MANAGEMENT OF SWEET POTATO WEEVIL *Cylas puncticollis* B. (Coleoptera: Curculionidae) THROUGH EARTHNIG-UP AND HARVESTING TIME AND VARIETAL RESISTANCE AT CHANO DORGA AND LANTE (ARBA MINCH ZURIA), HUMB AND BALE (WOLAYITA ZONE) IN SOUTHERN ETHIOPIA

M.Sc. THESIS

BY

WORKU WOLDE SHANKILO

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JIMMA UNIVERSITY

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A Thesis
Submitted to the School of graduate studies
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In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Agricultural Entomology

By

WORKU WOLDE SHANKILO

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APPROVAL SHEET

Jimma University College of Agriculture and Veterinary Medicine
Graduate studies

As thesis advisers, we here by certify that we have read and evaluated the thesis prepared by **Worku Wolde** entitled "**Management of Sweet potato Weevil Cylas puncticollis b. (Coleoptera: Curculionidae) through Earthnig-up and Harvesting time and Varietal resistance at Chano Dorga and Lante (Arba minch zuria), Humbo and Bele (Wolayita zone) in southern Ethiopia",** we recommend that it be submitted as fulfilling MSc. thesis requirement.

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As members of the Board of Examiner of the M.Sc. Thesis Open Defense Examination we certify that we have read, evaluated the thesis prepared by **Worku Wolde** entitled "Management of Sweet potato Weevil Cylas puncticollis b. (Coleoptera: Curculionidae) through earthnig-up and harvesting time and varietal resistance at Chano Dorga and Lante (Arba minch zuria), Humbo and bale (Wolayita zone) in southern Ethiopia". We recommended that it be accepted as fulfilling the thesis requirements for the degree of Master of Science in Agricultural Entomology.

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DEDICATION

This thesis is dedicated to my mother, AMENECH GO’A, and WOLDE SHANKILO.

STATEMENT OF THE AUTHOR

The author declares that this thesis work is his bona-fide work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree at the Jimma University College of Agriculture and Veterinary Medicine and is deposited at the University Library to be made available to borrowers under rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate. Brief quotations from this thesis are allowed without special permission provided that accurate acknowledgement of source is made. Requests for permission for extended quotation or reproduction of this manuscript in whole or in part may be granted by the Head of the Department of Plant Science and Horticulture or the Dean of School of Graduate Studies when in his or her judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author.

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BIOGRAPHICAL SKETCH

The author of this research study, Worku Wolde, was born in 1976 E.C at Waraza Shoho village, Wolayta Soddo town, Southern Ethiopia, from his father Wolde Shankilo Dangore and his mother Amenech Go'a. He attended his Elementary and Junior Secondary School education at Damota Bere and Soddo Georges Elementary and Junior Secondary Schools, respectively, from 1986 to 1994 E.C. Then he attended his high school and preparatory education at Soddo Comprehensive High School and completed in 1998 E.c. After completion of his secondary education he joined Mada Wolabo University in 1999 E.C. and graduated with B.ed.Degree in Biology on July 4, 2001 E.C. After his graduation he was assigned by Ministry of education as Assistant Lecture at Deber Berhan University in 2002 E.C. He has served as Assistant Lecture in Biology Department for one year. In October 2003 E.C he joined the Jimma University College of Agriculture and Veterinary Medicine for his postgraduate studies M.Sc., in Agricultural Entomology.

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LIST OF ACRONYMS

DTN	Damaged tuber number
FAO	Food and Agricultural Organization
IPM	Integrated pest management
LSD	Least Significant Difference
MW	Moisture weight
MY	Marketable yield
PSPW	Population of sweet potato weevils
PDTW	Percent damage tuber by sweet potato weevil
PDW	Percentage dry weight
PMC	Percentage moisture content
PYL	Percent yield loss
RBD	Randomized block design
TFW	Tuber fresh weight
RPR	Root pulling resistance
SDW	Shoot dry weigh
SFW	Shoot fresh weight
SNNPR	Southern Nations, Nationalities and Peoples Region
SPW	Sweet potato weevil
TTW	Total tuber weight
UY	Unmarketable yield

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ABSTRACT

Sweet potato weevil (*Cylas puncticollis*) B. (Coleoptera: Curculionidae) is the most destructive pest of sweet potato in Ethiopia, particularly in southern part of the country. It causes severe damage by producing bitter taste of tuber which make unsuitable for human consumption and animal feed. This problem necessitated the development of technically sound, environmentally friendly and economically feasible management strategy. Thus, experiments were carried out under field condition of Arbaminch and Wolayta Zone, Southern Ethiopia during the 2011/2012 cropping season from June to December to know the effect of different frequencies of Earthing-up, harvesting time and different varieties of sweet potato on the infestation of sweet potato weevil. The factors were Earthing- up with four levels (one, two, three times and no earthing –up as control), harvesting times with three levels (prompt harvesting, i.e., immediately when the plant attained physiological maturity, one month and two months delayed harvesting). The experiment was laid out in a randomized complete block design (RCBD) in factorial arrangement with three replications. There were two experiments; one of the experiment was conducted at two locations: Chano Dorga and Lante at Arba Minch Zuria. The other experiment was conducted at two locations of Wolayita Zone: Humbo and Bele. For the second experiment, twenty different varieties of sweet potato were planted in RCBD replicated three times. The variables measured in both cases including marketable and unmarketable yield (t/ha), sweet potato damaged tubers, yield loss, percent damage, root pulling resistant, dry weight, moisture content of sweet potato and sweet potato weevil density. The result obtained indicated that three times Earthing up and prompt harvesting significantly reduced number of damaged tubers per plot (25), SPW per plot (29.77), percent damage per plot (6.9 %), unmarketable yield (0.56 t/h) and yield loss (8.68%). This demonstrating that effectiveness of frequent earthing up and prompt harvesting in the management of sweet potato weevil. Among the tested varieties, Kero, TIS.908.7, Mayai, PIPI and Ukerewe were found to be resistant against sweet potato weevil. In this study, interaction effect of earthing up and harvesting time suppress sweet potato weevils' infestation on sweet potato. Hence**,** Hence, the use of resistant variety, prompt harvesting and three times earthing up were found effective and recommended in the integrated management of sweet potato weevil in southern Ethiopia.

