Potential for the establishment of *Cylas puncticollis* Boheman (Coleoptera: Apionidae) as a pest of sweetpotato in Lesotho.

by

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Submitted in fulfilment of the requirements for the degree

MAGISTER SCIENTIAE IN ENTOMOLOGY

IN THE FACULTY OF AGRICULTURE & BIOLOGICAL SCIENCES
DEPARTMENT OF ZOOLOGY & ENTOMOLOGY
UNIVERSITY OF PRETORIA

JUNE 2000

UNIVERSITEIT VAN PRETORIA
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I, Lefulesele Nteletsana declare that

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is my own work and has never been submitted for any degree purpose before. All the sources used or quoted in this study have been indicated and acknowledged by means of references.

Signed: L. Nteletsana

27th/June/'00
Date

This work is dedicated to the two most important people in my life, my husband, Katleho and my daughter, Khabiso.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to a number of people who contributed in various ways to the success of this work. Dr A.S. Schoeman and Dr M.A. McGeoch, my two supervisors, worked very hard and patiently to guide me through this work. The Agricultural Research Division (ARD) through different sections, contributed a lot by providing me with the necessary resources for my field work. The technical staff of the University of Pretoria is thanked a lot for helping me in various ways. I also wish to thank Dr Martin Kruger (Head Curator, Lepidoptera Section, Transvaal Museum), Dr C. Bellamy (Head Curator, Coleoptera Section, Transvaal Museum) and Elizabeth Grobbelaar (Entomologist, Agricultural Research Council) for helping with the identification of my specimen. I am also grateful to Dr I. Meiklejohn (Department of Geography, University of Pretoria) who assisted with the GIS maps.

A number of people made critical comments on this work, Professor S. Chown and Dr C. Chimimba (Dept. of Zoology & Entomology, University of Pretoria), Dr M. Phoofolo (Biology & Chemistry Department, National University of Lesotho) and others, their comments have been very valuable. Part of this study was sponsored by Southern African Regional Root Crops Network (SARRNET) and by the Lesotho Government through the National Manpower Development Secretariat (N.M.D.S.). Last but not least I wish to thank both my family and my friends for the support they gave me throughout the entire study period.

Contents

ABSTRACT

Sweetpotato, *Ipomoea batatas* (L.) Lamarck was introduced into Lesotho in 1992 in the hope that it would help alleviate poverty levels. Efforts are being made to learn the potential constraints to optimal production of this crop. Insect pests especially the sweetpotato weevils, *Cylas* species are a major production constraint worldwide. Hence the main objective of the study was to predict if these pests have potential to establish themselves in Lesotho. Two *Cylas* species, *C. formicarius* and *C. puncticollis* are present in South Africa and the latter is found in the northern Free State and the Eastern Cape both of which border the central and southern lowlands of Lesotho respectively.

Cylas puncticollis was chosen as the subject of this study because of its potential spread into Lesotho. Thermal requirements (lower development threshold and degree-days) of this pest were calculated in the laboratory by studying the effects of temperature on its development and survival at six constant temperatures (16°C, 19°C, 24°C, 26°C, 31°C and 36°C). The photoperiod was maintained at 12L:12D for all temperatures, but RH was not controlled. Thermal requirements (r and k) of this pest species were estimated for all the immature stages and for the total life-cycle using the linear regression method. The estimated lower temperature threshold (r) of the total development of the pest lies between 8°C and 12°C and the thermal constant (k) between 360°D and 380°D.

The thermal needs of this pest obtained from the laboratory work were used to predict the potential for its establishment in Lesotho as well as determining the possible areas of distribution if it invades Lesotho. Actual soil temperatures to which the pest would be exposed to in Lesotho were recorded for a year. Both the calculated thermal needs of the pest and the field-recorded temperatures were used in the degree-day model to predict potential establishment of this pest. The second approach, climate matching in Geographical Information System (GIS) used the bio-climatic profile of *C. puncticollis* calculated from the known areas of its distribution in both South Africa and Swaziland. The bio-climatic profiles of the two countries were matched to the climatic conditions of Lesotho to predict the potential for its establishment.

The two approaches, linear degree-day model and climate matching approach revealed that *Cylas puncticollis* is a potential pest in Lesotho. The former predicted the occurrence of this pest throughout the whole country with a maximum of eight generations per year being possible in the lowlands. Fewer generations (two to three) were predicted for the highlands and foothills agro-ecological zones, which are colder than the lowlands. The climate matching approach also confirmed the prediction although according to this method a patchy distribution of the pest was predicted.

A survey was then carried out in Lesotho, first to determine if *Cylas* species were already present in Lesotho, secondly to identify any other pests of sweetpotato and lastly to determine other possible production constraints other than insect pests. The survey was conducted in the form of questionnaire and field sampling. *Cylas* species were neither documented by the farmers who were interviewed nor by the field sampling. Numerous common pests of sweetpotato were recorded during the sampling survey. These included the following leaf-feeding pests: *Bedellia somnulentella* Zeller, *Acraea acerata* Hewitson, *Agrius convolvuli* Linnaeus and locusts and grasshoppers. The root pests that were recorded were mole-rats, *Blosyrus* sp. and millipedes (*Narceus* sp.).

According to the sampling carried out in Lesotho there were no insect pests that could be rated as major pests as yet. Sweetpotato farmers did not consider insect pests as an important production constraint for optimal yield of the crop. The major constraint was found to be lack of planting material, which contributed towards a slow adoption of the crop throughout the country.

Preface

Sweetpotato, *Ipomoea batatas* (Linnaeus) Lamarck has been documented as one of the most important crops in the developing countries of the world (Horton 1988, Plucknett 1991). It ranks high amongst the world food crops. It was ranked the seventh most important crop in the world by the Food and Agricultural Organisation (Proshold 1986) and the second amongst root crops after white potato (Horton 1988). The crop possesses the qualities that make it the most suitable crop for small subsistence farming. It has shown great adaptability to various climates (Horton & Ewell 1991). It is usually grown under poor conditions with very little or no fertilization (Bouwkamp 1985). Sweetpotato is used by many developing countries of the world as the staple crop (Horton *et al.* 1989). This crop makes a significant contribution towards diets not only by providing a lot of starch but also by providing vitamins and proteins (Bouwkamp 1985).

Although the crop has shown great adaptability to different environments, storing the planting materials for the following season is often a serious problem associated with this crop. This is especially serious in cold areas as the planting materials kept for the next plantings are often killed by frost (Rakotoarisoa & Ravoniarimanana 1994). Therefore, the use of tubers as the planting material seems to be an appropriate solution especially for cooler regions (O'Hair 1991) although this is not yet a widely adopted approach. Apart from the problem of planting material which often pose a serious problem for farmers, insects are regarded as the most important production constraint in the majority of sweetpotato growing countries (Skoglund & Smit 1994).

The most important insect pest of this crop throughout the world is the sweetpotato weevil, *Cylas* spp. (Wolfe 1991). Yield losses of up to 100% have been estimated as a result of damage by this pest alone (Jansson 1991). Efforts are taken by various organisations such as the International Institute of Tropical Agriculture (IITA) and Southern African Regional Root crops Network (SARRNET), to develop techniques that will combat problems associated with production of this crop. While a great emphasis is on insect pests especially sweetpotato weevils, other problems are also dealt with. The participating countries in the region (SADC) have a mandate of identifying the most important problems that contribute towards low production of the crop in their countries. Lesotho is one of the member countries of SARRNET and therefore it also has to identify such production constraints. The importance of knowing the production constraints of each country helps in the allocation of research resources for the most important issues. This study is part of the mandate to identify potential production constraints to optimal yield of sweetpotato in Lesotho.

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CHAPTER 1

Temperature Effects on development and survival of the sweetpotato weevil, *Cylas puncticollis* Boheman (Coleoptera: Apionidae).

INTRODUCTION

Sweetpotato is a drought tolerant crop (Smit 1997a). It requires rain shortly after planting, whereafter it can survive with relatively little moisture in the soil (du Plooy *et al.* 1984). In addition, this crop can be grown on marginal lands with very little fertilization and still give good yields (Horton & Ewell 1991). For these reasons it has become an important crop in developing countries. For example, it is a staple crop in developing countries of the world such as Uganda (Smit 1997b), Papua New Guinea and the Philippines (Selleck 1982). As a developing country that frequently suffers from droughts (Anonymous 1986) the Lesotho Government through the Ministry of Agriculture also realized the value of this crop. Sweetpotato was introduced into Lesotho in 1992 in the hope that it will alleviate poverty levels Since its introduction it has mainly been in production in the lowlands (1400 m.a.s.l – 2000 m.a.s.l.) of Lesotho.

The major biotic constraints on the production of sweetpotato worldwide are sweetpotato weevils in the genus *Cylas* (Anota & Odebiyi 1984; Chalfant *et al.* 1990; Smit 1997a). There are about eleven species of *Cylas* that attack sweetpotato and these are classified into three species groups, namely the *C. formicarius*, *C. puncticollis* and *C. brunneus* groups (Wolfe 1991). *Cylas formicarius* Fabricius is widely distributed throughout the world (Collins & *Mendoza* 1991; Talekar 1991). However, in Africa *C. puncticollis* has a wider distribution than *C. formicarius* (Wolfe 1991; CAB International 1993). *Cylas brunneus* Fabricius and *C. puncticollis* are of African origin (Smit 1997a), while *C. formicarius* is an introduced species (Meynhardt & Joubert 1982). Only *C. puncticollis* and *C. formicarius* have been found in South Africa (Daiber 1994).

It is well known that climatic factors, especially temperature, have a major influence on the life processes of insects, and are important determinants of their distribution and abundance (Andrewartha & Birch 1954; Cammell & Knight 1992; Briere *et al.* 1999). Low temperatures often limit the distribution and reduce survival of insects in temperate regions (Cammell & Knight 1992). For example, a pest species may invade a temperate country such as Lesotho, but fail to establish because it is not able to accumulate enough thermal units required for complete development. Temperature is believed to have a larger influence on the development of *Cylas* species than any other climatic variable (Mullen 1981). Apart from its direct effects, temperature can also indirectly affect survival and development by limiting the availability of resources, such as food (Cossins & Bowler 1987). For example, high and low temperatures during the early stages of sweetpotato growth result in a higher ratio of foliage to tuber growth and consequently affect density of weevils as they prefer tubers to foliage (O'Hair 1991). As a result of temperature preferences, sweetpotato weevils have been found to be more abundant during dry warm seasons (O'Hair 1991) and are generally more serious pests in tropical and subtropical regions, than in the temperate ones (Collins & Mendoza 1991).

While sweetpotato weevils contribute to a major loss of this crop in different parts of the world, the pest has not yet been found in Lesotho. However, due to the occasional occurrence of *C. puncticollis* in the northern Free State and Eastern Cape provinces of South Africa which border the central lowlands and the southern highlands of Lesotho, the possibility of the weevil becoming a future pest in Lesotho cannot be ruled out. Knowledge of the development and survival of the pest are important in determining or predicting potential establishment and possible distribution of such a pest into new areas.

The aim of this study was therefore to examine the effects of temperature on development rates and survival of the sweetpotato weevil, *C. puncticollis*. To achieve this, the following were determined; i) the lower temperature threshold (r) of the species, ii) the thermal units (k in degree days) that this species needs to complete each individual developing stages and a total development (egg to adult) and iii) the time duration of each developing stage as well as egg to adult duration.

Description and biology of *Cylas* species

Cylas puncticollis adults are entirely bluish black, whereas *C. formicarius* has a brown thorax and brown legs (Wolfe 1991). *Cylas brunneus* on the other hand may look like either of the above species, but it usually looks more like *C. formicarius* (Wolfe 1991). Females of all species lay cream coloured, oval shaped eggs that hatch into small white legless larvae. The larvae develop into white exarate pupae. Callow adults are white. At optimum temperature (25°C to 30°C) the life cycle, from egg to adult, takes about 30 days for both *C. puncticollis* and *C. formicarius* (Eulitz 1974; Mullen 1981; Annecke & Moran 1982; Skoglund & Smit 1994; Smit 1997a). *Cylas brunneus* however takes about 45 days to complete the life cycle at optimum temperatures (Skoglund & Smit 1994; Smit 1997a).

Cylas species attack all parts of the crop but the main damage is done to the tubers (Hahn & Leuschner 1982). All life-stages of the pest are found on and around the crop. Adults feed on the lower leaf surface causing round holes, and feed inside of the vines causing malformation, thickening and cracking of the affected vines (Skoglund & Smit 1994). The eggs are laid on the lower part of the vines especially near the buds and they hatch into legless larvae, which bore into the vines (Trehan & Bagal 1957). The larval feeding (Chalfant *et al.* 1990; Talekar 1982) does the greatest damage. The larvae bore into the tubers and make tunnels in a zigzag manner down into the inner core of the tubers. Tubers are attacked both in the field and during storage (Talekar 1982; Kays *et al.* 1993). The pest can breed successfully inside the tubers with repeated cycles if there is sufficient food available (Annecke & Moran 1982). Yield losses between 60% and 97% have been estimated due to these pest species if no control measures are taken (Mullen 1984).

MATERIAL AND METHODS

Adult weevils were collected on the leaves of sweetpotato plants at the University of Pretoria's experimental plots in Pretoria (1371 m.a.s.l., 25°44.96′S 28°15.51′E). Weevils were then reared in the laboratory by infesting fresh tubers. Plastic boxes, 19cm x 25cm x 27cm large, were used as rearing cages. The bottom of each box was lined with thin absorbent paper to absorb excess moisture, and the lid was perforated to allow air circulation. After one week, the freshly infested tubers were transferred to new incubating boxes, while new tubers were placed into the old boxes for infestation. This procedure was repeated until there were enough weevils to be used for the *Cylas* development study. The rearing procedure was carried out at 26.38 ± 0.01°C and 12L:12D photophase. Females aged one to six weeks were used for the development study to allow adequate egg laying capacity. The sex of the weevils was determined by their antennal differences. Female antennae have a terminal club-like shape and males have filiform antennae (Sutherland 1986;

Skoglund & Smit 1994).

Six temperature regimes of approximately 16°C, 19°C, 24°C, 26°C, 31°C, and 36°C were used. Temperature at each regime was recorded throughout the development at 30 minute intervals on a programmable Stowaway XTI data logger (Onset Computer Corporation 1995). Forty-eight medium sized fresh tubers were each infested in separate boxes by exposing each tuber to 40 female weevils. The boxes were kept at 27°C for 24 hours to allow the females sufficient opportunity to lay eggs. After 24 hours, sets of eight tubers were each transferred to their respective six temperatures regimes. The eight tubers were divided into two groups, four of which were peeled to remove the eggs from the surface (disturbed set as described below) while the other set was left in the boxes, untouched, until adult emergence (undisturbed set).

Eggs were collected from the tubers in the disturbed set and placed singly in petri-dishes (6.5cm in diameter) lined with moist filter paper. The petri-dishes were placed inside airtight plastic containers (44cm x 10cm x 26cm) that were also lined with moistened cotton wool. This was necessary to maintain sufficiently high humidity for egg development. Relative humidity was not measured. The initial number of eggs differed between temperature regimes. The number of eggs ranged from 72 to 97. Daily observations of egg development were made. In each petri-dish a small block of sweetpotato tuber was placed with an egg. The tuber pieces were dissected every day to monitor the development of the larva and once the shed head capsule was found (designating a new larval instar) it was removed and the duration of the instar was recorded. The tuber pieces and the filter paper were changed three times a week to minimize fungal infection.

When the immature stages were transferred to the new sweetpotato blocks, a triangular hole was made on the block, using a blade sterilized with 70% alcohol to minimize microbial infection. The immature individual was placed inside the sweetpotato block and then the block was turned upside down to ensure enclosure of the individual. This was necessary to ensure that the immature did not escape, and to avoid desiccation of the active larvae. Daily observations were made on all stages and mortalities were recorded throughout the experiment. When adults ermerged their gender was determined.

The second set of tubers was not disturbed between the onset of egg-laying and adult emergence. Once adults were seen in the jars, they were counted, their sex determined and they were then removed from the jars. Daily counting and removal of adults from the jars was done until no more adults emerged for several days in a row.

Analyses

Linear regression analysis using Statistica (Statsoft, Inc. 1995) was employed to determine the effect of temperature on the development of the immature stages of *Cylas puncticollis.* To obtain a linear relationship, rate of development (reciprocal of development duration) was plotted against temperature (e.g. Campbell *et al.* 1974; Cossins & Bowler 1987; Marco *et al.* 1997). The regression lines for each of the stages, as well as total development (egg to adult for undisturbed set and sum of development times of individual stages for disturbed set), were plotted. The linear regression model used was thus: $y = a + bx + e$, where: y = rate of development, a = intercept, b = slope, x = temperature and e = residuals.

The lowest temperature threshold for development (r) was taken as the point where the regression line intercepts the x-axis. The thermal constant (k) in degree-days was taken to be the inverse of the slope of the regression line. These parameters, the lower threshold and the thermal constant together with their standard errors were calculated using the following formulae from Campbell *et al.* (1974):

$$r = -(a)/b, \qquad (1)$$

$$k \text{ (in degree-days)} = 1/b, \qquad (2)$$

$$\text{S.E. of } r = {}^{\acute{y}/b}\sqrt{[\,(s^2/N\acute{y}) + (\text{S.E. of } b/b)]} \qquad (3)$$

$$\text{S.E. of } k = \text{S.E. of } b/b^2. \qquad (4)$$

The above parameters were obtained from the regression lines of each of the individual stages concerned where a and b are constant and intercept respectively (as above), s^2 = residual mean squares, N = sample size (number of individuals) and ý = an average of y-values of regression lines (development rate values).

T-tests were used to determine significant differences between development times in the disturbed and undisturbed treatments for each temperature regime. Temperature effect on sex ratio, development rate of each sex and survival of immature stages was tested using analysis of variance.

RESULTS

Development time

The mean development time of each immature stage and the total development time for both disturbed and undisturbed sets of *C. puncticollis* are given in Table 1.1. Development was largely inhibited at 16°C and 19°C, with development not progressing beyond the first instar stage at 16°C. One egg hatched and the resulting first instar larva lived for a short period (Table 1.1). Development was generally faster at temperatures above 26°C (Table 1.1). Of all the immature stages duration time for the larval stage was the longest (more than 50% of the total developmental period) for all temperatures. An extra larval moult (the fourth larval instar) was observed at the lowest temperature of the second trial (19°C) (Table 1.1). The egg and pupal stages each accounted for a small proportion of the total development (Table 1.1).

Total development (egg to adult) differed significantly between the two treatments (disturbed and undisturbed) for all temperatures except at 19°C (Table 1.2). With the exception of development at 19°C, weevils developed faster under the disturbed treatment than under the undisturbed one for all temperatures. Comparing emergence rate between sexes at individual temperatures for each treatment (disturbed and undisturbed) showed no significant difference (there was no interaction between sex and temperature $F_{(1, 9)} = 0.911$, $p = 0.51$). Although there was no significant difference between emergence rate of different sexes, adult females generally emerged earlier than males; or in slightly higher numbers than males on the first and second days. (Fig. 1.1).

Survival

Fig. 1.2 shows that survival was very low at the lowest and highest temperatures (16°C, 19°C and 36°C). The highest survival occurred at intermediate temperatures (24°C to 31°C). The lowest survival of immature stages was found for larval instar 1 (Fig. 1.2). Egg and pupal survival seemed to be high across temperatures (Fig 1.2). A highly significant difference in survival was observed (Table 1.3). Survival of developing stages at 16°C was significantly different from 24°C, 27°C and 31°C. However, between all other five temperature treatments, 19°C, 24°C, 27°C, 31°C and 36°C there was no significant difference in survival (Table 1.3).

Temperature Thresholds and Degree Days

The thermal requirements (lower threshold (r) and degree-days (k)) of each stage are presented in Table 1.4 The regression analysis showed a positive significant relationship between temperature and development rate for all stages (Table 1.4). A good fit for the linear model, indicated by high coefficients of determination, was generally obtained for the majority of the developing stages as well as the total development stages (egg to adult) (Table 1.4). However, this was not the case with instar 2 and the final instar stages (Table 1.4).

Both the egg and the pupal stages needed lower thermal units than the larval stage to complete their development. Under the undisturbed regime slightly higher number of degree-days were necessary for weevils to complete development from egg to adult than under the disturbed regime (Table 1.4). The lower developmental thresholds were different for all stages ranging from 3.3 ± 0.80°C to 12.56 ± 0.91°C. Lower development threshold for total development was lower for the disturbed set than for the undisturbed one. Tests of parallelism showed that difference in total development thermal requirements under the two treatments (disturbed and undisturbed) was not significantly different. The slopes of the two regression lines were parallel. As a result the two lines were pooled and the lower temperature threshold and the degree-days were estimated as 11.42°C and 377.37 °D respectively (Table 1.4).

DISCUSSION

Development time

Results obtained for development rate showed that, as expected, as temperatures were increased weevils also developed faster. While the rate of development increased with the increasing temperatures, it was obvious that at around 36°C there was no longer a significant increase. With the exception of the larval stage, generally there was a slight increase in development rate of the weevils developing under disturbed regime. However, a slight decline was observed in the total development rates in the undisturbed treatment. There are numerous reasons for such a decline. These include different moisture content that resulted in difference in development rate, differences in temperature in their micro-environments or simply the temperature fluctuations could have been possible as a result of frequent handling. Alternatively, a decline could be signifying that higher developmental threshold is around 36°C.

Development duration in this study was within the range of the values reported by Eulitz (1974) for the total development of *C. puncticollis*. However, preimaginal survival levels are different from those reported by Eulitz (1974). For example, in his study more than one egg hatched at 15°C although they also did not go beyond first larval instar. In this study however, only one egg hatched at 16°C. The difference was probably due to differences in relative humidities under which weevils in the two studies were exposed. Eulitz (1974) was placing weevils inside airtight tubes and hence providing high moisture content. Moisture might have an impact on development as it has an interactive action with temperature (Howe 1967; Cammell & Knight 1992) although humidity is said to have greater influence on survival than on development (Al-Saffar *et al.* 1994). In some arthropod species, however, moisture was found to affect development duration. For example, spider mites' development time was prolonged by both very low and very high percentages of relative humidity (Bonato *et al.* 1995).

Mullen (1981) also looked at the development of *C. formicarius* at temperatures that were close to the ones in this study. He recorded very high values for the total development time of that pest. For example, he recorded averages of 31.9 days and 33.3 days for 27°C and 30°C respectively while in this study the mean development time were found to be 21.3 days and 16.05 days at 26°C and 31°C respectively. The difference could also be a result of conditions set by different methods used in the two studies. Mullen (1981) could have overestimated the development time because he used the whole tubers that he dissected only twice a week to monitor the progress of developing stages. On the other hand, this might show that *C. puncticollis* develops significantly faster than *C. formicarius* contrary to reports that they have almost similar development rate at optimum temperate range (Skoglund & Smit 1994, Ames *et al.* 1996).

The disturbed sets gave shorter development times for this species compared to findings of other authors who worked on the same species (Nwana 1979; Anota & Odebiyi 1984; Smit 1997a). However, when the undisturbed sets alone are considered, development within the optimum range does not differ much between this study and others. Although development was faster above optimum range, mortality was also higher. This shows that the development may be faster at certain temperatures, but other conditions at that temperature may not be conducive for optimal development (Messenger 1959; Marco *et al.* 1997).

