Mango production practices and assessment of chemical and physical barriers in the management of mango seed weevil in Mbeere District

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DECLARATION

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

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This thesis is dedicated to my wife Catherine and son Antony

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LIST OF ABBREVIATIONS AND ACRONYMS

AICAD	African Institute for Capacity Development
CAIS	Carribean Agricultural Information Service
C.A.N	Calcium Ammonium Nitrate
FPEAK	Fresh Produce Exporters Association of Kenya
HCDA	Horticultural Crops Development Authority
ICIPE	International Centre for Insect Physiology and Ecology
IPM	Integrated Pest Management
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KARI	Kenya Agricultural Research Institute
KEPHIS	Kenya Plant Health Inspection Service
NAPPO	North American Plant Protection Organisation
N.P.K	Nitrogen Phosphorus Potassium
USDA	United States Department of Agriculture

ABSTRACT

Studies were undertaken in Mbeere district to determine farming practices among mango farmers including crop protection activities aimed at controlling general pests of mangoes as well as the Mango seed weevil *Sternochetus mangiferae* (F). This was done by carrying out a baseline survey in two divisions of Mbeere District, Eastern province of Kenya where mango growing is an important farming activity. Among the mango farmers in Mbeere District, the spacing arrangements were mostly as practiced in other mango growing areas of the country. On manure application, majority of the farmers did so at planting although a substantial proportion applied it once every per year. Fertilizer was mostly applied once per year while majority of the farmers practiced irregular pruning. Mango was recognised by majority of the farmers as the most important crop enterprise in terms of financial returns. Application of foliar insecticidal sprays was important in the control of both *S. mangiferae* and other general pests of mangoes. Pest and diseases were recognised as major production constraints.

Studies on use of physical and chemical barriers for the control of *S. mangiferae*, were carried out in three sites in the district. The studies indicated that Tanglefoot, Chlorpyrifos, Grease and Tangletrap as well as combination of Chlorpyrifos with the physical barriers were the most effective. Dimethoate as a foliar spray showed poor control. This finding was consistent in all sites and in all months.

Studies on the efficiency of control of *Sternochetus mangiferae* using Chlorpyrifos was undertaken in three sites in the district. These showed that efficiency of control depends

on frequency of application. The most effective frequency determined was once per month. At once every two months and once every three months, the damage level increased drastically. Sanitation plays an important role in the management of *S. mangiferae* but this has to be combined with other practices such as trunk application of Chlorpyrifos or Grease. Agronomic practices are not followed according to recommendations and there is therefore need to embark on serious technology dissemination work among mango farmers. Pest management in mango orchards is still largely dependent on foliar application of pesticides. There is also need to expose farmers to other proven alternatives such as trunk band application of Chlorpyrifos or Grease. The former when applied once per month proved to be very effective in the management of the Mango seed weevil under different orchard management conditions. There is need to evaluate other management options for *Sternochetus mangiferae* such as use of the predaceous "Maji moto ant", *Oecophylla longinoda* Latr. in an effort to give farmers a broad spectrum of control strategies.

CHAPTER 1

1.0 INTRODUCTION AND LITERATURE REVIEW

1.1 Origin and distribution of Mango.

The centre of origin and diversity of the genus Mangifera is regarded as Southeast Asia but the origin of the mango *Mangifera indica* L has been a matter of speculation for years (Douthett, 2000). Available records, however, indicate that *M. indica* is probably native to Southern Asia, especially eastern India, Burma and the Andaman Islands (Anon, 2007; Anon, 2006; Douthett, 2000; Mukherjee, 1997; Morton, 1987).

Cultivation of Mangoes in the Indian sub-continent has been ongoing for over 4000 years and the fruit has been a favourite of kings and commoners because of its nutritive value, taste, attractive fragrance and health promoting qualities (Anon; 2007). Organised cultivation of mangoes in India is associated with the Mughal Emperor Akbar (1556-1605) who planted about 100,000 mango trees in an orchard near Darbhanga in Lakh Bagh, India (Anon, 2007; Snyman, 1998; Mukherjee; 1997).

The distribution and spread of mangoes to other parts of the world occurred at different times through the agency of travelers and traders (Mukherjee, 1997). Hwen Sang a Chinese traveler, visited India between 632 and 645 AD and was the first person to take mango to the outside world (Anon, 2007). Previously, Buddhist monks are believed to have taken the mango on Voyages to Malaya and eastern Asia in the 4^{th} and 5^{th} centuries B.C (Morton, 1987).

Introduction of the mango to East Africa is believed to have been done by the Persians about the 10^{th} century A.D. It is recorded to have been grown in Eastern Somalia by AD

1331 (Anon, 2007; de Villiers, 1998; Snyman, 1998; Morton, 1987). Later on, the mango spread to the rest of the world such as Philippines (1600), Mexico (1778), Hawaii (1809), Florida (1861), West Africa (1864) and California (1880) (Anon, 2007; Anon, 2006; Rey *et al.,* 2006; Murkherjee, 2003; Griesbach, 2003; Snyman, 1998; Morton, 1987; Kiarie, 1986).

1.2 Importance of Mangoes in Kenya

Mango, one of the most important tropical fruits grown in Kenya was introduced in the coastal region by ivory and slave traders during the 14th century (Griesbach, 2003). Cultivation is mainly by small scale farmers with orchards ranging from a few trees to about 500 (MOA, 2000). In the last twenty years, a few individual farmers and private companies have established bigger orchards of between 20 and over 100 hectares (HCDA, 2004). Mango production area in the country has increased tremendously from 500 hectares in 1970 to about 21,264 hectares in 2006 (MOA, 2006; Griesbach, 2003).

The main mango production areas include Eastern, Coast and Nyanza provinces which in 2006 produced 93,343, 27,199 and 18,656 metric tonnes respectively (MOA, 2006). This production is for both domestic and foreign markets (MOA, 2006; Griesbach, 2003). In terms of total volume of fruits, mango production at 183,486 metric tones in 2005 is ranked third after bananas and pineapples whose corresponding figures for the same year were 1,006,870 and 393,712 metric tones respectively (MOA, 2006). In terms of earnings, mango has retained third position among the fruit crops grown in Kenya (MOA, 2006). In 2006 the total earnings from domestic and local markets stood at Kenya shillings 1.057b (MOA, 2006). This compares favourably with both bananas and pineapples whose corresponding figures were Kenya shillings 9.298b and 1.483b respectively. The total production value for all the fruits in the same year was 16.4b (MOA, 2006).

1.3 Important mango cultivars grown in Kenya.

Two types of *Mangifera indica* are distinguishable on the basis of their mode of reproduction and their respective centres of diversity. These two types are (a) a subtropical group with mono-embryonic seed (Indian type) and (b) a tropical group with a poly-embryonic seed (Southeast Asia type), (Griesbach, 2003; Fivaz, 1998; Mukherjee, 1997). Fruits from the original mango trees were small with scant fibrous flesh but it is believed that natural hybridization occurred between *M. indica* and *M. sylvatica* in Southeast Asia resulting in a multitude of hybrids (Morton, 1987). Selection for higher quality has been carried out for about 4000-6000 years and vegetative propagation for 400 years (Anon, 2007; Douthett, 2000; Fivaz, 1998; Morton, 1987. Currently there are about 500-1000 varieties described from India (Jedele *et al.*, 2003; Morton, 1987). In the 111 countries that grow mango in the world, different cultivars are encountered, but some are more popular than others depending on their characteristics (Anon, 2007; Anon, 2006; Griesbach, 2003 Fivaz, 1998).

In Kenya, there are two types of mangoes, the most dominant being the “local cultivars” mostly raised from seed and not vegetatively propagated. These are widespread throughout the country and are popular in the domestic market (MOA, 2002; 2001). The second group is the elite cultivars that were introduced in the 1970’s and 1980’s. These are mostly vegetatively propagated and their fruits are popular in both the domestic and the international markets. Cultivars in the latter group include Apple, Haden, Keitt, Van Dyke, Kensington, Ngowe, Kent, Tommy Atkins and Sensation (MOA, 2006; 2005; 2004; 2003; Griesbach, 2003; Human and Snyman, 1998; Knight, 1997; Morton, 1987). Fruits from these latter cultivars form the bulk of the mango exports to Europe and the Middle East countries (HCDA, 2006; Griesbach, 2003; Jedele e*t al.*, 2003; Morton, 1987).

1.4 Uses of mangoes.

The mango is one of the most delicious fruits of the world and is rightly designated as the "king of fruits" (Anon, 2006). The fruit is a large, freshy drupe with an edible mesocarp of varying thickness. The fruit colour is dependent on the genotype and ranges from green, greenish yellow, yellow and red blush (Douthett, 2000). In terms of food value, the mango compares favourably with other tropical and temperate fruits. It contains vitamins A, C, E, K and B-complex as well as many essential minerals such as Potassium, Copper, Selenium, Magnesium, Phosphorus, Zink, Calcium, Sodium and Manganese (Griesbach, 2003; Nanjundaswamy, 1997)

The mango is generally consumed as a fresh fruit but is also processed into various products such as jam, squash, mango juice, chutney, and pickle (achar) (Anon, 2006; Nanjundaswamy, 1997; Morton, 1987). In addition to the nutritive value, the seed kernel is used as feed for poultry and cattle, the wood for rafters and joists, window frames, shoe hills and crates, the bark for tannin extraction, the gum as a substitute for gum Arabica where it is employed as an adhesive, surfactant and emulsifier in food, chemical and textile industries. The dried flowers serve as astringents for diarrhorea, chronic dysentery, catarrhal of the bladder and chronic urethritis (Douthett, 2000; Colyn, 1997; Nanjundaswamy, 1997; Morton, 1987; Kiarie, 1986).

1.5 Pests of Mangoes

The mango, like all cultivated crops is attacked by some very key pests, others secondary and a large number of occasional pests in localized areas where the crop grows (Pena and Mohyuddin, 1997). World wide, the mango is a host to 260 species of insects and mites among which 87 are fruit feeders, 127 foliage feeders, 36 inflorescence feeders, 33 bud feeders and 25 branch and trunk feeders (Toledo *et al*., 2006; Joubert, 1998; de Villiers and Steyn, 1998; Pena and Mohyuddin, 1997; Morton, 1987). In the different parts of the world where mango is cultivated, the spectrum of pests has been identified and listed. Some of these lists contain both the life histories and control measures for the different pests (Pena and Mohyuddin, 1997)

In India, South Africa and Hawaii, the Mango seed weevil *Sternochetus* (*Cryptorhynchus*) *mangiferae* (Fabricius) and the Pulp weevil *Sternochetus gravis* (Fabricius) are both major Coleopteran pests while the fruitflies *Dacus ferrugineus* (Fabricius) and *Dacus zonatus* (Saunders) are both major Dipteran pests (Toledo *et al*., 2006; Morton, 1987). In Bangladesh, major mango pests include the Mango hoppers *Idioscopus atkinsoni* (Lethierry), *Idioscopus clypealis* (Lethierry) and *Idioscopus niveosparsus* (Lethierry), (Cicadellidae: Homoptera); the Mango fruit weevils, *Sternochetus frigidus (*Fabricius), *Sternochetus gravis* (Fabricius) and *Sternochetus mangiferae* (Fabricius) (Curculionidae: Coleoptera) and then mango fruitfly *Dacus dorsalis* (Tephritidae: Diptera). Both the Dipteran and Coleopteran pests attack the fruits while the homopterans infest the foliage (Anon, 2006). In Queensland, Australia, the fruitfly *Dacus tryoni* (Froggatt) and the mango seed weevil *Sternochetus Mangiferae* are major pests, the latter being widespread in all mango growing areas of the country (Peng and Christian, 2007; Morton, 1987). In Kenya, the recorded key pests are Mango seed weevil, *S. mangiferae* and the Fruitflies *Ceratitis corsyra* (Walker), *Ceratitis capitata* (Wieldemann) and *Ceratitis rosa* (Karsch) (MOA, 2006; MOA, 2005; Toledo *et al.*, 2006; MOA, 2004; MOA, 2003; Griesbach, 2003; Morton, 1987; Hill, 1975). In the rest of the mango growing areas including South America, the Carribean, Florida (USA), the Philippines, Indonesia, etc, all have their share of key, minor and occasional pests across many insect taxa (Pena, *et al.*, 1998; Pena and Mohyuddin, 1997; Hill, 1975).