Keywords: *Cylas puncticollis,* earthing up, harvesting time, sweet potato weevil infestation, and sweet potato varieties

1. Introduction

Sweet potato (*Ipomoea batatas* Lam.,) is an important food security crop in many of the poor regions of the world, including East Africa. The crop is grown both for home consumption and to supplement household income when sold in the local markets and in some urban center's (Stathers *et al*., 1999). It is one of the major traditional food crops of Ethiopia (Endale *et al.,* 1994). For some farmers, the crop also supplements family income and this strategy to reduce losses to pests and provide opportunities to enhance food security and improve livelihoods. Fresh sweet potato provides about 50% more calories than Irish potato (Backumisky, 1983). Apart from its high caloric content, sweet potato is also one of the cheapest potential sources of vitamin A which alleviate the problem of night blindness and infant mortality which millions of children from sub-Saharan Africa are facing. With all its desirable traits, Sweet potato greatly contributes to food security and farmers' income (Terefe and Geleta, 1994). The succulent, starchy storage tubers of sweet potato serve as a staple food, as animal feed (Ruyiz *et al*., 1980; Lu *et al*., 1989; Posas, 1989; Woolfe, 1992), and to a limited extent as a raw material for industrial purposes such as a source of starch and for alcohol production (Winarno, 1982; Yen, 1982; Collins, 1984).

It has been cultivated as food crop in Ethiopia for several years and over 95% of the crop produced in the country is grown in the South, South western and Eastern parts, where it has remained for centuries as an important co-staple for the community (Terefe, 1987). Southern Ethiopia is the principal sweet potato growing region of Ethiopia and its economic impact in the region is considerable where it is used as a major source of food to the people (Ejigu, 1993). Sweet potato grows in different parts of the region mainly in Wolayita, Kanbata Tenbaro, Gamo Gofa, and in other zones in smaller amount both as subsistence food crop and increasingly as cash crop to supplement house hold income (Ashebir, 2006)

The 2002 production estimate of Central Statistical Authority of Ethiopia (CSA) indicated that 23,643.84 ha of sweet potato were cultivated annually in the region, producing around 236,288.3 tons of tubers which occupied 3% of the crop area and contributed to 16% of the regional total volume of production which makes it the second most important root crop next to Enset in the region. According to the report of Teshome *et al* (2011) the national average yield of sweet potato in Ethiopia was 7 tons per hectare. However, previous result of Adami Tulu Agricultural Research Center (ATARC) reported the yield up to 37.1 tons per hectare from improved varieties. This indicates that the national as well as the regional yield is by far lower than the attainable yield which obtained at research station. There are a number of constraints that hinder the production and productivity of sweet potato under farmers' conditions which could be grouped under biotic and abiotic factors.

The major biotic constraints are insect pests and viral infection (Chavi *et al*., 1997). Among the insect pests, 63.8% of farmers indicated sweet potato weevil (*Clay's puncticollis*) to be the most important in southern Ethiopia (Ashebir, 2006). In Uganda, these species may cause yield losses of up to 80% (Smit *et al*., 2001). Even low levels of infestation can reduce tuber quality and marketable yield because infested plants produce unpalatable terpenoids in response to weevil feeding (Stathers *et al*., 2003).The sweet potato weevil larvae and adults feed on the tuber, causing extensive damage, both in a field and storage, in many parts of the World. The weevil may go several life cycles during a prolonged storage period. The principal damage of the pest is mining of the tubers by larvae. The infested tubers are often riddled with cavities, looks spongy in appearance and dark in color. Weevil damage produces quantitative losses and aesthetically unappealing tuber which may be discolored and have bitter taste. In Ethiopia, losses due to the insect pest range from 20-75% (Emana, 1990). In addition to damage caused directly by tunneling, larvae cause damage indirectly by facilitating the entry of soil borne pathogens.

Despite years of intensive research, effective management practices for *C. puncticollis* are not available yet (Stevenson *et al*., 2009). Some of cultural control practices, which are recommended in sweet potato growing region, are harvesting the crop as soon as tuber attains physiological maturity (Shrman and Tamashiro, 1954; Sutherland, 1986a, Talekar, 1991). However, the traditional practice in the southern Ethiopia is underground storage and extended harvesting, in which plants are allowed to remain in the field for prolonged period to maintain a supply of tubers for long possible period. Such extended harvesting scheme, however, poses problem in area where sweet potato weevil are prevalent by providing a continum food for the weevil (O’ Hair, 1991). The length of time the crop is left in the ground is one of the most significant factors which exacerbate the damage by weevils. The exact time of harvest differs with varieties and environmental conditions. In many traditional production practices, sweet potato is harvested when needed and there is no fixed harvesting time. Prevention of soil cracking by earthing up the area around the plant or irrigating frequently, are also suggested as an important method of reducing weevil damage (Emana, 1990). Though, none of the previous researchers integrated different cultural practices for the management of sweet potato weevil.

Varietals resistance is the cheapest pest control strategy with various advantages. It is easy to introduce, low cost, safe to the natural enemies, and is compatible with other control measures such as biological, cultural and chemical methods (Panda and Khush, 1995). However, varieties of sweet potato that could resist the pest damage and give good yield have not been developed. The development of resistant variety is considered as a viable component of integrated management (IPM) approach. *Cylas puncticollis* is a difficult target for conventional pest control measures as the larvae feed in the storage tubers in the ground, or inside the woody base of the stems. This means that with the possible exception of systemic insecticides, which are costly and pose the risk of residual contamination of the tubers, there is no effective chemical control of the larvae, or of the other stages found within the plant tissue (Allard *et al*., 1991). In addition to this widespread use of insecticides cause environmental hazards, resistance development, residues accumulation in the food and feed and harmful effect on non target organism and the cost of insecticides is getting too expensive from time to time for poor farmers (Dhuyo and Ahmed, 2007). In the current study, therefore, two experiments were carried out which tries to see the effect of earthing-up, harvesting time and their combined effect as well as resistance of different varieties of sweet potato to sweet potato weevils that could enhance the development of integrated management program. Therefore, the present study was conducted with the following objectives:

