high number of sub-adults in the population during vegetative stage of maize crop in the slash and burn fields suggests that breeding was occurring in these fields. These observations are supported by the high number of sexually active females (section 4.6) observed in these fields during this period. Probably the slash and burn fields provided a better environment for breeding, in particular, the availability food resources. In general, weed regeneration was faster in the slash and burn fields. These weeds provide supplementary food resources for rodents in the field. Other studies have shown that the onset of breeding in other species of rodents coincides with changes in the availability and type of food eaten and suggested that food quality rather than quantity was a major factor influencing breeding (Bomford, 1987 a and b). There is also strong evidence that nutritional factors such as green forage stimulate reproduction in small mammalian herbivores (Batzil, 1985; Bomford, 1997c).

In studies carried out in Australia (Redhead, 1982; Bomford and Redhead, 1987), it was hypothesized that the quality of food in the diet of mice was an important factor in the formation of mouse plagues. Further, Redhead (1982) reported that the time for which high-quality food is available determines the duration of the breeding season. For *M. natalensis*, an opportunistic species that highly dependent on favourable conditions for breeding, induced changes which affect the food source may determine the duration and where and when breeding takes place. Therefore one could generalize that the slash and burn fields were more conducive for breeding and consequently higher increase in the population of *M. natalensis* due to better food conditions.

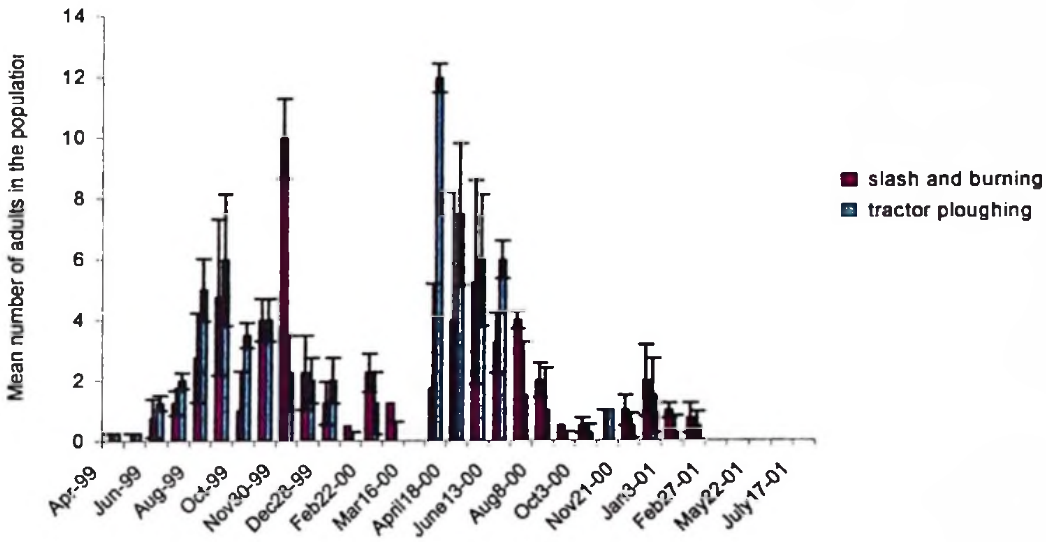


Figure 18. Mean number of adults in the slash and burn and tractor ploughed fields

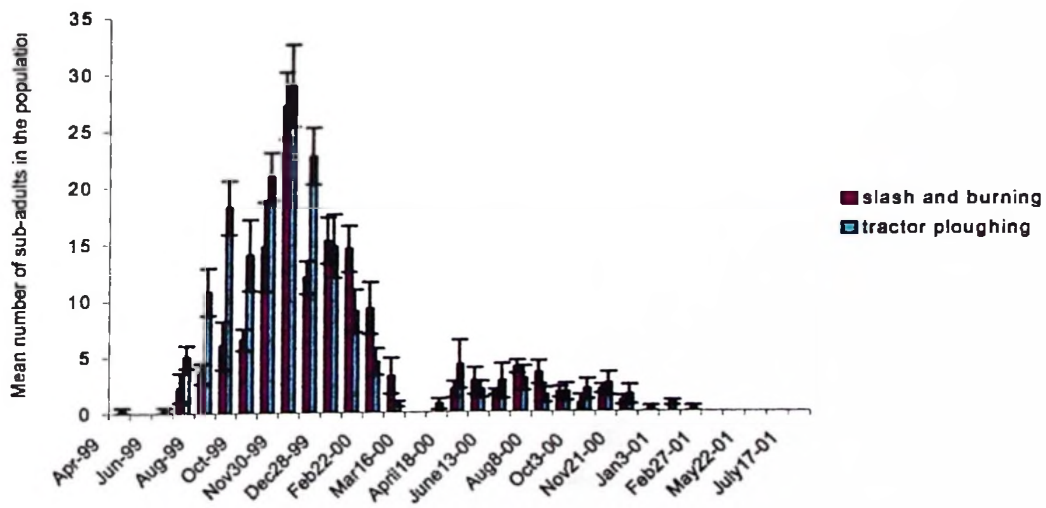


Figure 19. Mean number of sub-adults in the slash and burn and tractor ploughed fields.

4.8 Effect of soil types on rodent population and crop damage

4.8.1 Description of the soil types in the study area

The soil types in the study fields were sandy loam, sand clays and sandy clay loam (Appendix 7). The distribution of the different types of soils for the different treatments is shown in Table 9.

Table 9. Physical properties of the different soil types in the study area

Area	Treatment	Soil pH	P.S.D.			Text. Class
		H_2O (1:2:5)	%clay	% silt	% sand	
1	Tractor-Monocrop	6.2	15.6	8.3	76	Sandy loam
2	Slash and burn-monocrop	6.34	39	9.6	51.3	Sandy clay
3	Tractor – intercrop	6.19	24	10	66	Sandy clay loam
4	Slash and burn-intercrop	6.98	34.3	12.3	53.3	Sandy clay loam
5	Tractor-monocrop	6.48	35.5	9.5	55	Sandy clay loam
6	Slash and burn-monocrop	6.99	24.5	9	66.5	Sandy clay loam
7	Tractor-intercrop	6.46	22.5	8.5	69	Sandy loam
8	Slash and burn-intercrop	6.78	36	10	54.5	Sandy clay

P.S.D. = Particle size distribution

4.8.2 Rodent population size in relation to soil type

Soil is an important factor that determines distribution of rodent species and individuals. Ploughing brings about differences in the texture of the soil, organic matter content differences, and nutrient status. Furthermore, the soil type will determine the kind of vegetation in an area and the crop that may be cultivated. The fertility of the soil will therefore most likely influence the species abundance in an area. The importance of the soil factor in rodent population ecology has been expressed in several studies (Booth, 1960; Ajayi and Tewe, 1978; Yeboah and Akyeampong, 2001).

Table 10 shows the relative population size (total captures) in relation to soil type, land preparation method and cropping systems. The average total capture in relation to soil type is presented in Fig. 20. Rodent populations differed significantly with soil type in the study area regardless of the land preparation methods and the cropping systems ($F_{(2,5)} = 8.42$; $p = 0.025$), The sandy clay soils had the lowest rodent capture. Rodent populations did not differ significantly between the sandy clay loam and sandy loam soils.

The results show that there was no clear-cut relationship between crop damage, rodent population density and soil type. The type of soil will affect the depth of sowing, and most certainly there were variations between individual fields. Therefore the type of soil in the fields could have influenced seed retrieval by rodents and this could have affected the level of crop damage. It will therefore be of interest to investigate how soil types affect population size of *M. natalensis* in crop fields and how this relates to crop damage.

Yeboah and Akyeampong, (2001) commented that once the soils in an area are favourable, the other factors that matter are food availability and land preparation methods which control local distribution of rodents in the fields. Newsome (1969a & b) studied mice on non-irrigated cereal-farm at Turretfield, South Australia, containing black cracking clay soils. It was reported that successful colonization of crop fields was dependent on high winter rainfall to moisten the sub-soil, a hot, dry early summer to crack the soil surface and to give colonizing mice access to the subsoil, and high midsummer rain which moistens the linings of the cracks for burrowing and nesting. Newsome (1969a & b) further concluded that the supply of colonists, suitability of the soil for burrowing and food supply influenced the number of mice moving into a wheat field from adjacent reed bed. In the study area high rodent populations were found in the fields with loamy soils. Loam soils contain a good supply of nutrients, necessary for the organisms living in the soil and have texture, which is most suitable for the greatest variety of living organisms. With particle sizes and spaces between those of clays and sands, they warm fairly quickly and have good water-holding capacity. Probably these characteristics make rodents to thrive better in such soils. In the Victorian Mallee wheatlands, Australia, Newsome (1969a) observed that the light sandy loam soils were dug easily by mice to form nesting sites. On the other hand, the population size was lower in the sandy clay soils. These soils can hold a lot of water, but water movements are slow due to high surface tension forces. Clay soils are often waterlogged and poorly aerated. A lot of water in the spaces can mean that little air is available for living organisms to carry out cellular respiration and certain biochemical actions. These properties probably make clay soils not to be preferred by *M. natalensis*.

Table 10. Relative population size of rodents in relation to soil type, land preparation methods and cropping systems.