1.6 Biology of Mango Seed Weevil *Sternochetus mangiferae*

Early literature on some aspects of biology, ecology and life history of the mango seed weevil, *S. mangiferae,* has been confusing due to its similarity to two other closely related species *Sternochetus gravis* and *Sternochetus poricollis* (Woodruff and Fasulo, 2006; Reyes, 2003; Kiarie, 1986). The most accurate account on the biology is based on the study carried out by Balock and Kozuma in 1964 in Hawaii. Their work is extensively quoted in latter day research publications (Woodruff and Fasulo, 2006; Follet, 2002; Follet and Gabbard, 2000; Smith, 1996; Kiarie, 1986). According to the study by Woodruff and Fasulo (2006) eggs are laid in an incision made by the adult female on the surface of immature mango fruit. The female then covers the egg with a brown exudate and cuts a crescent shaped area ¼ - ½ mm in the fruit near the posterior end of the egg. The wound creates a sap flow, which solidifies and covers the egg with a protective opaque coating (Woodruff and Fasulo, 2006; Pinese and Holmes, 2005; Anon, 2005; Pena, *et al*., 1998). One female lays about 15 eggs per day, with a maximum of 300 over a period of three months (Joubet, 1998; Kiarie, 1986).

According to Smith, (1996) the eggs hatch in 5 – 7 days and the larvae burrow through the mango flesh to the soft developing seed. This observation is in agreement with work by Anon (2005), Anon (2003) and Follet (2002). Woodruff and Fasulo (2006) reported that the minimum time from hatching to seed penetration is one day. This view supports the earlier observations of Follet (2002). The newly hatched larva is reported by Woodruff and Fasulo, (2006) to undergo five larval instars in Hawaii.

Plate1.1 Adult mango seed weevil

According to Anon (2005), larval development in Southern India undergoes between five and seven instars under field conditions. Neither Woodruff and Fasulo (2006) nor Anon (2005) specified the actual field conditions such as temperature, and relative humidity under which information on larval development duration was collected. Follet (2002), however, reported that in Hawaii, larval development took between 20 – 30 days under field conditions while Anon (2005) reported that in Southern India the time taken was about one month and that this occurred between March and May. While studying the life history of the mango seed weevil, Kiarie (1986) reported a larval period of 19 – 30 days at 30º±1 and RH 73%. The mean larval period as reported by Kiarie (1986) was 23.9 days. This observation, although under controlled conditions, was within the range later reported both in Hawaii and India (Anon, 2005; Follet 2002). Follet (2002) reported that the tunnel and seed entry points are completely obliterated as the fruit and seed develop. This makes it impossible to distinguish between infested and non-infested fruits and seeds unless they are dissected to reveal the status of the internal structures (Anon, 2005; Follet, 2002). Similar observations were reported by Smith (1996) in Australia, Woodruff and Fasulo (2006) in Hawaii, Griesbach (2003) in Kenya and Joubert (1998) in South Africa.

Woodruff and Fasulo (2006) reported that pupation occurs within the seed and the pupal period in Hawaii is about seven days. Pupation in the flesh according to the authors is very rare. Similar observations were made by Pena *et al.* (1998), Smith, (1996), and Anon, (2005). While working on the duration of different stadia under laboratory conditions (30º±1 and RH 73% Kiarie (1986) reported a range of six to ten days and a mean of 7.1 days. This observation is very close to that reported in Hawaii under field conditions (Woodruff and Fasulo, 2006). Follet and Gabbard, (2000) reported that in Hawaii, the adult emerges two months after the fruits have fallen and rotted. Similar observations were reported by Pena *et al.* (1997) and Follet (2002). Anon (2005) reported similar findings in India and indicated that rarely do weevils emerge from the seed before fruit fall and eat their way through the flesh of ripe fruits.

In Hawaii, Follet and Gabbard (2000) reported the majority of infested seeds have one or two weevils, but seeds containing five or more weevils have been reported. Pena and Mohyuddin (1998) reported similar findings and further observed that under normal circumstances, only a single larva in a seed completes development to maturity. Follet (2004) reported almost similar findings on the occurrence of a single mature adult per seed but further indicated that as many as six have been reported.

The duration of the life cycle from egg to adult is reported by Joubert (1998) to take 49 to 56 days in South Africa. In Hawaii, Woodruff and Fasulo (2006) reported a duration of 35 to 56 days. In India, Anon (2005) reported a duration of 35 to 54 days. Woodruff and Fasulo (2006) further reported that there is only one generation produced each year. This observation supports that of Joubert (1998), Pena *et al.* (1998) and Pena and Mohyuddin (1997).

The information regarding the duration of adult survival is deficient on details. Griesbach (2003) reported that weevils can survive in the dropped fruits or seeds for about three hundred days. Follet and Gabbard (2000) reported that adult weevils can live for two years or more when provided with food and water. These authors however, did not specify the kind of food to be supplied. Woodruff and Fasulo (2006) concur with the above observation but provide no elaboration on the conditions required by the adult weevil in order to survive for that duration. Smith (1996) reported that adults can survive for 4-5 months without food and water and 21 months when food and water were supplied. The author again does not elaborate on the type of food to be supplied. Anon (2005) in an even more ambiguous report indicated that in India adults are capable of surviving long, unfavourable periods without clarifying both the duration and the unfavourable conditions in more precise terms. According to the author, adult *S. mangiferae* feed on leaves and tender shoots of mangoes.

In a study on the biology of *S. mangiferae* Smith (1996) reported that after emergence, adult weevils crawl to the nearest tree and shelter within crevices in the bark where they undergo diapause until the onset of flowering. Griesbach (2003) reported similar findings and further indicated that besides loose tree bark, crop refuse under the trees also act as suitable diapausing sites. Follet and Gabbard (2000) reported similar findings in Hawaii but also included crevices in rock walls as diapausing sites. Similar findings were reported by Pena *et al.* (1998) for mango ecosystems in the tropics and subtropics. Woodruff and Fasulo (2006) reported a pre-oviposition diapause for adults emerging in May or later in Hawaii. The authors indicated that diapause ceases with the onset of regular mango fruiting. Anon (2005) reported that after emergence, adults enter a diapause which varies in duration with the geographic region. In Southern India the report indicated that adults emerging in June enter into diapause from July until late

February of the following year. The latter month coincides with the onset of flowering of mangoes in Southern India.

The above reports indicate that the adults enter into diapause after emergence while cessation of the same is reported to be triggered by onset of flowering of mangoes (Anon, 2005; Griesbach, 2003; Follet and Gabbard, 2000; Smith, 1996). In Hawaii however, Woodruff and Fasulo (2006) report that onset of diapause seems to be associated with long-day photoperiod and the break with short-day photoperiod. The former observations, however, appear as consensus in most of the reported findings.

Follet and Gabbard (2000) reported that the mango seed weevil *S. mangiferae* is strictly a monophagous pest that infests the mango only and probably native to the India-Myanmar region, the origin of mango. Anon (2006a) reported that complete development is only achieved in mangoes. The author observed that under laboratory conditions, larval stages successfully thrived on a diet of potatoes, peaches, litchi or apples but complete development of larvae to adults was never achieved. Similar observations were reported by Anon (2006b) and Woodruff and Fasulo (2006).

Literature on the flight ability of mango seed weevil *S. mangiferae* is rather confusing. Some authors report that the weevil is nocturnal and flies readily while others maintain that it has strong, well developed wings but does not fly readily but rather prefer to crawl. Both Anon (2005) and Follet (2004), support the flight theory while Woodruff and Fasulo (2006); Joubert (1998) and Smith (1996) support the limited or non-flight theory.

1.7 Pest Status of *Sternochetus mangiferae*

Adult S. *mangiferae* is reported to feed on soft flush leaf tissue when these are available. The damage to the leaves is not considered serious (Anon, 2005; Smith, 1996). Adult female weevils oviposit into boat-shaped cavities that they make on the fruit (Anon, 2005; Follet, 2002; Smith, 1996). The larvae burrow through the pulp to the developing seed. The tunnel made by the larvae become undetectable after a short time (Woodruff and Fasulo, 2006; Joubert, 1998). The subsequent larval and pupal stages occur inside the seed (Follet and Gabbard, 2000).

On entering the seed, the larva of mango seed weevil makes extensive feeding tunnels depositing copious amounts of frass as it does so. The ultimate amount of tunneling is proportional to the initial number of larvae entering the seed and the stage in fruit development at which that oviposition occurred (Woodruff and Fasulo, 2006; Anon, 2005; Anon, 2003; Follet and Gabbard, 2000). There has been controversy as to the contribution infestation of *S. mangiferae* has on fruit dropping and subsequent reduced seed viability (Follet and Gabbard, 2000). Mueke (1984) reported that 20 out of 134 or 15% of apple mango seeds that had experienced heavy damage did not germinate at all. The author further reports that moderately and lightly damaged seeds had 30% and 55% germination rates respectively. Pena and Mohyuddin (1998) reported that the flesh of ripe fruit is damaged when weevils emerge from seeds and that weevil damaged seeds may limit propagation in nurseries and orchards. Severe weevil infestation was reported as a possible cause for premature fruit drop. Smith (1996) reported that the seed is often completely destroyed by the feeding activity of two or more weevils. The report further indicates that on poorly maintained mango trees, upto 80% of the seeds can be infested by weevils. Follet and Gabbard (2000) reported that physical destruction of seed cotyledons by 25, 50 and 75% did not significantly reduce germination. Further the authors observed that over a two year period out of 3602 mango fruit samples only 0.11% had any evidence of direct feeding damage to the pulp. When they conducted experiments with naturally infested seeds Haden mango variety, the germination rates for infested seeds were significantly lower than those for the uninfested seeds. The average germination for uninfested and infested Haden seeds was 89% and 73% respectively. In the artificially destroyed Haden seeds, 75% removal of the cotyledon resulted in a lower germination rate compared with controls and 25% and 50% damaged seeds. According to the authors, the mango seed weevil will, under normal circumstances consume less than 25% of the seed. There is, however, no data to support this assumption.