General Objective

To develop environmentally friendly and economically feasible management options for *Cylas puncticollis* in southern Ethiopia

Specific objectives

1. To evaluate the interaction effect of earthing up and time of harvesting against *Cylas puncticollis*
2. To identify resistance of sweet potato varieties against sweet potato weevil infestation

2. LITERATURE REVIEW

2.1. Sweet potato production in the Southern Nations, Nationalities and Peoples Region (SNNPR) of Ethiopia.

The Southern Nations, Nationalities and Peoples Region (SNNPR) is one of the region in Ethiopia. It covers about 10% of the country's area, i.e. 11, 3539 square kilometers. Population size in the area is estimated at 15,042,531 and density of 136 persons per square meter and growing at 2.9 % per annum (FDREPCC, 2008). Agriculture is the dominant sector in the region and it is the biggest employer of the economically active population. Maize, teff, enset, coffee, potato, sweet potato, wheat, fruit and vegetables are the major crops grown in the region (BoPED, 2001). Production of root crops, enset and sweet potato have important place in the region. The crops production was estimated to 99 million tons in 1994/95 and the figure has reached 15.3 million ton in 1999/2000 (BoPED).

Sweet potato is cultivated in the region for a long time and is the most important crop grown in the region. It is not known when the crop was introduced to the region, but speculated that the crop was initially introduced to the highland area and later advanced to the lowland parts of the region. Currently, SNNPR is the principal sweet potato growing region of Ethiopia. The CSA (2002) estimate indicated that a total of 23,643.84 hectares of land were allocated for sweet potato production having annual production of 236,288.3 tons. These indicated that sweet potato occupied 3% of the crop area of the region and contributed to 16% of the regional volume of crop production. Sweet potato is grown in different parts of the region mainly Wolayta, kembata Tembaro, Gamo Goffa zones, and in other zones of the region in smaller amount both as subsistence food crops and increasingly as cash crop (Ashebir, 2006). The crop is primarily produced by small-scale farmers mainly for home consumption and sale in surplus to supplement house hold income. In addition to playing important role in the diet, feed, and income source of farmers of the region, sweet potato is important for food as insurance crop in dry years and in months where other food is scarce (Ejigu, 1993).

Sweet potato is a crop of mid altitude under rain feed condition and of low altitudes with supplemental irrigation. Hot and non-shade area, sandy and well-drained soil and sufficient moisture at early stage specifically during the first six week, even though the crop is drought tolerant, is most preferable environment for sweet potato production (Talekar, 1987). However, it is widely grown by the farmers of the region in the different agro-ecologic zone with environment having different soil types, moistures and other factors. In the mid-altitude of important and potential sweet potato growing areas of Southern Ethiopia the dominant soil types are Nitosols, Acrisols and Cambisols and in the lowland it is mainly grown in Fluvisols, where supplement irrigation is needed to boost the yield (BoPED, 2001).

Currently there are eleven improved varieties of sweet potato under production in the country (NAIA, 2003). These varieties were released for Agro-ecologies of low to mid altitude with agronomic recommendation of 60 cm by 30 cm and 30 to 36 cm cutting length (Assefa, 2001). However, their reaction to sweet potato weevil was not known for most of the varieties.

2.2 Production Constraints of Sweet potato

Biotic and abiotic factors affect the production of sweet potato. A biotic (physical) stress such as drought, high temperature, lack of irrigation, poor land preparation, lack of high yielding and adapted cultivars, lack of sufficient quantity of good quality cuttings, sub or supra-optimal plant population, improper method of planting, careless harvesting, poor post-harvest handling, and lack of crop rotation. The major biotic constraints are insect pests and viral infection (Chavi *et al*., 1997). Among the insect pests, 63.8% of the farmers indicated that sweet potato weevil (*C.puncticollis*) is the most important sweet potato production constraint in southern Ethiopia (Ashebir, 2006). Sweet potato weevil reduces tuber quality and marketable yield both through physical damage and production of toxic terpenoids in response to weevil feeding as a result yield losses reach as high as 60-97% in East Africa (Stathers *et al*., 1999).

2.2.1 Sweet potato weevils

According to Charry *et al*. (1998) at least 18 species of insects feed on sweet potato tubers. Among those causing the greatest damage is the sweet potato weevil. Sweet potato weevil is the most destructive pest among several different insect attacking sweet potato. It was believed that sweet potato weevil originated on the Indian subcontinent, which is different from the origin of sweet potato (Northwestern South of South America) (Austin, 1988) and dispersed from the Indian region to other parts of the old world, particularly Africa. This was evidenced by the presence of weevil throughout Old World Tropics and its absence from large parts of the New World, particularly most of South America (Anonymous, 1970; Sorensen, 1984). The origin of the genus was long enough that numerous species evolved in the Old World. No species however is native to the new world. More recently, the weevil was carried by man to the New World. Austin *et al*. (1990) concluded that the sweet potato was not associated to weevil until after European began to spread both around the World. Sweet potato weevil taken as from the New World to Old World where they became associated weevil. Both were spread from point of contact as they were taken from port to port around the World. As the crop establish, so was the weevil. Native and introduced alternate host plants are probably aided in the establishment of the insect (Austin *et al*.,1990).

Several species of *Cylas* weevils are considered pest of sweet potato in various part of the world. From the systematic revision of *Cylas* are approximately 25 valid species of the genus and it has been specifically speculated that eleven species of *Cylas* attack sweet potato: *C. brunneus* (Fabricius), *C. compressus* Hartman, *C. cyanescens* Boheman, *C. elegantulus* (Summers), *C. femoralis* (Faust), *C. formicarius* (Fabricius), *C. nigrocoerulans* Fairmaire, *C. puncticollis* (Boheman), *C. puncticollis opacus* Voss, *C. turcipennis* (Boheman), and *C. vanderplasi* Voss (Burgeon, as cited by Jansson, 1991: Risbec, as cited by Jansson, 1991). However, currently there is adequate evidence to apply only nine of the above species are divided in to one of the three monophyletic pest species group as *C. formicarius* group, *C. brunneus* group and *C. puncticollis* (Wolfe, 1991).