In some insect species a definite pattern has been observed with the development time difference between individual instars (Weber *et al.* 1999). However no definite pattern was observed with this species. Three larval instars have been reported before, for this species with the exception of Eulitz (1974) and Nwana (1979). The two authors reported four larval instars at intermediate temperatures (i.e. between 25 and 30°C). In this study the prepupal stage was combined with the final larval instar because it is not a definite stage since there is no head capsule that is being shed. However, the prepupal stage has been reported as an independent stage by other authors (Eulitz 1974; Anota & Odebiyi 1984).

An extra larval instar was recorded at the lowest temperature (19°C). An extra larval moult by insects at low temperatures have been observed previously on some insect species such as *Uraba lugens* (Allen & Keller 1991) and the banana weevil, *Cosmopolites sordidus* Germar (Gold *et al.* 1999). According to Kamata & Igarashi (1995) contrasting reports have been given about temperature effects on the number of larval instars of different insect species where some authors have reported an extra moult due to high temperatures while others observe that behaviour at low temperatures. However, other factors such as high larval density, food availability or quality and others are also responsible for this behaviour of larval prolongation, which is often accompanied by extra molt in insects (Kamata & Igarashi 1995, Gold *et al* 1999). Insects usually undergo an extra molt to compensate the adverse effects of any of the causes mentioned above and ensure that they have larger body sizes so as to increase their fecundity ability (Kamata & Igarashi 1995).

The sex ratio of weevils in this study was approximately 1:1 for all temperatures. Eulitz (1974) and Mullen (1981) also recorded the same sex ratio. Therefore it was concluded that temperature has no effect on either sex ratio or the relative developmental rate of the two sexes. Although there was no significant difference in the emergence rate of the two sexes, females generally emerged earlier than males. This pattern was observed at all temperatures, under both disturbed and undisturbed conditions. In most insects species however, males often emerge faster than females (Urbaneja *et al.* 1999).

Survival

Survival of weevils showed that the lowest (16°C and 19°C) and highest (36°C) temperatures had adverse effects on the immature stages as higher mortalities were observed at these temperatures. Survival especially of the eggs was also highly negatively affected by reduced humidity as can be seen from the survival curves of the two trials. High egg survivorship was observed across all temperatures except for 16°C where only one egg reached first larval instar. Low survival for all other developing stages was observed at both 19°C and 36°C where the number of individuals that reached adult stage was less than 10. Another problem that contributes towards high observed mortality is the difficulty of handling individuals, especially the larvae (Vasques & Gapasin 1980; Marco *et al.* 1997). No other method other than this destructive one could be used to estimate duration of each stadium as the immature stages develop inside the tubers.

Comparing number of emerging adults at different treatments of each temperature was not possible because the initial number of eggs for the undisturbed treatment was not determined. However, low survival of adult weevils across temperatures for the disturbed set leads to the conclusion that frequent handling of weevils had a negative impact on their survival. For example, the numbers of adults emerging at highest and lowest temperatures under an undisturbed regime were far higher compared to the ones that emerged under disturbed treatment.

Thermal requirements (lower threshold and degree-days)

The temperature thresholds are different for each stage indicating that for development of this species the lowest temperatures at which the immature stages survive or develop are not the same. This is very important in the distribution of insects (Cammell & Knight 1992; Marco *et al.* 1997). Temperature can affect the different stages differently such that if one stage can not survive a certain temperature the distribution of such species is likely to be restricted (Andrewartha & Birch 1954; Cammell & Knight 1992). This pest has a wider distribution in the tropical and subtropical regions, which are characterized by warm climatic conditions.

The high values for the lower temperature threshold of the overall development (i.e. egg to adult) in this study confirm this observation too. However, according to Mullen (1981), *Cylas* species are still likely to be serious pests in temperate regions as they can feed and reproduce even during storage temperatures as low as 15°C. Constant temperatures have been criticized before for not representing the natural conditions that insects experience in the field (Bursell 1974; Hagstrum & Milliken 1991; Liu *et al.* 1995; Marco *et al.* 1997). Therefore, failure for weevils to develop and survive at 16°C could only be a reflection of the adverse effects resulting from exposing weevils to constant temperatures. The temperature thresholds obtained in this study are far below 16°C implying that development below that temperature is still possible. Contrary to what is expected because of their natural positions of development on the host the temperature thresholds of the larvae were much lower than the thresholds of the egg stage. Usually eggs are more exposed to harsh conditions as they are laid just below nodes on the stems or just beneath the periderm of the tuber. The larvae and the pupae on the other hand develop in protected environments (i.e. inside the tubers) and therefore would be expected to have a higher development threshold than for eggs.

Floyd (1942), reported that *C. formicarius* stops feeding at 8.3°C. In addition, he further showed that all activity ceases at 4°C. This might lead to the conclusion that lower thresholds for *C. puncticollis* were still possible if high humidities were used. *C. puncticollis* has been observed to occur even in colder areas where *C. formicarius* is excluded. For example, the former species occurs throughout the whole of Swaziland while the latter is excluded in the colder highveld (Nsibande & McGeoch 1999). It is also important to realise that thermal requirements of insects can be affected by the environments under which they were previously exposed (Messenger 1969; Wang & Tsai 1996). As a result of species acclimatising to the environment in which they occur different thermal constants and developmental thresholds may be observed for different strains of one species found on different geographical locations (Campbell *et al.* 1974). It is possible for *C. puncticollis* to have lower development thresholds in Lesotho or colder areas if they could adapt to cooler temperatures of that area.

Higher degree-days are required by the larval stage because this is the most active and longest stage of all the immatures. This longest stage is also the one that is most important in terms of crop damage. Other developing stages are shorter than the larval stage and these are almost inactive, therefore they do not need high thermal units. Weevils under the disturbed treatment needed fewer degree-days to complete development from egg to adult. Faster development observed in the disturbed group probably resulted from removal of adults from the tubers before they were fully developed (callow adults – white in colour). In the undisturbed treatment adults emerged when they had fully developed the colour, and as a result more heat units were accumulated. It has also been mentioned that weevils exit tubers after a few days (usually two to three) of adult emergence (Hahn & Leuschner 1982; Skoglund & Smit 1994) and the number of days varies with temperature regimes in which they occur. At lower temperatures they may take up to six days (Haque & Gul-e-Zannat 1985). Secondly, development may have been slowed down in tubers because of less moisture content while for the disturbed set moist environment was provided throughout the whole study.

Low temperatures definitely have a negative influence on the development of *C. puncticollis* by reducing the rate of development as well as increasing mortality. The low temperatures might restrict the distribution and abundance of these weevils. However, if they already occur in the cold areas they might still be serious pest as long as the temperatures allow their survival. Lesotho is divided into three agro-ecological zones, lowlands (1400-2000 m.a.s.l), foothills (2001-2750 m.a.s.l) and the highlands (>2750 m.a.s.l.). The highlands cover about 2/3 of the whole country. Both the highlands and the foothills are characterised by very low temperatures (annual averages ranging from 8°C - 19°C and 10°C - 22°C respectively). The lowlands, which are a bit warmer cover about 25% of the country and have annual average temperatures ranging from 12°C - 27°C. These temperatures are averages for the period October to May (the sweetpotato-growing season) from 1981 to 1998 (Lesotho Meteorological Services 1998).

Therefore given the temperature ranges in the three agro-ecological zones of Lesotho and the findings of this study it is highly likely that *C. puncticollis* may fail to establish in Lesotho due to the temperature requirements for the development and the survival of the immature stages. Should the pest become established in Lesotho, very low population numbers are likely to be obtained. Their distribution also is likely to be restricted to the lowlands, which are characterized by warmer temperatures than the foothills and highlands.

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Table 1.1: Mean development time in days ± S.E. of immature stages of *Cylas puncticollis* at different constant temperatures. Values in brackets represent 95% confidence intervals. Bold values = number of surviving individuals, n_1 , n_2 = initial number of eggs for each temperature at trial 1 and 2 respectively.

		Temperature (°C)				
Developing stages	16°C*	19°C	24°C	26°C	31°C	36°C
	(n_1 , n_2) 70 , –	(n_1 , n_2) 80 , 72	(n_1 , n_2) 97 , 90	(n_1 , n_2) 72 , 79	(n_1 , n_2) 80 , 80	(n_1 , n_2) 70 , 90
Egg	$12^{\#}$ **(0; 0)** **1**	7.98 ± 0.19 (7.61; 8.35) **53**	3.04 ± 0.02 (2.99; 3.08) **80**	3.06 ± 0.40 (2.98; 3.14) **71**	2.15 ± 0.05 (2.06; 2.24) **65**	2.05 ± 0.03 (2.00; 2.10) **76**
Instar 1	—	8.89 ± 0 .41 (8.02; 9.76) **18**	3.03 ± 0.75 (2.88; 3.18) **63**	2.76 ± 0.60 (2.64; 2.89) **51**	2.30 ± 0.08 (2.14; 2.46) **43**	2.00 (0; 0) **58**
Instar 2	—	8.08 ± 0.68 (6.59; 9.57) **13**	2.82 ± 0.11 (2.59; 3.05) **51**	2.79 ± 0.11 (2.57; 3.02) **44**	2.40 ± 0.11 (2.17; 2.62) **35**	1.59 ± 0.10 (1.38; 1.80) **34**
Instar 3	—	7.75 ± 0.54 (6.57; 8.93) **12**	9.12 ± 0.26 (8.59; 9.65) **42**	7.93 ± 0.16 (7.60; 8.25) **40**	5.80 ± 0.16 (5.46; 6.14) **25**	7.09 ± 0.41 (6.17; 8.01) **11**
Instar4	—	17.67 ± 0.67 (15.95; 19.38) **6**	—	—	—	—
Instar 1-4	—	42.33 ± 0.71 (40.50; 44.17) **6**	15.02 ± 0.35 (14.31; 15.74) **42**	13.45 ± 0.17 (13.11; 13.79) **40**	10.60 ± 0.20 (10.19; 11.01) **25**	10.73 ± 0.49 (9.64; 11.81) **11**
Pupae	—	10.17 ± 0.31 (9.38; 10.96) **6**	5.54 ± 0.27 (5.00; 6.08) **37**	4.76 ± 0.09 (4.57; 4.94) **37**	3.38 ± 0.13 (3.11; 3.65) **21**	3.2 ± 0.20 (2.64; 3.76) **5**
Egg to adult (disturbed set)	—	60.50 ± 0.99 (57.95; 63.05) **6**	23.41 ± 0.58 (22.23; 24.58) **37**	21.30 ± 0.19 (20.91; 21.69) **37**	16.05 ± 0.24 (15.54; 16.56) **21**	15.20 ± 0.37 (14.16; 16.24) **5**
Egg to adult (undisturbed set)	—	63.7 ± 0.54 (62.67; 64.89) **50**	33.77 ± 0.15 (33.47; 34.07) **159**	24.03 ± 0.18 (23.67; 24.38) **81**	17.76 ± 0.11 (17.55; 17.98) **245**	18.47 ± 0.21 (18.06; 18.88) **108**

* = only one egg hatched to instar 1, # = Number of days larva lived, — = No development

Table 1.2: T-tests between the total average development time (refer to the last two rows of Table 1.1 – Egg to adult stage) of *Cylas puncticollis* under two treatments (disturbed and undisturbed) at each temperature regime. N_1, N_2 = survived adults at disturbed and undisturbed sets respectively.

	Temperature (*C)				
	19°C	24°C	26°C	31°C	36°C
t-value	0.878	-25.33	-3.804	-5.875	-4.128
df	51	194	102	270	117
p	0.383	<0.0001	< 0.0001	< 0.0001	< 0.0001
N_1, N_2	6, 50	37, 159	37, 84	21, 245	5, 114

Table 1.3: Anova and HSD tests results on the survival percentage means of immature stages of *Cylas puncticollis* at different temperatures. Values in brackets are the number of surviving adults. Means are arranged in an ascending order. Means followed by the same letter within a column are not significantly different at $p<0.05$.

Temp (°C)	Mean (%) ± S.D.
	$F_{(4, 30)} = 6.87$ $p<0.001$
26	60.03 ± 15.82 (37)a
24	58.52 ± 18.08 (37)a
31	44.78 ± 20.43 (21)a
36	36.48 ± 31.98 (5)ab
19	25.35 ± 24.99 (6)ab
16	0.48 ± 0.74 (0)b*

*No individuals survived to adult stage at 16°C, only one egg hatched.

Table 1.4: Estimated development thresholds (r) and development time (k) in degree-days of *Cylas puncticollis* for trial 1 and 2. N = Number of individuals. E-A$_{dist}$ = Egg to adult under distrurbed conditions, E-A$_{und}$ = Egg to adult under undisturbed treatment.

Stages	r (°C) ± S.E.	k (°days) ± S.E.	Intercept (a)	Slope (b)	R^2	N	P<
Egg	9.89 ± 0.82	49.18 ± 8.96	-0.2012	0.0203	0.844	345	0.001
Instar 1	6.5 ± 0.84	56.08 ± 9.00	-0.1160	0.0178	0.649	231	0.001
Instar 2	12.56 ± 0.91	34.67 ± 17.27	-0.3623	0.0288	0.455	177	0.001
Instar 3	3.69 ± 0.80	141.40 ± 18.21	-0.026102	0.007072	0.143	138	0.0001
Instar 4	4.40 ± 0.83	172.95 ± 18.21	-0.0254	0.0056	0.453	124	0.0001
Instar 1 – 4*	5.82 ± 0.91	279.49 ± 68.00	-0.0208	0.0036	0.644	124	0.0001
Pupae	10.63 ± 0.66	71.18 ± 9.10	-0.1494	0.0140	0.584	106	0.0001
E-A (dist)	8.91 ± 0.70	364.17 ± 75.70	-0.0245	0.0027	0.747	106	0.001
E-A (und)	11.29 ± 0.84	378.93 ± 7.90	-0.0310	0.0026	0.785	640	0.001
E-A(dist. and undist.)$_{pooled}$	11.42	377.36	-0.0303	0.0027			

* At 19°C the final instar was the fourth larval instar while at other temperature regimes it was the third instar. E-A$_{pooled}$ parallelism test results (for the regression slopes of E-A development of disturbed and undisturbed treatments): $F_{(1,751)} = 0.746$, p = 0.388.

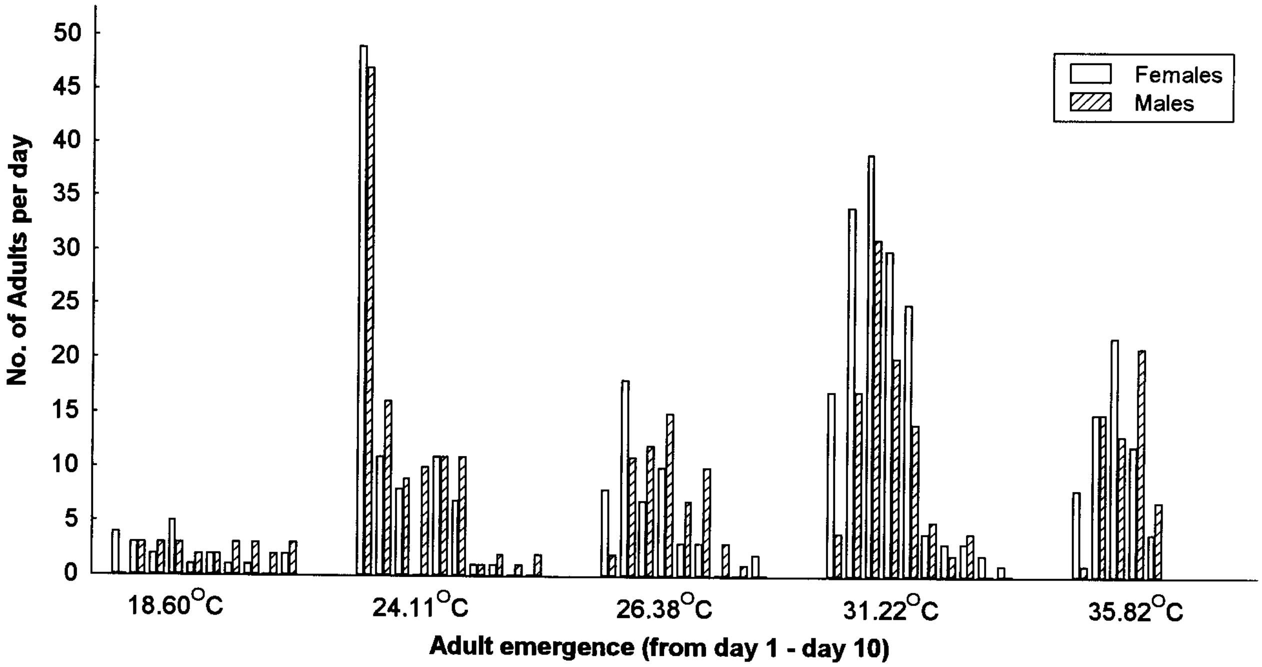

Fig 1.1: Emergence rate of females and males of *Cylas puncticollis* for the first 10 days of adult emergence at each of the five constant temperatures.

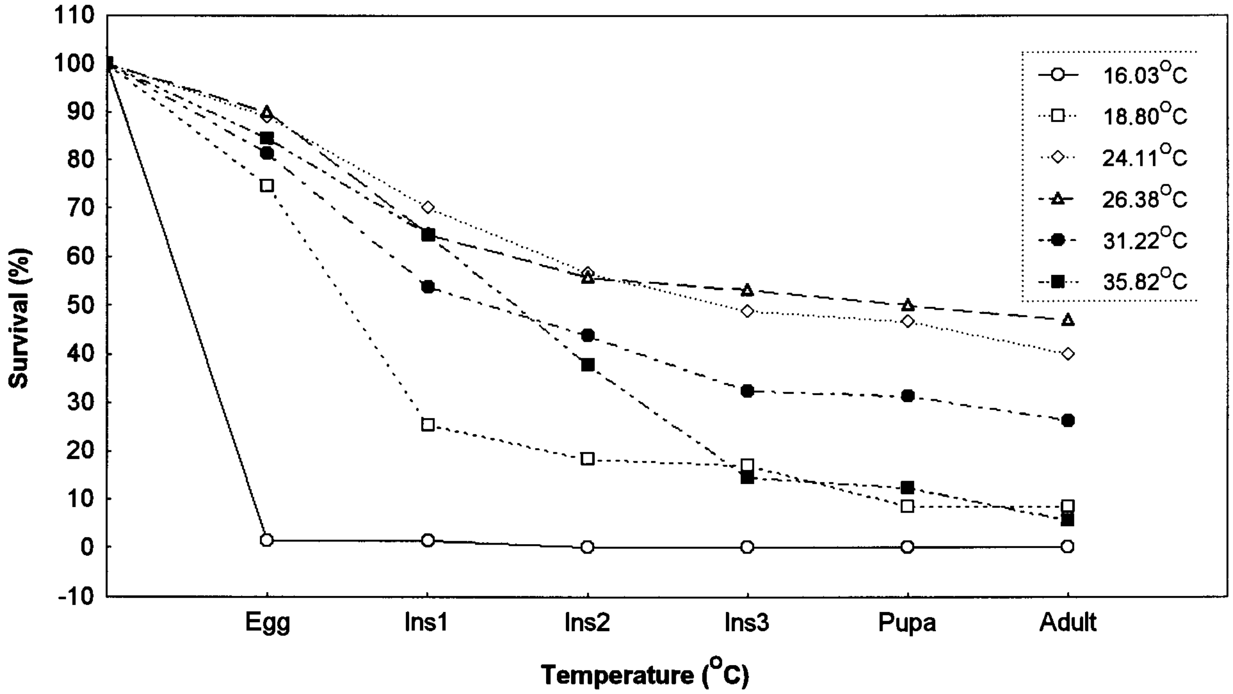

Fig. 1.2: Percentage survivorship of immature stages of *Cylas puncticollis* at different temperatures. Ins = Larval instar.

CHAPTER 2

Prediction of possible establishment of *Cylas puncticollis* in Lesotho

INTRODUCTION

Climate is one of the major abiotic factors that influences the distribution and abundance of animals (Andrewartha & Birch 1954). Weather conditions also play a major role in population ecology by exerting an influence on factors that determine the population dynamics such as distributions and populations size, as well as, affecting the physiological processes of individuals directly (Kingsolver 1989). Among the climatic, or weather factors, temperature seems to play a larger role than any other factors, especially in poikilothermic organisms (Pedigo 1996; Virtanen *et al.* 1998; Willot & Hassall 1998). These organisms need thermal environments that are warm enough to allow them to complete their development (Messenger 1969; Pedigo 1996).

Indirect effects of temperature can result in restructuring of ecosystems such that either positive or negative impacts on an insect's population dynamics are observed (Davis *et al.* 1998; Lindsay *et al.* 1998). For example, Buse *et al.* 1999 observed that exposure of Pedunculate oak to elevated temperatures resulted in a poor host quality for the winter moth, *Operophtera brumata* Linnaeus. Consequently, a reduced fecundity of the winter moth, feeding on this poor host quality, was observed. In most cases, these effects are mediated through the availability of host plants (Baker 1972; Cammell & Way 1987; Risch 1987).

A correlation has been observed on several cases between temperature and species' distributions (Ayres & Scriber 1994, Bryant *et al.* 1997; Whittaker & Tribe 1998; Hill *et al.* 1999). Thus many authors have used the effects of temperature on the characteristics of an insect's biology to predict insects' possible range limitations. For example, the distribution or potential for establishment into new areas was predicted for the following species, *Praon exsoletum* (Messenger 1969), *Diuraphis noxia* (Bernal & Gonzales 1995) and British butterflies (Bryant *et al.* 1997).

Temperature effects are more profound on insects found in temperate or the high latitude areas (Cammell & Knight 1992; Drake 1994). In contrast, distributions of insects in tropical or lower latitudes are influenced more by the availability of resources than by temperature effects. Because of this, tropical insects may fail to establish in cold areas, as they are not able to complete their development because of insufficient thermal units (Cammell & Knight 1992). Consequently thermal limitations restrict tropical species from extending their ranges into cooler areas, even where suitable food resources are available. If such species manage to extend their ranges they often have very low abundance in cold areas (Bryant *et al.* 1997).

Thermal limits of development

If temperature is assumed to play such a crucial role in the distribution limits of insects it is therefore important to know the thermal requirements of any insect species likely to be introduced into a new area to be able to predict its likelihood of establishment (Bernal & Gonzales 1995). The thermal constant (k) and thermal threshold for the development (r) are the most important thermal requirements in determining whether a species will complete part or all of its developmental stages successfully (Messenger 1969; Bernal & Gonzales 1995; Pedigo 1996). The thermal constant is the amount of heat an insect or a plant needs to complete a certain stage of development, or total development (Eckenrode & Chapman 1972; Dent 1991). Thermal thresholds are either the minimum or maximum developmental temperatures. Minimum development threshold is the temperature at which there is little or no development below the given temperature (Zalom *et al.* 1983; Bryant *et al.* 1997). Maximum development threshold is the temperature where there is no further increase in development rate above given temperature (Ferro 1987; Snyder *et al.* 1999); instead development starts to decline and eventually mortality occurs.

Estimation of such thermal constants and thresholds is usually done in the laboratory under constant temperatures. Thermal constants are generally estimated in physiological time (degree-days i.e. the amount of heat an insect accumulates above the lower development threshold to complete development) (Bernhardt & Sherpard 1978; Beasley & Adams 1996). The use of degree-day has been observed to be more useful than calendar days, as the former is often more accurate than the latter in predicting the insects' phenologies in the field (Beasley & Adams 1996). With the degree-day the amount of heat necessary for completion of development does not vary but what varies is the time, such that to accumulate such heat unit at low temperatures might take longer than at high temperatures (Zalom *et al.* 1983; Pedigo 1996). This can therefore serve as a reliable way of predicting when the next stage or generation of an insect would start.