In Barbados, Anon (2001) reported that germination tests indicated that viable seedlings could be obtained from damaged seeds depending on the extent of damage. The author reported that as long as the embryo was intact, destruction of upto 50% of the cotyledons did not affect seed viability. Follet (2002) reported that in Hawaii, mango fruits collected from the ground had a significantly higher seed infestation than fruit of the same age picked from the tree. The author observed that the age distribution of the weevils and the number of insects in infested fruits were similar for ground and tree fruits on all collection dates. This study, however, did not resolve controversy over the role of *S. mangiferae* on premature fruit dropping. Some of the earlier studies indicated that infestation caused premature fruit drop while others disagreed with this. Earlier studies and that of Follet (2002) cannot be compared since according to the author, previous workers failed to give information on fruit size, stage of fruit maturity, age distribution of the weevil population or the number of weevils per seed. The field experiments component of the current study will concentrate on establishing the damage levels by mango seed weevil with respect to the various treatments that will be tested.

Plate 1. 2 Mango fruit showing seed destruction by Mango seed weevil

1.8 Economic Importance of *Sternochetus mangiferae*

Jedele *et al.* (2003) reported that world mango production at 23 million tons accounted for approximately 50% of all tropical fruits produced worldwide. India with a production of 10m tons accounted for almost half of that total (Jedele *et al.* 2003; Colyn 1997). Kenya's mango production as reported by MoA, (2003) was 183,486 metric tonnes valued at Kenya shillings 1.1billion. Of this total, 2236.5 metric tonnes (or 1.21%) valued at Kenya shillings 273.6m was exported (HCDA 2003) while 181,249.5 metric tonnes (or 98.88%) was absorbed by the domestic market (MoA, 2003). The estimated mango production in 2006 was 163,726 metric tonnes MoA (2006). This represented a drop of 19,760 tonnes from the 2003 production figures and is attributed to several production constraints including pests and diseases (MoA, 2006). The impact of mango seed weevil as an economic pest in the domestic markets of the mango producing countries is considered minimal. Follet (2002) reported that infestation by mango seed weevil does not directly affect marketability because the weevil resides inside the seed within a thick husk in mature mangoes and is rarely encountered. Anon (2003) reported that in Kenya, the mango seed weevil does not damage the fruit and therefore, is considered an inconsequential pest in the domestic market. Similar observations were made by Pinese and Holmes (2005). The authors reported that in Australia, the mango seed weevil is considered a minor pest as it causes no significant economic damage to the fruit.

Although the domestic market of mangoes is not seriously affected by infestation by the *S. mangiferae*, the international market regards the pest as a major constraint. Anon (1991) listed *S. mangiferae* as a quarantine pest. The quarantine status of this pest is recognised by several other authors. Pinese and Holmes (2005) reported that a number of markets have imposed quarantine restrictions on the movement of mango fruit infested by *S. mangiferae.* USDA (2006) lists *S. mangiferae* as a quarantine pest of mangoes in India and outlines phytosanitary measures required before importation of mangoes from India into USA. Anon (2003) reported that *S. mangiferae* is not a serious pest in Kenya as far as local consumption is concerned. The author noted that infestation, however, hinders development of fresh fruit market in the Middle East and other countries due to imposition of strict quarantine regulations.

1.9 Management options for *Sternochetus mangiferae*

Management of mango seed weevil is based on either orchard sanitation alone, a combination of orchard sanitation and pesticide application, biological control exerted by general predators and to a lesser extent varietal resistance. With respect to sanitation, collection and destruction of all fallen fruits and seeds during the fruiting period is recommended (Plate 1.3 and 1.4). This method is reported to have reduced infestation by *Sternochetus gravis* by 22% in India but failed to produce similar results when tried in Hawaii. (Griesbach 2003; Pena *et al*., 1998)

Sanitation combined with foliar application of pesticides is recommended in Australia, India, Hawaii, Kenya and South Africa. The foliar application pesticides such as such as Carbosulfan, Malathion, Azinphos, Deltamethrine, Acephate, and Carbaryl at 2-3 week intervals combined with orchard sanitation are recommended. The reduction in infestation levels resulting from this approach was reported to be between 15% and 17%. In addition, use of long lasting synthetic pesticides such as Carbosulfan, Malathion, endosulfan and Fenthion as trunk and branch sprays has been recommended in Kenya. There is no data on the efficacy of this procedure. In India, use of pesticides of synthetic, plant and animal origin has been evaluated in the control of mango seed weevil. The pesticides tested were Deltamethrine Acephate, Carbaryl and Ethofenprox, Azadirachtin and fish oil rosin soap. The synthetic pesticides reduced infestation by between 3.3% and 14.8% while reduction of infestation by use of Azadirachtin and fish roshin oil was between 27.4% and 23.0% respectively (Stonehouse 2005; Verghese *et al*., 2005; Pinese and Holmes 2005; Griesbach 2003; Follet 2002; Joubert 1998; Pena *et al*., 1998; Smith 1996; Tandon and Shukla 1989)

Biological control by natural enemies has been dependent on a variety of general predators that include ants, rodents, lizards and birds. These natural control agents are reported to be effective against adults after they emerge from mango seeds. The immature stages are however not affected since they are concealed inside the seeds and hence not accessible to these control agents. Deliberate introduction of the ant *Oecophylla smaragdina* (Fabricus) into mango orchards in Australia combined with use of soft chemicals is reported to have reduced downgraded fruits to 0.5%. In orchards where only soft chemicals were used downgraded fruits were between 2.5% and 15.7% (Peng and Christian 2007; Flint and Dreistadt 1998; Pena *et al.*,1998).

Plate 1.3 Fallen mango fruits

Plate 1.4 Example of mango seeds from the orchard

1.10 Treatment of Mango fruits with Gamma Irradiation

Most countries that trade in mango fruits have imposed strict quarantine regulations with regard to *S.mangiferae*. Accordingly most markets recommended that mango fruits should undergo gamma irradiation at a dose of 300 Gy in order to prevent adult emergence, reduce longevity of any adults that might emerge and ensure infertility. This dose is recommended for mangoes from Hawaii meant for exportation to continental USA. A similar dosage is applied for mangoes exported from South Africa and India. In general, it has been observed that adults emerging from fruits that underwent a gamma irradiation dosage of between 100Gy and 300 Gy were lethargic, short lived and laid no eggs (Anon., 2006c; Follet and Neven, 2006; USDA 2006; Pinese and Holmes, 2005; Follet, 2004; Anon., 2003; Anon., 1991)

1.11 Statement of the Problem

Farming practices employed by mango farmers influence both productivity and management of pests and diseases in mango orchards hence failure to adhere to recommended practices result in low yields as well as high infestation levels by diseases and pests. Foliar application of pesticides to control mango seed weevil in small scale mango holdings has been largely unsuccessful. This study is anticipated to assess mango farming practices in Mbeere district and evaluate through field experimentation various pest control options for effective management of the mango seed weevil.

1.12 Justification of the study

Mango has been cultivated on the East African coast for over six hundred years but the introduction to the highland regions is not clearly documented (Griesbach, 2003; de Villiers, 1998). In the last 20-30 years, commercial mango production has been developed based on locally adapted as well as imported elite cultivars. This has resulted in the increase of the area under production from 500 hectares in 1970 to about 21,264 hectares in 2006 and a corresponding increase in annual export volume (MOA, 2006; Griesbach, 2003). In the horticulture sub-sector, the importance of mango is underlined by the fact that it is the 3rd most important fruit crop after bananas, and pineapples in terms of hectarage, production and value (MOA 2006; 2005;2004). In addition, it is widely spread across almost all agro-ecological zones in Kenya (MOA, 2005; MOA/GTZ , 1983). The nutritive value of the fruit is underlined by studies that have shown that one fruit can provide a large proportion of the daily human requirements of essential minerals and vitamins (Griesbach, 2003; Douthett, 2000). The mango is a major resource contributor for many small scale farmers as well as a foreign exchange earner to the country (MOA, 2006).

In the international market, the Kenyan mango has suffered drawbacks due to infestation by *S. mangiferae*. In the last 10 years, stringent phytosanitary market requirements have resulted in interceptions and destruction of export mango consignments from Kenya (HCDA, 2006; MOA, 2006; Griesbach, 2003). As a consequence, development of new markets has been difficult and this situation is not expected to change unless acceptable mango seed weevil management practices are developed, adopted and practiced by the Kenyan mango farmers (HCDA, 2006; Griesbach, 2003).

The Mango seed weevil is an insidious pest that spends most of its life cycle inside the mango seeds (Pena *et al*., 1998). The adult female weevil oviposits on premature fruits and the neonate burrow through the pulp to the developing seed where the immature stages spend their entire life cycle (Follet and Gabbard, 2000. This cryptic nature of the pest has made it difficult to control by use of conventional methods. In Kenya, the mango seed weevil is a common pest in all mango growing areas (Anon, 2003; Griesbach, 2003). Control of this pest has relied mainly on foliar application of a varied range of insecticides and this has been uneconomical and ineffective (MOA, 2006; 2005; Anon, 2003; Griesbach, 2003). This is supported by the fact that interceptions of Kenyan mango consignments to international markets are still a regular occurrence (HCDA, 2006). In addition, Ministry of Agriculture field reports from mango producing regions regularly cite Mango seed weevil as one of the most important pests (MOA, 2006; 2005).

The need to develop a more sustainable management strategy for Mango seed weevil is strengthened by the current market requirements with regard to maximum residue limits on exported produce (EurepGap, 2001). This study is based on the above premises and is anticipated to clearly elucidate on economical, environmentally acceptable and sustainable management strategies for the mango seed weevil, *S. mangiferae*.

1.13 Hypotheses

1. Mango farmers in Mbeere district do not practice recommended farming practices
2. Both physical and chemical barriers are not effective in controlling mango seed weevil infestation
3. Frequency of application of Chlorpyrifos by trunk painting does not affect infestation level of Mango seed weevil in mango orchards

1.14 General objective

- To determine efficacy of managing mango seed weevil by use of chemical and physical barriers

1.15 Specific objectives

- To determine mango farmers' production practices in Mbeere district.
- To evaluate efficacy of chemical and physical barriers in the control of mango seed weevil

- To determine the optimum frequency of trunk painting with Chlorpyrifos (Dursban 4E) necessary for effective control of mango seed weevil

CHAPTER 2

2.0 MATERIALS AND METHODS

2.1 Survey of mango farming practices

2.1.1 Survey site description

The survey on mango farming practices and related constraints was carried out in Mbeere district in the Eastern province of Kenya. The district is one of thirteen such districts in Eastern province and it borders with Embu district to the North West, Meru South to the North and Tharaka to the North East. The district also borders with Mwingi district to the South and South East and kirinyaga district to the West (MOA-Mbeere, 2009; MOA-Mbeere, 2006).