2.2.2 *Cylas puncticollis* group

These group includes*: C. puncticollis, C. puncticollis opacus, C. compressus, C. nigrocoerulans and C. hovanus* Hustache are placed in this group (Wolfe, 1991). All members of these species are uniformly black with the eye dorsally separated in males. *C. puncticollis*, *C.formicarius* and *C.brunneus* are found in East Africa (Lenne, 1991). *C. puncticollis* was reported to be found in all Woredas surveyed in southern Ethiopia; although there were differences in the extent of stem and tubers damage and weevil population density per plant parts (Ashebir, 2006). High levels of stem and tuber damage and high number of larvae per tuber was recorded in Goffa Zuria, Arba Minch Zuria Waredas (Ashebir, 2006), Nazareth and Werer (Emana, 1987), Awassa and Areka (Emana and Amanuel, 1992; Adhanom and Tesfaye, 1994) and Humbo (Tesfaye,2003)

2. 2.3 Biology of *Cylas puncticollis*

The knowledge of the biology of the insect is of vital importance, since such information is basic and necessary for the application of control measures, mainly when desired to implement programs of handling of plagues. Study on the biology of *Cylas spp.* was made by Sharma and Tamashiro (1954), IITA, (1982), Sorensen and Kidd (1983), Sathula *et al.* (1997) and CIP (1997).The life cycle of *C.puncticollis* pass through four stages of developments: egg, larva, pupa and adult. The egg, larva and pupal stage development always take place hidden inside sweet potato tuber or vines towards the bases (Sathula *et al*, 1997). The adults prefer to live in the canopy of vines and leaves, feeding on all parts of the sweet potato plant. The adult females oviposit with in cavities excavated either in the old portion of the stems or the tubers (Sathula *et al*., 1997), preferring the latter, where the larvae develop. Some time the adult will crawl down cracks in the soil to access tubers for oviposition, in preference to depositing egg in stem tissue.

The female deposit creamy white, oval shaped eggs signally at a time, and seal the egg within the oviposition cavity with a gray fecal plug that preserves moisture, protects the egg from predation mites and also disguises the location of the oviposition site. The egg has a size of 0.7mm length and 0.5mm in mm in width. The average fecundity under room temperature is one per female per day. The average longevity of this species ±16 days and the total number of eggs during her life, range between 103 ±16 at 27 ±1^{o} C temperature and 45± 5% relative humidity (CIP, 1992). Hatching takes places within seven days of incubation at temperature of 27^{o} C relative humidity of 60% with 12 day night length (CIP. 1992). In other experiment with temperature of 25-30^{o} C and RH of 79%, the development of *C. puncticollis* averaged 20.2 days; preoviposition period average 3.6 days and the oviposition period was 71.4 days. The incubation period averaged 3.3 days, larval and pupal period averaged 11.1 and 6.2 days, respectively,(IITA, 1982). Larger span of *C.puncticollis* adult was observed in semi controlled natural environment (Sathula *et al*., 1992) than under controlled laboratory condition reported by IITA (1982) and CIP (1992). The adult longevity and fecundity of *C. puncticollis* have important implication on field infestation and control of the weevil in sweet field (Sathula *et al*., 1997).

The larvae feed and develop within the vine and tuber of the sweet potato and pass through four instars. Pupation occurs in a small chamber prepared by the final larval instars. After emerging from the pupal the adult remain within the pupation chamber or larval tunnel for some day and emerges from the vine or tuber by eating themselves a way out of the tuber or vine after attaining full coloration. Adult *C.puncticollis* is uniformly black and relatively larger than the counter *Cylas species* (CIP, 1991). Females weevil are smaller than male and adults may be conventionally sexed by the shape distal antennal segment, which is filiform (thread like, cylindrical) in male and club like in female. *C. puncticollis* generally needs 32 days on the average to complete one generation (egg-to egg) (CIP, 1992). According to Terefe (1987), one generation of *C. puncticollis* is completed within 26 to 30 days and six to eight generation where observed per season in southern Ethiopia.

The female lays its eggs in small hollows which are eaten into the base of the stems or in tubers, when the latter can be reached. The larvae hatch after approximately one week and feed in the tubers and veins, causing mining symptoms the larval period lasts for two-three weeks, depending on temperature (Schmutterer, 1969). Pupation takes place either in the tuber or in the soil nearby and lasts for approximately one week. The adult weevils remain within the pupa chamber for some days before leaving the plant; to reach above-ground they tunnel through the stems or make their way through the soil. Adults are long-lived and activities of more than one month have been observed, even in storage. If conditions are favorable there are several generations per year, for example, in Sudan. *C. puncticollis* prefers drier climates and larval development lasts longer in damp climates or during rainy seasons, and in such conditions the activity of the adults is at a considerably lower level (Geisthardt and van Harten, 1992)

Allard (1990) observed a distinct pre-oviposition period (dependent on feeding) of 3 days, in a population of laboratory-reared weevils originally collected from western Kenya. From 2 days post-emergence, females laid eggs singly on the tuber surface, but after 5 days eggs were laid in an excavation plugged with frass. Egg lying continued for up to 60 days, but most eggs were laid in the first 30 days. Eggs laid in stems and tuber hatched after 3-5 days under laboratory conditions. After four larval instars, adult emergence occurred approximately 22-25 days after egg lying. Experiments also revealed that newly-emerged adult weevils can survive for up to 8 days in the absence of any food source and for up to 90 days if fed on sweet potato foliage. Mean adult longevity was 42.5 days. The sex ratio did not differ from a 1:1 ratio (Allard *et al.*, 1991). The biology sweet potato weevil was studied in Awassa and Nazareth Research centers. The weevil required 30 and 31.5 days to complete its life cycle in Awassa and Nazareth, respectively. It was also reported that the weevil could complete nine generation at Awassa and eight at Nazareth (Emana, 1987; Emana and Amanuel, 1992).