Area	Soil type	Ploughing	System	Total Captures
1	Sandy loam	Tractor	Monocrop	387
2	Sandy clay	Slash and burn	Monocrop	279
3	Sandy clay loam	Tractor	Intercrop	415
4	Sandy clay loam	Slash and burn	Intercrop	426
5	Sandy clay loam	Tractor	Monocrop	350
6	Sandy clay loam	Slash and burn	Monocrop	349
7	Sandy loam	Tractor	Intercrop	389
8	Sandy clay	Slash and burn	Intercrop	279

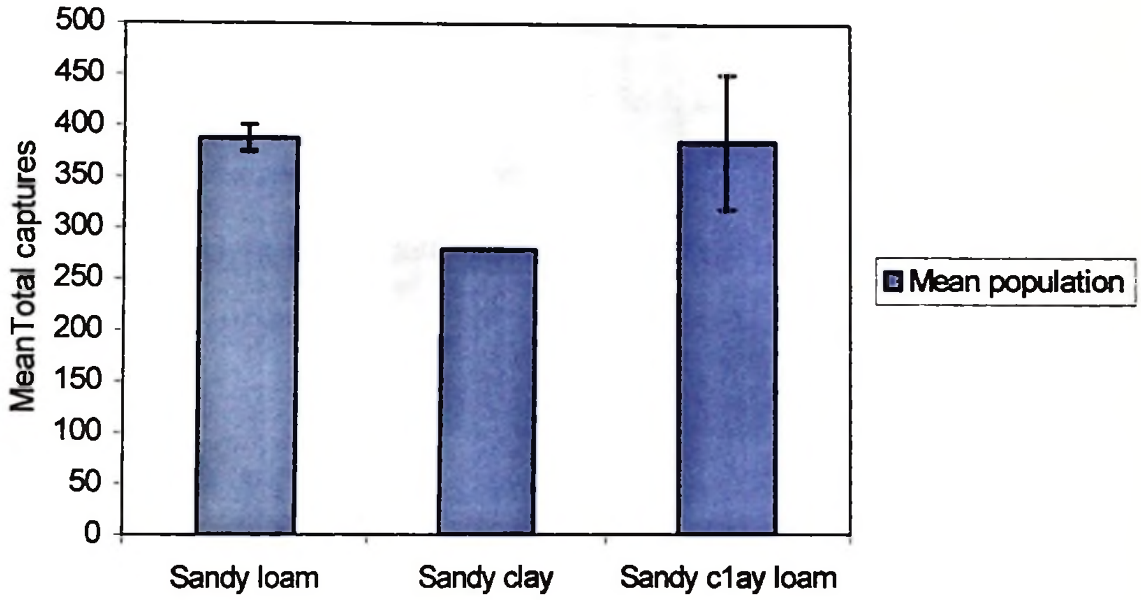


Figure 20. Relative population size (± 95% confidence interval) of *M. natalensis* in relation to soil type

4.9 Crop damage in the different treatments

4.9.1 Effect of rodent population on crop damage in the different treatments

In East Africa, *M. natalensis* causes severe damage/losses to maize crop at planting by removal of seeds and emerging seedlings and later in the cropping season at cob maturity depending on locality, planting season and whether there is a rodent outbreak in the area. Although damage to maize by *M. natalensis* occurs sporadically, most fields either have high or very little damage, depending on the population density during the most susceptible stage of the crop. The land preparation methods in the current study had an impact on crop damage in the fields. Figure 21 shows the effect of rodent population on maize damage in the different fields during the short rains (1999 and 2000), and the long rains (2000). Damage was higher in all the fields during the short rains than the long rains. The pattern of damage in the short and long rains followed a similar trend in both years.

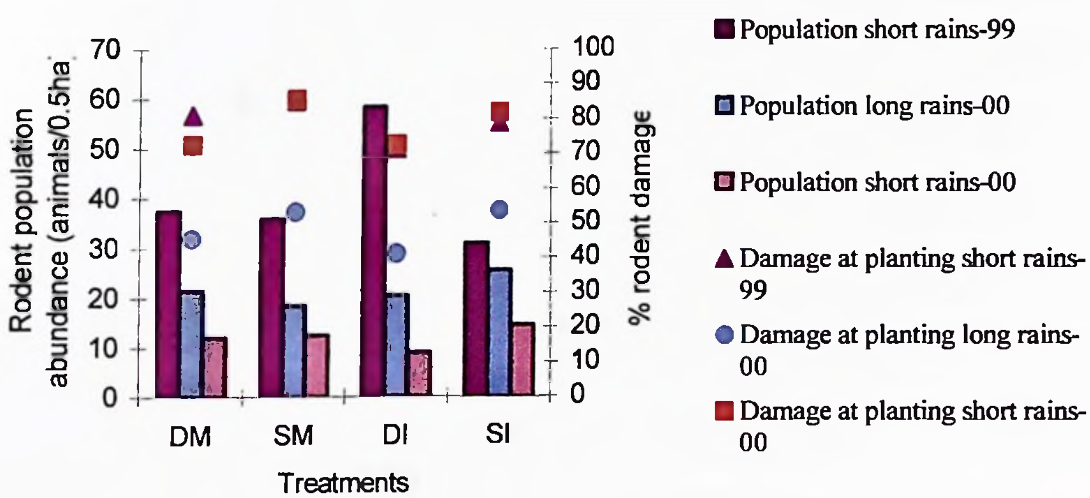


Figure 21. Effect of rodent population on crop damage in the treatments during the short rains 1999 and 2000 and long rains (2000).

DM = Tractor ploughed-monocrop, DI = Tractor ploughed- intercrop, SM = slash and burn- monocrop, SI = slash and burn- intercrop

4.9.2 Effect of land preparation methods and cropping systems on rodent damage to maize crop

In this section, two different analyses were performed. First the data were analyzed separately in order to establish the effect of the different treatments on rodent damage and secondly, the whole data set was used to establish the seasonal effects on rodent damage. From the analysis, there were significant effects of tractor ploughing and slash and burn on rodent damage ($F_{(1,12)} = 18.701$; $p < 0.001$)(Appendix 8). More crop damage occurred in the slash and burn fields than in the tractor ploughed fields (Tukey LSD test; Means: 73.1% and 64.2% respectively, $p = 0.001$). Rodent damage to maize crop at planting differed significantly between seasons ($F_{(2,12)} = 94.46$; $p < 0.001$). Damage was higher during the short rain seasons than the long rain season (Tukey HSD test; Means: 79.15 ± 2.294 for short rains 99, 48.5 ± 2.267 for long rains 2000 and 78.25 ± 2.720 for short rains 2000; $p \leq 0.05$). When the data were analyzed for each season separately, it was found that during the short rain seasons (1999 and 2000), there were no significant effects of the different treatments on rodent damage to maize crop ($P \leq 0.05$). In the long rain season (2000) significant differences occurred between the two types of land preparations where more damage occurred in the slash and burn fields than in the tractor ploughed fields (Tukey HSD test: $P = 0.024$). Cropping systems didn't show significant effects on rodent damage to maize crop ($p \leq 0.05$).

The lower damage in the tractor ploughed fields could be due to the reason that, the spatial distribution of the animals was aggregated with more animals at the periphery of the fields than the centre (cf. slash and burn fields) and also for the fact that the seeds are sown deeper in the soil than in the slash and burn fields. However, other yet unidentified factors could also account for the damage pattern. Lower damage by rodents was reported in mechanically cultivated monocultures (Taylor, 1968). Bang (1975) also commented that areas with regular disturbance, like ploughed fields, usually are not very much affected by field voles as the populations do not increase to levels where damage becomes important. Bang (1975) further commented that in relatively undisturbed fields the populations might reach such densities that damage to crops become serious. For *M. natalensis,* whether or not population increase causes economic damage in a particular field depends on several factors such as the history of the fields, the type of edge surrounding the crop fields, the type of cropping system, method of land preparation and whether the climatic conditions precipitate an outbreak. In this study, it is shown that there are also seasonal effects on crop damage in addition to the above-mentioned factors.

4.9.3 Damage distribution in the different treatments

The damage distribution patterns in the different treatments are presented in Table 11. The damage pattern was randomly distributed in the tractor ploughed fields (except for DI5 where the damage distribution was uniform), whereas in the slash and burn grids damage distribution was uniform. Figure 22 (a-d) shows the damage distribution maps for the different fields.

Although the distribution pattern of crop damage was random and uniform in the tractor ploughed and slash and burn fields respectively, some few variations occurred. The damage distribution maps show that in the tractor ploughed fields with mono-crop and in slash and burn fields with maize inter-cropped with beans, there were some variations in damage. Obvious variations in crop damage occurred in DM1 and S18 compared to DM2 and S17. These variations could be accounted for by the soil type in the different treatments and probably also by the nature of the rodent habitats in the surrounding fallow land. In DM1 and SI8 damage was more intense compared to DM2 and SI7. DM2 and SI7 had similar soil type (sandy clay loam), which is light and easily excavated by rodents. The DM2 field was surrounded by fallow land dominated by *Rhottbolia cochinchinensis* (Guinea fowl grass), which is more preferred by rodents to maize seeds (Mwanjabe, P.S. personal communication, 2000). The SI7 field was surrounded by *Hyperhania rufa*, which is also preferred by rodents than maize. The SI8 comprised of sandy clay soils, which are hard when dry and very sticky when wet and appeared less attractive for rodents, but surprisingly damage was more intense in this field. The DM1 field comprised of sandy loam soils, which are light soils, and maize seeds could easily be retrieved from the soil. On the other hand, the fallow land around SI8 and DM1 comprised of the red top weed, *Rhynchelytrum repens,* which is less preferred by rodents.

Therefore, it shows that damage levels for the different land preparation methods were almost similar, but the distribution of damage in the fields differed significantly. In the slash and burn fields, damage distribution was uniform while in the tractor ploughed fields it was random. This suggests that tractor ploughing reduces crop damage and that most damage at the edge of the fields is not caused by a resident population of *M. natalensis*. Studies elsewhere have shown that rodent damage can be greater in direct seeding, zero tillage and chemical fallow systems because of the reduced mechanized disturbances (Bourne, 1999). Also White *et al.* (1998) reported that the manipulation of habitats adjacent to macadamia orchards in Australia resulted to a reduction in damage due to rodents of up to 65% and that damage was most severe in the first rows of orchard adjacent to temporally stable habitats.