The district lies between 0^0 50´ South and longitude 37^0 16´ and 37^0 56´East. It has a total area of 2,097 km^2 and is subdivided into four administrative divisions namely Siakago, Evurore, Mwea and Gachoka. The district has an estimated population of 172,226 people occupying 37,318 households. The district is sparsely populated with an average of 82 persons per km^2. The actual sites for the survey were Siakago and Evurore divisions which occupy about 782km^2 with a total population of about 72,000 persons (MOA-Mbeere, 2009, Fig. 2.1).

The district has a bimodal rainfall which averages between 500 and 1100mm per year although most of the areas receive less than 550mm annually. Although farming in the district is mainly subsistence, the exotic mango cultivars are grown for both the export and local markets. Besides mangoes, other important crops include millet, cassava, sorghum, grams, papaya, cotton, tobacco, bananas and Asian vegetables. The latter are grown in the Kathigi-Ishiara irrigation scheme mainly for the export market.

2.1.2 Survey methodology

The survey on mango farming practices was conducted in Siakago and Evurore divisions of Mbeere District (Fig. 2.1), the same divisions where the sites for field experimental work on assessment of management options for mango seed weevil were located. The questionnaire was first pre-tested on ten mango farmers randomly selected by use of random numbers from a list of mango farmers provided by the District Agricultural Office-Siakago (Anyango & Muriuki 2008). Five farmers were selected from each of the two candidate administrative divisions. After pre-testing, the necessary adjustments were done and the questionnaire was considered ready for use during the actual survey. During the survey, farmers were selected through systematic random sampling whereby the interviewer followed a transect running across each of the divisions and interviewed farmers at a spacing of 5km. In cases where there were mango farmers on either side of the route, a toss of the coin was used to determine the farmer to be interviewed. In total 70 mango farmers from the two divisions were interviewed.

The questionnaire contained thirteen sections each of which dealt with a specific aspect of mango farming including individual farmer's records, general farm records, crop enterprises, mango production constraints, pests of mangoes and control strategies, mango seed weevil management and constraints, general integrated pest management information, alternative crop protection practices and record keeping. Each of the main sections of the questionnaire provided space for ranking the responses to the subject under inquiry. The questionnaire is included in Appendix 1.

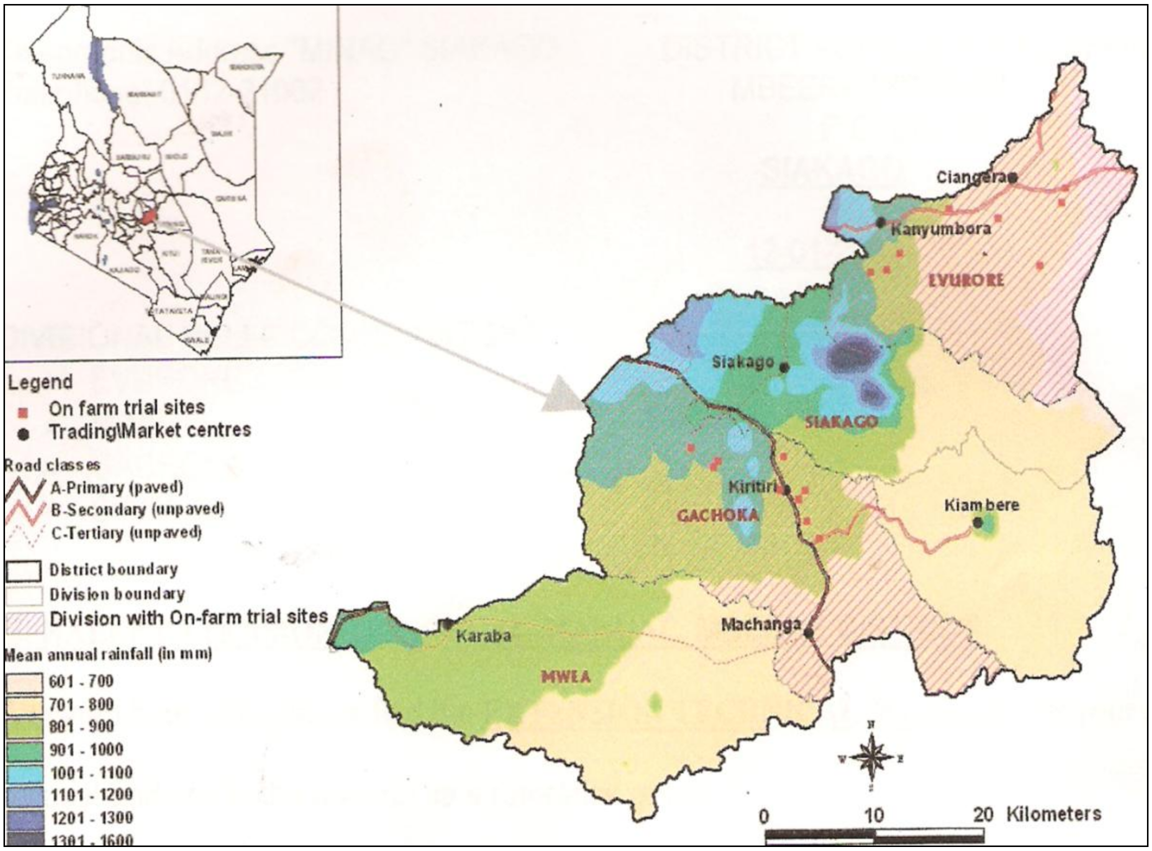

Figure 2.1 Map of Mbeere district (adopted from NALEP Extension Technical Manual- Mbeere district, January, 2009)

2.1.3 Field experiments on management of MSW

Three field experiments were carried out in order to determine the most effective approach to the management of the Mango seed weevil. In the first experiment, four physical barriers, two chemical barriers and different combinations of these barriers were evaluated in a randomized complete block design experiment with sixteen treatments replicated three times (Ciba-Geigy 1981). The following is a description of the physical and chemical barriers:

a) Grease

This is the ordinary lubricating grease which consists of an oil and a fluid lubricant mixed with a thickener substance to form a semi solid (Anon 2009)

b) Tanglefoot

This is a tree pest barrier effective against crawling insects who must reach the top of trees in order to feed, mate or deposit eggs (Anon 2002)

c) Tangletrap

This is a pesticide free clear and odourless trapping adhesive used against aphids, whiteflies and crawling insects etc in gardens and greenhouses. The product is specially formulated to adhere virtually to any surface. It is available as a brush, paste and aerosol (Anon 1998)

d) Grease paper (Tangle guard tree banding material)

This is a non toxic polythene ribbon impregnated with grease on one side. It prevents crawling insects from climbing along tree trunks to the foliage. It is effective against caterpillars, ants and crawling insects (Anon 2002)

The chemical barriers used in this experiment are as described below:

a) Chlorpyrifos (Dursban)

This is an organophosphate insecticide with widespread application against a wide spectrum of field and household pests. It is a heterocyclic compound with some of the carbon atoms in the ring displaced by oxygen, nitrogen and sulfur (Ware, 1989)

b) Dimethoate (Cygon, Rogor)

Dimethoate is an organophosphate insecticide which belongs to the aliphatic derivatives group. It has systemic action and is widely used in the control of pests in field crops, public health and domestic situations (Ware 1989; Bohlen 1978).

The above physical and chemical barriers were combined in different arrangements as described under 2.1.3.5 in order to determine whether different arrangements of the barriers had any effect on eventual infestation levels by *S. mangiferae.* The purpose of this experiment was to eliminate the control options that were found ineffective after data analysis. The experiment was conducted in a mango orchard at Karurumo located at the Embu/Mbeere Districts boundary. The site details are in sub-section 2.1.3.3 below.

In the second experiment, three physical barriers, one chemical barrier and one combination treatment were evaluated in a randomised complete block design experiment with six treatments replicated four times. The physical barriers included Tangletrap,

Grease and Tanglefoot while Chlorpyrifos was the selected chemical barrier. The combination treatment was composed of Chlorpyrifos and Grease. The pest control products were applied as described under methods of treatment application (2.1.3.5). The purpose of this experiment was to determine the pattern of effectiveness of the pest control products in the control of *S.mangiferae*. This experiment was conducted in three sites namely Siakago, Karurumo and Kanyuambora. Details of the sites appear in sub-sections 2.1.3.2, 2.1.3.3 and 2.1.3.4 below.

In the third experiment, the effect of frequency of Chlorpyrifos application on the infestation levels of mango seed weevil in Mango orchards was evaluated. This was a randomized complete block design experiment which had six treatments replicated four times. The application frequencies evaluated included once per fruiting season, once per month, once in two months and once in three months. Each of these treatments was combined with orchard sanitation although sanitation alone was also evaluated. Application of treatments commenced three weeks after the onset of flowering and continued at the frequency described above.

2.1.3.1 Description of experimental sites for field trials

In order to have the appropriate sites for carrying out the field experiments, several considerations were regarded as important. The considerations included farmer's consent, location of the farm/orchard, number of mature mango trees in the orchard, general orchard management and accessibility. The investigator together with the local Agricultural officers visited a total of ten mango orchards in both divisions evaluating each against the above considerations. The following sites were selected after considering all the above criteria.

2.1.3.2 Siakago site

The site in Siakago was located at the south western side of the study area. The orchard is 15 years old with about 3,000 mature trees. There was very little intercropping of the mangoes, except at the edges where a few bushes of cassava and small patches of cowpeas were grown. The orchard had most of the elite cultivars that are popular in the export market. The orchard had no irrigation system. Regular management activities included soil fertilization, manual weeding disease and pest management. The farmer however did not practice such important activities as pruning and clean orchard hygiene. The orchard relied heavily on pesticides chemicals for both disease and pest management.

2.1.3.3 Karurumo site.

This site was in a 118 hectare mango orchard situated 30km North East of Embu town and 2.5km south of Embu-Ishiara-Meru road. The orchard is about 30 years old and has most of the elite mango cultivars. The recommended orchard management practices including soil fertilization, weeding, collection and burying of fallen fruits, pruning as well as irrigation are carried out regularly. The actual site of the experiment was a block of 4 ha just near the farm office. This block has mixed mango cultivars spaced at 8mx8m apart and planted in rows running from north to south.

2.1.3.4 Kanyuambora site

The Kanyuambora site was a small orchard with 220 mature trees. It is located on the North Eastern end of the study area just on the outskirts of Kanyuambora Township. The orchard setting is a typical small scale farming operation, the mango trees being intercropped with such food crops as maize, beans, pigeon peas and a variety of indigenous vegetables. The orchard was about 10 years old and had many of the elite cultivars. Orchard management comprised of regular soil fertilization, weeding, pest and disease control. The farmer did not practice such important activities as pruning and clean orchard hygiene.