2.2.4. Morphological description of *Cylas puncticollis*

The egg is oval, and yellowish-white (Schmutterer, 1969). The larva of *C. puncticollis* was briefly described and figured by Schmutterer (1969). It is whitish, legless, slightly curved, approximately 5-10 mm in length, maximum width 1.5 mm; cuticle coarsely speculate. Head unrestricted, pale brown with darker brown mandibles; frontal sutures distinct, reaching basal membrane of mandible; one pair of ocelli (stemmata), each containing 2 contiguous pigment spots; antennae 2-segmented; mandibles very bluntly bidentate. Body elongate, slightly curved, tapered at posterior; entirely covered with very short setae. Mesothoracic spiracle located on a lobe very close to the prothorax. Abdominal segments 1-7 with 2 dorsal folds.

Abdominal segments are 2-7 having paired ampullae's. First eight abdominal segments bearing one pair of spiracles. According to Allard (1990) the head widths of the various larval instars ranged from 0.25 to 1.00 mm.

The pupa of *C. puncticollis* was briefly described and figured by Schmutterer (1969). It is white and approximately 5-6 mm in length; pronotal width 1.0 mm. Cuticle glabrous. Setae pallid, short and fine, on minute tubercles, those of abdominal segments 5-7 on larger tubercles. It is elongate; antennae roughly tubrrculate. The head and rostrum are provided with setiferous tubercles as follows: one pair between the eyes at base; one pair immediately behind eyes; two small pairs between eyes; and two pairs on the rostrum; the posterior pair being close to the eyes and the anterior behind the middle. The femoral apices bear two or three setae. The ninth abdominal segment is provided with two large curved processes, slender, bicurvate, acute apically.

Adults are entirely black, with a faint, metallic blue luster, and not with a distinctly shiny, copper-like sheen. Body length is 6-8 mm and Rostrum never extremely short and blunt. Antennae distinctly sexually dimorphic; length of male antennal club equal to or greater than combined length of all preceding segments. Eyes close together in dorsal view; distance between eyes about one sixth of minimum width of rostrum. Pronotum in lateral view more distinctly arched, posterior constriction evident. Hind femora are not projecting or only slightly projecting beyond elytra apex. Abdomen is always elongate and cylindrical (Schmutterer, 1969).

2.2.5 Host range and dispersal of *Cylas puncticollis*

Although it has been shown that the preferred host plant for *Cyla*s ssp. is *Ipomoea batatas* (Cockerham, 1943), several other species of Ipomoea and a few related genera also serve as alternate host. The presence of alternate host as a source of infestation is considered by some authors, who recommend their removal as a control measure (Hua, 1970; Butani and Varma, 1976). However, Talekar (1983) found out that destruction of alternate host had no effect in continuous cropping which indicates that the importance of volunteer crops and carry over effects of leftover of the last sweet potato crop. Most authors seem to agree that the principal mechanism of infestation is by females gaining access to the surface of the tuber, either when it is exposed on the surface as they enlarge (Hua, 1970) or by tunneling through soil crack under low rainfall condition or loose earth (Trehan and Bagal, 1957). Once at the tuber, oviposition follows and the developing larvae later damage tuber.

One of the major factors influencing the method of control of any pest is the means by which it disperses. These have been much speculation but little careful study on the mechanisms of weevil dispersal (Sutherland, 1986a). Adult weevils are most inclined to flight at temperatures between 23-37^{o} C, with relative humidity at 75% and regular rainfall (Sanchez as cited by Sutherland, 1986a). Talekar (1983) showed that a vine dips only reduces damages if the nearest weevil source was at least 0.5 km away. Sherman and Tamashiro (1954) considered flight of minimal importance and rated mechanical transmission on planting material as the more possible means of dispersal. However, until more is known about weevil flight, it is not possible to say that constitute safe source to neither field distance nor when mechanical dispersal becomes more important than immigration by flight (Sutherland, 1986a).

2.2.6 The extent of damage

Sweet potato weevil is the major pest constraint of sweet potato production. It causes economic reduction in area with a marked dry season (Bourke, 1985). The weevil spends its entire life cycle on the host plant, and both larval and adult stage damage the tuber and vines, damage to tuber due to sweet potato weevil may reach 50 to 100% under low input subsistence agriculture (Chalfant *et al.*, 1990) and relatively minor damage can reduce yield and hinder infested tubers unmarketable due to the presence of feeding marks and oviposition holes. Tuber shrinkage also occurs due to loss of water through feeding or oviposition cavities made by the weevil. Mining of the tubers by larvae is the principal form of damage, but yield loss also occurs due to adult and larvae feed on the vines (Sutherland, 1986a). Frass is deposited in the tunnels, in response to the damage the tuber produce Terpene phytoalexins, which hinder the tuber inedible at low concentration and low level of physical damage (Sato *et al*., 1981). The adult have also been recorded browsing on the surface of vine, petioles, leaves, causing superficial damage.

Attempts were made to establish the relationship between sweet potato weevil damage and time of the sweet potato remains in the field. Sherman and Tamashiro (1954) work in Hawaii showed that damage increased sharply between 24 and 30 weeks after planting. Different research work (Sherman and Tamashiro, 1954; Sutherland, 1986b; CIP, 1997) indicated that the relationship between damage caused by sweet potato weevil and time have positive relationship and sharply increased towards maturity. Sutherland (1986b) demonstrated that at low levels the relationship towards maturity.

This damage decreases the quality of sweet potato by marring appearance, providing entry points for decay organisms, causing waste when cooked, and sometimes causing objectionable tastes. Tubers containing insects or their excrement are usually unfit for human consumption. Young sweet potato plants which develop from infested cuttings may be so badly damaged that they wilt and die (Schmutterer, 1969). During heavy infestations, larvae can be found in the young stems close to the leaf axils, representing potential planting material for nurseries (Allard *et al*., 1991).