Table 11. Coefficient of dispersion values (Variance-to-mean ratio calculations) and pattern of damage distribution in the different fields during the 2000 long rainy season.

Field	Mean No. of seeds retrieved/hole	Variance	CD	Distribution
DM1	1.36	0.95	0.7	Random
DM2	1.29	0.904	0.71	Random
SM3	1.52	0.869	0.57	Uniform/regular
SM4	1.68	1.03	0.61	Uniform/regular
DI5	1.35	0.92	0.68	Uniform/regular
DI6	1.106	0.824	0.74	Random
SI7	1.59	1.017	0.64	Uniform/regular
SI8	1.627	0.972	0.597	Uniform/regular

Coefficient of dispersion scale: Random distribution = 0.7-1.3; aggregated (clustered) distribution = > 1.3; regular/uniform distribution = < 0.7.

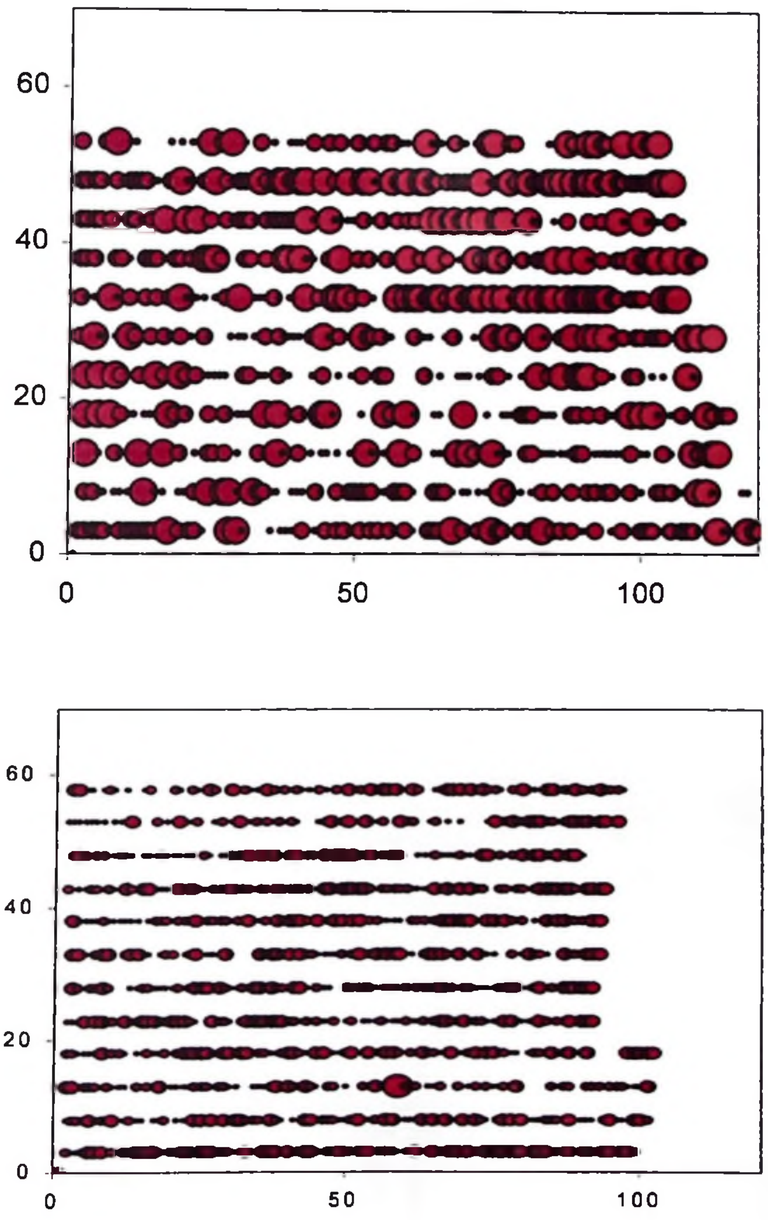


Figure 22(a). Damage distribution in the tractor ploughed fields-monocrop, during the long rainy season (2000) (Y-axis = planting line; X-axis = planting hole; bubble size increase with number of seeds retrieved per hole (1-3))

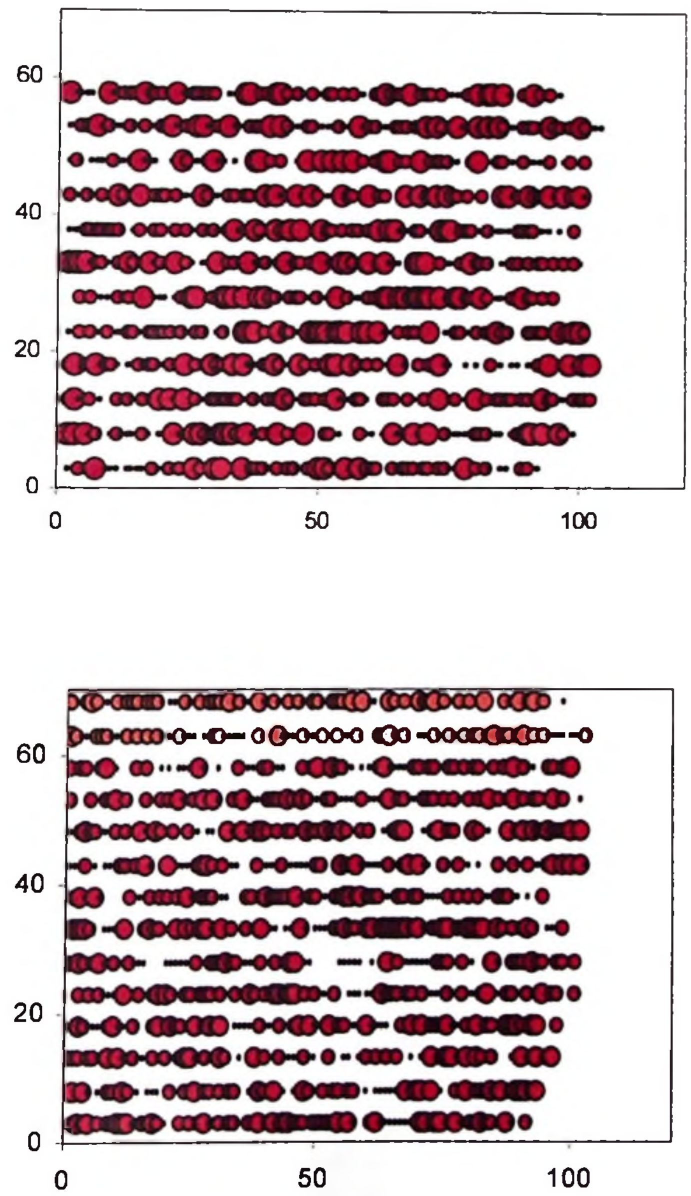


Figure 22 (b). Damage distribution in the slash and burn fields-monocrop, during the long rainy season (2000) (Y-axis = planting line; X-axis = planting hole; bubble size increase with number of seeds retrieved per hole (1-3))

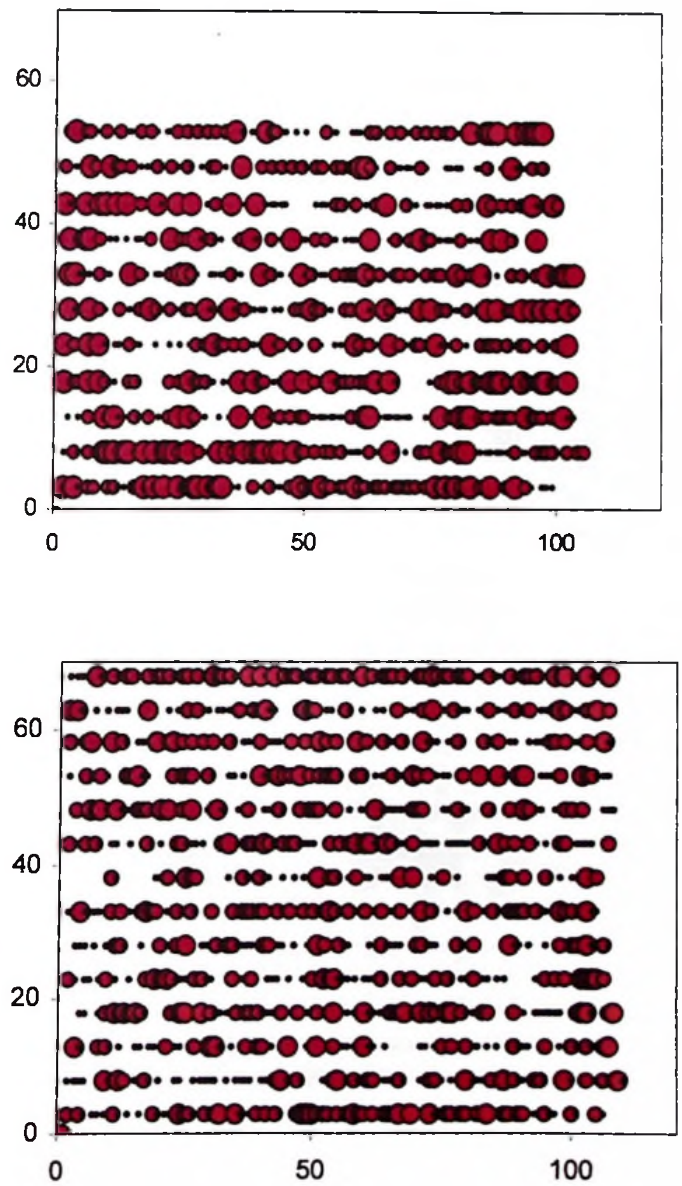
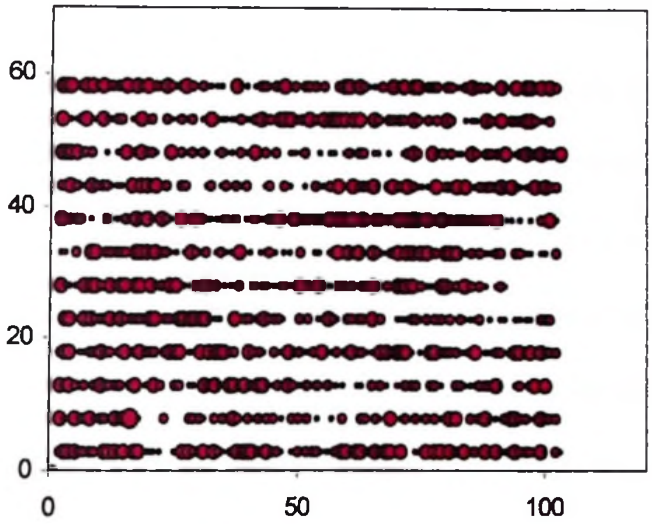