2.1.3.5 Method of treatment application

The various treatments required different method of application and these were done as follows:

i) Grease- Applied as a 15cm wide band around the tree trunk. The height of the band was about 30 cm from the ground. Care was taken to ensure that grease was uniformly spread around the tree trunk and that no "paths" were left uncovered.

ii) Tanglefoot- Applied in a similar way to grease above but using a plastic applicator.

iii) Chlorpyrifos (Dursban 4E)- This was diluted at the rate of 40ml to 1 litre of water mixed with 1gm of methylene blue and applied as a 15cm band on the tree trunk at 30cm height using a 5cm wide paint brush. Special attention was taken to cover all the crevices. Similar bands were also applied on the main limbs from the point they made a junction with the main trunk.

iv) Tangletrap - Applied the same way as Tanglefoot

v) Grease paper - This is a 7.5cm clear polythene sheet impregnated with grease on one surface. This was fastened around the trunk at 30cm height with the adhesive coated side on the outside. Long stemmed staples were used to tightly hold the trap in close contact with the bark. Care was taken not to leave uncovered "paths" under the grease paper.

vi) Dimethoate 40EC - This was diluted at the rate of 15ml in 10 litres of water. A knapsack sprayer with an extension lance was used to thoroughly spray the mixture onto the foliage, flowers, the trunk and main limbs.

vii) Chlorpyrifos (Dursban 4E) + Grease 1 - A 15cm band of Chlorpyrifos (Dursban 4E) was applied at 30cm height from the ground and a 15cm band of Grease was applied immediately above.

viii) Chlorpyrifos (Dursban 4E) + Grease 2 - A 15cm band of Grease was applied at 30cm height from the ground and a 15cm band of chlorpyrifos (Dursban 4E) was applied immediately above.

ix) Chlorpyrifos (Dursban 4E) + Tanglefoot 1 - A 15cm band of chlorpyrifos (Dursban 4E) was applied at 30cm height from the ground and a 15cm band of Tanglefoot was applied immediately above.

x) Chlorpyrifos (Dursban 4E) + Tanglefoot 2 - A 15cm band of Tanglefoot was applied at 30cm height from the ground and a 15cm band of Chlorpyrifos (Dursban 4E) was applied immediately above.

xi) Chlorpyrifos (Dursban 4E) + Tangletrap 1 - A 15cm band of Chlorpyrifos (Dursban 4E) was applied at 30cm height from the ground and a 15cm band of Tangletrap was applied immediately above.

xii) Chlorpyrifos (Dursban 4E) + Tangletrap 2 - A 15cm band of Tangletrap was applied at 30cm height from the ground and a 15cm band of Chlorpyrifos (Dursban 4E) was applied immediately above.

xiii) Chlorpyrifos (Dursban 4E) + Grease paper1 - A 15cm band of Chlorpyrifos (Dursban 4E) was applied at 30cm height from the ground and a 15cm band of Grease paper was a stuck immediately above.

xiv) Chlorpyrifos (Dursban 4E) + Grease paper 2 - A 15cm band of Grease paper was applied at 30cm height from the ground and a 15cm band of Chlorpyrifos (Dursban 4E) was a applied immediately above.

xv) Chlorpyrifos (Dursban 4E) + Dimethoate - Chlorpyrifos (Dursban 4E) was applied as in (iii) above while Dimethoate 40EC was applied as in (vi) above.

xvi) Untreated control - No treatment was applied at all.

2.1.3.6 Experiment 1: Preliminary assessment of chemical and physical barriers

The purpose of carrying out a preliminary assessment of both physical and

chemical barriers was to eliminate those that were less effective in order to assess those selected for consistency in reducing infestation levels by *S. mangiferae*. The experimental plots consisted of two trees on the same row and every plot was separated by a mango tree on either side. Every experimental block had 16 plots each corresponding to a treatment. The design was Randomised Complete Block Design with 16 reatments replicated 3 times. The treatments were as listed under 2.1.3.5 above. All the treatments were applied once three weeks after onset of flowering. Coded labels identified treatments.

Plate 2.1 Chlorpyrifos and Grease bands on a mango tree trunk about 15cm from the ground

2.1.3.7 Experiment 2: Assessment of five treatments selected from Experiment one

This experiment was carried out in the sites described above while the treatments were as in 2.1.3.5 above**.** The five treatments were selected on the basis of effectiveness in reducing infestation levels by *S. mangiferae*, acceptance in terms of EurepGap requirements, ease of application and availability in the market.

2.1.3.8: Experiment 3- Assessment of chlorpyrifos application frequency in the control of mango seed weevil

This experiment was carried out in the three sites described above while the treatments were as described under 2.1.3 above**.** The sanitation referred to in this experiment involved regular collection of all fallen fruits and burying them in a 60cm deep hole in the soil. Seeds from the previous season were all collected from the corresponding treatments in the four blocks and destroyed by burning (Plate 2.2)

Plate 2.2. Seed destruction by burning on a raised wire mesh using firewood

2.2 Data collection

Data collection in the three experiments was similar. From the two trees in each plot, 10 fruits were picked randomly from the four sides of the compass. Four were picked from the lower canopy, four from the middle and two from the upper canopies of the two trees in the treatment plot. The picked fruits were put into net bags which bore the experiment and the block number as well as the treatment codes. The net bags were secured tightly and carried to a central place outside the orchard for fruit dissection and recording of infestation data (Sutherland *et al*., 1996; Ciba-Geigy 1981).

2.3 Sample processing and recording

Each of the harvested mango fruits was dissected longitudinally and the seed removed (Plates 2.4 and 2.5). The seed coat was carefully cut along the edges in order to gain access to the seed itself. The latter was examined for presence or absence of larvae, pupae, adults or weevil damage. For each treatment, the seeds were separated into two groups – namely those that had damage and those without. Both numbers were recorded in the field notebook according to the respective treatment. After sample processing and recording, the seeds were buried in 60cm deep holes in the soil. Any larvae, pupae or adults were preserved in specimen bottles containing 70% ethyl alcohol.

Plate 2.3 Dissected mango fruits showing seed damage

Plate 2.4 Damaged mango Seed and a newly emerged adult weevil

2.4 Data analysis

The survey data was analysed by Chi-square method while data from the field experiments was subjected to ANOVA test. Means were separated using Student Newmann Keuls Procedure (p=0.05). SAS program was used.

CHAPTER 3

3.0 RESULTS

3.1 Baseline Survey of mango farming practices in Evurore and Siakago administrative divisions of Mbeere district.

The results from the survey indicated a wide range of responses with respect to the study subjects . These results appear in the sections below.

3.1.1 Number of mango trees in farmers' orchards in Evurore and Siakago divisions, Mbeere district.

42 of the 70 orchards had 1-20 trees category, while the remaining 28 orchards were distributed in the remaining five categories. The number of trees in each category differed significantly from one another χ^2 (5, 0.05) =126.4 (Figure 3.1).

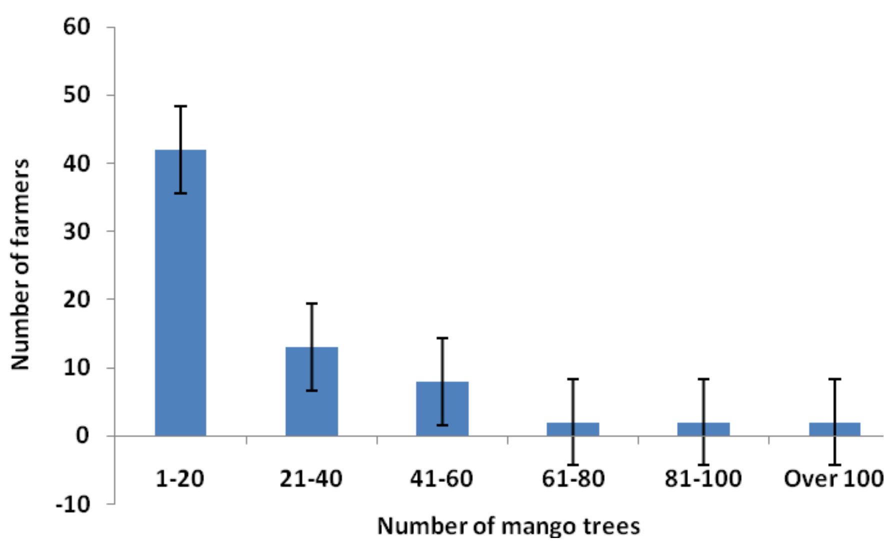

Figure 3.1 Number of trees per farmer in mango orchards in Evurore and Siakago divisions, Mbeere district

3.1.2 Mango spacing

Of the 70 farmers interviewed, 28 practiced a spacing of 8 x 8m while 17 established orchards at a spacing of 10m x 10m. The remaining 25 farmers practiced other spacing arrangements. The number of farmers in each spacing arrangement did not differ significantly from each other χ^2 (2, 0.05) = 4.1 (Fig 3.2)

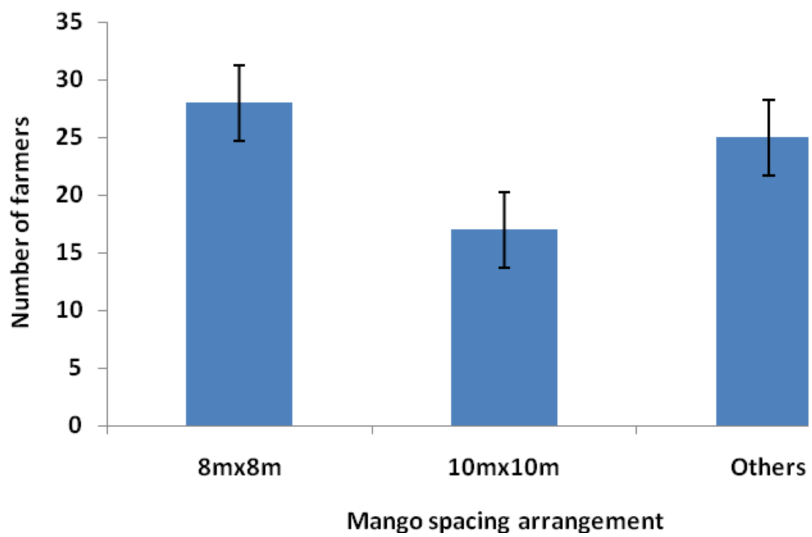

Figure 3.2 Farmers' responses with respect to mango spacing in Evurore and Siakago divisions, Mbeere district.