Adults feed on the epidermis of vines and leaves, scraping oval patches off petioles, young vines and leaves. Serious damage may cause the leaf to shrivel and die. Adults prefer to feed on lower leaf surfaces (Nottingham *et al*., 1988), whereas in the tubers, adults feed more on the periderm than on the inner core (Nottingham *et al*., 1987). Adults also feed on the external surfaces of tubers producing circular feeding punctures which can be distinguished from oviposition sites by their greater depth and the absence of a faecal plug (Allard *et al*., 1991). Sweet potato weevils are a particularly serious problem under dry conditions, because the insects, which cannot dig, can reach tubers more easily through cracks that appear in the soil as it dries out. It is for this reason that during the dry season, unlike cassava, sweet potato tubers cannot be stored in-ground for any significant period of time. In addition to attacking tubers in the field, losses of sweet potatoes in storage to the SPW are also significant (Rajamma, 1983; Raman 1989).

2.3. Management of *Cylas puncticollis*

2.3.1 Cultural managements

Cultural pest management practice involves changing or modifying cultivation which directly or indirectly reduce the pest population. Allard *et al*. (1991) reported many techniques that have used in the management of *Cylas spp*. in sweet potato. However, the choice of suitable cultural control practice is site specific and depends on agro- ecological and socio economic condition in addition to its site specificity and need to be thoroughly understood since farmers differ greatly in their management system (Pardales and Cerna, 1987). Although most recommended cultural control practice are meant for *C. formicarius* group, in principle, recommended cultural practice that would reduce damage by *C. puncticollis* as they are similar in the ecology and biology considering flight activity, host range and mode of entry in to the plant except for production of pheromone (CIP, 1997).

2.3.1.1 Harvesting time and earthing up

Sweet potato tubers can be ready for harvesting in 3-8 months after planting. The exact time of harvest differs with variety and environmental conditions. In many traditional production practices, sweet potato is harvested when needed (AARC, 1996). Early harvesting reduces weevil damage, where as delay harvesting enhances the activity of the weevils (Emana, 1994). Smith (1997) from Uganda also reported that damage by sweet potato weevil linearly increase with the delay of harvesting time beyond the physiological maturity of the crop. Prevention of soil cracking by earthing up the area around the plant or irrigating frequently, are also suggested as an important method of reducing weevil damage (Franssen, 1934; Holdaway, 1941; Sherman and Tamashiro, 1954). Similar result also reported by Emana (1990) in that earthing up of soil around the plant three times at monthly intervals starting from the second month after planting significantly reduce the infestation of sweet potato weevil to sweet potato tubers. Earthing up in combination with early planting also reduced infestation of sweet potato weevil and increase tuber yield (AARC, 1996).

2.3.1.2 Planting date

Effect of sowing dates on sweet potato weevil infestation was evaluated at the Awassa and Areka Research centers in the 1994 cropping season (Adhanom and Tesfaye, 1994). Among the six planting dates extending from June to September, higher tuber infestation was obtained from the late plantings. The highest tuber attack (over 64%) and the lowest yield was obtained from September planted sweet potato followed by the early and August planting at Areka The second planting date July 10 gave the highest yield with low weevil infestation. Similarly, higher levels of tuber infestation were recorded from September planting followed by the early and last week of August at Awassa. In general, late planted sweet potato sustained high levels of sweet potato weevil damage at both locations. A similar study conducted in Wolayta indicated that sweet potato planted in August sustained lesser damage than September planted ones (Tesfaye, 2003).

2.3.1 .3 Crop rotation

Crop rotation appears to be the most effective method of preventing infestations of *C. puncticollis*, since the adults cannot move rapidly from one plantation to another because they are wingless (Geisthardt and van Harten, 1992). Allard *et al*. (1991) also described this techniques have been used as in the management of *Cylas spp*. in sweet potato: planting only in fields that have had no weevil infestations within the last 12 months and preferably more than one km away from any infested land. A survey of farmers' cultural practices in Kenya by Smit and Matengo (1995) suggested that crop protection workers should concentrate their research and extension efforts on crop sanitation and the avoidance of adjacent planting of successive crops.

2.3.2 Varietals resistance

Varietals resistance is the cheapest pest control strategy with various advantages. It is easy to introduce, low cost, safe to the natural enemies, and is compatible with other control measures such as biological, cultural and chemical methods (Panda and Khush, 1995). Sweet potato weevils attack stems, crowns and tubers which hinder them difficult to control and their cryptic habit reduces the effectiveness of control by chemical or biological insecticides and parasites (Smit *et al*., 2001). Despite years of intensive research, varieties with resistance to *C. puncticollis are* not available despite the progress in finding weevil resistant components in some varieties (Stevenson *et al*., 2009).Varieties of sweet potato that could resist the pest damage and give good yield have not been developed. However, there are variations in varietal resistance for damage and can be utilized as one option of management to reducing loss to growers (Weddill and Conover, 1987; Rolston *et al*., 1979; Mullen *et al*., 1981a). Postulated that antixenosis (non- preference), antibiosis or tolerant are the important factors for cultivars resistance. This is evidenced by the different level of varietal infestation despite high number of adult weevil. Antixenosis and Antibiosis in sweet potato related towards tuber chemical composition.

Several characteristics of the sweet potato plant affect growth and concomitant attack by these weevils. These include anatomical characteristics of the plant, growth phase, cultural factors, cultivars or genotypic variation and environment factors (O' Hair, 1991). Cultivars with smaller hard crown, long rooted than set scattered tuber (Edmond, 1991), and tuber with high in moisture content and carotenes and low starch content showed low infestation. A number of field trails suggest the importance of physical traits, like root tuber depth, arrangement, root size and shape, of sweet potato cultivars playing important role in conferring resistant to *Cylas ssp*. in the field (Cocker ham and Deen, 1947; Sing *et al* 1987; Talekar, 1987b).