Figure 22(c). Damage distribution in the tractor ploughed fields-intercrop, during the long rainy season (2000) (Y-axis = planting line; X-axis = planting hole; bubble size increase with number of seeds retrieved per hole (1-3))



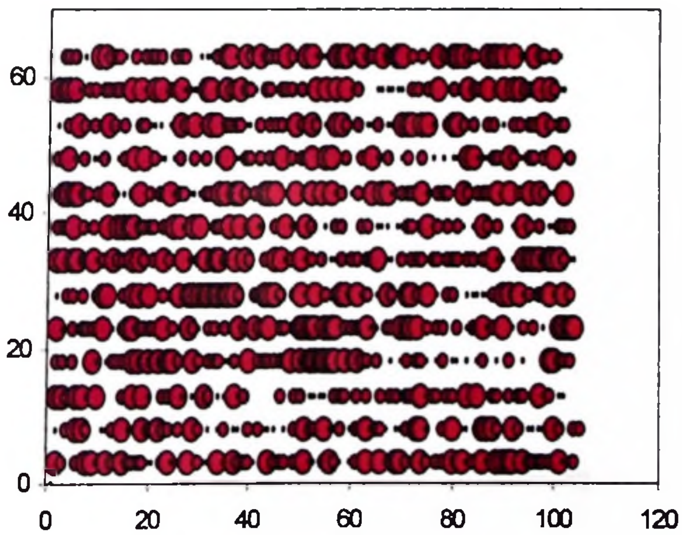


Figure 22(d). Damage distribution in the slash and burn fields-intercrop during the long rainy season (2000) (Y-axis = planting line; X-axis = planting hole; bubble size increase with number of seeds retrieved per hole (1-3))

4.10 Vegetation cover and rodent population

The population dynamics of *M. natalensis* in the study area followed an already established pattern (Telford, 1989; Leirs, 1995), but showed marked variations between individual fields brought about by land preparation methods and cropping systems. The various activities carried out (slash and burn, tractor ploughing; mono and intercropping) obviously created differences in the habitats occupied by rodents. Shelter and production of plant biomass were specifically altered by the land preparation methods. Slash and burning took place in November and new vegetative growth occurred immediately after the onset of the short rains. This was followed by an increasing population size, due to an invasion from the fallow land (Mercelis and Leirs, 1999) and early breeding, which for *M. natalensis* occurs with the onset of short rains (Leirs, 1992).

Figs 23 a-d show that in the slash and burn fields, rodent population abundance and distribution were strongly influenced by vegetation cover in both the mono-crop and inter-cropped fields. The population peaks were reached in high vegetation cover. In contrast, there were no obvious associations between vegetation cover and population abundance in the tractor ploughed fields, particularly in the mono-crop. A negative correlation between vegetation cover and population abundance of *M. natalensis* was obtained in the fallow land (Pearson Product – Moment correlation; $r = -0.63$, $p \leq 0.05$).

Fig. 24a shows the relationship between vegetation cover in the field (X-axis), vegetation cover in the fallow land (Y-axis) and rodent population size (Z-axis) for the two land preparation methods. Population sizes increased with increasing cover in the slash and burn fields and decreasing cover in the fallow land (r^2 = -0.62; $p \leq 0.05$). In the tractor ploughed fields population size remained low in the fields as cover increased (r^2 = - 0.51; $p \leq 0.05$). When vegetation cover was low in both fallow land and in the tractor ploughed fields, there were no animals captured. The relation between vegetation cover in fallow land and crop fields in the two cropping systems is presented in Fig. 24b. In the mono-crop fields, rodent population size increased with decreasing cover in the fallow land (N = 76; r^2 = - 0.54; $p \leq 0.05$). In the inter-cropped fields rodent population increased with decreasing cover in the fields. A high rodent population occurred in the inter-cropped fields when cover was low. Seasonal variation in population size in relation to vegetation cover was observed (Fig. 24c). During the short rains and non-cropping season (dry period), population size increased with increasing cover in the fields.

The selection for suitable habitat by *M. natalensis* is viewed to be a behavioral process, which maximize survival. Vegetation, apart from providing food resources, acts as cover for protection from predators. *M. natalensis* generally avoid exposed places to reduce the risks of predation (Mohr, 2001). The habitat changes were an important factor in the abundance of *M. natalensis* in the different fields. In crop fields, the changes are usually drastic and occur over a short period of time, which also bring about changes in the rodent populations. The different types of treatments (tractor ploughed vs slash and burn and mono vs inter-crop) were associated with a sequence of habitat changes both temporally and spatially, and these are reflected in variation in the rodent population abundance in the different fields.

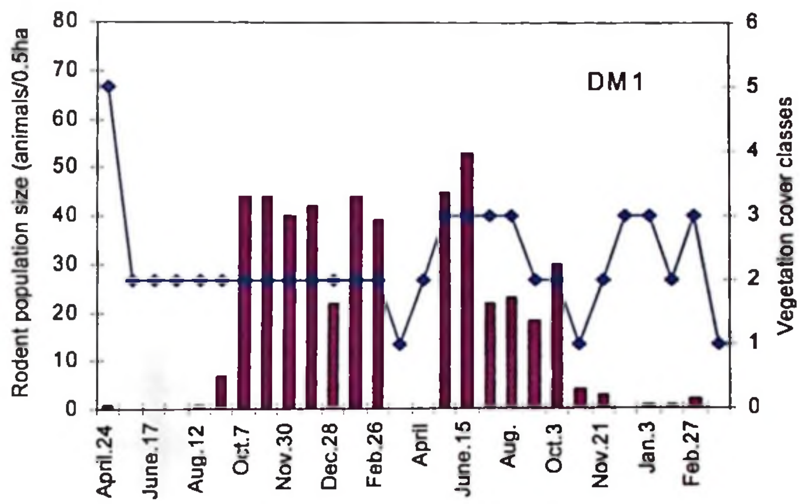
The fallow land with dense grass and weed cover became more and more unfavourable for *M. natalensis* particularly when new vegetation got established in the slash and burn and tractor ploughed fields. This is reflected in the negative correlation between cover and population abundance in the fallow land. Makundi *et al.* (2000) reported that agriculture is a major disturbing factor in any ecosystem, and further commented that the timing and intensity of this activity may affect the species diversity and richness. It therefore suggests that animals migrated from the fallow land to the crop fields and established new home ranges.

The opportunistic behaviour enables *M. natalensis* to take advantage of changes in habitats, particularly in relation to food resources. According to Taylor and Green (1976), when cereals and weed seeds were abundant, both grass and dicotyledonous plants (as found in the fallow land) were eaten sparingly or were absent in the diet of *M. natalensis*. It has been suggested that the fallow land at certain stages during the growth of the crop is a less suitable habitat compared to the crop fields.

It is apparent that agricultural activities may increase species richness (*M. natalensis*) whereas in the undisturbed fallow land the dominance of this species is reduced. This hypothesis conforms to general trends in species succession (Odum, 1971). In Australia, Stickel (1979) reported that in a crop field – hay mosaic (analogous to crop –fallow land mosaic in our study area) the entire population of house mice moved from their long established home ranges in a hay field to a field of ripening wheat where they established new home ranges. Other studies have also shown the importance of farming practices on movements of populations of rodents. According to Newsome (1969 a & b) the growth and harvest of wheat in Australia had major influence on the migration of house mice.

The current study also showed that in the slash and burn fields there was strong association between population size and cover. It is apparent that these fields were less disturbed than the tractor ploughed fields. It therefore appears that populations of *M. natalensis* were building up faster within the slash and burn fields (mono and intercrop fields) indicating higher survival and recruitment than in the tractor ploughed fields. Since the distribution of animals in the tractor ploughed fields was not random but was restricted to the edges, it is an indication that there was less migration and colonization of these fields irrespective of the cover.

It is apparent that surrounding fallow lands in crop fields are an important consideration in rodent pest management. For example, studies in Australia in the Victoria Mallee showed that fence-lines were the most important donor habitats because they provided abundant grass seed early in the breeding season (Singleton 1989; Twigg and Kay 1994). Rodent management in such fields should aim at destruction of ground cover which affects rodents immediately by exposing them to predators and, more slowly, by removing their food supplies. Populations of *M. natalensis*, have been observed to increase after cover removal in adjacent fields (Green and Taylor, 1975). Green and Taylor (1975) therefore suggested that any attempts to reduce rodent numbers over wide areas by means of cover destruction would have to be coordinated so that all harborage is removed at more or less the same time. In the current study, the observations made show that the fallow land was a preferred habitat for escape of animals particularly following land preparation. Therefore, removal of the fallow patches and field sanitation measures such as weeding, when conducted by all or the majority of farmers will most certainly be successful in reducing rodent populations in the fields.