3.1.3 Manure application frequency

With respect to manure application, 46 farmers did so at planting while 20 applied once a year. The remaining 4 applied manure twice a year. The number of farmers corresponding to each of the above application frequencies differed significantly from one another χ^2 (2, 0.05) =57.7 (Fig 3.3)

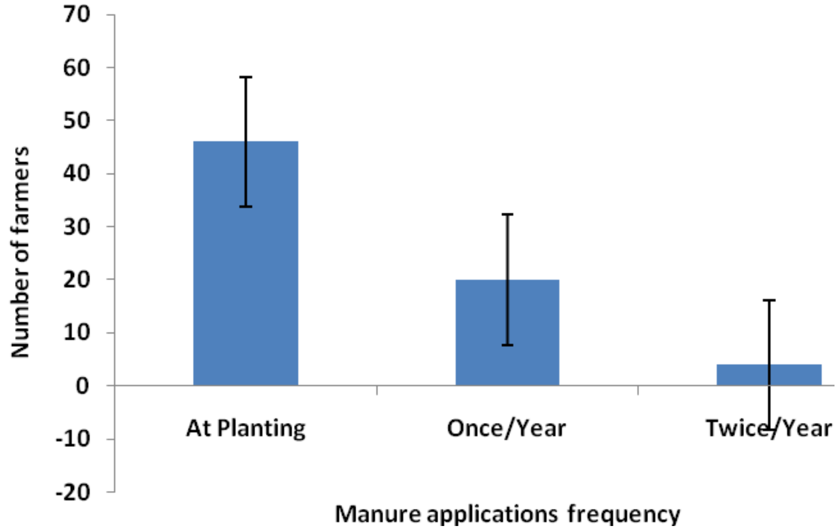

Figure 3.3 Farmers' responses with respect to manure application frequency

3.1.4 Fertilizer application frequency

The responses for fertilizer application frequency showed that 31 of the 70 farmers interviewed applied fertilizer once per year while 11 did so twice. The remaining farmers 28 did so irregularly. The number of farmers in each of the above application frequency category differed significantly from one another χ^2 (2, 0.05) = 14.9 (Fig 3.4)

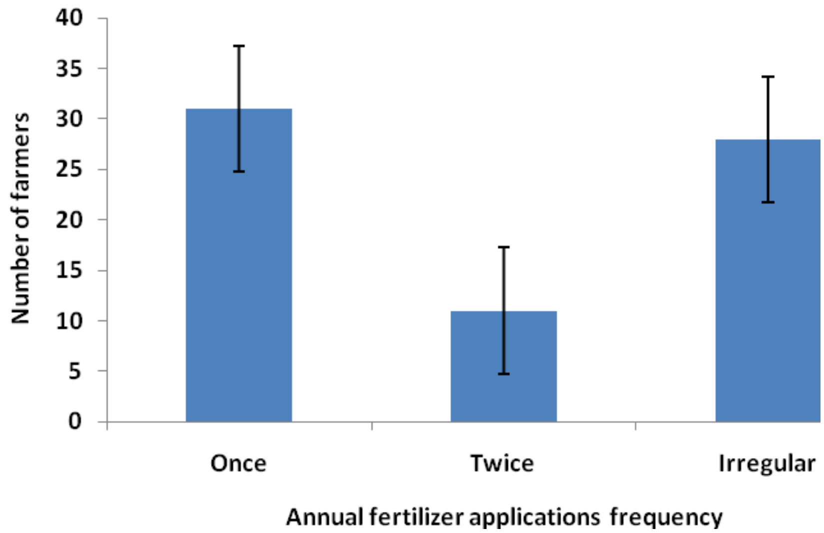

Figure 3.4 Farmers' responses with respect to fertilizer application frequency

3.1.5 Mango pruning

With respect to mango pruning18 farmers did so once a year while and 10 pruned twice a year. 42 did so irregularly. The figures in each category differ significantly from one another χ^2 (2, 0.05) = 35.6 (Fig 3.5)

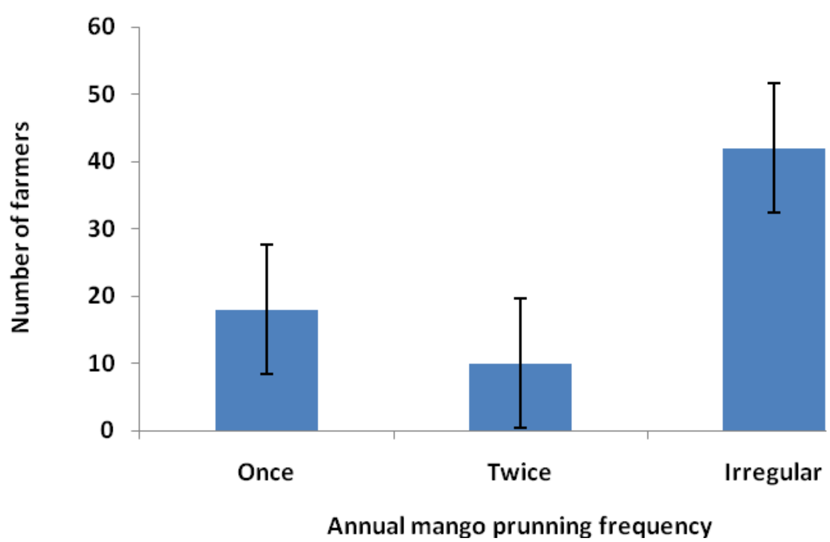

Figure 3.5 Farmers' responses with respect to pruning

3.1.6 Mango importance in terms of annual monetary returns to farmers.

37 of the 70 respondents interviewed were in position 1 while there was only one respondent in position 7. The respondents in each category differed significantly from one another χ^2 (6, 0.05) = 116.9 (Fig 3.6)

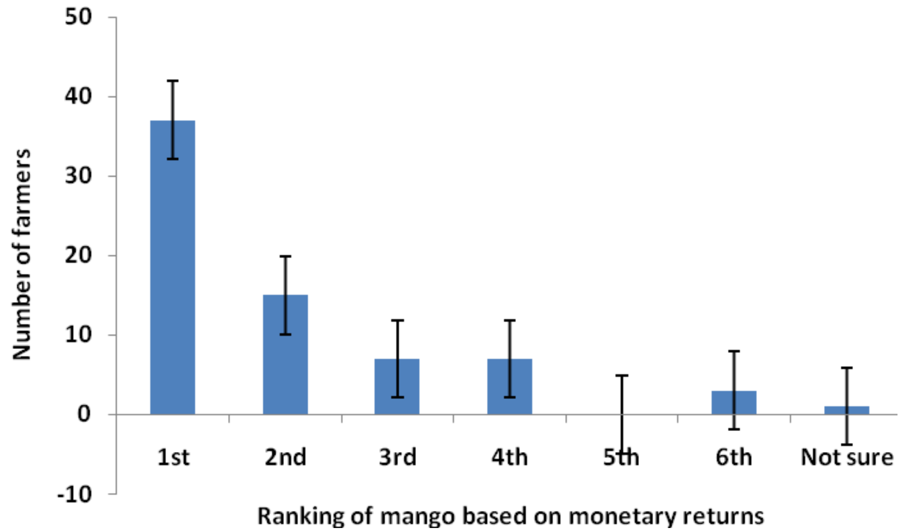

Figure 3.6 Farmers' responses with respect to mango ranking

3.1.7 Management of general pests of mangoes

Majority of the farmers interviewed (32 out of 70) used foliar spray to control general pests of mangoes while the remaining ones used either of the three other methods or none at all. The number of respondents in each category differed significantly from all the others χ^2 (4, 0.05) = 82.0 (Fig 3.7)

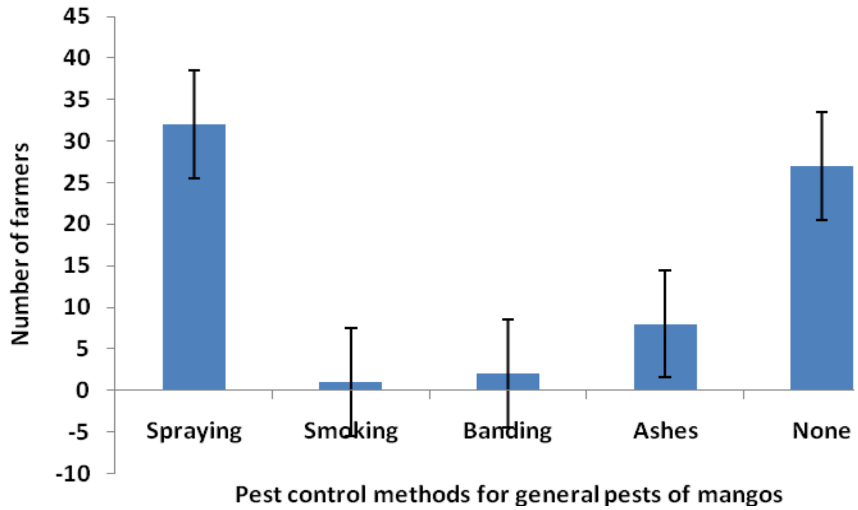

Figure 3.7 Management practices for the control of general pests of mangoes

3.1.8 Crop protection practices against mango seed weevil

The responses were grouped into five categories. 27 farmers used spraying to control mango seed weevil and a similar number did nothing. The rest of the farmers used either smoking, banding or cultural methods. The numbers in each category differed significantly from one another χ^2 (4, 0.05) = 51.2 (Fig 3.8)

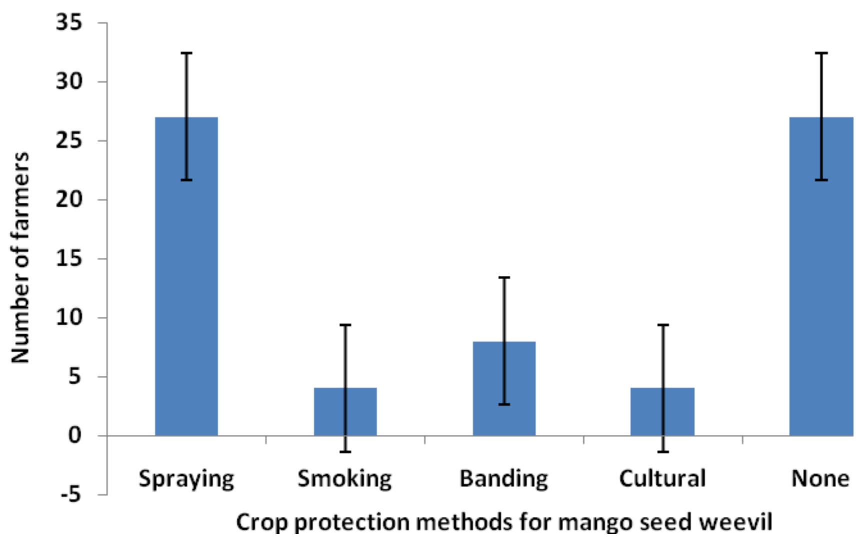

Figure 3.8 Crop protection practices against mango seed weevil

3.1.9 Major constraints in mango production

Of the six categories of constraints, 28 farmers chose pests as the most important while 24 identified diseases. The remaining 18 farmers indicated any of the four remaining categories as important. The number of farmers in each category differed significantly from one another χ^2 (5, 0.05) = 65.1 (Fig 3.9)