The relationship between insect damage and soil depth of roots is well recognized (Burdeos and Gapasin 1980). Stathers *et al*. (2003) associated depth of roots, degree of soil cracking, and amount of foliage with degree of pest resistance of sweet potato varieties. Sutherland (1986) reported that certain less susceptible varieties in India have thin tubers scattered within the ground well below the soil surface, whereas Pillai and Kamlam (1977) reported that deep rooting sweet potato with a long "neck" are less susceptible to weevil attack. Talekar (1997) reported that cultivars with thin, woody stems received less damage from weevils than those with crowns. Early maturing varieties also generally have less insect damage than later maturing genotypes (Collins *et al*. 1991, Alca´zar *et al*. 1997). These pseudo resistance factors that allow the roots to escape insect damage also can be exploited in IPM programs (Smit 1997). Edmond (1971) found that deep tuber forming sweet potato cultivars were less affected by weevils. O'Hair (1991) also reported that cultivars with long, thin tuber, which are less likely to develop close to the soil surface where weevils could oviposit, will be less productive, less prone to weevil damage than cultivars with globular shaped tuber. Laboratory and evaluation based on tubers, leaf and stem condition conducted at Awassa revealed that Wonago I, Tis-1999, Koka-9, Tis-2544 and Arbaminch II were found to less damage to SPW (Emana, 1989).

Several researchers have verified the presence of variability in sweet potato genotypes for resistances to sweet potato weevil. However, some of the materials reported to resistant succumb under high weevil population pressure. Emana (1990) evaluated sweet potato varieties for resistance to the weevil 1987-1989 and found that 38% of the varieties for to be resistant and remaining were moderately resistant at Areka. At Awassa, however, 55% of the varieties were reported to be moderately resistant and rest was susceptible. The reason for variation in the level of resistant at two locations was attributed to the difference in population density of the pest. Fields at Areka had been cultivated for only three years with sweet potato when the trial was conducted and the pest has not yet established itself. At Awassa, sweet potato repeatedly cultivated for more than a decade in the same field. Some of the varieties like Arba Minch I and II, which seemed to be resistant at Areka, were susceptible at Awassa. However, the low level of infestation at Areka could not be enough to Level a variety was resistant or not. Tesfaye (2003) found all of the varieties he tested were damaged by the sweet potato weevil and there was no resistant variety. However, the varieties differed in the degree of damages and infestation levels they sustained. Varieties Koka 26 and Cemsa had the lowest level of infestation and adult weevil density in the field. On the other hand, varieties TIB-1102 andTIB-1-1102 had higher levels of tuber infestations. It is known that varieties with deeper tuber suffer less from the attack of sweet potato weevils. The study also showed that Koka 26 and Cemsa had deeper tubers than the other varieties considered (Addis and Tesfaye, 1995).

2.3.3. Biological control of *Cylas puncticollis*

Biological control is well suited for low-input cropping systems. It requires minimal physical input, is often cost-effective, and offers the potential for long- lasting control of the target pest. In addition, biological control is safe, specific for the target pest, and minimizes insecticides resistant, contamination of the environment, and human health problems associated with improper handling of pesticide.

2.3.3.1 Predatorrs and parasitoids

Several predators and parasitoids of *cylas spp*. have been recorded. These predators have been reported, two of which are ants in the family Formicide. These ants are centralistic feeders. The Argentine ant, *Iridomymex humilis* (Mayr) (Cockrhan *et al*., 1954) and the big headed ant, *Pheidole megacephala* (fabricus). Castineiras *et al.*, as cited by Janson (1991) were reported to be an effective biological control agent. They showed that this ant was more effective than chemical insecticide at management weevil population. Experiment in Cuba indicated that yield in plot where the big-headed ant was used to control weevil were 21.5 t/ha compared with only 7.8 t/ha in plots that relied solely on chemical insecticide (Morales, as cited by Jansson, 1991). Sweet potato fields colonized 30 days after planting with two species of predatory ants, *Pheidole megacephala* and *Tetramorium guineense*, showed only 3-5 % weevil infestation (CIP, 1997).

Fifteen parasitoid of *Cylas spp*. have been reported (Jansson, 1991). In general, most of these are not effective at suppressing weevil's population. Several other parasitoids of *C. puncticollis* have been reported in Africa; however, their impact on population of *C. puncticollis is* not known (Jansson, 1991). Although several parasitoids have been reported to attack *Cylas* weevil, no studies have examine the impact of these parasitoids on weevil population (Jansson, 1991).

2.3.3.2 Entomopathogenic fungi and bacteria

Lobo-Lima (1990) conducted bioassays to evaluate the pathogenicity of the fungal pathogens *Metarhizium anisopliae* and *Beauveria bassiana* against *C. puncticollis*. Mortality rates obtained were encouraging for further research on the control of *C. puncticollis* with these fungi. The subterranean habitats of *C. puncticollis,* whilst making it less accessible to predators and parasitoids may enhance the impact of fungal pathogens which require a protected cool, humid environment for survival and reproduction; conditions generally found under the dense foliage of sweet potato. The eggs are also well protected as they are laid within vines, or in tubers and the egg cavity are sealed with a faecal plug that preserves moisture, disguises location and protects the eggs from predatory mites. Potential candidates for use as biological insecticides include *B. bassiana* and *M. anisopliae*; isolates of the former have been collected from laboratory reared adults originally collected in Kenya (Allard *et al*., 1991).

Four isolates of *B. bassiana* were found to be pathogenic to adult *C. puncticollis* in Cuba and 49, 48, 47 and 42% adult mortality was recorded from this four isolates after 12 days at 25% temperature. Higher level of adult mortality (80-90%) was also achieved in the laboratory when spores of *B. bassiana* isolate (JG-78) applied to sterile soil (Diaz and Grillo, 1986). Report from Cuba indicates that fields planted with disinfected cutting with *B. bassiana* showed 3-4 times lower weevil populations than those with non-disinfected cutting (CIP, 1997).

2.3.4. Chemical control

Several insecticides were tested for the management of SPW by using them after planting, either by foliar spray or basal granular applications Emana and Adhanom (1989) evaluated seven insecticides as dipping, foliar sprays and combination of both at Awassa and Areka during the 1987 and 1989 cropping seasons. Spraying began two months after planting and ocnttinuea up to the fourth month at fortnightly interval. Of the seven insecticides, cypermethrin and pirimiphos-methyl gave best control of the sweet potato weevil which resulted in higher marketable yield. In another study, dipping of sweet potato vines used for planting in diazinon 60% improved the yield of sweet potato and reduced the level of weevil infestation (Tesfaye, 2003).