However, it has been realized that the thermal thresholds are affected by various factors such as different seasons and geographical locations under which an organism is found. As a result of acclimatization to different environmental conditions the two strains of the similar species raised or found in different locations may have different thermal requirements (Campbell *et al.* 1974; Wang & Tsai 1996). For example Campbell *et al.* (1974) showed that *Pieris rapae* in England had lower temperature thresholds than *P. rapae* in Vancouver because these species had adapted to the cooler climates of England and therefore had lower thresholds. Because of this, it is important to determine the thermal needs of each species within as many geographical locations as possible as well as for the location for which the information is required (Pruess 1983).

The Linear degree-day model

The Degree-day is the amount of heat an insect accumulates in 24 hours above the lower development threshold. Thus the amount of heat it accumulates to complete development or one stage of development over a certain period of time is referred to as the degree-days (Zalom *et al.* 1983; Dent 1991). In the linear degree-day model the lower temperature threshold is estimated from the linear portion of the temperature development curve (Campbell *et al.* 1974; Wagner *et al.* 1984; Wang *et al.* 1997; Tsai & Liu 1998). Use of the linear portion is based on the assumption that development at the non-linear portions is negligible (*Zalom et al.* 1983). The degree-day approach has frequently been used in pest management as a predictive tool. It is not a new concept and it dates as far back as the 18th century (Zalom *et al.* 1983; Pedigo 1996).

Nonetheless its importance is apparently increasing because more efforts are taken to devise the method that can best calculate degree-days to achieve more precise predictions of pest emergence in the field (Arnold 1960; Allen 1976; Sevacherian *et al.* 1977; Parajulee *et al.* 1997). For example, Pruess (1983) reviews different methods such as conventional or historic method sine wave method, bias-corrected sine wave method and others. In his discussion he makes an attempt to show which method is suitable for which particular field. Although the sine-wave method is considered the most suitable for insects (Pruess 1983), there are cases where it is still similar to the historical method, for example, when an insect's development is considered to be between both the lower and upper thresholds (Allen 1976; Snyder *et al.* 1998).

It is important to note that the microhabitat of a species plays a large role in determining their developmental temperature range (Baker 1980; Allsopp *et al.* 1990). For example, it has been shown that the development temperature range for insects found on or below the ground is different from what might be expected under normally recorded air temperatures (Parajulee *et al.* 1997). According to Higley *et al.* (1986), McDonald (1990) and Roltsch *et al.* (1999), among numerous errors introduced with the degree-day method is the use of temperatures recorded at sites much different from where the species actually occurs because meteorological stations are often distances apart. Apart from the use of degree-days there are other models that make use of the influence of climate on different life-processes of insects or plants to predict their distribution and or potential for establishment in new areas. Chown and Gaston (1999) have made an elaborate review of these correlation models including the climate matching approach, which has been used in this study. Most of these methods can be performed with the Geographic Information Systems (GIS) software, for example climate matching or Overlap analysis and Logistic Regression Analysis (Brito *et al.* 1999).

The Climate matching approach in GIS

The climate matching approach combines the climatic variables of a species in its area of occurrence and matches them to the other places to determine the potential for range expansion into such areas (Surthest & Maywald 1985; Sutherst *et al.* 1989; Brito *et al.* 1998). The bioclimatic mapping in GIS is based on the ecological theory that describes the species distribution-climate relationships (Aspinall 1994). Climate matching approach has been applied before in many studies where climate has been shown to have a great influence on species' distributions (Busby 1986; Sutherst *et al.* 1991; Julien *et al.* 1995).

The two approaches (degree-day and climate matching) provide promise for predicting the expansion of species distribution of species into new areas and have each been used previously with success. As mentioned previously, sweetpotato weevil is not yet a pest in Lesotho but given the geographical situation of Lesotho in relation to South Africa (Fig. 2.2) where the pest is present the possibility of the pest invading Lesotho is high. The main objective of this study was therefore to predict the potential for establishment of this pest should it invade Lesotho. Therefore, both the linear degree-day model and the climate matching approaches were employed to predict the potential establishment and distribution of this pest in different agro-ecological zones of Lesotho. Potential establishment of this pest was predicted by the linear-degree day model, which used thermal requirements of this pest (estimated by laboratory work, Chapter 1), and the actual field temperatures in Lesotho. In the climate matching approach prediction was based on matching the climatic conditions of the areas in Swaziland and South Africa (where *C. puncticollis* is already a pest) with the climatic conditions of Lesotho.

METHODS

Degree-day approach

Study sites

Lesotho is divided into three agro-ecological zones, the highlands, lowlands and the foothills (Fig. 2.1 redrawn from Anonymous 1986). The highlands cover mostly the extreme north and the extreme south of the country with altitudes above 2750 m.a.s.l. and temperatures ranging from 8°C - 19°C. This part constitutes about 70% of the whole country. The foothills (2001 - 2750 m.a.s.l) which constitute only about 5% of the whole country are also characterized by low temperatures which range from 10°C to 22°C. The lowlands cover about 25% of the country, and extend through the central, southern and the northern part of the country. Their altitudes range from 1400 - 2000 m.a.s.l. with average temperatures ranging from 12°C - 27°C. The above temperature information is for the period October to May (the sweetpotato-growing season) 1990 - 1998 (Lesotho Meteorological Services 1998). Five sites representing the three agro-ecological zones were chosen for this study. The sites were Thaba-Tseka (highlands), Nyakosoba (foothills), Maseru, Siloe, and Leribe (central, southern and northern lowlands respectively).

Data logging of soil temperatures in the field

Soil temperatures were recorded at the afore-mentioned sites in Lesotho. Stowaway XT1 temperature data logger, with a thermistor probe was used to record soil temperatures in a continuous mode. The temperature range of the instrument was -40°C to +75°C (±2.5). One logger was placed in the middle of a sweet potato field at an Agricultural Station at each of the five sites mentioned above. At the site where there were no sweet potato plants, the logger was placed in one of the fields that had previously been used for sweet potato production. The logger was placed in a sealed bottle, and a hole was made on the bottle lid to serve as an exit for the probe that recorded the soil temperatures at a soil depth of 10cm. Data loggers were set to continuously record hourly average temperatures for a period of 75 days. New data loggers were set to replace the old ones between the 70th and 75th day. The recorded data was then offloaded onto a computer (Onset Computer Corporation 1995). Recordings were started in March 1998 and ended in May 1999.

Analyses

Often, different linear degree-day models or approaches yield different results. For example, Roltsch *et al.* (1999) observed different results between the triangulation and sine-wave methods. According to them, both sine-wave and triangulation methods seem to be the best methods for estimating the degree-days accumulations with the former being the most frequently used. In this study the conventional averaging method was used because of its simplicity. The method still yields quite accurate results when the hourly temperatures were recorded instead of minimum and maximum temperatures of the day (Watson & Beatie 1995; Roltsch *et al.* 1999). Therefore, instead of averaging the minimum and maximum temperatures of the day the daily mean temperature was computed from the average of hourly temperature readings recorded in the field. The daily degree-days were therefore calculated as follows:

°D = $T_d - r$ instead of $\frac{T_{min} + T_{max}}{2} - r$ (which is the commonly used approach where only the minimum and maximum temperatures of the day are averaged)

°D = degree-days

T_d = Average daily temperatures (temperatures recorded/no. of hours for the day)

T_{min} = minimum daily temperature and

T_{max} = maximum daily temperature

°D = 0 when Td < or = r

From the laboratory-calculated thermal requirements of *Cylas puncticollis* (Chapter 1), the possible daily degree-days *C. pucticollis* could accumulate per site were calculated. The development threshold (r) used was the lower threshold for total development (i.e. egg to adult development).

The two development thresholds, 8.91°C and 11.29°C obtained from the laboratory as a result of two treatments, disturbed and undisturbed respectively, *puncticollis* (see chapter 1) were used to calculate the likely number of degree-days per day. Two sets of degree-days were calculated based on the two r-values and they were treated as minimum and maximum possible degree-days per site where minimum represented disturbed set and maximum represented undisturbed set. The minimum and maximum were represented by the disturbed and undisturbed respectively because the estimated degree-days for total development in the laboratory were higher for the weevils placed under undisturbed treatment than those of the disturbed treatment.

The time for starting accumulations of the degree-days of the pest or plant in the field varies between species and is usually based on the sound knowledge of pest/plant's biological events or activities (Pruess 1984; Dent 1991; Spano *et al.* 1999; Wielgoslaski 1999). For example, the planting dates or the end of diapause for diapausing insects are usually used (Wilson & Barnett 1983). In this study the 01 November as starting date for degree-day accumulation was based on two factors, planting dates of the host plant and the seasonal activities of *C. puncticollis*. First, the planting date of the host plant is towards the end of September and early October. Second, the weevil adults are usually observed on the crop about 30-40 days after planting (Nsibande pers. comm.). The duration of each generation in the field was taken to be the number of days giving the accumulated degree-days value that was approximately equal to minimum (364.17) and maximum (378.93) degree-days obtained from the laboratory work (Chapter 1).

Due to electronic failure some data was lost for Maseru in January and February. Temperature values for these months were estimated by extrapolation from the available data of the preceding and following months. As a result two curves were produced, Maseru1 which shows the original data and Maseru2 which shows the original data plus the extrapolated one. To predict the possible number of generations per year for *Cylas puncticollis* the time period was extended from the growing season (November-May) to a year by using the temperature readings recorded during June-October of the previous year (1998). Analysis of variance was performed on the degree-days per day between the five sites and differences were separated using Tukey's Honestly Significant Difference for unequal samples (HSD

Unequal N test).

The Climate matching approach

Study Sites

Cylas puncticollis is an established pest of sweetpotato in South Africa and Swaziland. As a result South Africa (29°00′S, 29°00′E) and Swaziland (26°30′S, 31°30′E) were chosen as the base areas for calculating bioclimatic profile of this species. The two countries were also chosen because they are neighbouring countries to Lesotho (29°30′S, 28°30′E) and are therefore likely to experience similar climatic conditions. In South Africa the Northern Free State and places falling within the former northern Transvaal such as Pretoria, Rustenburg and others were used to calculate the bioclimatic profile of this pest. In Swaziland the whole country was used as the pest occurs throughout the country. Lesotho was the third country for which predictions were made.

Data Resources

Different literature sources were used as references for the distribution of *Cylas puncticollis* in Southern Africa. References used included CAB International (1993) which includes distribution maps of pest species throughout the world. Other texts used that list the distribution of this pest species were (Eulitz 1974), Hill (1975), Wolfe (1991), Daiber (1994) and Nsibande & McGeoch (1999). The long-term (1961-1990) climatic data for South Africa including Lesotho and Swaziland was collected from the climatic databank of the Computing Centre for Water Research (CCWR) (CCWR 1999).

Analyses

Because rainfall is also one of the important climatic variables that contribute in determining species distribution ranges (Cammell & Knight 1992; Malone *et al.* 1998) it was included in this analysis. Using a Boolean operation the climatic profile for known distribution (areas in terms of both temperature and rainfall) of the pest were calculated using the Arcview (Arcview 1996). From *Cylas puncticollis*' bioclimatic profile the suitable areas for occurrence within the whole of South Africa, Lesotho and Swaziland were determined.

Two approaches were used for the prediction of suitable areas of establishment of *C. puncticollis*. Other texts such as CAB International (1993) and

Hill (1975) did not give details of distribution areas of the pest in South Africa and Swaziland. As a result the whole prediction was based on information from Eulitz (1974), Daiber (1994) and Nsibande & McGeoch (1999). The two suitability criteria were based on the distribution pattern of *Cylas puncticollis* in South Africa and Swaziland. In Swaziland, the pest occurs throughout the country (Nsibande & McGeoch 1999), while in South Africa it is found mainly in the Traansvaal area and occasionally in the Northern Free State (Eulitz 1974; Daiber 1994). Temperature and rainfall data for South Africa and Swaziland was mapped, and this was matched to the distribution pattern of *C. puncticollis* in each of these regions.

The first criterion was based on Eulitz (1974). According to Eulitz (1974) the following temperature ranges are suitable for these weevils, a minimum of 10-15°C and a maximum of 30-35°C and rainfall ranging from 500mm-800mm. Because Lesotho is a cold country the maximum temperatures were not considered as limiting factors therefore the suitability of establishment were based only on minimum temperature and rainfall. The two categories that were drawn were a) 0 = unsuitable (i.e. any temperature value below 10°C multiplied by rainfall value below 500mm), and b) 1 = suitable (i.e. temperatures above 10°C multiplied by rainfall above 500mm). For example temperature below 10°C and rainfall below 500mm each is equal to zero hence if any of the two is below the minimum value given the resulting outcome was the first category (0). Likewise for the second category each of the parameters was equal to one if it was above the minimum value given above hence 2nd category if the outcome was 1. Therefore, any of the areas whose climatic data were falling in the first category was taken as unsuitable for occurrence of the pest while the one falling in the second was then considered suitable for occurrence.

The second criterion was based on Daiber (1994) and Nsibande & McGeoch (1999). According to these two sources *C. puncticollis* was occurring at places colder than 10°C. For example in South Africa it has been recorded in the northern Free State (Daiber 1994) and throughout Swaziland (Nsibande & McGeoch 1999). Based on these and the available long-term climatic conditions, the least mean annual minimum temperature for both South Africa and Swaziland was found in the Free State as -1°C. The two suitability classes, 0 and 1 were set as above. 0 = unsuitable where temperatures were below -1°C and 1 = suitable where temperatures were above -1°C. The two distribution maps of this pest were then produced based on the two criteria explained above. The two maps were then compared with the results of the degree-day models.

RESULTS

The degree-day model

Maximum soil temperatures recorded throughout the whole temperature recording period was 35.82°C at Siloe (Table 2.1). Temperatures around 30°C were observed mostly during the summer months (December to February) and mostly in the lowlands. Although Thaba-tseka is in the highlands the highest maximum average temperature was above 30°C which was approximately 3°C higher than the maximum mean temperature recorded in the foothills (Nyakosoba) (Table 2.1). The lowest recorded temperature was 1.98°C which was recorded at Leribe (lowlands) (Table 2.1). The low temperatures were recorded from May to August, and that extended to September in the foothills and highlands. The number of possible generations for the growing season was three to five for both the foothills (Nyakosoba) and the highlands (Thaba-tseka) sites (Table 2.1). For the sites in the lowlands, Maseru, Leribe and Siloe six to eight generations were likely to be completed by this pest (Table 2.1). January and February data for Maseru were lost due to electronic failure, but these were estimated from the available data for the preceding and following months.

During cold months, i.e. during Winter (May to July) and early Spring (August to October), little or no degree-days (°D) were accumulated (Fig 2.2). As a result the accumulation of number of degree-days showed a steady increase from November when accumulations were started until end of April where there were no further increases (Fig. 2.2). Towards end of April the degree-days accumulated reached a plateau and started to level off then an increase was observed again from August (Fig 2.2). In Figure 2.2 the curve labelled Maseru1 was the original curve obtained with the temperature recordings that excluded data that were not available for January and February in Maseru. Then the corrected version of that curve, Maseru 2 was very similar to the degree-day cumulative curves of other lowlands' sites (Leribe and Siloe).

Extending the period for degree-day accumulation from a growing season (November to May) to a whole year (November to October) resulted in an extra two generations in the lowlands while in the highlands only one extra generation was predicted (Table 2.1). The generations completed after May took much longer period to complete. For example, the time taken to complete each of these generations in Leribe was 127 and 120 when the lower thresholds were 8.91°C and 11.29°C (Table 2.2) respectively. Analysis of variance showed that the average number of degree-days per day between the five sites was significantly different (Table 2.3). There was no significant difference in the average number of degree-days per day for the three lowlands sites but a significant decrease was observed in the average number of possible daily degree-days for both the highlands and foothills sites. However, between the highlands and foothills there was no significant difference in the number of degree-days per day (Table 2.3).

Climate matching

The two maps that were produced according to the two criteria used for climate matching were very different. Fig. 2.3 showed that given the criteria based on Eulitz's description of the temperature and rainfall ranges of this pest in South Africa, this pest would be entirely excluded from Lesotho, the northern Free State as well as the cooler regions of Swaziland. Fig. 2.4 however, showed a widespread occurrence of *Cylas puncticollis* in Swaziland. The potential areas for establishment were also predicted for Lesotho although the distribution was sporadic (Fig 2.4 and Fig. 2.4). The high elevation regions such as Mokhotlong, Qacha's Nek (the highlands districts) did not prove to be suitable areas. However, the sparse pattern of distribution for *C. puncticollis* was also predicted even in the lowlands. With the exception of Nyakosoba (the foothills) all the study sites are apparently suitable for establishment of this pest (Fig. 2.5).

DISCUSSION

The degree-day model

Although different thresholds were observed between developing stages of *C. puncticollis* (chapter 1), an overall development (i.e. egg to adult) threshold was used for degree-day accumulation. While this could lead to some inaccuracies Kelker (1990) has shown that with the species he was working on (*Ostrinia nubilalis*), different thresholds did not result in any difference in the accuracy of prediction of adult emergence. Use of micro-environmental temperatures like soil temperatures, as is the case in this study, is encouraged as they give more reliable and consistent results through years (AliNiazee 1976). Although uses of micro-environmental temperatures are encouraged their specificity makes them not easily applicable to other areas, as similar data might not be available for comparison (Pruess 1983). Furthermore, it is important for authors to mention the exact methods used in calculating degree-days so that comparative studies are made with correct methods to avoid making false conclusion as a result of comparing different methods (McMaster & Wilhelm 1997).

The method used in this study has been criticized for being less accurate in predicting the insects' phenologies in the field (McMaster & Wilhelm; Spano *et al.* 1999). Generally different methods of the linear degree-day models are sensitive to differences in seasons or geographical locations but the level of sensitivity differs between each. Some methods for example, the sine wave and the triangle method are believed to be more reliable (Pruess 1983; Wilson & Barnett 1983; Roltsch *et al.* 1999; Spano *et al.* 1999). However, short temperature logging interval such as a period of less than 2 hours helps for correcting such variation in temperature between areas with differing climates and between seasons. Consequently these methods known to be less accurate, like the one used in this study, can still produce reliable results (Raworth 1994; Watson & Beattie 1995).

The accumulative degree-days were highest in the lowlands (Maseru, Leribe and Siloe) compared to both foothills (Nyakosoba) and highlands (Thaba-tseka). There was no significant difference in an average number of possible degree-days per day for a growing season (November - May) between the lowland sites. The number of generations the pest is likely to complete in the lowlands was very high, five to six generations in a growing season given the soil temperatures recorded there. Since foothills and highlands of Lesotho have almost similar temperatures and other environmental factors such as rainfall, the accumulated degree-days as well as generations per growing season (November to May) were found not to be significantly different. Six generations per season have been estimated as possible for *C. formicarius* in the near East (Rivnay 1962) while Haque & Gul-el-Zannat (1985) and Jayaramiah (1975) observed five to six generations and seven to eight generations per year respectively in India. *Cylas formicarius* usually has a longer developmental period than *C. puncticollis* thus the predicted possible number of generations for *C. puncticollis* in Lesotho is assumed to fall within the possible range of generations per year for this pest.

If degree-day accumulations were calculated for a year instead of a growing season it was observed that additional generations were likely to be completed within a year for all the sites sampled. High temperatures of the summer, autumn and late spring resulted in faster development and therefore fewer days were needed for completion of development as opposed to cooler days. As temperatures started to drop towards winter, an increase in number of days was observed such that more than 100 days were needed for completion of one generation. Usually if observed temperatures are below the lower temperature threshold of an organism, no degree-days are accumulated (Pruess 1983; McDonald 1990). From winter to early spring most soil temperature readings in Lesotho were below the lower thresholds hence no degree-days were accumulated. That was especially the case with the highland (Thaba-tseka) and foothill (Nyakosoba) sites. As a result it would take weevils a longer time to complete one generation because most of the time they would be accumulating no heat units for their development.

However, the chance that these extra generations, especially in winter would be completed would depend on several factors such as availability of host plants, ability of the pests to feed given the prevailing temperatures as well as the lower lethal temperatures of survival (Urbaneja 1999). The lower lethal temperatures often differ within the individual growth stages of the same organism (Cammell & Knight 1992), and as a result they would determine the possibility of the weevils to maintain their populations. The lower lethal limits of survival were not determined for *C. puncticollis*. However, based on findings of chapter 1 it is obvious that within the growing season, temperatures is not likely to have adverse effects on survival of this pest as the temperature readings were near or above 16°C. One can also safely assume that given the temperatures ranges recorded in the soil the higher lethal limits (which could be estimated to be above 36°C) also are not likely to affect this pest in Lesotho.

This general trend of longer duration period per generation in winter could have serious implications on the maintenance of populations of these weevils to restart reinfestation for the next season. The chances of weevils facing local extinction in the case of extremely low temperatures especially in the highlands and foothills due to failure to maintain minimum viable populations are very high. According to Rivnay (1962) the reproduction threshold of a sister species *C.*

formicarius is 15-16°C (Rivnay 1962). Given the climatic preferences of the two species in Swaziland, where *C. formicarius* is excluded from cooler regions (Nsibande & McGeoch 1999), one would assume that *C. puncticollis* would probably have a slightly lower reproduction threshold than the former. If such a value is assumed to be around 10°C for *C. puncticollis*, this pest is likely to have low fecundity in Lesotho where temperatures are often below 10°C for both winter and spring seasons. Furthermore these weevils do not have a diapausing stage meaning they need host plants for maintaining their populations.

The ability of *C. puncticollis* to reproduce and maintain viable populations would depend on whether the pest's alternative hosts, which are other *Ipomoea* species are available in Lesotho because sweetpotato plants are only available during the summer and autumn seasons. These weevils can not survive without food for more than eight days (Schalk & Jones 1985; Smit 1997). Mullen (1981), however, indicated that *Cylas* spp. could be a serious pest during storage, even in the low temperatures as long as those temperatures allow its survival. The ability of the pest to feed and reproduce inside tubers as long as there is enough food material can also make it a difficult pest to control especially if the control is based on low temperature limits.

This study however shows that *C. puncticollis* certainly has a high probability of establishing in Lesotho if it is introduced. It is important to point out that the summation used for the prediction was done on the weevil populations occurring in Pretoria, South Africa. This could then mean that the population used had higher thermal thresholds as it was found in the warmer areas (Campbell *et al.* 1974; Wang & Tsai 1996). Therefore, it is possible that with acclimation of the pest to colder areas (Messenger 1969) the pest could even have lower lethal limits of both survival and development. As a result of that even a higher number of generations per year than was predicted in this study could be completed given availability of hosts. With an increased effort by various root crops research organizations such as Asian Vegetable Research Development Centre (AVRDC) and South African Regional Root crops Network (SARRNET) to produce varieties which are highly cold tolerant (Yanfu *et al.* 1989), this is possible as the crop might be available all year round.

Climate matching

The two criteria used to predict potential establishment of *Cylas puncticollis* gave quite different results. These differences are due to difference in the distribution areas of this pest in South Africa. Various reasons could have contributed towards the difference in distribution of *C. puncticollis* in the two papers Eulitz (1974) and Daiber (1994). It is likely that during the time Eulitz (1974) was writing, insufficient surveys had been taken on the pest or simply the pest had not yet expanded its ranges into areas such as the Free State and the Eastern Cape which are reported by Daiber (1994). Due to the high temperature ranges that were given by Eulitz (1974) the prediction resulted with the entire exclusion of this pest in Lesotho.