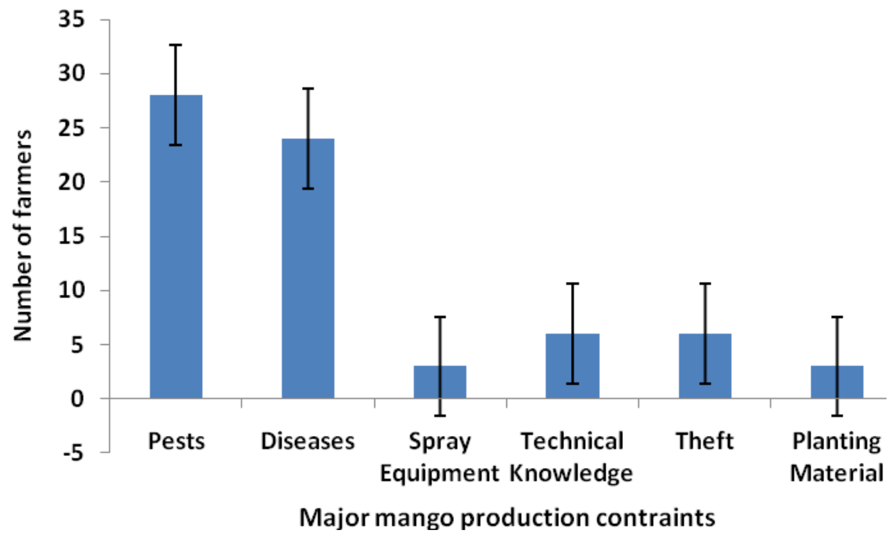

Figure 3.9 Major Mango Production Constraints in Evurore and Siakago, Mbeere District

3.2 Experiment 1-Preliminary evaluation of physical and chemical barriers

In this assessment, information was collected to determine the most effective treatment or combination of treatments which would later undergo further evaluation to confirm consistency in effectiveness. When the means for the test period were analysed, Tanglefoot had the lowest mean number of infested fruits while Chlorpyrifos + Grease 2 had the highest mean number of infested fruits. These means differed significantly (F = 20.50, df = 15, p = 0.05) from one another and from that for the untreated control. The means for Grease, Tanglefoot, Chlorpyrifos, Tangletrap and Chlorpyrifos + Grease did not differ significantly from one another but did so from the untreated control. The analysed results of this experiment indicated that the above five pest control products were the most effective among the sixteen products that were tested for the control of *S. mangiferae* (Table 3.1). On the basis of these results and based on information gathered from available literature on attributes of these products such as ease during application, acceptability in terms compliance with current regulatory market as well as cost the products were therefore selected for the second experiment in section 3.3

Table 3.1 Mango seed weevil mean infestation from the different treatments expressed as number of infested fruits out of ten per treatment

	Treatment number and type	**Mean ± SE**
1.	Grease	4.11± .11efg
2.	Tanglefoot	3.88± 0.20g
3.	Chlorpyrifos	4.22± .32efg
4.	Tangletrap	4.44± 0.24defg
5.	Grease paper	5.33± 0.23bcd
6.	Dimethoate	5.00± 0.23bcdef
7.	Chlorpyrifos+ Grease-1	4.22± 0.22efg
8.	Chlorpyrifos+ Grease-2	4.22± 0.22efg
9.	Chlorpyrifos+ Tanglefoot-1	4.33± 0.23efg
10.	Chlorpyrifos+ Tanglefoot-2	4.66± 0.33bcdefg
11.	Chlorpyrifos+ Tangletrap-1	4.22± 0.27efg
12.	Chlorpyrifos+ Tangletrap-2	4.00± 0.16fg
13.	Chlorpyrifos+ Grease paper-1	5.55± 0.17bc
14.	Chlorpyrifos+ Grease paper-2	5.66± 0.23b
15.	Chlorpyrifos+ Dimethoate	5.11± 0.20bcde
16.	Unteated control	8.11± 0.30a
	CV (%)	14.35
	p-value	0.05

Means followed by the same letter along the columns are not significantly different at the specified p= value by SNK procedure.

3.3 Experiment 2: Evaluation of five treatments selected from experiment 1

The pest control products for evaluation in this experiment were selected on the basis of efficacy as per the results of experiment 1 in section 3.2. above, availability in the market, cost and ease of application. The five products that fulfilled the above criteria were Chlorpyrifos, Tangletrap, Grease, Tanglefoot and the Chlorpyrifos + Grease combination. These were further evaluated in three sites namely Siakago, Karurumo and Kanyuambora in order to determine consistency in performance under different orchard management situations.

3.3.1 Performance of selected pest control products at Siakago Site

At this site, Tangletrap was the most effective in the reduction of fruit infestation by the mango seed weevil. The mean for this treatment differed significantly ($F = 63.86$, $df = 5$ $p = 0.05$) from those of the other products and from the untreated control. There was no significant difference between the means of Chlorpyrifos + Grease, Grease and Chlorpyrifos although all differed significantly from the mean of the untreated control (Table 3.2).

3.3.2 Performance of selected pest control products at Karurumo Site

The mean fruit infestations from plots treated with either Tangletrap or Grease were significantly lower than those from plots treated with Chlorpyrifos, Chlorpyrifos + Grease and Tanglefoot respectively ($F = 49.23$, $df = 5$ $p = 0.05$). All the mean fruit infestations from plots treated with the test pest control products were significantly lower than those from the untreated plots (Table 3.2).

3.3.3 Performance of selected pest control products at Kanyuambora Site

The results indicated that means from plots treated with Tangletrap, Chlorpyrifos + Grease and Grease were not significantly different from one another (F = 52.63, df = 5, p = 0.001). The above means however, were significantly lower than means from plots treated with either Chlorpyrifos or Tangletrap respectively. All the means from plots treated with the test products however, were significantly lower than the mean from the untreated control plots (Table 3.2).

3.3.4 Overall performance of the selected pest control products

The results indicated that the mean score from plots treated with Tangletrap was significantly lower than means from plots treated with the other pest control products and that from the untreated control (F =108.47, df = 5 p = 0.05) (Table 3.3).

Table 3.2: Performance of selected pest control products in all sites expressed as number of infested fruits out of ten fruits sampled

	Mean ± SE			
Treatment type	Siakago	Karurumo	Kanyuambora	Overall
Chlorpyrifos	5.42 ± 0.16b	5.63 ± 0.33b	5.38 ± 0.25b	5.47 ± 0.13b
Tangletrap	3.88 ± 0.39d	2.79 ± 0.28d	4.04 ± 0.40c	3.57 ± 0.17d
Grease	4.71 ± 0.24c	3.38 ± 0.18d	4.33 ± 0.25c	4.14 ± 0.19c
Chlorpyrifos + Grease	4.67 ± 0.14c	4.42 ± 0.29c	4.33 ± 0.21c	4.47 ± 0.13c
Tanglefoot	5.54 ± 0.17b	4.83 ± 0.32c	5.50 ± 0.15b	5.29 ± 0.17b
Control	9.08 ± 0.22a	7.67 ± 0.30a	9.08 ± 0.19a	8.61 ± 0.32a
Cv (%)	20.24	25.36	13.26	16.00
p-value	0.05	0.05	0.05	0.05

Means followed by the same letter along the columns are not significantly different at the specified p=value by SNK procedure.

3.4 Experiment 3: Effect of Chlorpyrifos application frequency on infestation by mango seed weevil

Studies were undertaken to determine the effect of application frequency of Chlorpyrifos on the infestation levels of Mango seed weevil. The application frequencies tested included once per month, once in two months, once in three months and once per fruiting season. All these treatments were combined with sanitation involving collection and destruction of fallen fruits and seeds. Sanitation as a specific measure was also tested.

3.4.1 Comparative performance of different application frequencies of Chlorpyrifos at Siakago site

The results showed that mango fruits treated with Chlorpyrifos at a frequency of once a month had a significantly lower infestation level than the fruits from all the other application frequencies tested. The mean infested fruits from this treatment frequency differed significantly ($F = 154.64$, $df = 5$, $p = 0.05$) from the means from the other application frequencies and from that from the untreated control. The mean infestation level for mango fruits treated with Chlorpyrifos at a frequency of once per season and that for sanitation alone had no significant difference. Similarly the mean infestation for Chlorpyrifos applied once every two months and once every three months respectively too had no significant difference. The two sets of means however differed significantly from one another and from the mean of the untreated control ($F = 154.64$, $df = 5$, $p = 0.05$). (Table 3.3)

3.4.2 Comparative performance of different application frequencies of Chlorpyrifos at Karurumo site

The mean infestation level for fruits treated with Chlorpyrifos at a frequency of once per month differed significantly (F = 80.11, df = 5, p = 0.05) the means of all the other frequencies and from that of the untreated control. The mean infestation level for mango fruits treated with Chlorpyrifos at a frequency of once per season was the highest when compared with the means of the other treatment frequencies. There was no significant difference between the mean infestation level for mango fruits treated with Chlorpyrifos at a frequency of once per three months and sanitation alone but each of these differed significantly (F 154.64, df= 5, p= 0.05) from the untreated control (Table 3.3).

3.4.3 Comparative performance of different application frequencies of Chlorpyrifos at Kanyuambora site

At this site the mean infestation for Chlorpyrifos applied once per month was the lowest and differed significantly (F =155.69, df = 5, p = 0.05) from those of the other application frequencies and that of the untreated control. The mean for Chlorpyrifos applied once per season was the highest among the application frequency means but nevertheless differed significantly (F = 155.69, df = 5, p = 0.05) from the untreated Control (Table 3.3).

3. 4. 4 Performance of different application frequencies of Chlorpyrifos in all sites

The results showed that the mean number of fruits infested by mango seed weevil when Chlorpyrifos was applied once a month was significantly lower than the means from all the other application frequencies and from the untreated control (F =112.15, df = 5, p =

0.05). Conversely the mean number of infested fruit when Chlorpyrifos was applied once per season was significantly higher than the means from all the other treatments as well as that from the untreated control. The mean infestation number for the other application frequencies and sanitation alone lay in between these two (Table 3.3).

Table 3.3 Performance of different application frequencies of Chlorpyrifos expressed as number of infested fruits out of ten fruits sampled

	Mean SE			
Application frequency	Siakago	Karurumo	Kanyuambora	Overall
Chlorpyrifos once / season	5.67±0.19b	6.58±0.50b	6.33±0.19b	6.19±0.19b
Chlorpyrifos once/month	2.08±0.15d	1.58±0.19e	2.42±0.31e	2.02±0.14f
Chlorpyrifos once/2months	4.17±0.24c	3.08±0.29d	3.50±0.26d	3.58±0.16e
Chlorpyrifos once/3months	4.58±0.19c	5.00±0.52c	3.67±0.22d	4.41±0.21d
Sanitation alone	5.67±0.14b	5.50±0.560c	5.58±0.15c	5.58±0.19c
Untreated control	9.33±0.22a	8.00±0.56a	9.08±0.29a	8.58±0.32a
Cv (%)	12.70	18.17	13.21	25.38
p-value	0.05	0.05	0.05	0.05

Means followed by the same letter along the columns are not significantly different at the specified p=value by SNK procedure.

CHAPTER 4

4.0 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

4.1 Discussion

The results from the studies on mango spacing in Mbeere District indicate that the mango spacing arrangements practiced are similar to those in some of the mango growing regions of the world. Although the spacing dimensions practiced by mango farmers in Mbeere district vary from one area to another, majority of the farmers interviewed adopted a spacing of either 8m x 8m or 10m x 10m irrespective of the variety of mango planted. This is in agreement with the recommendations of Crane *et al.*, (1997) and Muller, (2008) in Florida and parts of Western Australia respectively. This finding varies slightly from the recommendations of Griesbach (2003) who advocated a spacing of 8m x 10m or 10m x 12m for grafted mangoes in Kenya. The spacing of 10m x 10m is further supported by the practice in Phillipines where the Department of Agriculture (2008) recommends a spacing of either 10m x 10m or 14m x14m but indicates that individual orchards can vary the spacing depending on the growing conditions.