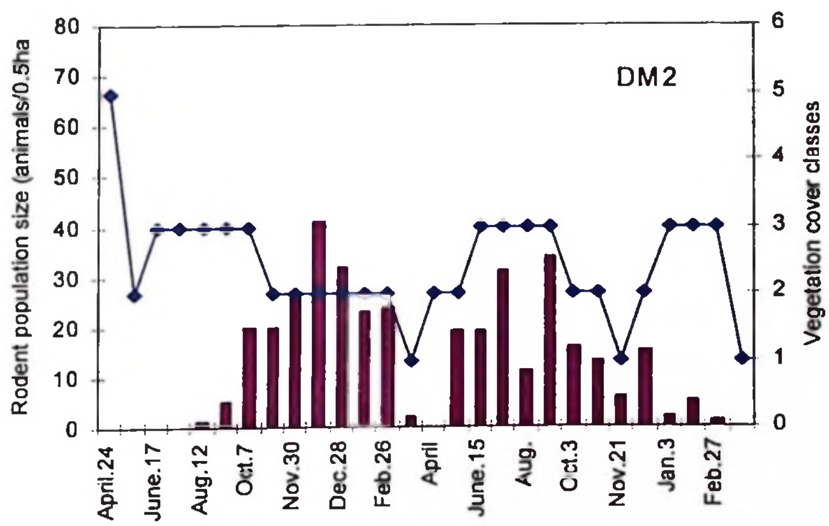
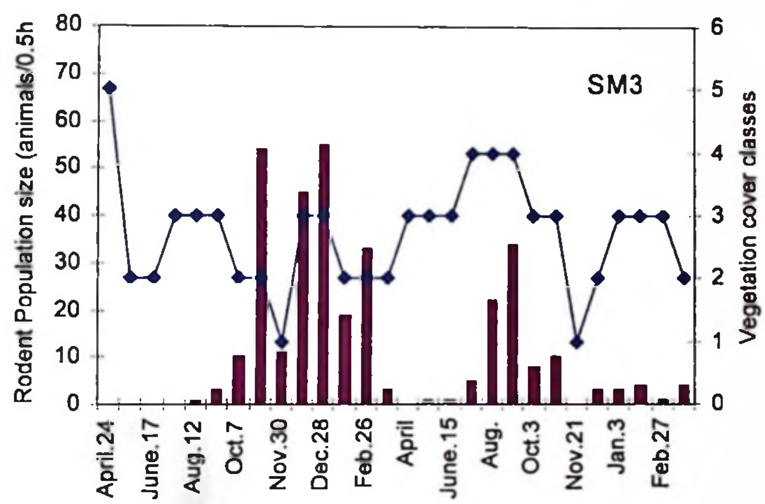


Fig 23a. Rodent population abundance (bars) and vegetation cover (lines) in tractor ploughed fields (monocro)(DM1 and DM2)



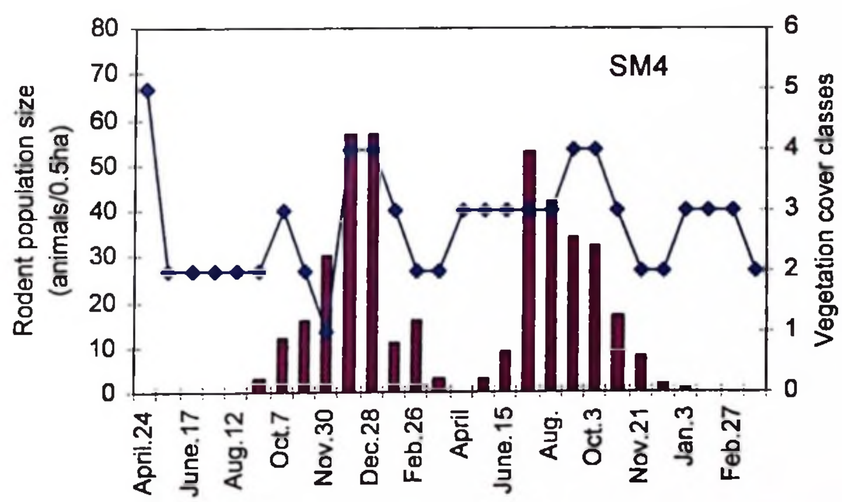
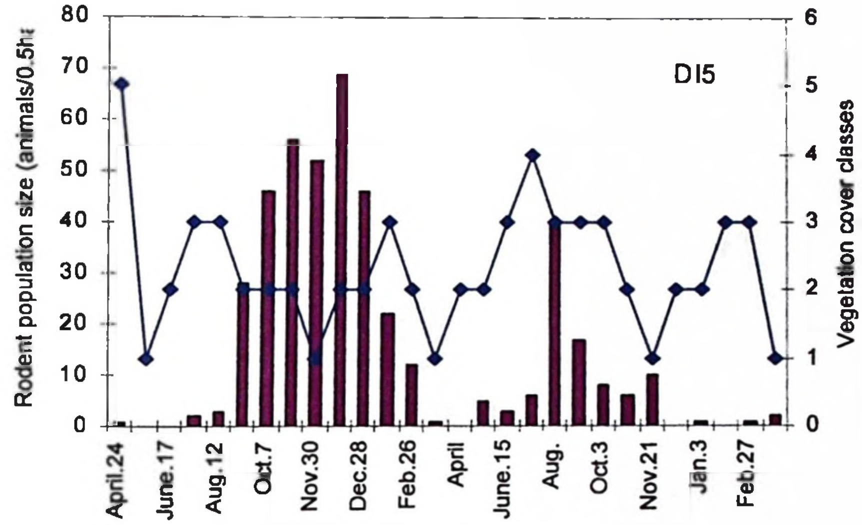


Fig 23b. Rodent population abundance (bars) and vegetation cover (lines) in slash and burn fields (monocrop)(SM3 and SM4).



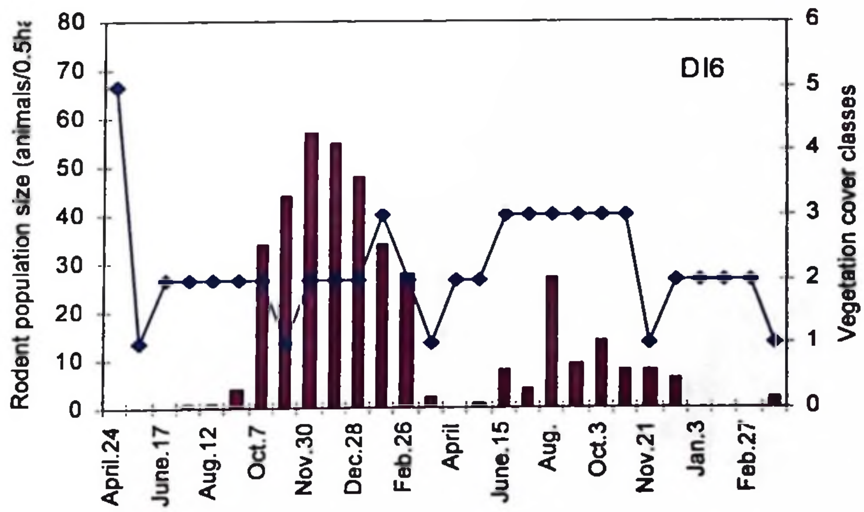
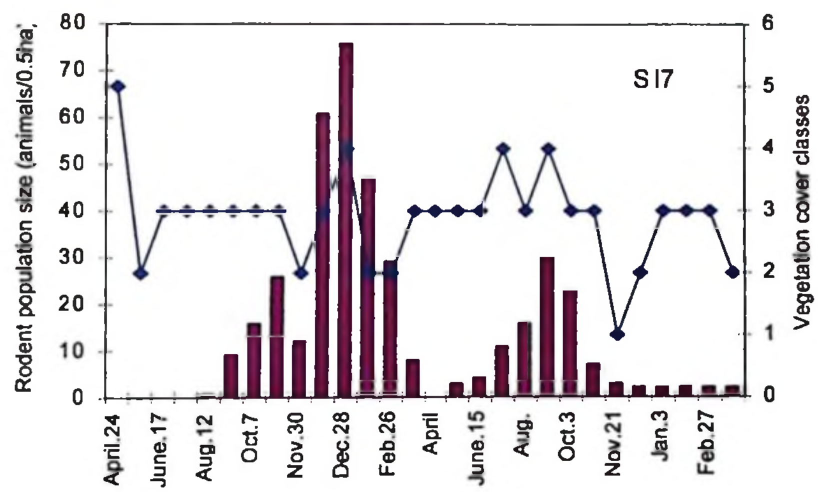


Figure 23c. Rodent population abundance (bars) and vegetation cover (lines) in the tractor ploughed fields (intercrop)(DI5 and DI6)



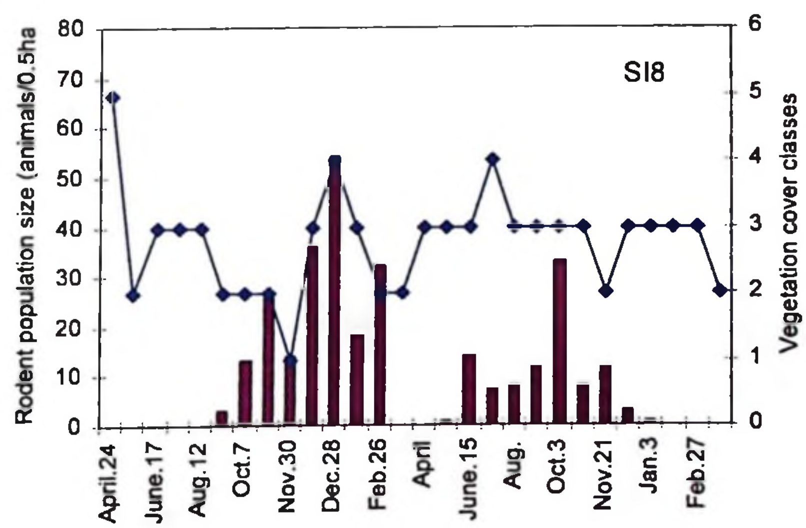


Figure 23d. Rodent population abundance (bars) and vegetation cover (lines) in the slash and burn fields (intercrop)(SI7 and SI8).