The second criteria based on Daiber (1994) was taken to be a more reliable one because it was a recent publication implying the pest was found later on other locations in South Africa as Daiber (1994) reports in his paper. Secondly, when the first criterion was used some parts of Swaziland were also excluded but according to Nsibande & McGeoch (1999) *Cylas puncticollis* is present throughout the country as opposed to its sister species, *C. formicarius* which is restricted to the warmer areas. An exclusion of *C puncticollis* in some parts of Swaziland when Eulitz's criteria was used also rules out the high temperature ranges of this pest given by Eulitz (1974). The results obtained as a result of using distribution ranges by Daiber (1994) seem a lot more reasonable because the pest was found to be widely distributed in Swaziland. Therefore the results obtained in this study generally predict the potential establishment of *Cylas puncticollis* in Lesotho. The occurrence of this pest in the cool area such as the Free State highlights the possibility of this pest occurring even under cooler climates.

Although a patchy distribution of *Cylas puncticollis* was predicted in Lesotho, the outcome clearly indicates that this is a potential pest. It is important to realize that the site chosen to represent the highlands (Thaba-tseka) was probably not the best site as it lies in the valley. As a result the altitude was low and hence experienced warmer temperatures compared to other highland areas. From the predicted distribution of the pest this site was shown as one of the sites with a high likelihood for occurrence or establishment of the pest (Fig. 2.4). Chances of the pest establishing here are even higher than at the foothills. Foothills are not very much different from the highlands but usually slightly higher temperatures are observed in the former agro-ecological zone.

Degree-day approach versus climate matching approach

Although a climate matching model is mainly a mathematical model and therefore takes little account of the biology or ecology of the pest it has the capacity of predicting with near accuracy the distribution of the pest. Another possible weakness of this model is lack of incorporating other climatic variables such as snow cover, wind patterns etc as these usually have a great influence also on the dynamics of the pest (Cammell & Knight 1992). The advantage of the degree-day model is that although it is still biased towards temperature it is based on the sound knowledge of the pest biology and ecology. The model also has its own disadvantages, for example, the lower developmental threshold is affected by seasonal variations (Roltzch *et al.* 1999) and consequently affecting the degree-days calculations. The two models used temperatures recorded from different media, soil and air for the degree-day approach and climate matching approach respectively. However, the results from the two approaches (i.e. if only the second criterion in climate matching is considered) concurred.

Busby (1986) did observe that in his climate matching study, there were some descrepancies where the areas predicted as suitable were actually lacking the species (*Nothofagus cunninghamii* Hook) he was working on. However he did highlight that other factors such as low dispersal ability of the species could have been the restriction or exclusion factor. It is therefore important to realize this weakness of exclusion of some ecological or biological knowledge of the pest in models that take into consideration mainly the impact of abiotic factors in the species' distributions. Whenever possible it is best to include the species' biological or ecological activities by either incorporating them into such models or combine such models with the ones based on the knowledge of the species' biology. The two methods used in this study are examples of cases where such two models are used to compliment each other. Whether the pest is observed at its suitable area or not the climate matching analysis highlights an important aspect of distribution of the pest, its possibility to expand its ranges or establishment in a new area should it invade such an area.

One could therefore conclude that given the above results *Cylas puncticollis* is a potential pest in Lesotho. Climate matching might not have predicted with pure accuracy the possible areas in Lesotho or South Africa that this pest may establish but it has highlighted the most important point, i.e. the potential for the establishment of this pest in Lesotho or expansion of its ranges in South Africa. It is important to realize that if all other factors such as host availability that will enable colonization of *C. puncticollis* in Lesotho this is likely to be a pest in the future. The pest managers for the two countries will therefore be able to plan their pest control programmes better with the knowledge of exactly how far the pest could expand its ranges. This knowledge will contribute towards encouraging strong quarantine regulations in these two countries for the control of sweetpotato exchange between the two countries and within each country.

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Table 2.1: Annual (November - October) mean (± S.E.) soil temperature readings, total cumulative degree days per growing season (November - May) and mean (± S.E) number of generations per season predicted for *Cylas puncticollis* at each of the five sites in Lesotho. Values in brackets = minimum and maximum. CL, NL and SL = central, northern and southern lowlands, F = foothills and H = highlands.

Sites	*Annual mean temperatures (°C)	Cumulative degree-days/season (°D)	Generations per season
Leribe (NL) 1737 m.a.s.l. (28°55.25'S, 28°12.66'E)	17.56 ± 0.05 (1.98, 31.61)	2154.99 (1915.24, 2394.74)	5.80 ± 0.29 (5.05, 6.58)
Siloe (SL) 1676 m.a.s.l. (29°56.43'S, 27°16.09'E)	17.47 ± 0.56 (5.10, 35.82)	2128.95 (1891.94, 2365.97)	5.73 ± 0.28 (4.94, 6.50)
Maseru (CL) 1560 m.a.s.l. (29°17.29'S, 27°30.47'E)	16.86 ± 0.86 (3.22, 31.59)	2151.20 (1914.54, 2382.86)	5.79 ± 0.30 (5.06, 6.54)
Nyakosoba (F) 2070 m.a.s.l. (29°31.34'S, 27°46.66'E)	16.50 ± 0.05 (4.73, 27.91)	1389.66 (1168.02, 1610.10)	3.74 ± 0.19 (3.08, 4.42)
Thaba-tseka (H) 2174 m.a.s.l. (29°22.57'S, 28°32.07'E)	13.82 ± 0.05 (3.21, 30.12)	1384.29 (1151.88, 1616.70)	3.73 ± 0.20 (3.04, 4.44)

*Values in brackets for the annual mean temperatures reflect the actual minimum and maximum temperatures recorded at each site, not an average of minimum or maximum temperatures recorded.

Table 2.2: The possible number of generations, the number of days and dates *Cylas puncticollis* is likely to take to complete each generation throughout the whole year with accumulations starting from 01/November ending 30/October at each sites used for prediction of its potential establishment in Lesotho. D.O.C. = Date of completing each generation

Generation	Lowlands						Foothills		Highlands	
	Leribe		Siloe		Maseru		Nyakosoba		Thaba-tseka	
Lower Threshold = 8.91°C (Using the disturbed treatment results)										
	Days	D.O.C	Days	D.O.C	Days	D.O.C	Days	D.O.C	Days	D.O.C
1	34 d	04/12	34 d	04/12	32 d	03/12	63 d	17/12	46 d	16/12
2	29 d	02/01	29 d	02/01	26 d	30/12	36 d	22/01	41 d	26/01
3	25 d	27/01	27 d	29/01	26 d	26/01	34 d	25/02	36 d	04/03
4	23 d	19/02	25 d	23/02	28 d	23/02	51 d	09/04	47 d	20/04
5	25 d	16/03	27 d	22/03	31 d	26/03	204 d*	31/10*	20 d	10/05
6	33 d	18/04	32 d	23/04	29 d	24/04	--	--	170 d*	31/10*
7	127 d	23/08	134 d	07/09	133 d	07/09	--	--	--	--
8	51 d	13/10	44 d	20/10	40 d	17/10	--	--	--	--
9	18 d*	31/10*	11 d*	31/10*	14 d*	31/10*	--	--	--	--
Lower Threshold = 11.29°C (Using the undisturbed treatment results)										
	Days	D.O.C	Days	D.O.C	Days	D.O.C	Days	D.O.C	Days	D.O.C
1	43 d	13/12	43 d	13/12	42 d	12/12	63 d	03/01	63 d	03/01
2	35 d	17/01	35 d	17/01	33 d	14/01	46 d	18/02	54 d	27/02
3	29 d	15/02	30 d	16/02	36 d	19/02	63 d	23/04	204 d	23/09
4	31 d	18/03	34 d	22/03	42 d	02/04	190 d*	31/10*	38 d*	31/10*
5	50 d	27/05	148 d	17/08	37 d	09/05	--	--	--	--
6	120 d	25/10	71 d	27/10	160 d	17/10	--	--	--	--
7	6 d*	31/10*	4 d*	31/10*	14 d*	31/10*			--	

*The last generation was not completed.

Table 2.3: The average degree-days ± S.E. accumulated per day for a growing season (November – May) at each of the 5 sites representing the three agro-ecological zones of Lesotho. The top row presents ANOVA results. Significant differences between the means were separated by Tukey HSD test. Means followed by similar letters within one column are not significantly different at $p<0.05$. DD_{min} = Minimum possible °D and DD_{max} = Maximum possible °D.

Sites	Agro-ecological Zones	$°D_{min}$ $F_{(4, 972)} = 54.594$ $P<0.00001$	$°D_{max}$ $F_{(4, 972)} = 60.134$ $p<0.00001$	Sample size, N (days)
Leribe	Lowlands	9.57 ± 0.52a	11.79 ± 0.52a	212
Maseru	Lowlands	9.53 ± 0.52a	11.72 ± 0.53a	212
Siloe	Lowlands	9.40 ± 0.52a	11.66 ± 0.53a	212
Nyakosoba	Foothills	5.98 ± 0.50b	8.07 ± 0.51b	212
Thaba-tseka	Highlands	5.74 ± 0.50b	7.93 ± 0.50b	212

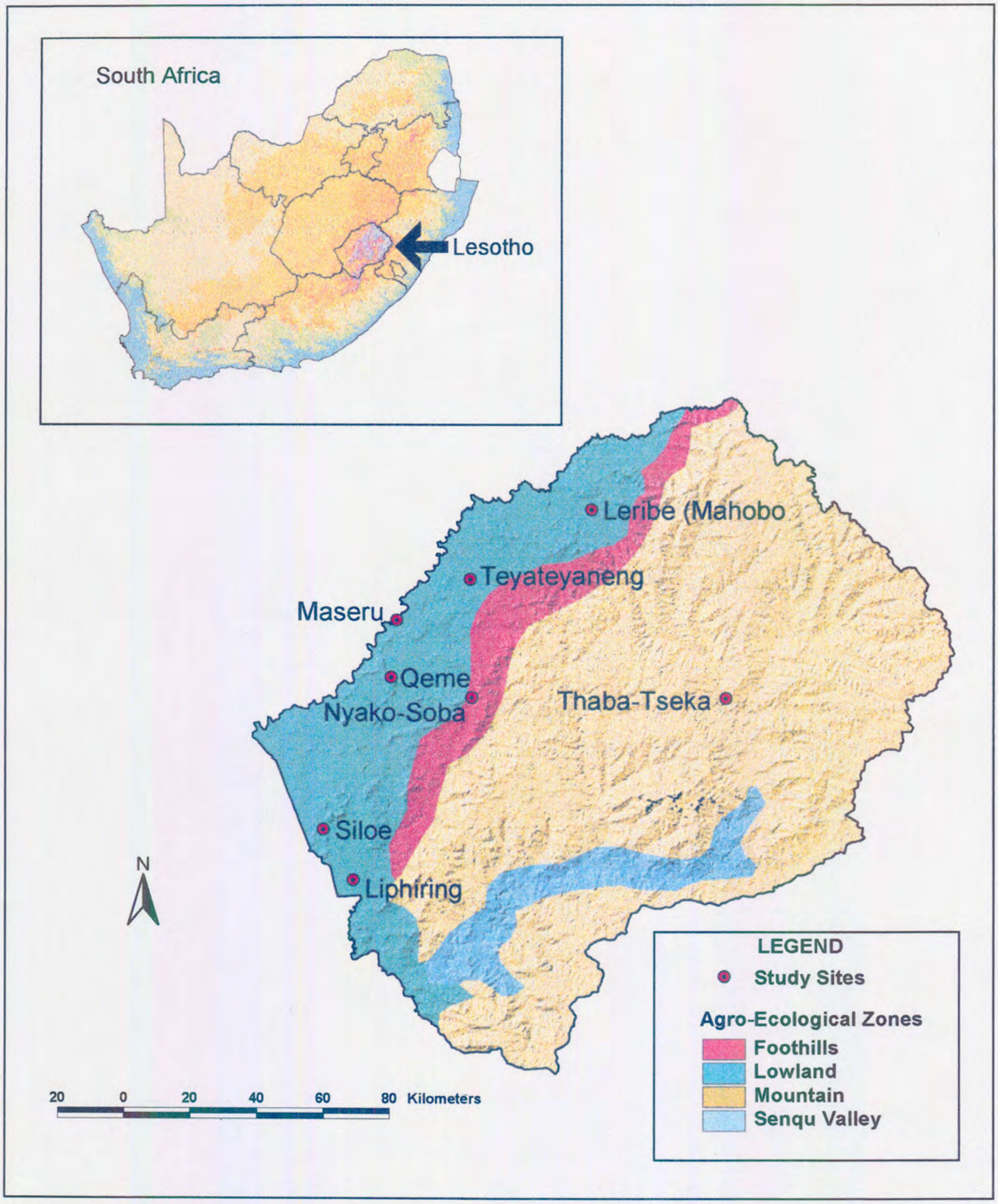

Fig. 2.1: Map of Lesotho showing the three main agro-ecological zones of Lesotho as well as the Senqu valley. (Modified from Anonymous 1986).

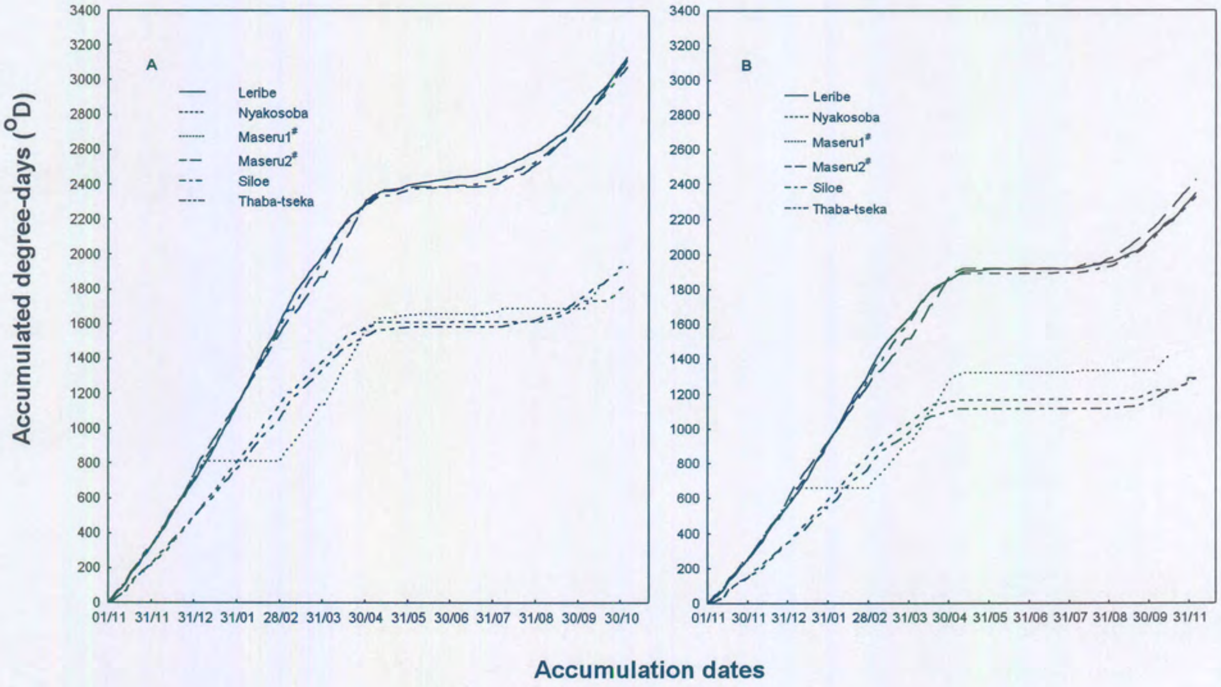

Fig. 2.2: Possible minimum and maximum degree-days accumulated by C. puncticollis in the three agro-ecological zones of Lesotho. Lowlands are represented by Leribe (north), Maseru (central), and Siloe (south); foothills by Nyakosoba and highlands by Thaba-tseka. Accumulations were started from 01/November. # data for Jan. & Feb were lost for Maseru and Maseru2 was estimated from the available data.

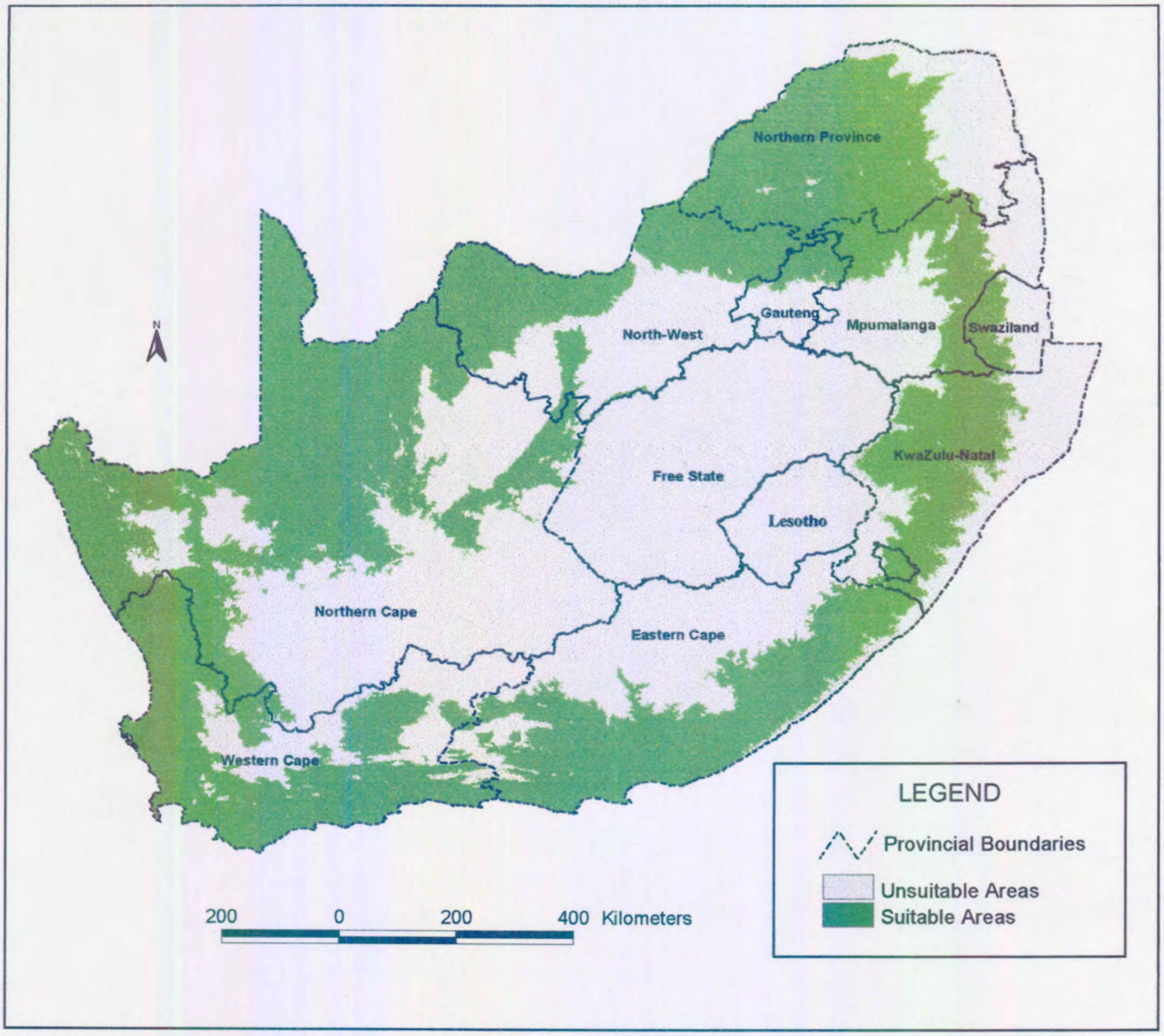

Fig. 2.3: Areas suitable in South Africa, Lesotho and Swaziland for *Cylas puncticollis* using climatic criteria from Eulitz (1974)

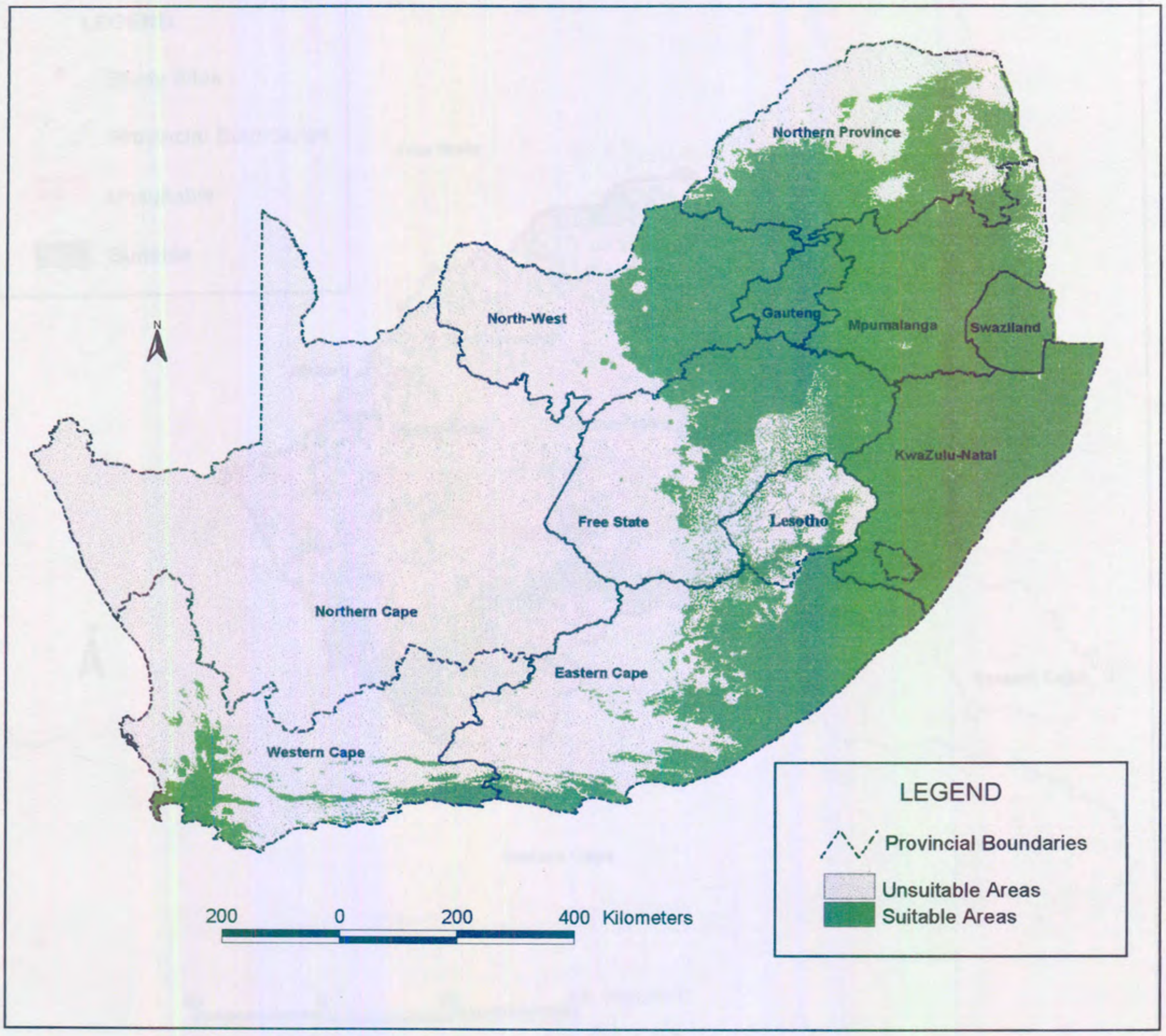

Fig. 2.4: Areas suitable in South Africa, Lesotho and Swaziland for *Cylas puncticollis* using its climatic profile calculated from current distribution in South Africa (Daiber 1994) and Swaziland (Nsibande & McGeoch 1999).