The findings vary from the practice in some areas of Western Australia, Queensland and Florida where mangoes are spaced variously at either 6m x 6m and later later thinned to give a spacing of 6 x 12m, or 6 x 2.5m. Other spacing arrangements from which these spacing arrangements differ include 3.8m x 3.8m; 6.4 x 6.4m; 10.5 x 10.5m and 15.2 x 15.2m (Guiyate *et al.*, 2008; Muller 2008; Bally 2004; Morton 1987).

Mango farmers in Mbeere district appreciate the role of manure in the provision of nutrients necessary for growth and development of mango trees. These findings are in agreement with those from related work (Chege, 1982). While reporting on analytical methods used for soil analysis at the National Agricultural Laboratories, Nairobi, Kenya Chege recommended application of manure to mangoes as it was beneficial for plant establishment, growth and development as it supplied essential nutrients and modifies soil structure and aeration (Samra and Arora (1997; Chege 1982).

In general, only a minority of mango farmers in Mbeere district applied fertilizer twice per year as recommended. Majority of the farmers applied fertilizer either once per year or irregularly. This finding contrasts the recommendations in other mango growing areas such as South Africa, Australia, India and Florida. In these countries, fertilizer is applied at least twice in a year (Crane, *et al.,* 2006; Griesbach 2003, Tomlinson *et al.* 1998, Samra and Arora 1997, Morton 1987).

Pruning of mangoes and indeed most of the fruit trees is an important aspect of crop management but this notwithstanding, only about 25% of the farmers in Mbeere district practiced proper pruning. Majority of the farmers either practiced irregular pruning or did not prune at all. The probable reason could be lack of technical knowledge as deduced from findings on major mango production constraints. This contrasts with the practice in other mango growing areas of the world such as Israel, Australia, Florida, Puerto Rico, Hawaii, California and South Africa whereby pruning is carried out on a regular basis or at specific times during tree development (Leo 2008; Crane *et al*., 2006;

MOA, 2006, 2005, 2004, 2003; Varela and Seif 2005; Bally 2004; Yeshitela *et al.*, 2004; Griesbach 2003 Crane *et al.*, 1997; Morton 1987).

Although different types of fruit trees and many cereal crops are grown in Mbeere district, mango emerged as the most important crop enterprise in the district in terms of annual monetary returns to the farmer. This finding agrees with previous reports on mango farming in Eastern Province where the district is located (MOA 2006; 2005; 2004; 2003). Indeed fruit tree farming in the district is an important enterprise and is considered a major cash earner. Other important fruit trees that are grown include bananas, papaya and citrus (MOA/Mbeere, 2006).

An assessment of crop protection practices among mango farmers in the study area indicated that farmers use various methods to control the general insect pests of mangoes (MOA/Mbeere, 2006; Griesbach 2003). Spraying is the most important method accounting for although a significant proportion of the farmers do not practice any method at all. The emphasis on spraying is common in other man go growing areas of the world such as Australia, Egypt; Florida, Hawaii, India, South Africa and Phillipines (Leo 2008; Anon 2007; Follet 2004; Anyango and Muriuki, 2007; Pinese and Holmes, 2005; Anon 2003; FAO 2004; Griesbach 2003; de Villiers and Steyn 1998; Flint and Dreistandt 1998; Joubert 1998 ; Pena and Mohyuddin 1997; Smith, 1996)

Although mango is an important crop enterprise in the district, production is affected by such constraints as pests and diseases, lack of technical knowledge, theft, high cost of inputs, poor infrastructure, lack of effective spray equipment and lack of planting materials. These constraints with the exception of ranking and severity are similar to those identified in most of the other mango producing areas in the country (MOA, 2006; FAO, 2004). Indeed the type of production constraints identified by this study closely follows those contained in studies from other mango producing areas of the world although the severity and management strategies vary from one area to the other (Rajput and Rao, 2007; Al Adawi *et al*., 2006; Nofal and Haggag, 2006; Ploetz *et al*., 2002; Reuveni, 2000; Dodd, *et al.*, 1997).

Trunk painting using Chlorpyrifos once per month during the fruiting period was found to be the most effective treatment in the control of mango seed weevil. Although mango produces flowers continuously for about two months, the once per month Chlorpyrifos banding frequency is able to prevent the gravid females from crawling up the tree to the developing fruits to oviposit and subsequently cause damage to the seed. Similar results have been experienced in other mango growing areas such as Australia, India and Hawaii where chemical application is used for the control of mango seed weevil (Pinese and Holmes 2005; Verghese *et al.* 2004; Ngowi *et al*. 2001; Cunningham 1991; Tandon and Shukla 1984). The advantage of this application method over the conventional one the reduction of the possibility of contaminating the fruits with pesticides hence drastically reducing the chemical residue as well as minimizing exposure of biotic and abiotic components of the ecosystem from the possible deleterious effects of pesticides.

Sanitation as a method of controlling mango seed weevil was found to reduce infestation in the field and this finding concurs with findings in reports from other mango growing areas such as Florida, Australia, India (Woodruff and Fasulo 2006; Bruno and Pinese 2005; Anon 2003; Pena *et al* 1998; Smith 1996)

Infestation of mango fruits by the mango seed weevil is recognized as a major constraint in the maintenance of the current foreign markets and also the development of new ones (MOA 2006; HCDA 2006, 2004; Griesbach 2003) The findings of this study have indicated an effective control strategy for this important pest of mangoes. These findings should, therefore, form a strong component in the dissemination of pest management technology aimed at reducing the infestation levels of mango seed weevil in the various production regions of the country. The study also clearly identified weaknesses in mango production technology among farmers in the areas studied. Similar studies should be carried out in the other mango growing areas of the country in order to find out the level of technology adoption in an effort to take ameliorative action.

This study has identified some of the critical mango production technologies that mango farmers in Mbeere district have not adopted fully and has also provided an effective management strategy for the mango seed weevil. These findings led to the conclusions presented in the next section.

4.2 Conclusions

The first objective of this study was to determine mango farmers' farming practices in Mbeere district. This objective was achieved through the identification of six major practices among mango farmers in the district. The important practices that were identified include mango spacing, frequency of manure application, frequency of fertilizer application, pruning control of major pests and management of major diseases. Although mango farming in Mbeere District is a relatively new enterprise farmers are generally aware of the recommended practices. In general, application of these methods requires to be improved in order for the farmers to benefit fully from this enterprise. This is very important since mango farming is ranked highly in terms of annual financial returns to the farmers. Spacing of mango trees is generally satisfactory but needs to be rationalized with respect to varieties as is done in other mango producing areas of the world. Application frequency for both manure and fertilizer is below optimum while pruning is not practiced widely as should be the case. Most of the farmers in the district rely on spraying as a strategy to control both the general pests and also the mango seed weevil. There is need to diversify this approach in order to increase the level of control.

The second objective of this study was to evaluate the efficacy of two chemical and three physical barriers and their combinations in the control of mango seed weevil. This objective was achieved through two types of field experiments. Sixteen test products were evaluated in an experiment that was sited in Karurumo. The most efficacious chemical and physical barriers included Chlorpyrifos, Tangletrap, Grease, Tanglefoot and a combination of Chlorpyrifos and Grease. Of these, Chlorpyrifos and Tangletrap were identified as the most efficacious chemical and physical barriers respectively.

The third objective was to determine the optimum frequency of trunk painting with Chlorpyrifos (Dursban) necessary for effective control of mango seed weevil. This objective was achieved through the assessment of four application frequencies. The most efficacious method of managing the pest in mangoes was found to be a monthly application of Chlorpyrifos as a 15cm band at a height of 30cm from the ground. The other tested frequencies had damage levels that were considered to be too high and therefore inappropriate for recommendation.

4.3 Recommendations

1. A holistic technology dissemination project to manage mango seed weevil in mango growing regions should be embarked on in order to reduce the economic losses being experienced by farmers.
2. The management strategies for mango seed weevil should be monthly band application of Chlorpyrifos.
3. Further investigation should be done on the efficacy of frequency of application of Tangletrap, Grease and a combination of Chlorpyrifos and Grease in the control of mango seed weevil in mango orchards.
4. Investigations should be made on possible natural enemies of Mango seed weevil e.g. “maji moto” ant *Oecophylla longinoda* Latr. in an effort to incorporate them in a management program for mango seed weevil.
5. In order to address prevalence of diseases, the management strategies for the major ones such as powdery mildew, anthracnose and gummosis should be assessment and any necessary modifications done.
6. Enhancement of farmer training combined with establishment of demonstration plots addressing various mango technologies should be initiated.

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APPENDICES

Appendix 1: Survey questionnaire

Survey of mango production practices and constraints in Mbeere district

1. Personal data

Name of Farmer --

Division --

Nearest School --

Total number of mango trees --

Other fruit trees ---

Type	Number
a) ---	---------------------------------------
b) ---	---------------------------------------
c) ---	---------------------------------------
d) ---	-------------------------------------

2. Income from crop enterprises

Main sources of income from crops farming activities
(Rank from 1-5 in order of importance)

Crop	Rank
a) ---	---------------------------------------
b) ---	---------------------------------------
c) ---	---------------------------------------
d) ---	---------------------------------------
e) ---	---------------------------------------

3. Mango spacing arrangements in mango orchards.

What is your most common mango spacing arrangement? Please tick (√)

a) 10m x 10m_______(b) 8m x 8m _______(c) Others _________________

4. Fertilizer and manure application in mango orchards in Mbeere district.

Do you apply manure or fertilizer in your orchard? Yes_____No__________

Manure _________Fertilizer______________ Both_____________________

If yes, at what frequency? At planting (a)____(b) x1/year____(c) x2/year____

5. Mango pruning practices in Mbeere district

Do you prune your mango trees? Yes_____ No________

If yes, at what frequency? (a) x1/year____ (b) x2/year___ (c) irregularly___

6. **Five major production constraints (**Rank in descending order of importance)

Constraint	**Rank**
a) ---	--------------------------------------
b) ---	--------------------------------------
c) ---	--------------------------------------
d) ---	--------------------------------------
e) ---	--------------------------------------

7. Major pests of mangoes and control strategies employed

Pest	Control strategy

8. Mango seed weevil management information

Strategy	Time strategy applied

9. List problems associated with control of mango seed weevil

a) --

b) --

c) --

d) --

10. List effects of mango seed weevil on marketing of mangoes

a) ---

b) ---

c) ---

d) ---

11. Information on IPM knowledge

a) IPM awareness Y/N ---

b) MRL awareness Y/N --

c) Pest scouting practiceY/N --

d) PHI awareness Y/N ---

e) How do you reduce pesticide residue in your crops? ------------------------

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12 Alternative crop protection practices

Do you use non-conventional pest control methods? ----------------------------

If yes, which ones? --

If not, why? --

13.Farm records keeping

Do you keep farm records? ---

What records? --

Name of interviewer ------------------------------------Date -----------------------