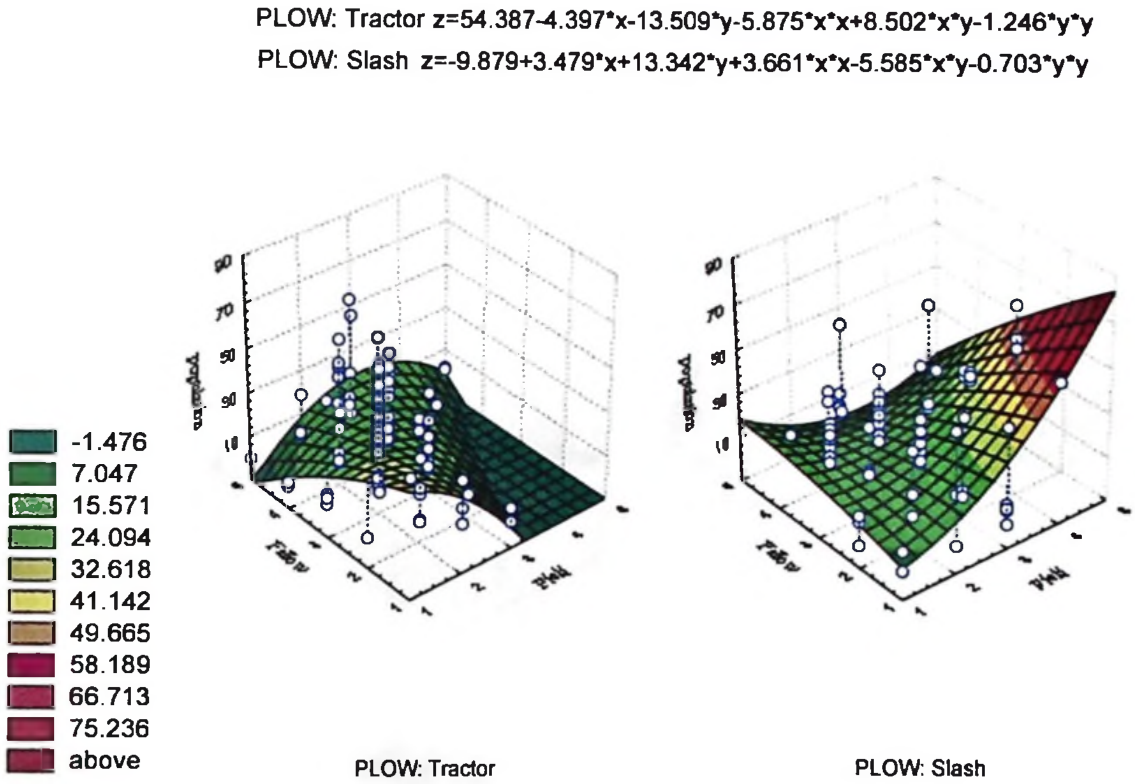


Figure 24a. Relationship between vegetation cover (in the crop field and fallow land) and rodent population size in tractor ploughed and slash and burn fields (X = cover in the field, Y = cover in the fallow land, Z = Rodent population abundance).

SYST: mono z=1.917+14.315*x-0.179*y-1.199*x*x-1.336*x*y-0.194*y*y

SYST: inter z=-1.101-0.245*x+16.581*y+1.773*x*x-2.025*x*y-2.782*y*y

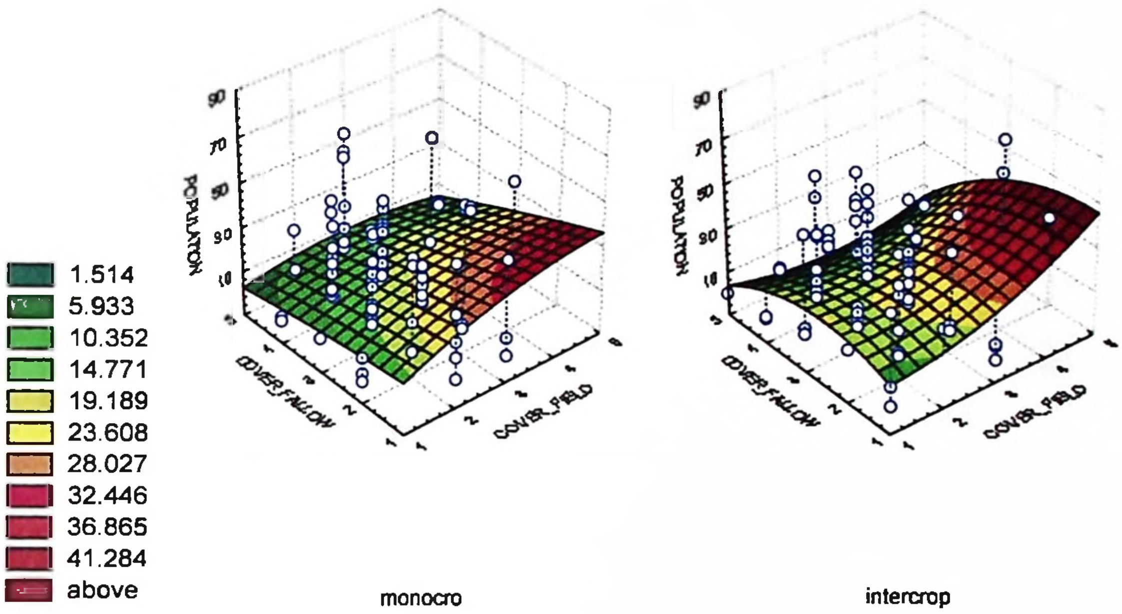


Figure 24b. Relationship between vegetation cover (in the crop field and fallow land) and rodent population size in mono and intercropped fields (X = cover in the field, Y = cover in the fallow land, Z = Rodent population abundance).

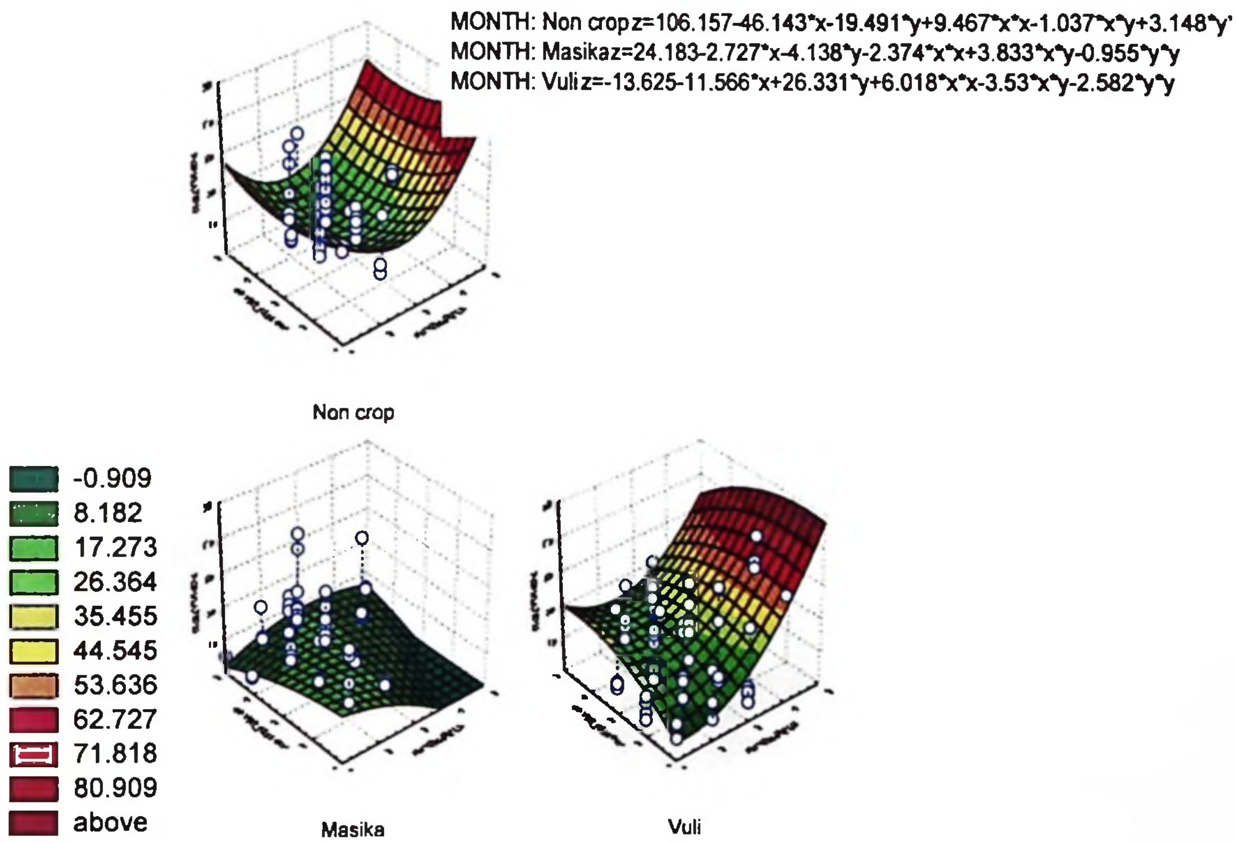


Figure 24c. Relationship between vegetation cover (in crop fields and fallow land) and rodent population size in the different seasons. (X = cover in the field, Y = cover in the fallow land, Z = Rodent population abundance).