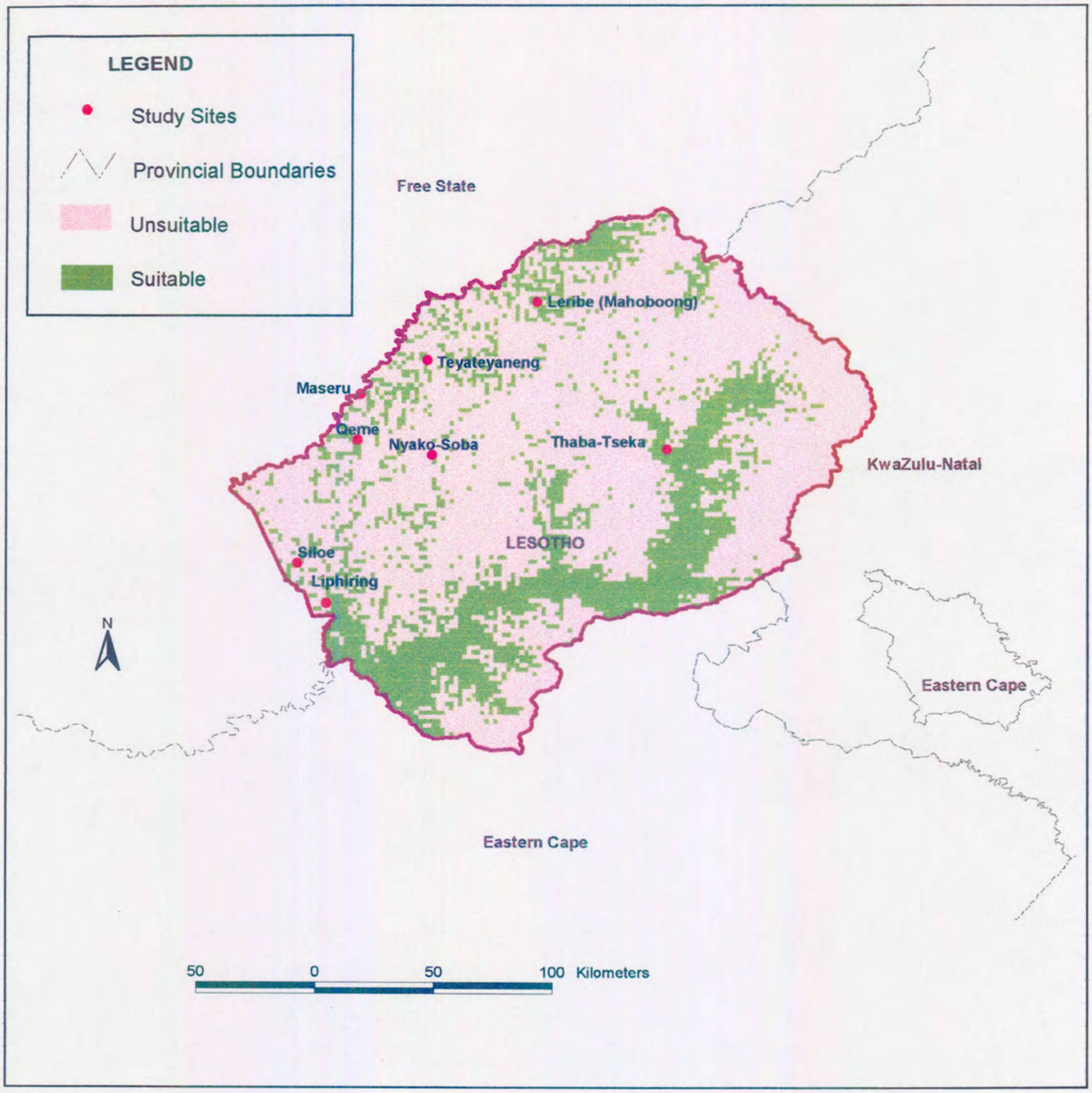

Fig. 2.5: Areas suitable in Lesotho for the establishment of *Cylas puncticollis* using its climatic profile calculated from current distribution in South Africa (Daiber 1994) and Swaziland (Nsibande & McGeoch 1999).

CHAPTER 3

Survey of sweetpotato production practices and pests in Lesotho.

INTRODUCTION

Sweetpotato in Lesotho: history and production

Sweetpotato was recently introduced as a crop in Lesotho. Knowledge of its insect pests worldwide and in regions bordering Lesotho will help towards achieving better production of the crop in this country. Initially twelve sweet potato varieties were introduced as seeds from the International Potato Center (CIP) in Peru, and from the Asian Vegetable Research and Development Center (AVRDC) in Taiwan in 1992. Only seven varieties survived. The following year more varieties were introduced, but these were received as tissue culture material from CIP (Makhata pers. comm.). Since 1992 most of the sweet potato production has been carried out in the research stations of the Agricultural Research Division (ARD) across Lesotho.

There has however been little success in the mountainous regions (i.e. highlands). Production of this crop at the main station, Maseru, has been carried out under regular irrigation. A number of farmers in different agro-ecological zones have been supplied with cuttings since 1995, although some have stopped growing the crop because of problems associated with the supply of the cuttings (such as receiving the cuttings late or travelling long distances to get them).

Even at this stage sweet potato production in Lesotho is still on a very small scale. Planting by the ARD researchers is being carried out only in the lowlands and foothills (see Fig. 2.1, Chapter 2). The few farmers who are involved in sweetpotato production are those who get cuttings from the main research stations and those who kept their planting materials from the past. However, despite the low production level at present the Lesotho government still hopes that with an increased production, sweetpotato will help in the alleviation of poverty levels as it is capable of returning good yields even under poor planting conditions (Prashak 1994).

Lesotho is dependent on agriculture as a source of income and subsistence but the agricultural productivity ranks lowest among the countries of Southern Africa

(SADC) (Anonymous 1995). Because of the capability of sweetpotato to produce good yields even under poor planting conditions the government of Lesotho still encourages large scale production of this crop. Many factors, including erratic rains, soil erosions, low soil fertility and pests (Ebenebe 1998) are considered contributing factors towards low agricultural productivity in Lesotho. However, the effects of insect pests and plant diseases on crop production have received little attention.

The aim of the study was to determine the potential pest problems that might limit production of sweetpotato in Lesotho. The specific objective of this survey was to determine if sweetpotato weevils, *Cylas spp.*, the major biotic constraints to production of this crop worldwide, were already present in Lesotho. Other potential pests of this crop were also surveyed to develop baseline pest information for this crop in Lesotho. Farmers' opinions on what they perceived as production constraints were obtained through the use of questionnaires, while field sampling at representative areas in the country where the crop was in production were used to identify sweetpotato pests that were already present in Lesotho.

Sweetpotato production worldwide

Sweetpotato, *Ipomoea batatas* (Linnaeus) Lamack originated in South America around 8,000-6,000 B.C. (Purseglove 1988; Austin 1991), and was brought to Africa during the 16th century (Kays *et al.* 1993). Sweetpotato is grown from 35°N to 35°S, and from sea level to altitudes above 2500m.a.s.l. (Bourke 1982; Horton *et al.* 1989) and has shown great adaptability to different climates (Horton & Ewell 1991; Prashak 1994). Sweetpotato is grown widely in the developing countries across the globe (Horton 1988).

Sweetpotato production practices and constraints

Production of sweetpotato is through planting of the vine cuttings and storage roots (tubers) (O'Hair 1991; Raman & Alleyne 1991). However, storage roots are recommended more than vine cuttings because they result in higher yields, early harvested tubers and reduced insect infestations (Raman & Alleyne 1991). Despite these advantages, vine cuttings still remain the widely used propagation material. Great care is taken to choose the appropriate vine to be used as planting material because vines are a potential cause of spread of pests (O'Hair 1991; Raman & Alleyne 1991). Various characteristics such as the quality of vines, the size or length of the cuttings, orientation of the propagating materials during planting and others are usually taken into consideration to reduce chances of pest infestations (O'Hair 1991).

There are several constraints for production of this crop and they usually differ between regions and climatic zones (Horton *et al.* 1989). The constraints are grouped as production and post-harvest constraints (Horton & Ewell 1991). Included in the production constraints are the use of unsuitable varieties, lack of planting materials, diseases and insect pests and unsuitable environmental conditions. The most important production constraints are insects, planting material and environmental conditions across all the climatic conditions (Horton & Ewell 1991). The post-harvest problems include storage and marketing problems. A survey carried out in 45 different countries across the world showed that marketing was always the highest problem across all climatic conditions (Horton & Ewell 1991).

The major insect pests of sweetpotato are sweetpotato weevils (*Cylas spp* and *Euscepes postfasciatus* Fairmaire) and vine borers (*Omphisa anastomasalis* Guenee, *Megastes grandalis* Guenee and *Megastes pucialis* Snell). Among these major insect pests, *Cylas* species are the most important pests worldwide (Anota & Odebiyi 1984; Chalfant *et al.* 1990; Talekar & Pollard 1991; Jansson & Raman 1991). Other insects that are common pests of sweetpotato are sweetpotato hornworm (*Agrius convolvuli* Linnaeus), sweetpotato butterfly (*Acraea acerata* Hewitson), rough sweetpotato weevil (*Blosyrus sp.*), tortoise beetles (Cassidinae), clear wing moth, wireworms (larvae of *Conoderus spp.*), *Diabrotica* spp and *Systena* spp. Leaf miners (*Bedellia sp.*) are usually considered to be minor pests of this crop (Bolton & du Plooy 1984; Chalfant *et al.* 1990).

Brief description of sweetpotato pests

(i) *Bedellia somnulentella* Zeller (Lepidoptera, Lyonetiidae)

The moth of the sweetpotato leaf miner is fawn with fringes of hair on the edges of the wings (Herbison-Evans 1998). The moth has a wingspan of about 1cm (Bolton & du Plooy 1984; Herbison-Evans 1998). The caterpillars of this moth feed on the sweetpotato plants and various other Convoluvulaceae species by mining the leaves, (Herbison-Evans 1998). The larvae are found inside these mines and when they pupate they spin webs where pupae are usually held on the plant. Although it is a sporadic pest of sweetpotato, it can cause up to 23% yield losses during an outbreak (Bolton & du Plooy 1984; Chalfant *et al.* 1990; Girma 1994).

(ii) *Acraea acerata* Hewitson (Lepidoptera, Acraeidae)

Acraea acerata (sweetpotato butterfly) is a yellowish butterfly with brownish margins. Pale yellow eggs are laid in batches of 100-400 on the leaves (Ames *et al.* 1996). Its spiny greenish-black larvae feed on the upper leaf surface but the older larvae feed voraciously on the leaves leaving only the primary midribs (Ames *et al.* 1996)

(iii) *Agrius convolvuli* Linnaeus (Lepidoptera: Sphingidae)

This is a common pest of sweetpotato in Africa (Bolton & du Plooy 1984). The *Agrius convolvuli* (sweetpotato hornworm) moth is grey in colour with light and dark pattern on the wings. The lateral sides of the abdomen have pinkish streaks (Bolton & du Plooy 1984; Schalk & Jones 1985; Daiber 1994; Herbison-Evans & Crossley 1999). The wingspan is approximately 10cm. It lays large green eggs (about 1mm in diameter) which are oviposited singly anywhere on the surface of the plant (Schalk & Jones 1985). The larvae have a conspicuous horn on the last abdominal segment hence the name hornworm (Schalk & Jones 1985). The larvae are either green (usually the first instars) or brown. The first instar is as small as 5cm while the fully-grown last (fifth) instar is about 10 cm long. The larvae are responsible for the damage as they can feed voraciously on the leaves. They are also of sporadic nature but sometimes they can cause a complete defoliation of the crop (Schalk & Jones 1985; Herbison-Evans & Crossley 1999).

(iv) *Blosyrus spp.* (Coleoptera: Curculionidae)

Blosyrus spp. (rough sweetpotato weevil) has a rough surface hence the common name rough sweetpotato weevil. It is a common pest in the Gauteng area in South Africa (Bolton & du Plooy 1984). It causes a minimal damage on the leaves but it can cause considerable damage on the tubers. *Blosyrus* lays its eggs on the leaves. Upon hatching the larvae drop on the soil where they find their way to the tubers. The larvae do not bore into the tuber like *Cylas* species do but they feed on the surface causing a typical path on the skin of the tuber that renders them ugly and reduces their market potential.

(v) Cassidinae (Coleoptera: Chrysomelidae)

Several tortoise beetles in the subfamily Cassidinae, feed on sweetpotato plants and other Convolvulaceae plants; for example, *Aspidomorpha tecta* (the fool's gold beetle), *A. miliaris, A. elevata, Cassia circumdata, C. obtusa* and others

(Ames *et al.* 1996; Daiber 1994; Robertson 1998). Both adults and larvae feed on the leaves and vines of this crop (Robertson 1998). Generally adults have a broad and flat shape, larvae are spiny with exuviae often carried on the fork-like posterior end (Scholtz & Holm 1986; Borror *et al.* 1989). They lay eggs in packets on the underside of the leaves. After 10-12 days the larvae hatch and start feeding on the leaves. Their feeding results in puncture-like marks. The final instar feeds on the surface and margin of the leaf (Robertson 1998).

(vi) *Spodoptera spp.* (Lepidoptera, Noctuidae)

The following three armyworm species attack sweetpotato, *Spodoptera eridania, S. exiqua* and *S. littoralis* (Ames *et al.* 1996). The caterpillars of these moths feed on the leaves, initially causing round holes eventually the leaves are defoliated by older instars, which spare only the veins. Both *S. exiqua* and *S. eridania* have wider distribution in Africa than *S. littoralis* (Hill 1975; Ames *et al.* 1996). Although they normally attack leaves, they still do damage on the storage roots (Daiber 1994).

MATERIAL AND METHODS

Study sites

In this study five districts namely Thaba-tseka, Leribe, Berea, Maseru and Mohales'hoek, were chosen to represent the three agro-ecological zones of Lesotho. The questionnaire-based survey was conducted in all of these districts, while the field based survey was carried out in the latter four. Field sampling for *Cylas* species and other sweet potato pests was conducted in the lowlands because sweet potato was in production only in this agro-zone at the time. Six sites were used for field sampling and these were Leribe, Teyate-yaneng in Berea, Maseru and Qeme in Maseru, Siloe and Liphiring in Mohales'hoek (see Table 3.1 for full description of sites).

Questionnaire Survey

A list of farmers supplied with sweet potato cuttings by the Lesotho Government since 1992 was obtained from Agricultural Research Division. Active farmers as well as farmers who had stopped growing the crop in the interim were interviewed. Farmers that were interviewed were selected at random at each of the sites that represented the three agro-ecological zones (Table 3). Some of the farmers interviewed were not on the official list; neighbours or friends who had supplied them with cuttings from their gardens added their names to the list.

Ten farmers were interviewed from each region. Their responses were noted on a questionnaire form, which contained 28 questions (Appendix 1). A total of 50 farmers were interviewed. Rangi *et al.*'s (1994) questionnaire was modified for this purpose. To avoid any external influence, each farmer was interviewed individually.

Analyses

The information collected about sweetpotato production and production constraints was summarised and analysed with non-parametric tests. Kruskal-Wallis analyses of variance and Dunn's multiple comparison tests were used to test differences between responses to production practices and production constraints.

Survey of the sweet potato fields

The survey of sweet potato pests in Lesotho was carried out in 1998 and 1999. Only two sites Maseru and Siloe (central and southern lowlands) were surveyed in 1998 because ARD had sweetpotato research activities only in these areas. In 1999, there were ARD research activities in the northern lowland as well and consequently this region was included in the sampling survey. Also, fields from one farmer in each region were included in the survey. Thus in 1999 six sites were sampled. As sizes of the fields were different, the sample sizes (number of plants) taken from each field was different to be as representative as possible of each field.

The number of plants sampled from each field differed between the two years, but the pattern and the procedure was the same for the two years. Plot sizes in all fields were the same ($16m^2$ with 40 plants per plot) except for the two farmers' fields (Teyateyaneng and Liphiring) where the fields were not subdivided into plots. The samples were taken using a random sampling procedure.

During the 1998 survey, two plants were taken from the outside two lines and three from the inner two rows of each plot in Maseru. From the field at Siloe six plants were taken, two from the outer two lines and four from the two inner rows. In 1999, six plants were taken per plot for all the fields except for Siloe, Teyateyaneng and Liphiring. For those sites, one plant was sampled from each of the outer rows while from the inner rows two per row were taken. At Siloe two plants were taken from each of the four rows. The fields in Teyateyaneng and Liphiring, each field consisted of long rows with wide and inconsistent spacing which made it difficult to divide the field into plots. Therefore 10 plants were randomly taken from each row (Fig. 3.1).

The first survey was carried out on the above-ground parts (leaves and vines) because early in the season there are no tubers. The second survey was carried out on the above ground parts and part of the underground parts (i.e. on the stems 15 cm below the ground). The leaves and vines were observed for any damage and scored on a 1 – 5 scoring basis. The score was as follows; 1 = no damage, 2 = 1 - 25% damage, 3 = 26 – 50% damage, 4 = 51 – 75% damage and 5 = 76 – 100% damage (see Table 3.2 for full description). The third survey was carried out only on the below ground (i.e. the tubers) part of the plant. The plants were harvested and the damage on the periderm and inside tubers was noted and rated again on a 1 – 5 scoring system. The score again was similar to that of the leaves, where 1 = no damage on the tuber; 2 = a portion of the tuber with either holes or grooves was not exceeding 25%, and so on (see Table 3.2 for full description).

The survey was based entirely on damage done to the crops by different pests. If the kind of damage was not known it was assigned its own category (indicating unknown pest). Damaged specimens together with sampled insects (both known and unknown) were taken to the laboratory. The specimens were separated. The insects were placed separately in labelled bottles and supplied with fresh crop to feed on. Laboratory damaged foliage or tubers were then compared with the damage on foliage/tuber specimens from the field in an attempt to match the type of damage to each pest. The immature stages were reared in the laboratory to obtain adults for correct identification of each pest.

Analyses

Kruskal-Wallis analysis of variance by ranks and Dunn's multiple comparison test were used to test for significant differences between the extent of damage done by different pests: i) between pests themselves within each site, ii) between sites and ii) for each pest (Zar 1996). Friedman' s analysis of variance was used to test for differences between damage due to each pest during the two leaf sampling periods to determine if there was any population build up.

RESULTS

Questionnaire Response

General background on the crop and the production practices

A summary of the answers from different farmers is presented in Appendix 2. There was no difference in the age of farmers growing the crop across all zones (Kruskal-Wallis test: $H_{(2,\ 50)} = 2.82$, $p=0.244$). Sweetpotato farmers were generally above 25 years of age and 50% of them were between 41 and 60 years. The sex ratio of farmers was almost 1:1 (27 females and 23 males). Most of the farmers (50%) had grown the crop for less than a year, and only 1 farmer had more than 5 years of experience with the crop.

Production of sweetpotato in Lesotho took place in small plots, mostly between $10m^2$ and $30m^2$ and 98% of the people interviewed had, or used to, grow the crop in plots smaller than or equal to $30m^2$. More than half of the interviewed farmers planted the crop in ridges. Sweetpotato was mono-cropped throughout the whole country, and was planted between August and February. More farmers planted in November than any other month. Generally farmers did not apply synthetic fertilizers for production of the crop. Although 8% of farmers used synthetic fertilizers and 25% used cow dung, the majority of farmers (~70%) did not apply any form of fertilization for production of this crop.

With the exception of one farmer who fed his vines to cattle, all others used only the tubers for home consumption. Some farmers (36%) did not use the crop at all but left it in their plots. Those who harvested the crop (72%), did so between April and May. Of those who harvested 83% removed the crop all at once and the rest harvested in a piecemeal fashion. The main source of planting material was the Agricultural Research Station (90%). Alternatively, farmers kept the planting material from the previous plantings (only 14% of the interviewed people) or were supplied by their neighbours in villages or friends in South Africa (~14%).

Production Constraints

Lack of planting material was mentioned by 84% of the interviewed farmers who all rated it as a severe production constraint. Only 36% mentioned insects as a problem (Fig 3.2a) and the majority (20%) thought insects were not a serious problem (Fig 3.2a). Farmers who complained about frost were mostly farmers from the highlands and foothills. Only 6% of farmers mentioned mole-rats as one constraint, and they all rated it as a serious pest (Fig 3.2a). Other constraints, floods and drought, were each mentioned by less than 20% of the farmers (Fig. 3.2a).

Although frost was among the constraints mentioned (mainly highland and foothill farmers), no significant difference in frost between the three zones were found (Kruskal-Wallis test: $H_{(2, 50)} = 1.36$, $p=0.506$). There were also no significant differences between the agrozones in lack of planting material and drought (Kruskal-Wallis test: $H_{(2, 50)} = 0.82$, $p=0.665$; $H_{(2, 50)} = 0.08$, $p=0.960$) respectively. However, a significant difference was observed between the constraints (Kruskal-Wallis test: $H_{(5, 300)} = 130.35$, $p<0.00001$). Dunn's multiple comparison tests showed that a lack of planting material was the greatest production constraint followed by frost and insects, and then the remainder (Fig 3.2a).

Farmers, who listed insects as a production constraint, observed more damage on leaves than on other parts of the crop. There was no mention of any damage on stems (Fig 3.2b). However all farmers rated the damage on leaves as a minor one compared to other parts (Fig. 3.2b). There was a significant difference in damage between the three plant parts (Fig. 3.2b). There was also a significant difference in insect pest incidence between the three agro-zones (Kruskal–Wallis test: $H_{(2, 50)} = 2$, $p=0.035$). The incidence of insects on the sweetpotatoes in the highlands was lower than at the other two agro-zones.

When farmers were listing the pests they knew the list consisted mainly of leaf feeding pests (Fig 3.3). Only two pests, millipedes and mole-rats, were listed as root/tuber pests (Fig. 3.3) and they were both rated as moderate and major pests. There was no mention of sweetpotato weevils (*Cylas sp.*). Pictures of the pest revealed that the interviewed farmers had not seen the pest before.

Field Sampling

Observed pests and the frequency

Cylas spp. individuals were not recorded at any of the sites in either of the two years. Different leaf and root (tuber) pests were recorded during the 1998 and 1999 sampling of the sweet potato fields (Table 3.3). The number of plants attacked by leaf pests was higher than the number attacked by root pests. For example, the total percentage plants attacked by any of the root pests did not exceed 30% for either of the two years (Fig. 3.4). The common insects feeding on the leaves of the sweetpotato plants were locusts, *Bedellia somnulentella* Zeller (leaf miners) and

Agrius convolvuli (hornworms). The overall percentage occurrence of the first two pests were as high as 60% (Fig 3.4). The percentage of plants damaged by all other leaf pests except the leaf miners and locusts was 10% or less (Fig. 3.4). Mole-rats and *Spodoptera sp.* were not recorded in 1998 (Fig. 3.4).

Damage on leaves

No *Spodoptera* species were observed during the 1998 pest survey and *Blosyrus sp.* was absent in Maseru during the leaf sampling (Fig. 3.5). *Spodoptera sp.* individuals were however recorded in 1999 in Maseru, Siloe and Teyateyaneng. Most pests were recorded at Maseru and Siloe (Fig 3.5). *Acraea acerata* was only found in Maseru while *Blosyrus sp.* and Cassidinae (*Conchyloctenia sp.*, *Acrocassis sp.* and *Cassida sp.*) species were recorded at Maseru and Siloe (Fig. 3.5). Locusts were recorded at all six sites; followed by leaf miners which were absent only at Qeme (Fig. 3.5).