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMENDATIONS

5. 1. Conclusions

5.1.1. Population abundance and spatial distribution of *M. natalensis* were significantly affected by tractor ploughing and slash and burn practices. Before land preparation animals were randomly distributed in the fields, but after land preparation and the consecutive stages of maize growth, animals were clustered around the edges in the tractor ploughed fields whereas in the slash and burn fields animals were randomly distributed.

5.1.2. Slash and burn modulates food and other resources that sustain a higher population of *M. natalensis*.

5.1.3. The proportion of new individuals entering the trappable population during the cropping season was high in the slash and burn fields and therefore, this practice creates favourable conditions for colonization by *M. natalensis*.

5.1.4. Home range and movement in crop fields are reduced by tractor ploughing with implication that total area for foraging is reduced. This indicates that survival of rodents is reduced in tractor ploughed fields.

5.1.5. Slash and burn creates favourable conditions for breeding, probably due to more food availability in these fields.

5.1.6. Soil type strongly influenced rodent population abundance and damage to crops in the fields, with loamy soils being more preferred by rodents to clay soils.

5.1.7. Vegetation cover is an important factor contributing to rodent population fluctuations in the fields. Therefore, limiting habitat quality in the fallow land surrounding crop fields could be useful in reducing invasion of the crop.

5.1.8. Tractor ploughing affects spatial distribution of rodents in the fields, disrupts their home range and limits rodent movement and consequently reduces crop damage. Therefore, tractor ploughing can be a useful tool for management of rodents when practiced over a large area and is supplemented by clearing of surrounding fallow land.

5.1.9. Cropping systems had no significant effects on rodent population characteristics in the current study.

5.1.10. Land preparation methods should not be assumed to be adequate to effectively control rodents on their own, but should be integrated with other strategies to reduce crop damage by rodents.

5.2. Recommendations

5.2.1. Similar studies should be extended to other cropping systems which are practiced in the country, including mixed cropping and agro-forestry systems.

5.2.2. Since rodent population size varied with soil type, it will be important to carry out intensive studies on the relationship between soil type, rodent population size and damage in different agro-ecological zones in Tanzania

5.2.3. Studies should be conducted to investigate how cropping systems and different land management strategies affect survival of rodents.

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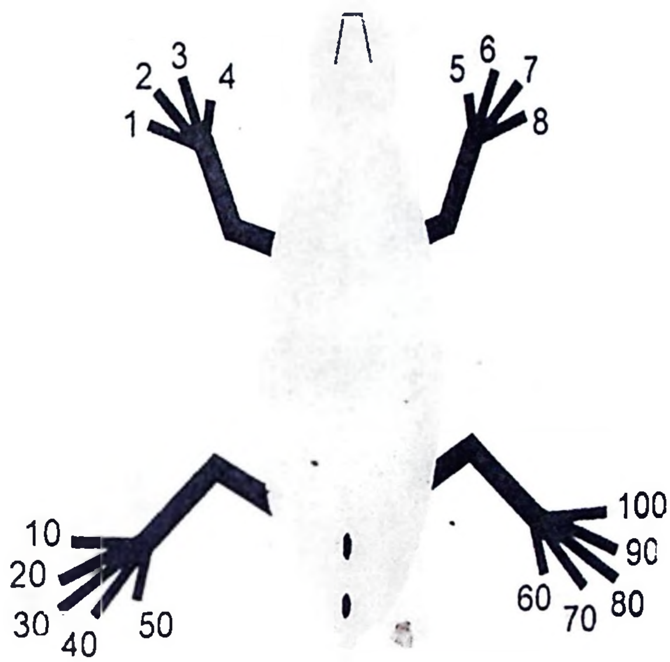
7.0. APPENDICES

Appendix 1. Weather data during the study period (Obtained from the Meteorological station at the Sokoine University of Agriculture).

Year	Month	Total rainfall	Mean radiation	Total pan Evapo-transpiration	Mean maximum temperature	Mean minimum Temperature
1999	Jan	116.1	19.89	216.5	33.4	22.3
1999	Feb	29	21.88	201.6	33.8	21.8
1999	March	185.7	16.5	149.6	30.3	21.8
1999	April	196.3	15.06	100.2	28.6	20.6
1999	May	96.3	14.28	97.7	28.9	19.4
1999	June	28.8	15.01	87.8	27.6	16.4
1999	July	38.7	14.28	91.8	26.5	18.2
1999	August	21.4	13.43	86.9	28.7	16.7
1999	September	16.1	17.99	140.6	29.6	22.3
1999	October	11.5	19.22	182.5	30.9	18.8
1999	November	35.7	20.17		32.8	19.8
1999	December	60.9	19.38	168.4	31.6	20.5
2000	Jan	68.8	22.6	219.8	33.1	21.4
2000	Feb	37.9	23.6	224.4	31.7	21.3
2000	March	207.4	17.57	127.4	31	20
2000	April	113.1	16.07	100	30.8	19.9
2000	May	32	14.98	90.8	28.5	19
2000	June	47.8	15.06	92.8	27.9	17.4
2000	July	5.2	15.13	109.7	27.1	15.9
2000	August	17.3	15.49	133.2	28.4	17
2000	September	4.1	17.09	164.1	29.8	17.2
2000	October	0	20.17	220	32.4	18.6
2000	November	49.4	18.06	226.9	33	21.4
2000	December	207	17.39	162.5	30.9	21.6
2001	Jan	104.3	16.99	139.2	30.4	21.7
2001	Feb	99	20.23	137.8	29.1	21.2
2001	March	171.9	20.37	149.7	31.3	22.1
2001	April	224.6	16.78	105.1	29.7	21.7
2001	May	90.4	15.48	88.7	28.7	19.8
2001	June	4.6	15.62	85.6	27.7	17
2001	July	5.8	14.59	86.4	26.4	15.7
2001	August	Trace	17.81	138	28.5	16.2
2001	September	0	18.67	159.1	29.3	17.1
2001	October	11.1	20.21	192.7	31.4	18.5
2001	November	0	21.43	229.5	33.7	20.3
2001	December	72.3	22	239.7	33.2	22.6

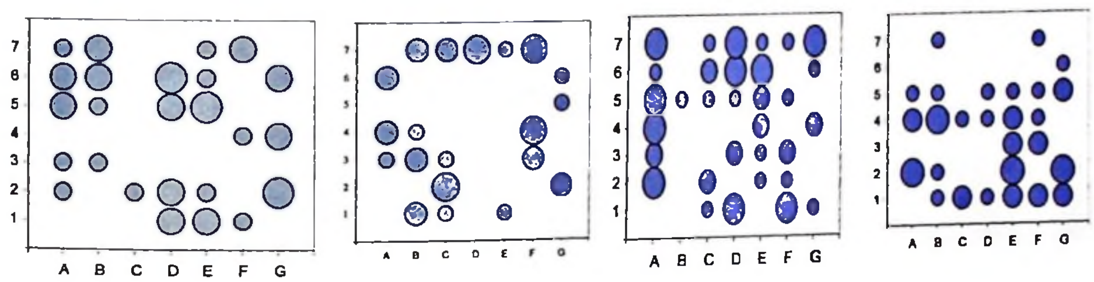
Appendix 2. Schematic diagram showing the toe clipping codes



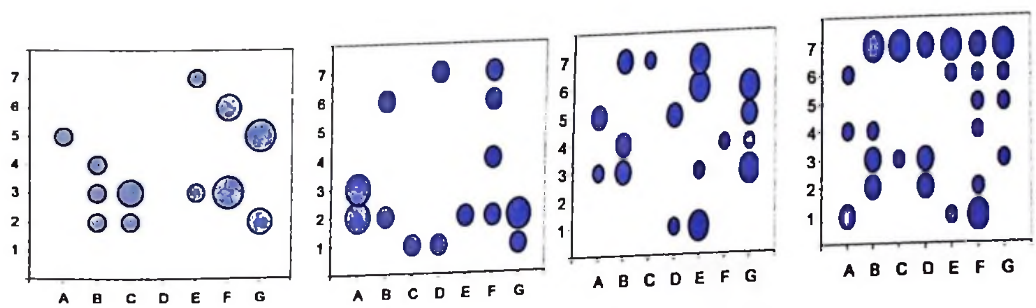
Appendix 3. Procedure followed for vegetation cover assessment in Mazimbu CMR grids; numbers 1-7 are trapping lines and letters A-G are trapping stations.

1G	2G	3G	4G	5G	6G	7G
1F	2F	3F	4F	5F	6F	7F
1E	2E	3E	4E	5E	6E	7E
1D	2D	3D	4D	5D	6D	7D
1C	2C	3C	4C	5C	6C	7C
1B	2B	3B	4B	5B	6B	7B
1A	2A	3A	4A	5A	6A	7A

Appendix 4. Distribution of trapped individuals over the different trapping stations during the short rains (1999) and long rains (2000)

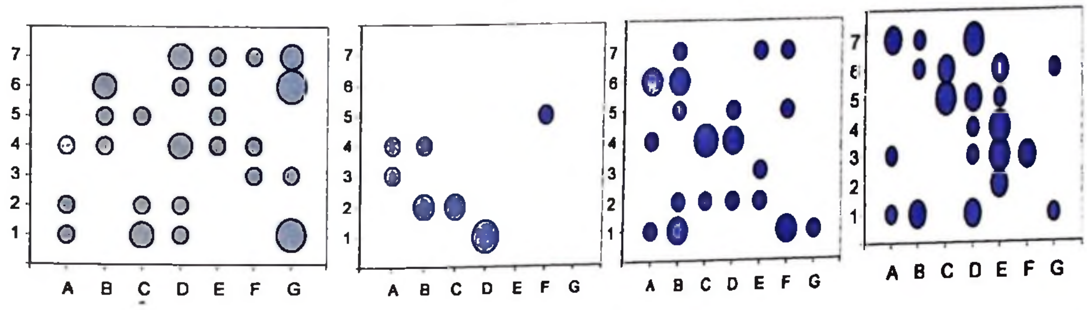


(i). Distribution of trapped individuals over the different trapping stations in the tractor ploughed fields (intercrop) during the short rain season:- Dot size increases with the number of captures. (a- before ploughing; b- after ploughing; c- after seed emergence; d- at vegetative stage).