Feeding damage by the following pests, *Agrius convolvuli, Acraea acerata,* Cassidinae species and *Blosyrus sp.* did not differ significantly in 1998 (Table 3.4). Damage by *B. somnulentella* was lower than the damage by locusts at Siloe (Table 3.4). Pooling of the two leaf sampling surveys showed that the highest pest damage was due to *B. somnulentella*, followed by locusts, while other pests showed the least amount of damage (Table 3.4).

A comparison of damage between different pests at each site for 1999 shows that for all the sites the greatest leaf damage was due to locusts followed by *B. somnulentella* except for Teyateyaneng and Maseru (Table 3.5). *B. somnulentella* was the only leaf-pests that caused damage as high as 100% on leaves (Fig. 3.6). Locust damage was observed at all six sites, however the highest damage rating observed was below 75% level of damage (Fig. 3.6). *A. convolvuli, A. acerata* and Cassidinae species had significantly lower levels of damage across all sites. Damage between the three pests generally did not differ significantly except for the second sampling at Maseru where Cassidinae species had slightly higher damages than the other two. *Spodoptera sp.* recorded during the second sampling, had high levels (up to 75% damage on leaves) (Fig 3.6).

Significant differences in the extent of damage by some pests were observed between the six sites (Table 3.6). Leaf miner damage was observed to be highest at Teyateyaneng and Maseru for the two sampling periods (Table 3.6). It was followed by damage at Leribe and Siloe. Liphiring seemed to be the least affected by both locust and *B. somnulentella*. Locust damage gave inconsistent results, but Qeme stood out as the most affected site by this pest. The extent of damage by *A. convolvuli* was significantly higher in Leribe than in Maseru. Qeme, and Siloe, which all had the same level of damage due to this pest (Table 3.6). Damage by Cassidinae species was observed only at Maseru and Siloe whereas damage by *Spodoptera spp.* was observed in Maseru, Siloe and Teyateyaneng. A significantly greater damage by Cassidinae species was observed at Maseru. Damage due to *Spodoptera spp.* was significantly different between the three sites where the pest was observed. The highest damage was observed at Teyateyaneng followed by both Maseru and Siloe.

Pest buildup

There was a significant difference in pest damage between the two sampling periods (Friedman analysis of variance) (Fig. 3.6 and 3.7). In 1998 a significant increase in the rate of damage during the second leaf sampling was only observed by *B. somnulentella* and locusts (Fig. 3.6). In 1999 the majority of pests showed a significantly higher damage at the second sampling than the first sampling for all sites except Liphiring (Table 3.7). Locust damage did not show any significant increase at Teyateyaneng, Liphiring and Siloe. An increased damage *by A. convolvuli* was observed at Leribe and Teyateyaneng (Fig 3.7).

Damage on tubers

Tubers were attacked by only three pests, mole-rats, millipedes and the *Blosyrus sp.* No mole-rat damage was observed in 1998. Despite the feeding of *Blosyrus sp.* on the leaves in 1999, no damage due to this pest was observed on tubers. Inspite of its feeding on leaves at Siloe in 1998 (Table 3.4) there was no feeding on the tubers due to this pest at that site during harvesting period (third sampling time) (Table 3.7). Instead, the pest's damage was observed on tubers sampled at Maseru (Table 3.7), although it did not appear during the leaf sampling (Table 3.4). With the exception of Liphiring, millipedes had attacked tubers from all sampled sites (Table 3.7). In 1998 however, tubers from Siloe were clean. The two pests (*Blosyrus sp.* and millipedes) recorded during that period were found in Maseru (Table 3.7). Mole-rats caused the highest damage across sampling occasions. Damages due to this pest were assigned ratings as high as 5. The highest score for millipede damage was 3, while for *Blosyrus sp.*, damage ratings of

3 was not reached (Table 3.7).

DISCUSSION

Questionnaire survey

Production practices

Most farmers interviewed were the ones supplied with the cuttings when ARD introduced the crop to people for the first time. Cuttings were given to as many people as possible per district, resulting in few cuttings per farmer. Thus production of sweet potato in Lesotho took place in small plots. Because it was grown in vegetable plots little or no fertilization (14 farmers applied cow dung and 4 others applied synthetic fertilizers) was applied to this crop, which is the normal practice for vegetable production in Lesotho. Although the foliage can be used for both human consumption as vegetables and as animal feed (Horton & Ewell 1991) farmers were not aware of this. As a result only one farmer fed the foliage to his cattle, all others did not use the foliage of the crop.

Production constraints

For all the 50 farmers interviewed throughout the whole country the serious constraint to sweet potato production was lack of planting material. This constraint has been rated as one of the highest production constraints for this crop in several countries throughout the world (Horton *et al.* 1989; Nsibande & McGeoch 1999). Farmers who did not find a lack of planting material to be a constraint were farmers from the central part of the lowlands. Some of these farmers did not think it was a problem because they could easily get to the main agricultural research station in Maseru, where the initial supply had been from. Lack of planting material was a problem not only for farmers that had stopped growing the crop, but also for those who were still growing it.

According to this survey damage by insects was not seen to be a serious problem for this crop. As a result, few pesticides were applied. Of the 18 farmers who mentioned insects as a constraint, 15 were from the lowlands. This shows that farmers from other regions do not think insects were a potential problem. None of the farmers could identify the *Cylas spp.* as any pest they had ever seen before. Although insect pests are apparently not a problem at present it is important to note that farmers interviewed grew the crop because they were supplied with the cuttings on a trial for the establishment of the crop. It is not easy to document the impact of insect pests for crops grown on a smaller scale. Until now the crop has been mainly produced by farmers in the lowlands. Once the crop is planted throughout the country there could be different production practices such as intercropping, less crop rotations and others that might have an effect on the pest populations.

Farmers in Lesotho generally do not control pests, even most important crops such as maize and sorghum (Ebenebe 1998). Ebenebe (1998) observed that a very small percentage of farmers in Lesotho controlled stalkborer although they rated it as the most important pest. Therefore, it is not surprising that generally sweetpotato farmers practiced no form of control for the sweetpotato pests. This, therefore, explains why insects were not perceived as the most important constrain in this study. In addition to the crop being new the country is also cold. The survey carried out in different countries that represented the four types of climates tropical rainy, semiarid, mild temperate and cold climates revealed that insect pests were not the most important constraint for cold areas (Horton & Ewell 1991). The most important problem was planting material and unsuitable varieties for cold environments as was observed in this study.

Other surveys in other countries, however, revealed insect pests as the most important constraint (Smit & Matengo 1995; Nsibande & McGeoch 1999). Farmers in Kenya rated lack of planting material as the fourth highest problem after insects, drought and moles (Smit & Matengo 1995). In Swaziland lack of planting material was found to be the second most important constrain after insects (*Cylas spp.*) which was considered the most important by approximately 95% of the farmers (Nsibande & McGeoch 1999). However, comparing the farmers' perceptions in Lesotho with the farmer's perception from other countries might be biased, as the farmers from other countries have a longer experience with production of this crop.

Field-sampled pests

Leaf-feeding pests

Although field sampling revealed locust/grasshoppers and leaf miners as widespread leaf pests, these are not likely to be serious pests because they did not attack the most important part of the crop (tubers). It will be difficult at this point to say whether these leaf pests had any effect on the yield of the crop because no yield assessment was carried out. However, according to Daiber (1994) little or no effect on root yield can be assigned to feeding damage by leaf miners even though their feeding might often be conspicuous.

Sweetpotato leaf miners (*Bedellia somnulentella* Zeller) have been reported in South Africa as a minor pest that rarely causes serious damage (Bolton & du Plooy 1984). In this study the highest damage was during the second sampling where complete mining was observed leaving window-like appearance on the leaves. However, this was observed towards harvesting period when all the tubers have been produced and are almost fully-grown. According to the way the survey was carried out it was not easy to say whether an increased damage was a result of population build-up or aging of the pest, hence more feeding. Despite this dilemma, an increased feeding injury was observed with time although this has unlikely contributed to yield reduction if such an exercise was carried out as the increase was observed towards harvesting period of the sweetpotato. Although *Agrius convolvuli* was observed as the third most important leaf pest in Lesotho, its damage levels were very low. This is a sporadic pest (Schalk & Jones 1985), although it can result in complete defoliation of the crop during outbreaks (Bolton & du Plooy 1984).

Numerous other minor leaf pests of sweetpotato such as *Colaposoma sp.*, aphids and others were observed during the sampling survey but only those with conspicuous damage were assessed. Apart from *B. somnulentella*, locusts and *Spodoptera sp.* other observed pests (*Blosyrus sp.*, *A. acerata*, *A. convolvuli and* Cassidinae species) had very low damage levels (less than 50%). Damage by *Spodoptera sp.* was only observed during the second sampling survey. Their damage was very serious at Maseru and Teyateyaneng. During the first sampling the damage due to this pest was not recorded. There are two possibilities for this, either the pest was absent in the first sampling probably due to low densities or the damage could not be distinguished from damage by other pests.

Storage roots/tuber pests

Both questionnaire and field sampling surveys revealed that tuber damage was low. Smit & Matengo (1995) and Nsibande & McGeoch (1999) found that the highest damage was observed on tubers as a result of *Cylas* species, which were absent in this study. The potential pests of tubers in Lesotho are millipedes and mole-rats; the former was recorded in all sites except Liphiring whereas the latter had a higher damage rating. With the exception of the Siloe site, millipedes never caused damage levels as high as 50%. Higher damage at this site in 1999 was probably a result of overwintering of the pest on the crop, as the crop was not harvested the previous year. Mole rats were only observed at Siloe in 1999. According to Smit & Matengo (1995) mole rats has been mentioned as a pest with moderate severity by more than 70% of farmers in Kenya. Compared to insects, damage due to mole-rats is likely to be a major one since their attack resulted in eating up of all tubers, in some cases plants in the whole row or plot were consumed.

Pests observed in this study are the common minor pests of sweetpotato that rarely pose any serious problem. However, several cases have been recorded where such minor leaf and root feeders turned out to be major pests of sweetpotato after having been regarded as minor pests for a long time. For example, leaf miners (*Bedellia spp.*) sometimes become serious pests during outbreaks in Ethiopia, and the sweetpotato butterfly (*A. acerata*) has become one of the most devastating insect pests in the same country (Belehu & Girma 1994; Girma 1994). Therefore, this study has highlighted the presence of important potential pests of this crop in Lesotho. Several factors could contribute towards a change in dynamics of these pests resulting in their pest statuses being changed from minor to major. For example, a wider availability of sweetpotato due to its wider adoption and incorporation in farmers' cultural practices may result in the pests shifting from their original host plants and making sweetpotato an alternative or the most suitable host.

Therefore, based on the findings of this survey, the leaf miners *B. somnulentella* may be a serious pest of this crop once it is produced on a larger scale. Leaf miners were observed in all the sites surveyed except only one site. Although the highest damage was observed towards harvest, with changing growth practices that pattern might change. As a result of that its attack on the leaves at an early stage might result in significant yield reduction. Mole rats are also likely to be a serious root pest as their damage often results in complete destruction of the crop. Although they were only encountered at one site very serious damage was observed there.

However it is, important to realize that there is still a lot of work to be done by the Agricultural Research Division before the crop can be widely adopted by farmers across the country. Lack of planting material emerged as the most serious constraint for large scale production of this crop and only once this has received enough attention will the crop become widely established in Lesotho. Absence of *Cylas* species in Lesotho could mean the pest has not yet been introduced into Lesotho. Based on the findings of chapter 1 it is apparent that the pest has higher chances of establishing in Lesotho should it reach the country. Farmers should be cautioned about the pest and ways of its infestation, which include use of infested tubers and vines as planting materials. Practices such as acquiring planting materials from friends in South Africa should be discouraged as farmers might not know whether tubers are infested or not. In addition, the Lesotho Government should control for the import of sweetpotato into Lesotho to reduce any chances of possible spread of this pest into Lesotho by strengthening its quarantine rules, which are currently almost never applied.

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Table 3.1: Description of sampling sites from the three-agro-ecological zones of Lesotho, used in the survey of the sweet potato pests. ✓ = sampling or temperature recording, X = no sampling or temperature recording at the concerned site. DAP = days after planting. 1, 2, and 3 are first, second and third sampling respectively. Sites' names in bold, agroecological zones capitalized and underlined. Q-Survey = Questionnaire-based survey.

Agro-ecological zones	Data Logging	Q-Survey	1998 sampling	1999 sampling	Field size (1998)	Field size (1999)	No. of plants sampled/site	
<u>LOWLANDS</u>							<u>1998</u>	<u>1999</u>
South								
Siloe 1676 m.a.s.l. (29°56.43'S, 27°16.09'E)	✓	✓	✓ 1. (59 DAP) 2. (95 DAP) 3. (122 DAP)	✓ 1. (170 DAP) 2. (220 DAP) 3. (249 DAP)	570.0 m^2 (19.0 m x 30.0 m)	570.0 m^2 (19.0 m x 30.0 m)	72	96
Liphiring 1610 m.a.s.l. (30°05.70'S, 27°22.67'E)	X	✓	X —	✓ 1. (94 DAP) 2. (141 DAP) 3. (170 DAP)	—	288.0 m^2 (18.0 m x 16.0 m)	—	90
Central								
Maseru 1560 m.a.s.l. (29°17.29'S, 27°30.47'E)	✓	✓	✓ 1. (91 DAP) 2. (131 DAP) 3. (153 DAP)	✓ 1. (103 DAP) 2. (145 DAP) 3. (176 DAP)	544m^2 (34.0 x 16.0)m	484 m^2 (22.0 m x 22.0 m)	90	96
Qeme 1645 m.a.s.l. (29°27.91'S, 27°29.62'E)	X	✓	X —	✓ 1. (106 DAP) 2. (148 DAP) 2. (180 DAP)	X —	484 m^2 (22.0m x 22.0m)	—	96
North								
Leribe 1737 m.a.s.l. (28°55.25'S, 28°12.66'E)	✓	✓	X —	✓ 1. (101 DAP) 2. (152 DAP) 3. (183 DAP)	X —	484 m^2 (22.0 m x 22.0 m)	—	96
Teyateyaneng 1593 m.a.s.l. (29°09.42'S, 27°45.6'E)	X	✓	X —	✓ 1. (140 DAP) 2. (188 DAP) 3. (219 DAP)	X —	192 m^2 (12.0 m x 16.0 m)	—	70
<u>FOOTHILLS</u> **Nyakosoba** 2070 m.a.s.l. (29°31.34'S, 27°46.66'E)	✓	✓	X —	X —	—	—	—	—
<u>HIGHLANDS</u> **Thaba-Tseka** 2174 m.a.s.l. (29°22.57'S, 28°32.07'E)	✓	✓	X —	X —	—	—	—	—

1998 sampling from March to May, 1999 sampling from February to May.

Table 3.2: Description of the scoring system used for rating the damage by each pest on the sweetpotato plants during the 1998/99 pest survey.

Scores	Description
Leaf-sampling	
1 = 0% damage	No damage was observed.
2 = 1-25% damage	Any sign of damage (i.e. holes, chewing or mining) on the leaves, from one hole on one or more leaves up to 25% of all leaves of each plant. Alternatively, damage on each leaf was up to ¼ of the whole leaf area if all leaves were attacked.
3 = 26-50% damage	More than ¼ up to ½ of the leaves of each plant were attacked. Alternatively, if all leaves were attacked, damage on each leaf was only up to ½ of the whole leaf area.
4 = 51-75% damage	More than ½ up to ¾ of the leaves of each plant were attacked. Alternatively, if all leaves were attacked, damage on each leaf was only up to ¾ of the whole leaf area.
5 = 76-100% damage	More than ¾ up to all of the leaves of each plant were attacked. Alternatively, if all leaves were attacked, damage on each leaf was exceeding ¾ of the whole leaf area or there was complete defoliation.
Root-sampling	
1 = 0% damage	No damage observed.
2 = 1-25% damage	One or more holes or feeding marks were observed on tubers. From one up to about ¼ of all the tubers of each plant were attacked. Alternatively if all were attacked the damage on each tuber did not exceed ¼ of the tuber (for example grooves or holes on the surface were covering less than ¼ of the whole tuber for Blosyrus sp. and millipedes respectively).
3 = 26-50% damage	More than ¼ of all tubers up to ½ of all tubers were attacked. Alternatively, if all were attacked damage on each tuber was up to ½ of the whole tuber.
4 = 51-75% damage	More than ½ of all tubers up to ¾ of all tubers were attacked. Alternatively, if all were attacked damage on each tuber was up to ¾ of the whole tuber.
5 = 76-100% damage	More than ¾ up to all tubers were attacked. Alternatively, if all were attacked damage on each tuber was exceeding ¾ of the whole tuber or there was complete damage to the tuber (for example the whole tuber or tubers eaten up e.g. mole-rate damage).

Table 3.3: Pests recorded during the 1998/99 field–based pest survey at various sites in Lesotho.

Common names	Scientific names	(Order: Family)
Leaf feeders		
Sweetpotato leaf miner	*Bedellia somnulentella* Zeller	(Lepidoptera: Lyonetiidae)
Locust and grasshoppers mainly elegant grasshopper and variegated grasshoppers. And many more[#]. Referred to as locusts throughout the study	*Zonocerus elegans* Linnaeus *Zonocerus variegatus* Linnaeus	(Orthoptera: Pyrgomorphidae) (Orthoptera: Acrididae)
Sweetpotato hornworm	*Agrius convolvuli* Linnaeus	(Lepidoptera: Sphingidae)
Sweetpotato butterfly	*Acraea acerata* Hewitson	(Lepidoptera: Acraeidae)
Tortoise beetles	*Conchyloctenia sp.*, *Cassida sp.* and *Acrocassis sp.* Referred to as Cassidinae species throughout the study	(Coleoptera: Chrysomelidae)
Rough sweetpotato weevil	*Blosyrus sp.*	(Coleoptera: Curculionidae)
Armyworms	*Spodoptera spp.*	(Lepidoptera: Noctuidae)
Aphids‡ (e.g. green peach aphid)	*Myzus persicae* Sulzer	(Hemiptera: Aphididae)
Shiny leaf beetles‡	*Colasposoma spp.*	(Coleoptera: Chrysomelidae)
Stink bug‡	*Dorycuris paraninus* Westwood	(Hemiptera: Pentatomidae)
Root/tuber pests		
Mole-rats[#]		(Bathyergidae)
Millipedes[#]	*Narceus sp.*	(Spirobolidae)
Rough sweetpotato weevil*	*Blosyrus sp.*	(Coleoptera: Curculionidae)

*Adults feed both on leaves and tubers/roots, and larvae feed on tubers. [#] Not identified. ‡ Noted but were not included in the analyses.

Table 3.4 The median and range of damage on sweetpotato plants by several leaf pests at each of the two sites sampled in Lesotho in 1998. (Damage rating was based on a 1-5 scoring system where 1 = no damage, 2 = 1-25% damage on leaves, 3 = 26 –50%, 4 = 51-75% and 5 = 76-100% damage on leaves). Medians followed by similar letter in a column are not significantly different. Sampling was done on leaves for the first two surveys, and on tubers for the third survey. n = number of damaged plants and n for pooled data = the sum of damaged plants for the pooled surveys.

	Surveys					
Sites	Survey1		Survey2		Survey1 & 2 pooled	
MASERU						
	$H_{(4, 216)} = 132.54$, $p < 0.0001$	n	$H_{(4, 450)} = 353.96$, $p < 0.001$	n	$H_{(4, 666)} = 471.13$, $p < 0.001$	n
Bedellia sp.	2 (1,3)a	(51)	3 (1,4)a	(89)	2 (1,4)a	(140)
Locusts	0	(0)	1 (1,3)a	(15)	1 (1,3)a	(15)
Agrius convolvuli	1 (1,2)c	(19)	1 (1,2)b	(4)	1 (1,2)b	(23)
Acraea sp.	1 (1,3)c	(1)	1 (1,2)b	(2)	1 (1,2)b	(3)
Cassidinae spp.	1 (1,2)c	(1)	1 (1,2)b	(1)	1 (1,2)b	(1)
SILOE						
	$H_{(4, 360)} = 102.39$ $p < 0.0001$	n	$H_{(4, 360)} = 174.49$ $p < 0.001$	n	$H_{(4, 720)} = 270.82$ $p < 0.001$	n
Locusts.	1 (1,2)a	(40)	2 (1,2)a	(58)	1 (1,2)a	(98)
Bedellia sp.	1 (1,2)b	(19)	1.5 (1,2)b	(36)	1 (1,2)b	(55)
Agrius convolvuli	1 (1,2)c	(2)	1 (1,2)c	(3)	1 (1,2)c	(5)
Cassidinae spp.	1 (1,2)c	(2)	1 (1,2)c	(1)	1 (1,2)c	(3)
Blosyrus sp.	1 (1,2)c	(3)	1 (1,2)c	(5)	1 (1,2)c	(8)
BOTH (SILOE & MASERU)						
	$H_{(5, 576)} = 169.56$ $p < 0.0001$	n	$H_{(5, 811)} = 393.74$ $p < 0.0001$	n	$H_{(5, 1388)} = 539.10$ $p < 0.0001$	n
Bedellia sp.	2 (1,3)a	(70)	2 (1,4)a	(125)	2 (1,4)a	(195)
Locusts	2 (1,2)a	(40)	1 (1,3)a	(73)	1 (1,3)a	(113)
Agrius convolvuli	1 (1,3)b	(21)	1 (1,2)b	(7)	1 (1,3)b	(28)
Acraea sp.	1 (1,2)b	(1)	1 (1,2)b	(5)	1 (1,2)b	(3)
Cassidinae spp.	1 (1,2)b	(4)	1 (1,2)b	(2)	1 (1,2)b	(6)
Blosyrus sp.	1 (1,2)b	(3)	1 (1,2)b	(2)	1 (1,2)b	(8)

Table 3.5: The median and range of damage on sweetpotato plants by several sweetpotato pests at each of the six sites sampled in Lesotho in 1999. (Damage rating was based on a 1-5 scoring system where 1 = no damage, 2 = 1-25% damage on leaves, 3 = 26 –50%, 4 = 51-75% and 5 = 76-100% damage on leaves). Medians followed by similar letter in a column are not significantly different. n = number of damaged plants and n for pooled data = the sum of damaged plants for the pooled surveys.

	Surveys					
Sites	Survey1		Survey2		Survey1 & 2 pooled	
LERIBE						
	$H_{(2, 288)} = 90.21$ $p < 0.0001$	n	$H_{(2, 288)} = 98.07$ $p < 0.0001$	n	$H_{(2, 576)} = 175.16$ $p < 0.0001$	n
Locusts	2 (1,3)a	(79)	2 (1,3)a	(93)	2 (1,3)a	(172)
Bedellia sp.	1 (1,2)b	(27)	2 (1,3)b	(59)	1 (1,3)b	(86)
Agrius convolvuli	1 (1,2)c	(19)	1 (1,2)c	(26)	1 (1,2)c	(45)
TEYATEYANENG						
	$H_{(1, 140)} = 17.87$ $p < 0.0001$	n	$H_{(2, 210)} = 63.75$ $p < 0.0001$	n	$H_{(2, 420)} = 88.41$ $p < 0.0001$	n
Bedellia sp.	3 (1,4)a	(67)	3.5 (1,5)a	(67)	3 (1,5)a	(134)
Spodoptera sp.	0	(0)	3 (1,4)a	(60)	3 (1,4)a	(60)
Locusts	2 (1,3)b	(55)	2 (1,3)c	(57)	2 (1,3)b	(112)
MASERU						
	$H_{(4, 480)} = 255.84$ $p < 0.0001$	n	$H_{(6, 672)} = 395.16$ $p < 0.0001$	n	$H_{(6, 1152)} = 632.06$ $p < 0.0001$	n
Bedellia sp.	3 (1,5)a	(91)	3 (1,5)a	(95)	3 (1,5)a	(186)
Spodoptera. sp.	0	(0)	2 (1,4)b	(51)	2 (1,4)b	(51)
Locusts	2 (1,3)b	(54)	2 (1,3)b	(77)	2 (1,3)b	(131)
Cassidinae spp.	1 (1,3)c	(14)	1 (1,3)c	(38)	1 (1,3)c	(52)
Acraea sp.	1 (1,3)c	(12)	1 (1,2)d	(10)	1 (1,2)d	(22)
Agrius convolvuli	1 (1,2)c	(8)	1 (1,3)d	(7)	1 (1,3)d	(15)
Blosyrus sp.	0	(0)	1 (1,2)d	(1)	1 (1,2)d	(1)
QEME						
	$H_{(1, 192)} = 166.15$ $p < 0.0001$	n	$H_{(1, 192)} = 268.99$ $p < 0.773$	n	$H_{(1, 288)} = 329.06$ n.s.	n
Locusts	2 (1,4)a	(94)	2 (1,4)a	(96)	2 (1,4)	(190)
Agrius convolvuli	1 (1,2)b	(2)	1 (1,2)b	(2)	1 (1,2)	(4)
SILOE						
	$H_{(1, 288)} = 56.65$ $p < 0.0001$	n	$H_{(5, 576)} = 219.47$ $p < 0.0001$	n	$H_{(5, 864)} = 310.78$ $p < 0.0001$	n
Locusts	1 (1,4)a	(58)	2 (1,4)a	(57)	2 (1,4)a	(115)
Bedellia sp.	1 (1,2)b	(4)	1 (1,3)a	(39)	1 (1,3)a	(44)
Agrius convolvuli	0	(0)	1 (1,3)b	(2)	1 (1,3)b	(2)
Cassidinae spp.	0	(0)	1 (1,2)b	(1)	1 (1,2)b	(1)
Blosyrus sp.	0	(0)	1 (1,2)b	(1)	1 (1,2)b	(1)
Spodoptera. sp.	0	(0)	1 (1,2)b	(2)	1 (1,2)b	(2)
LIPHIRING						
	$H_{(1, 180)} = 15.15$ $p < 0.0001$	n	$H_{(1, 180)} = 15.15$ $p < 0.0001$	n	$H_{(1, 360)} = 30.34$ $p < 0.00001$	n
Locusts	1 (1,2)a	(39)	1 (1,2)a	(39)	1 (1,2)a	(78)
Bedellia sp	1 (1,2)b	(15)	1 (1,2)b	(15)	1 (1,2)b	(30)

Table 3.6: The median and range of damage of each pest at different sampling sites surveyed for sweet potato pests in Lesotho in 1999. (Damage rating was based on a 1-5 scoring system where 1 = no damage, 2 = 1-25% damage on leaves, 3 = 26–50%, 4 = 51-75% and 5 = 76-100% damage on leaves). Medians followed by similar letter in a column are not significantly different. n = number of damaged plants and n for pooled data = the sum of damaged plants for the two surveys.

	Surveys					
Pests	Survey1		Survey2		Survey1 & 2 pooled	
Bedellia sp.						
	$H_{(4, 448)} = 296.88$	n	$H_{(4, 448)} = 283.39$	n	$H_{(4, 896)} = 547.98$	n
	$p < 0.0001$		$p < 0.0001$		$p < 0.0001$	
Maseru	3 (1,5)a	(91)	3 (1,5)a	(95)	3 (1,5)a	(186)
TY	3 (1,4)a	(67)	3.5 (1,5)a	(67)	3 (1,5)a	(134)
Leribe	1 (1,2)b	(27)	2 (1,3)b	(59)	1 (1,3)b	(86)
Siloe	1 (1,2)b	(4)	1 (1,3)bc	(39)	1 (1,3)bc	(43)
Liphiring	1 (1,2)b	(15)	1 (1,2)c	(15)	1 (1,2)c	(30)
Locust						
	$H_{(5, 544)} = 81.10$		$H_{(5, 544)} = 157.74$		$H_{(5, 1088)} = 212.40$	
	$p < 0.00001$		$p < 0.0001$		$p < 0.00001$	
Qeme	2 (1,4)a	(94)	2 (1,4)a	(96)	2 (1,4)a	(190)
TY	2 (1,3)ab	(70)	2 (1,3)bc	(57)	2 (1,3)bc	(112)
Leribe	2 (1,3)bc	(93)	2 (1,3)b	(96)	2 (1,3)b	(172)
Siloe	2 (1,4)bc	(58)	2 (1,4)c	(57)	2 (1,4)c	(115)
Maseru	2 (1,3)cd	(54)	2 (1,3)bc	(77)	2 (1,3)bc	(131)
Liphiring	1 (1,2)d	(39)	1 (1,2)d	(38)	1 (1,2)d	(78)
Agrius convolvuli						
	$H_{(2, 288)} = 17.04$		$H_{(3, 384)} = 45.60$		$H_{(3, 768)} = 77.37$	
	$p < 0.0002$		$p < 0.00001$		$p < 0.00001$	
Leribe	1 (1,2)a	(19)	2 (1,3)a	(26)	1 (1,3)a	(45)
Maseru	1 (1,2)ab	(8)	1 (1,3)b	(7)	1 (1,3)b	(15)
Qeme	1 (1,2)b	(2)	1 (1,2)c	(2)	1 (1,2)b	(4)
Siloe	0	(0)	1 (1,2)b	(1)	1 (1,2)b	(1)
Cassidinae spp.						
	—		$H_{(1, 192)} = 43.73$		$H_{(1, 288)} = 28.76$	
			$p < 0.0001$		$p < 0.00001$	
Maseru	1 (1,2)	(14)	1 (1,3)a	(38)	1 (1,3)a	(52)
Siloe	0		1 (1,2)b	(1)	1 (1,2)b	(1)
Blosyrus sp.						
			$H_{(1, 192)} = 0.0001$			
			n.s.			
Maseru	0	0	1 (1,2)	(38)	—	
Siloe	0	0	1 (1,2)	(1)	—	
Spodoptera sp.						
			$H_{(2, 262)} = 126.89$			
			$p < 0.0001$			
TY	0	0	3 (1,4)a	(60)	—	
Maseru	0	0	2 (1,4)b	(51)	—	
Siloe	0	0	1 (1,2)c	(2)	—	

Table 3.7: Pest damage (median and range) observed on the tubers of sweetpotato plants during the 1998/99 pest survey at six sites in Lesotho. (Damage rating on tubers was based on 1-5 scoring basis where 1 = 0% damage, 2= 1-25%, 3 = 26-50%, 4 = 51-75 and 5 = 76-100% damage). Medians followed by similar letter within a column indicate insignificant difference.

	Median (range)	no. of damaged plants	N
1998 root survey (3rd)			
MASERU#			
	$H_{(1, 180)} = 2.061$ n.s.		
Millipedes	1 (1,2)	17	90
Blosyrus sp.	1 (1,2)	4	90
1999 root survey (3rd)			
SITE COMPARISON			
Millipedes			
	$H_{(5, 544)} = 168.65$ $p<0.001$		
Leribe	1 (1,5)b	7	96
TY	1 (1,2)b	3	70
Maseru	1 (1,2)a	55	96
Qeme	1 (1,2)b	9	96
Siloe	1 (1,5)a	49	96
Moles*			
Siloe	1 (1,5)	50	96
PEST COMPARISON			
	$H_{(1, 550)} = 50.12$ $P<0.0001$		
Moles	1 (1,5)a	50	96
Millipedes	1 (1,5)b	123	454
1998 & 1999 (pooled)			
PEST COMPARISON			
	$H_{(2, 640)} = 92.66$ $p<0.0001$		
Moles	2 (1,5)a	50	96
Millipedes	2 (1,5)b	140	454
Blosyrus sp.	2 (1,2)c	4	90

*moles were recorded only at Siloe. #Damage on tubers was observed only at Maseru in 1998.

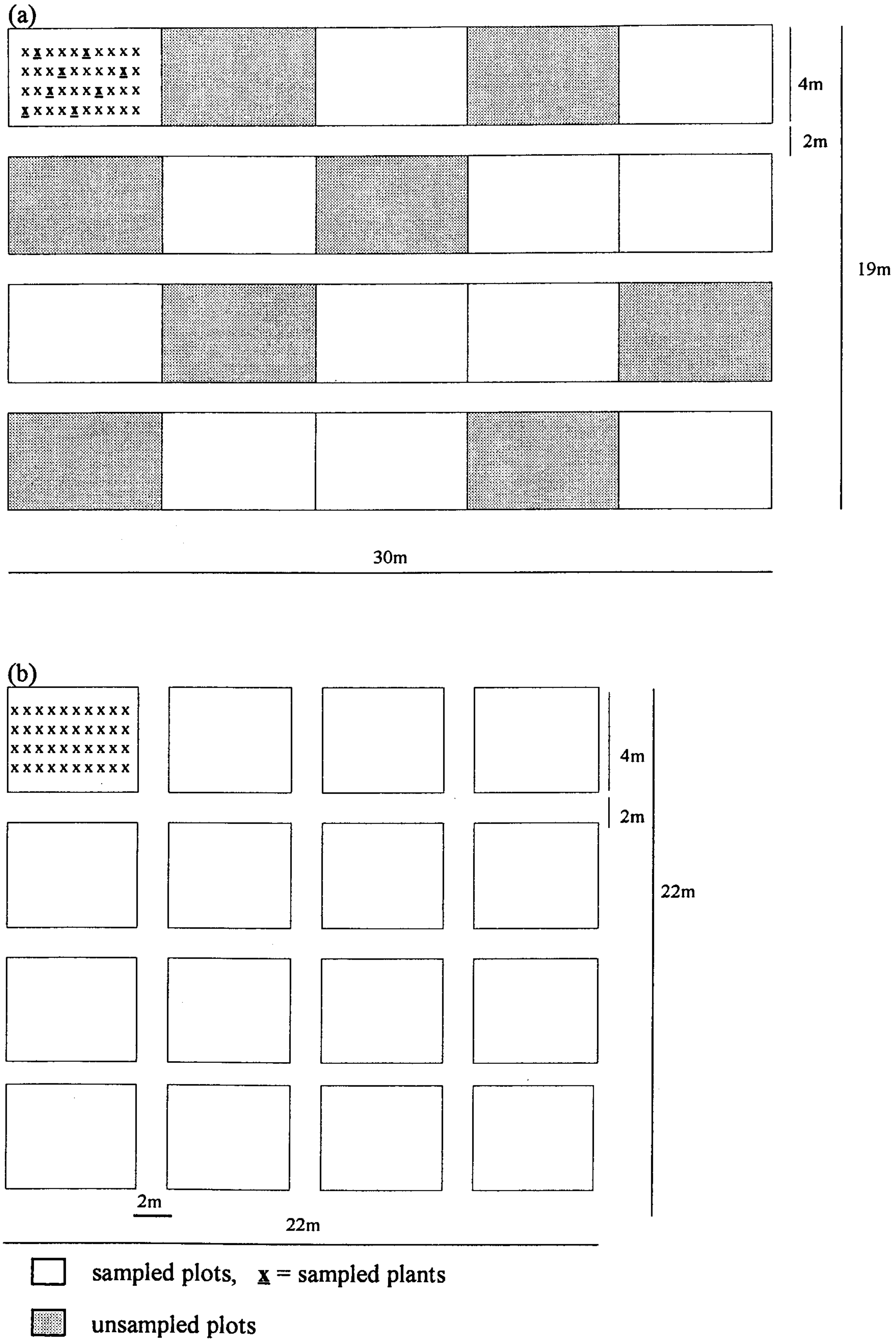
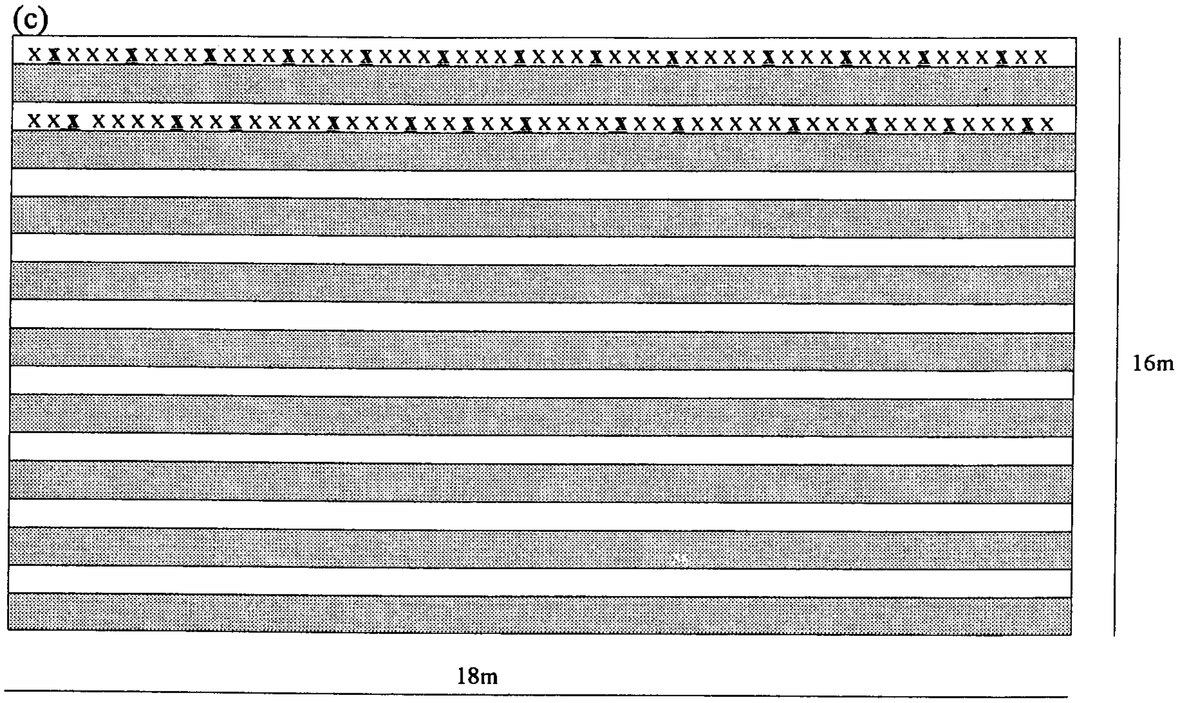


Fig. 3.1: Field layout for (a) Siloe, (b) Maseru as an example of all other fields except Liphiring, Siloe and TY. (c) Liphiring and Teya-teyaneng (TY), Liphiring used as an example.



☐ sampled lines, x = sampled plants

▨ spaces between lines

Fig. 3.1: (cont.).

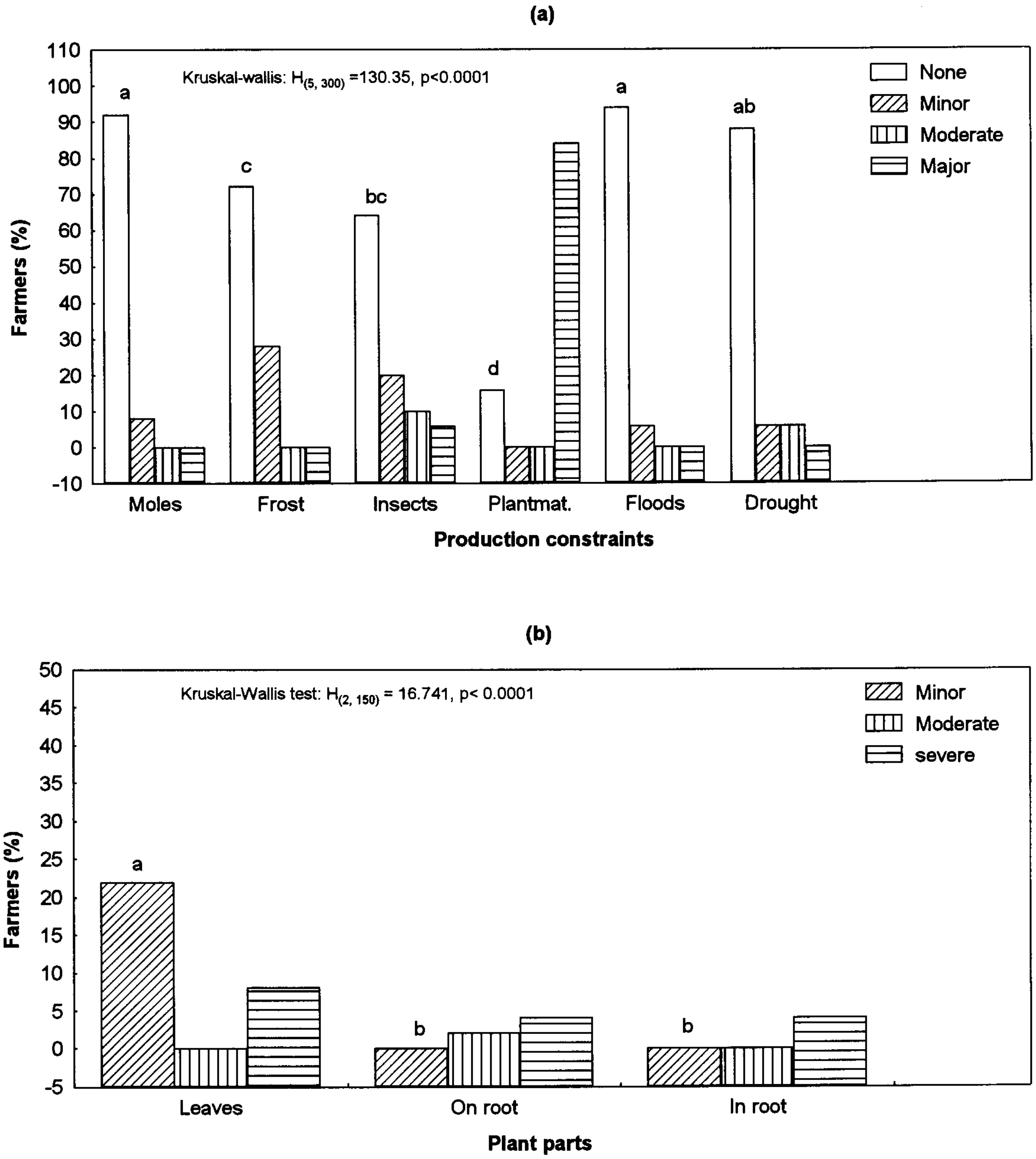


Fig. 3.2: (a) Percentage of famers who (a) listed particular sweetpotato production constraints in Lesotho and the severity of occurrence of each constraint. (b) The severity of damage of the insect pests on various parts of the crop rated by those farmers who listed insect pests as production above. No significant difference between constraints with similar letters above their bars.

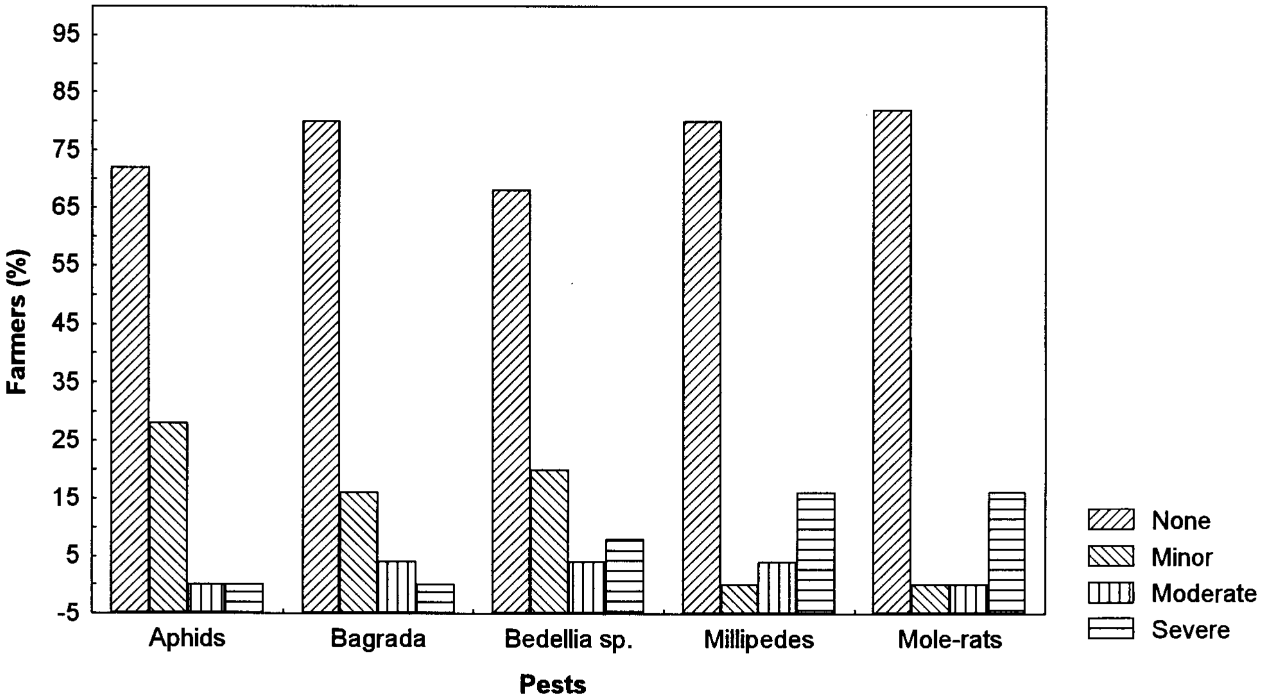


Fig. 3.3: Percentage of farmers who listed the pests they had observed on sweetpotato plants and the extend of damage due to each pest on the crop.

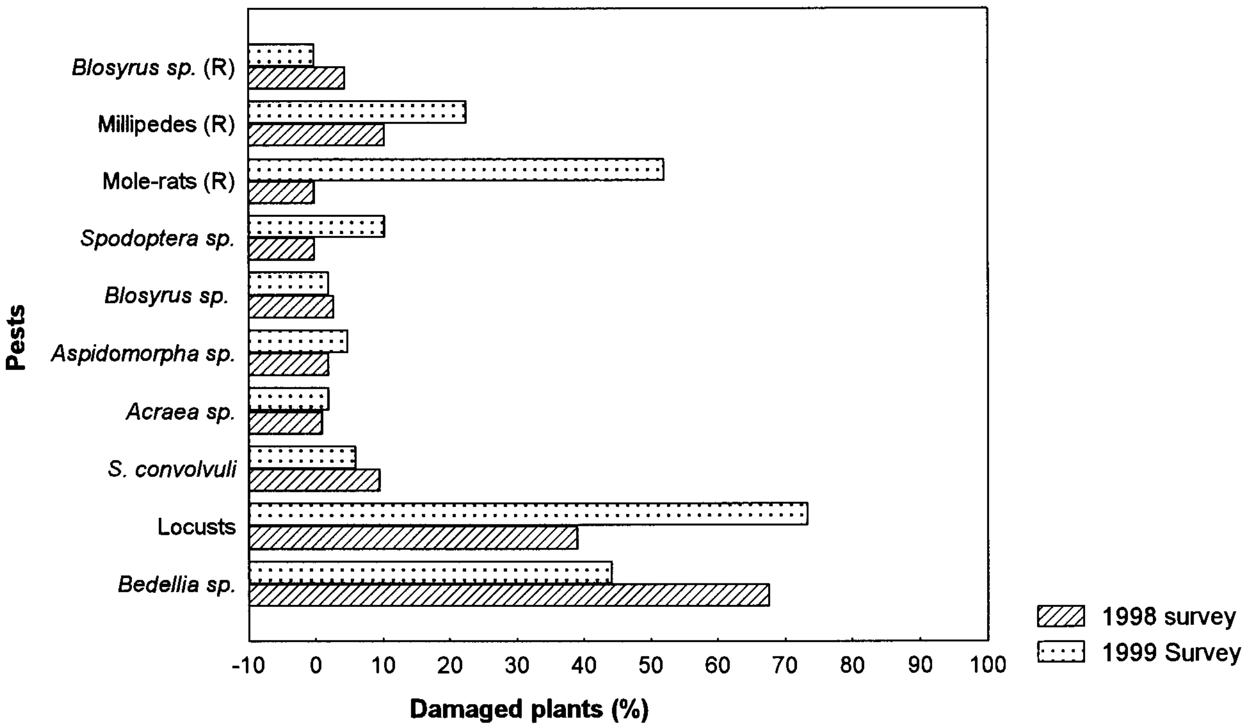


Fig 3.4: Percentage occurrence of all pests on sweetpotato recorded during the 1998/99 pest survey at six different sites in Lesotho. R = root/tuber pests, others are leaf-feeding pests. n (total number of plants) = 576 for 1998 and 1088 for 1999.