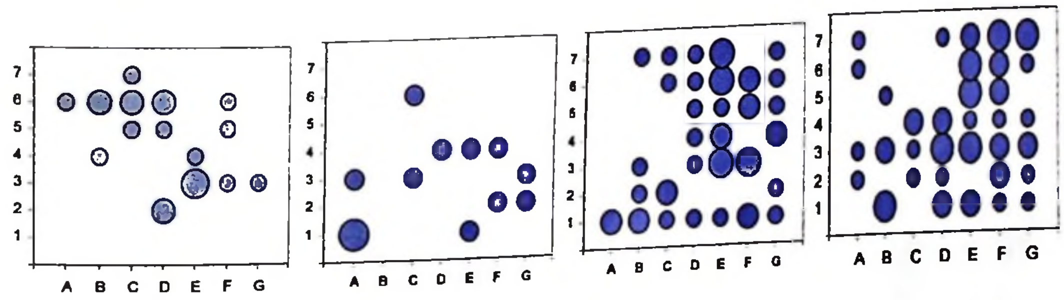


(ii). Distribution of trapped individuals over the different trapping stations in the tractor ploughed fields (monocrop) during the 1999 short rain season:- Dot size increases with the number of captures. (a- before ploughing; b- after ploughing; c- after seed emergence; d- at vegetative stage).

Appendix 4: continued

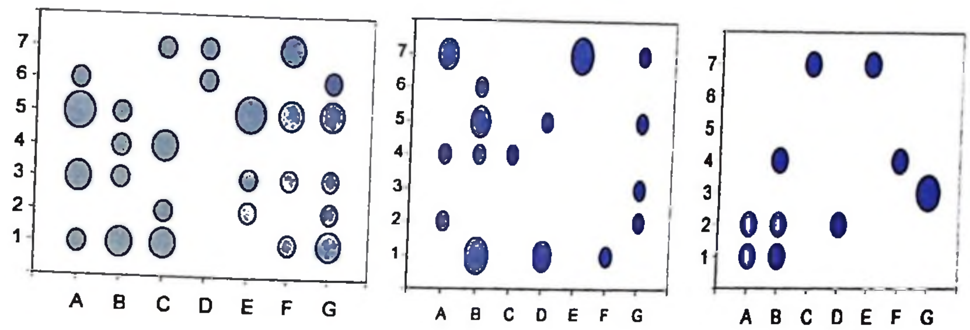


(iii).Distribution of trapped individuals over the different trapping stations in the slash and burn fields (monocrop) during the short rain 1999 season:- Dot size increases with the number of captures (a- before ploughing; b- after ploughing; c- after seed emergence; d- at vegetative stage).

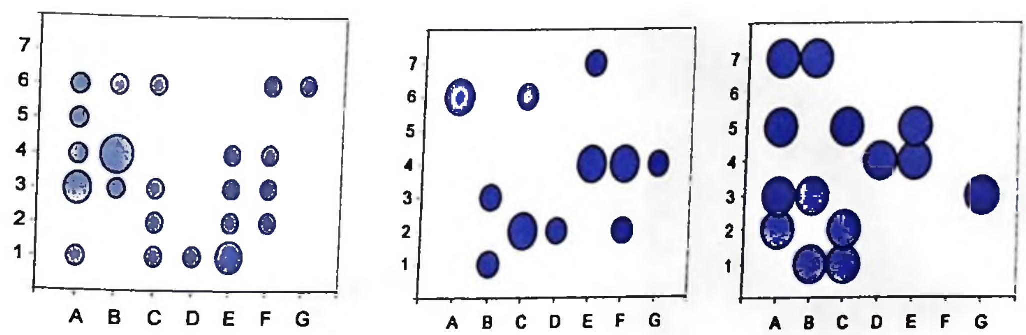


(iv). Distribution of trapped individuals over the different trapping stations in the slash and burn fields (intercrop) during the 1999 short rain season:- Dot size increases with the number of captures (a- before ploughing; b- after ploughing; c- after seed emergence; d- at vegetative stage).

Appendix 4; continued

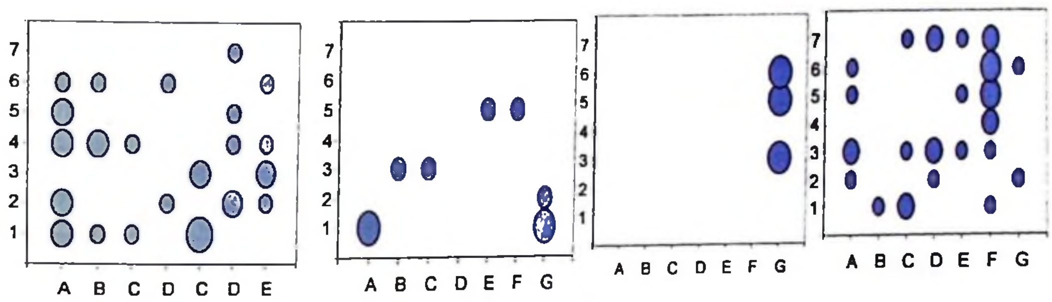


(v). Distribution of trapped individuals over the different trapping stations in the tractor ploughed fields (intercrop) during the 2000 long rain season:- Dot size increases with the number of captures. (a- before ploughing; b- after ploughing; c- after seed emergence).

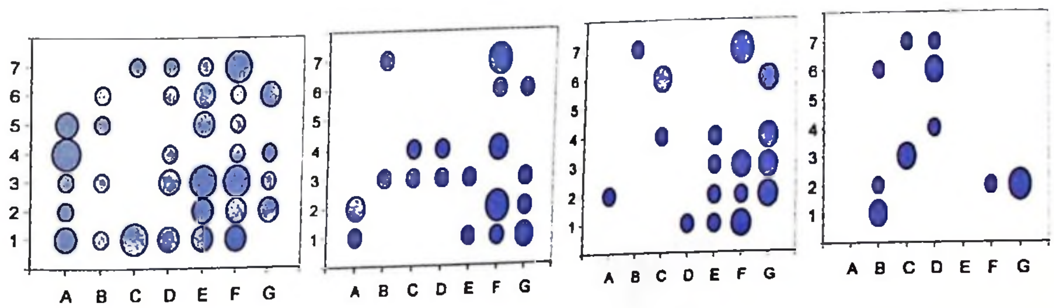


(vi). Distribution of trapped individuals over the different trapping stations in the slash and burn fields (monocrop) during the 2000 long rain season:- Dot size increases with the number of captures (a- before ploughing; b- after ploughing; c- after seed emergence).

Appendix 4: continued



(vii). Distribution of trapped individuals over the different trapping stations in the tractor ploughed fields (monocrop) during the 2000 long rain season:- Dot size increases with the number of captures. (a- before ploughing; b- after ploughing; c- after seed emergence; d- at vegetative stage).



(viii). Distribution of trapped individuals over the different trapping stations in the slash and burn fields (intercrop) during the 2000 long rain season:- Dot size increases with the number of captures (a- before ploughing; b- after ploughing; c- after seed emergence; d- at vegetative stage).

Appendix 5. Analysis of variance showing the effect of the different treatments on the proportion (%) of females in the population.

Effect	SS	Df	MS	F	P-level
Time	71091.2	29	2451.4	4.06	0.00000*
Plough	621.5	1	621.5	1.03	0.312
System	115.9	1	115.9	0.1921	0.662
Time * Plough	10788.6	29	372.0	0.6168	0.9336
Time * sytem	28197.8	29	972.3	1.6121	0.039*
Plough * system	1329.0	1	1329.0	2.2035	0.1403
Time * plough * system	17844.8	29	615.3	1.0202	0.449
Error	72375.9	120	603.1		

Appendix 6. Analysis of variance showing the effect of the different treatments on the proportion (%) of males in the population.

Effect	SS	Df	MS	F	P-level
Time	106871.8	29	3685.2	6.975	0.00000*
Plough	4.2	1	4.2	0.008	0.928
System	0.9	1	0.9	0.001	0.9661
Time * Plough	32715.2	29	1128.1	2.1352	0.0023*
Time * sytem	8573.8	29	295.6	0.5596	0.9639
Plough * system	1550.5	1	1550.5	2.9345	0.0892
Time * plough * system	22300.5	29	769.0	1.4554	0.0830
Error	63401.8	120	528.3		

Appendix 7. Soil types in the study area.

Sandy loam

Sandy clay

Sandy clay loam

Appendix 8. Analysis of variance showing the seasonal and treatment effects on rodent damage to maize crop during the short rains (1999) long rains (2000) and short rains 2000.

Effect	SS	Df	Ms	F-value	p-level
Season	4868.3	2	2434.1	94.467	< 0.001
Plough	481.9	1	481.9	18.701	<0.001
System	99.2	1	99.2	3.851	0.073
Season*plough	33.2	2	16.6	0.644	0.542
Season*system	51.3	2	25.6	0.995	0.398
Plough*system	3.1	1	3.1	0.120	0.734
3 way interruction	19.4	2	9.7	0.377	0.693
Error	309.2	12	25.8		