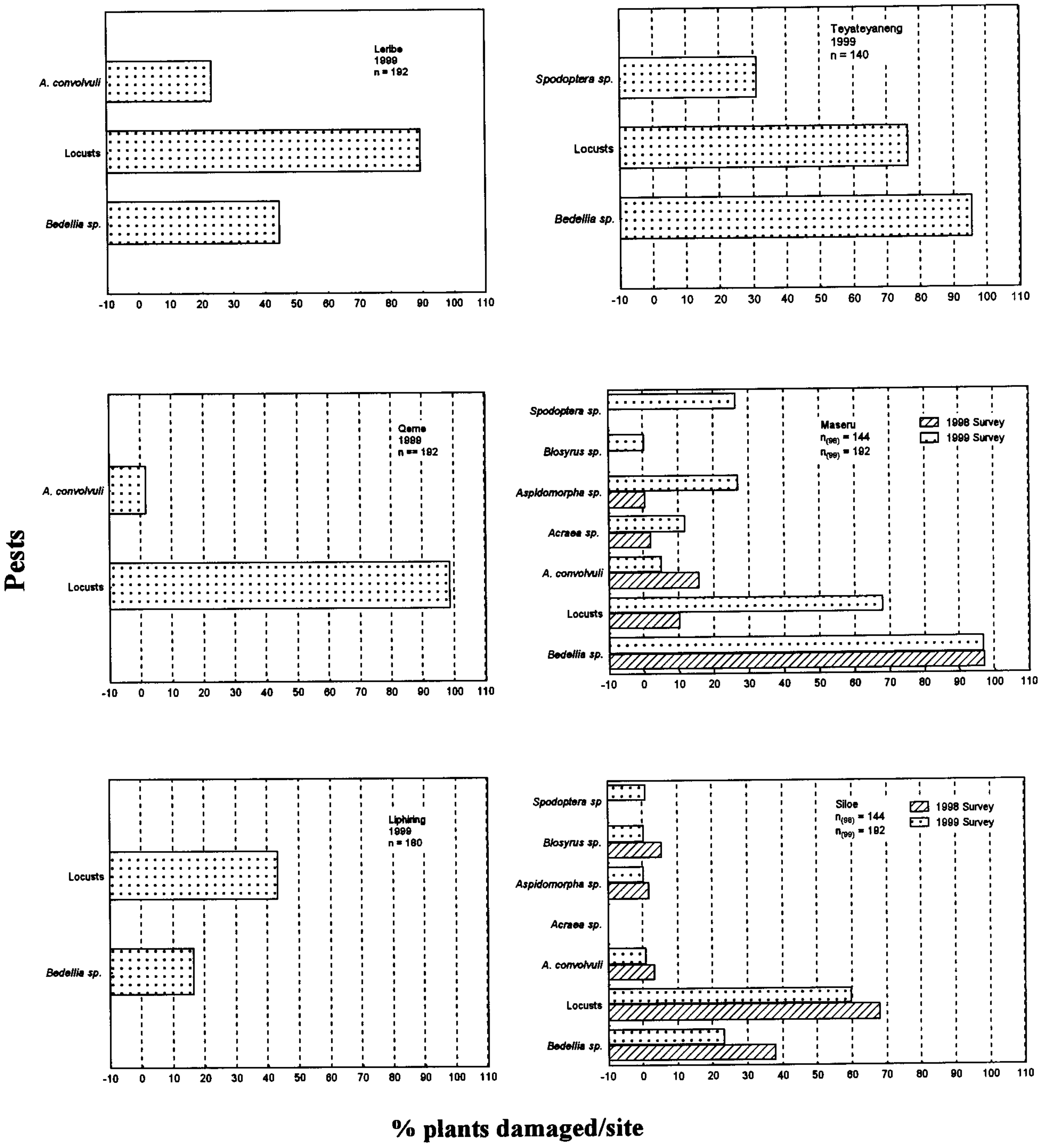


Fig 3.5: The number (percentage) of sweet potato plants attacked by different leaf insect pests at each site for the survey in both 1998 and 1999. Two sites (Maseru & Siloe) were surveyed in 1998. n = number of plants sampled multiplied by two because sampling was carried out twice. $n_{('98)}$ and $n_{('99)}$ = number of plants sampled in 1998 and 1999 respectively.

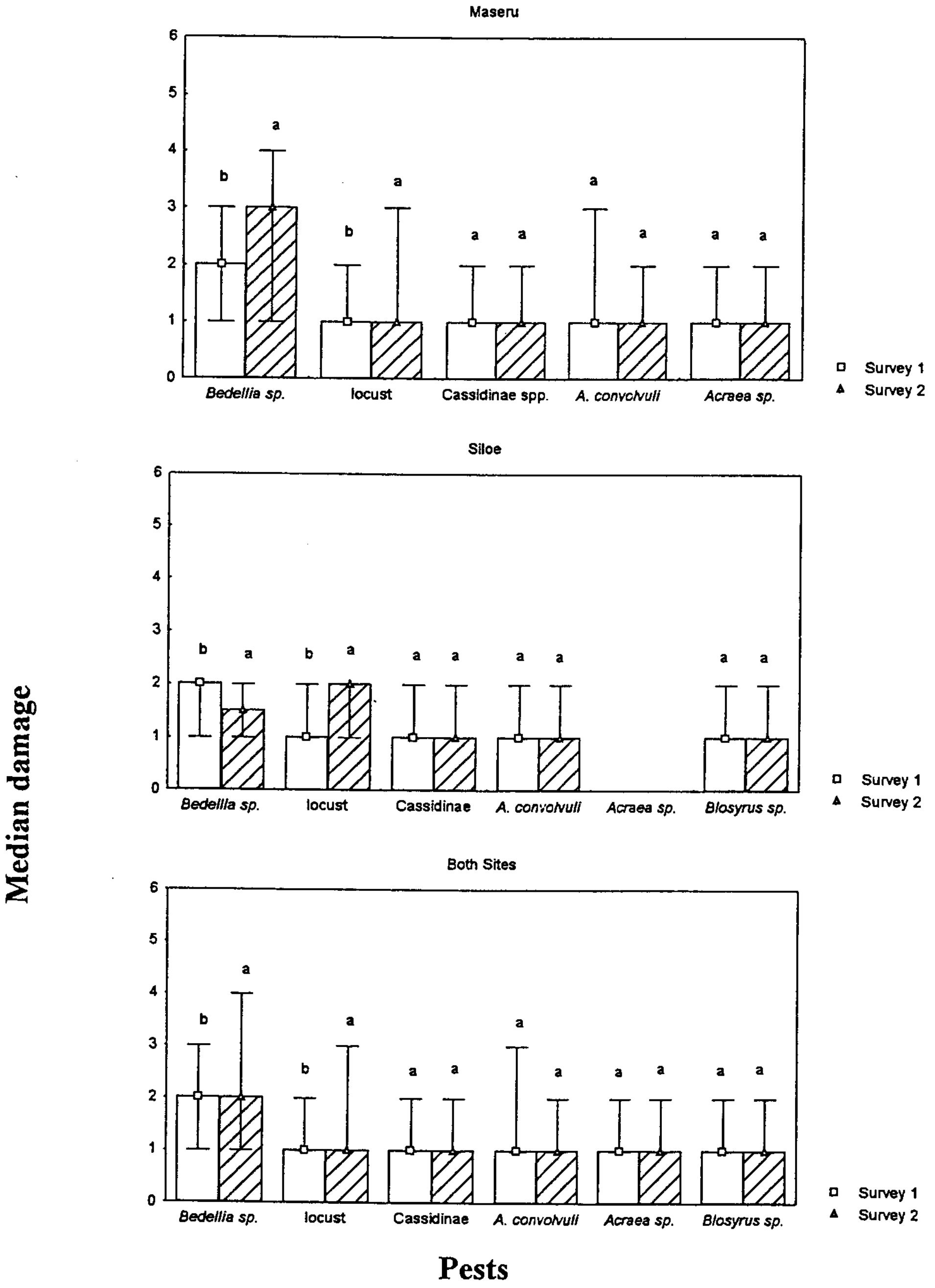


Fig. 3.6: The severity of damage on the leaves by different sweetpotato pests recorded during the 1998 field survey. Open bars = first sampling period and hashed bars = second sampling period. Differences in damage between the two sampling times were tested with Friedman analysis of variance. Similar letter for bars of one pest indicates no significant difference. (Damage was scored on a 1-5 scoring system where 1=0% damage, 2=1-25%, 3=26-50%, 4=51-75% and 5=76-100% damage). Error bar = Max. and min. rating. *A. convolvuli* = *Agrius convolvuli*.

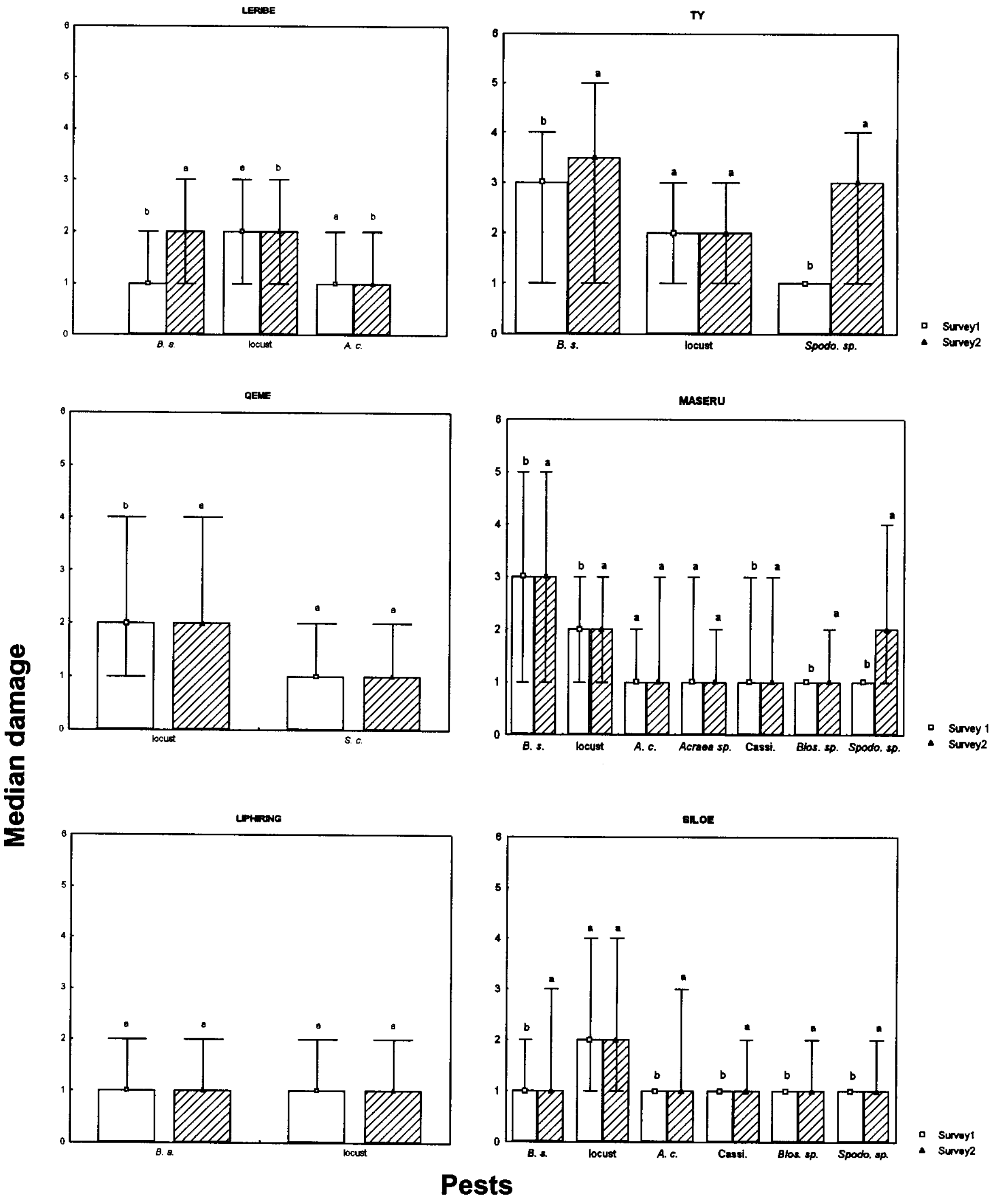


Fig 3.7: The severity of damage on the leaves by different sweetpotato pests recorded during the 1999 field survey of six sites in Lesotho. Open bars = first sampling period and hashed bars = second sampling period. Difference tested with Friedman analysis of variance Similar letter for bars of one pest indicates no significant difference. (Damage was scored on a 1-5 scoring system where 1=0% damage, 2=1-25%, 3=26-50%, 4=51-75% and 5=76-100% damage). Error bar = Max-Min. *B.s.= Bedellia somnulentella*, *A.c.* = *Agrius convolvuli*, *Spodo. sp.= Spodoptera sp.*, *Aspido. sp. Aspidomorpha sp.*, and *Blos. sp.* = *Blosyrus sp.*

Appendix 1

Questionnaire for the survey of constraints/problems in sweet potato production in Lesotho

Questions	**Answers**
1. Agro-ecological zone	1. Lowlands 2. Foothills 3. Highlands
2. Altitude	1.1500 – 1800m 2. 1801 – 2050m 3. >2050
3. Farmer's gender	1. Female 2. Male
4. Farmer's age (years)	1. 15-25 2. 26-40 3. 41-60 4. >60
5. Farmer's experience with growing sweet potato (years)?	1. <1yr 2. 1-5 yrs 3. 5-10 yrs 4. >10 yrs
6. Terrain	1. Flat 2. Slight slope 3. Steep slope
7. Soil type	1. Heavy soil (easily cracks) 2. Medium soil 3. Light soil (does not crack)
8. Planting method	1. Ridges 2. Mounds 3. Beds 4. Flat
9. Field/plot size	1. <10m^2 2. >10 m^2<30 m^2 3. >30 m^2
10. Do/did you practice intercropping of sweet potato	1. Yes 2. No
11. Do/did you apply anything to the sweet potato?	1. Nothing 2. Manure (animal dung) 3. Fertilize 4. Don't know
12. How many varieties of sweet potato do/did you grow in your plot?	1. One 2. Two 3.Three 4. Don't know

Appendix 1 (cont.)

13. When did you plant this sample plot or the last sample plot?	1. August 2. September 3. October 4. November 5. December 6. January 7. February
14. When will/did you harvest?	1. January 2. February 3. March 4. April 5. May 6. June 7. Did not harvest
15. How do/did you harvest?	1. Piecemeal 2. Portion by portion 3. All crop at once 4. Did not harvest
16. What did you plant in the sample plot last season or the season before that?	1. Cereal 2. Legumes 3. Sweet potatoes 4. Vegetables 5. Field lay fallow
17. What part do you use as the planting material?	1. Tip cutting only 2. All sections of vine 3. Whole vine 4. Root sprouts
18. Where do you get your planting material?	1. Own fields 2. Neighbours 3. Research station 4. Other (RSA)
19. How many times do/did you weed per year?	1. Zero times 2. Once 3. Twice 4. Thrice 5. Four times
20. How many times do/did you rehill per year?	1. Zero times 2. Once 3. Twice 4. Thrice 5. Four times
21. How do/did you use your tubers?	1. Home consumption 2. Selling 3. Did not use (not harvested)
22. What do/did you do with your vines	1. Left in the field 2. Fed to animals 3. Not applicable (not harvested)

Appendix 1 (cont.)

23. Looking back on all the seasons that you grew sweet potato, what constraints or problems do/did you face and rate their severity (1-4 where 1=none and 4 = severe)

1. Mole-rats
2. Insects
3. Frost
4. Lack of planting material
5. Flooding
6. Drought
7. Others (such as other small or big animals, thieves etc)

24. For insect damage, where do/did you see it, and how severe is/was it?

	None	Slight	Moderate	Severe
1. On the leaves	1	2	3	4
2. On/in the stem	1	2	3	4
3. On the outside of the root	1	2	3	4
4. Inside the root	1	2	3	4

25. Is there a particular season when you noticed more insect damage?

1. Dry season
2. Rainy season
3. No difference
4. Don't know

26. (a) Do/did you take any control measures?

1. Yes
2. No

26. (b) If yes, what measures do/did you take?

1. Pesticide application
2. Handpicking

27. Do you store tubers?

1. Yes
2. No

28. List the insect pests that you know, and rate them according to the severity of damage on sweetpotato.

1. Aphids (Aphididae)
2. Beetles (*Bagrada* sp.)
3. Leaf miners (*Bedellia sp.*)
4. Millipedes (*Narceus sp.*)
5. Mole-rats (Bathyergids)

Appendix 2

A Summary of the Questionnaire survey results. Number of times a particular response was recorded

Question no.	Answers							
	0	1	2	3	4	5	6	7
1		30	10	10				
2		30	10	10				
3		27	23					
4		1	12	25	12			
5		25	24	1	0			
6		22	17	11				
7		14	23	13				
8		35	5	10				
9		19	30	1				
10		0	50					
11		33	14	3				
12		23	27	0				
13		3	3	5	21	9	3	5
14		1	0	4	22	8	1	14
15		6	0	30	14			
16		1	2	0	43	3	2	
17		48	2	2	2			
18		7	5	46	2			
19	3	14	21	3	9	3		
20	3	14	23	9	0			
21		32	0	18				
22		49	2					
23		3	18	14	42	3	6	3
24		16	0	4	0			
25		2	0	15	33			
26		3	47					
27		1	49					
28		8	4	9	4	5		

Appendix 2 (continued).

	Severity ratings for answers to questions 23, 24 and 28			
	1	2	3	4
23.				
1	47	0	0	3
2	32	10	5	3
3	36	0	0	14
4	8	0	0	42
5	47	0	0	0
6	44	0	3	3
7	47	0	3	0
24.				
1	N\A	12	4	0
2	N\A	0	0	0
3	N\A	0	1	3
4	0	0	0	0
25.				
1	N\A	5	3	0
2		3	1	0
3		8	1	0
4		1	1	2
5		5	0	0

N.B. Answers for Questions 1-3 were not from farmers.

CHAPTER 4

Summary and Recommendations

Summary

In this study, the most important insect pest of sweetpotato worldwide, *Cylas* species, were not found. Instead the study revealed numerous other pests of sweetpotato in Lesotho. The survey, which was conducted in the form of both questionnaire and field-based sampling, did not reveal any insect species that could yet warrant pest status. Numerous leaf-feeding pests were recorded and among them pests such as leaf miners (*Bedellia somnulentella* Zeller), locusts and grasshoppers (including *Zonocerus elegans* and *Zonocerus variegatus*), and armyworms (*Spodoptera sp.*) can be quoted because of some significant damage they caused on leaves.

Locusts displayed a widespread occurrence although generally their damage was very low. Although damage by leaf miners was highest in some areas an increased leaf feeding was observed towards harvesting period. Only three root pests were recorded in this study and these were mole-rats, millipedes and *Blosyrus sp.* Damage by mole-rats was conspicuous, while damage by millipedes was very minor although the pest was more widespread than others. Damage by *Blosyrus sp.* on the roots was recorded on only two plants throughout the sampling survey.

Other leaf-feeding pests such as *Colasposoma* sp., aphids and others that feed on other cultivated crops were also observed. However, the recorded pests whose damage was assessed in the study are common pests of this crop but their damage is usually minor. They normally don't cause a significant damage except in cases of outbreaks.

Although, *Cylas* species were not recorded in this study the study revealed that it is possible for *Cylas puncticollis* to establish in Lesotho given the temperature requirements of the pest calculated from the laboratory. The thermal needs of this species were estimated by the linear regression method. The lower temperature threshold of the total development of the pest lies between 8°C and 12°C. The thermal constant for the pest was estimated to be between 360°d and 380°d.

The thermal needs of this pest were used to predict the potential for its establishment in Lesotho as well as determining the possible areas of distribution if it invades Lesotho. The linear degree-day model coupled with climate matching approach in GIS revealed that *Cylas puncticollis* is a potential pest in Lesotho. The former predicted the potential occurrence of this pest throughout the whole country with a maximum of eight generations per year being possible in the lowlands. Although fewer generations (two to three) were estimated for both highlands and foothills, it is clear that this pest has high establishment potential throughout Lesotho. The GIS approach confirmed the prediction, although according to this method a patchy distribution of the pest was predicted.

Recommendations

Based on the whole study the possibility of *Cylas puncticollis* establishing in Lesotho should it invade that country has addressed the most important objective of this study. There seems to be no area that will be immune to this pest in Lesotho. As a result strong pest management practices will have to be used to prevent the invasion of this pest. These will include first of all the use of stringent quarantine measures both within and between countries. There is free-trade between South Africa and Lesotho mainly through the informal border gates. Usually there is an interchange of anything between these two countries and control is therefore going to be very difficult. As a result thorough training of farmers will be necessary to make them aware about the pest and its potential impact on sweetpotato production. Farmers should also be made aware that the major infestation and transfer mode of the sweetpotato weevils is by planting material. Therefore, wherever possible farmers should avoid acquiring their planting materials from South Africa because they might come across infested tubers.

While the issue of *Cylas spp.* being the potential production constraint if they invade Lesotho has been given more weight in this study, it is obvious that the study did not address the most pressing issue that is currently affecting large scale production of this crop in Lesotho. Therefore the foremost recommendations would be to ensure wider adoption of the crop in the country by addressing lack of planting material. The lack of planting material could be addressed by providing training to the farmers on how to keep their planting material for the next season. Furthermore, the usual practice of using vines as planting material would probably have to be changed. The tubers have been recommended in cold areas as the best method because vines are more prone to frost damage hence tubers can play a better role in this case. Therefore, further research is necessary in this approach to couple it with the vine cuttings so as to evaluate which method is more suitable for the conditions in Lesotho.

Until now it seems as though more efforts of sweetpotato production in Lesotho should be more oriented towards agronomic problems than pest problems. However, the study will serve as a guideline towards the potential pest problem in the country. It has also identified the sweetpotato pests that are present in the country; an exercise that has not been taken before on the crop as the crop is still among the newly introduced crops.

The following paper, which is part of this work was send for publication to the African Entomology.

Nteletsana, L. Schoeman, A.S. & McGeoch, M.A. Temperature Effects on development and survival of the sweetpotato weevil, *Cylas puncticollis* Boheman (Coleoptera: Apionidae).