C. puncticollis is a difficult target for conventional pest control measures as the larvae feed in the storage tubers in the ground, or inside the woody base of the stems. This means that with the possible exception of systemic insecticides, which are costly and pose the risk of residual contamination of the tubers, there is no effective chemical control of the larvae, or of the other stages found within the plant tissue (Allard *et al*., 1991). Soil application of carbofuran at planting to control *C. puncticollis* increased tuber yields of the susceptible cultivar TIb1 in both wet and dry seasons (IITA, 1974). In Ethiopia, insecticidal screening trials tested the use of foliar sprays applied 3 months after planting, followed by four applications at fortnightly intervals, and also tuber dipping prior to planting. Deltamethrin and pirimiphos methyl gave good control of sweet potato pests (Adhanom and Tesfaye, 1994).

3. MATERIALS AND METHODS

3.1. Description of study sites

Experiment one (earthing up versus harvesting time) was conducted in Arbaminch zone at Chano Dorga and Lante (Keble's in Arba Minch Zuria) in farmer's field, and located about 18 and 24 Km North of Arbaminch town, respectively. The area is known for its Sweet potato cultivation and hot spot for sweet potato weevils (Emana, 1990; Ashebir, 2006). The research sites are located at an elevation of 1200 meters above sea level. The areas receive mean annual rainfall of 888.5mm and has mean maximum and minimum temperatures of 30.4 ^{0}C and 17.2 ^{0}C, respectively (average of 6 years data) (Appendix Table1).

Experiment two (Varietal screening) was conducted in Wolayta zone at Humbo and Bele Districts. They were located about 18km and 40km south and west of Wolayta Soddo town, respectively. Humbo Wereda is located at an altitude of 1632 m.a.s.l and receives a mean annual rainfall of 1615.2 mm and has a mean maximum and mean minimum temperatures of 29^{0}c and 15 ^{0}c respectively (Appendix Table 1). Similarly, Bele is located at an altitude of 1100m.a.s.l and receives a mean annual rainfall of 900mm and a mean maximum and mean minimum temperatures of 40 ^{0}C and 25 ^{0}C, respectively (6 years data from National meteorological agency of Ethiopia, Appendix Table 1).

3.2 Experimental Materials and Design

Experiment I. Effect of Earthing up and Harvesting Time on the Management of Sweet potato Weevil

Sweet potato variety Awassa-83, a moderately resistant variety to *Cylas puncticollis* was used for this study. The experiment consisted of four levels of Earthing up and three levels of harvesting times. The levels were one time earthing up (one month after planting), two times Earthing up (one month and two months after planting), three times Earthing up (one month, two month and three month after planting) and farmers practice (no earthnig up) used as a control while harvesting times include prompt harvesting (harvesting, immediately when the crop attained physiological maturity) and one month and two months delay. The treatment combinations were laid out in RCBD using factorial arrangement with three replications. The plot size was 3 m by 3 m and with the spacing of 0.6m and 0.3m between rows and plants, respectively. The experiment was conducted at Chano Dorga and Lante Kebeles'.

Experiment II: Evaluation of Sweet potato Varieties against Sweet potato Weevil

In this experiment, twenty sweet potato varieties namely, Temesgen, Mayai, Beletech, Koka-12, Kulfo, Resisto, Tulla, TIS-9068.7, Falha, Boreda, Dubo, Ukerewe, Kero, Eujumula, Kudade, Belela, Ordollo, PIPI, Awassa-83 and Damota were used. The varieties were obtained from Awassa agricultural Research Center. The varieties were arranged using randomized complete block design with three replications. The plot size was 2 m by 6 m consisting of single row. The spacing was 2m and 0.30 m between rows and plants, respectively. Cultural practices were applied as recommended for the area uniformly for all varieties. The experiment was conducted at Humbo and Bele.

3.3 Data collected

Number of weevils: Weevil count was started 30 days after planting and continued up to maturity at 15 days interval. For counting sweeping net and visual methods were used. Counting was done on six randomly selected plants per plot. At harvest, the tubers and vines (15 cm above the crown) of each plant were dissected and the number of weevil larvae, pupae and adults were counted (Alexander, 1992)

Percentage infestation: The infestation level of sweet potato by SPW was determined from 12 randomly selected plants per plot and percentage colonization was computed as follows:

$$C= \frac{N}{T} X\ 100$$ (Alexander, 1992)

Where, C=Percentage of colonization of the sweet potato plant in a plot

N= number of samples colonized

T= total number of samples per plot

Percentage of damaged tubers: At harvest, the number of tubers with sweet potato weevil damage and healthy tubers were recorded against the total tubers per plot. From this percentage damaged tubers were computed using the following formula:

$$PIT= \frac{I}{I + H} X\ 100$$

Where: PIT=Percentage of infected tuber

I=Infected tubers

H=Healthy tubers (Alexander, 1992)

Marketable (healthy) tuber yield (MTY): MTY is the weight of healthy or uninfected tubers by weevils. It was taken by weighting all the tubers collected from the plot by using bean balance. It was expressed as kg/plot and converted in to t/ha (Alexander, 1992)

Unmarketable (infected) tuber (UMT): UMT is the weight of infected tubers by sweet potato weevils. It was taken by weighting all the tubers collected from the plot by using bean balance. It was expressed as kg/plot and converted in to t/ha.

Yield losses: yield loss was determined using the total weight of the harvested tuber per plot against the weight of clean/healthy tubers using the following formula:

$$\text{Yield loss}= \frac{TW - HW}{TW} X100$$

(Kabi *et al.*, 2001)

Where, TW= Total tuber weight, HW= clean tuber weight

Root pulling resistance (depth) (RPR): RPR was measured 60 days after planting. Pulling of individual sampled plants was done by wrapping a piece of cloth around the base of the plant and tying it to a rope which was then attached to pulling device (spring balance) to measure the resistance and it was expressed in terms of kg (CIP,1989).

Shoot Fresh Weight (SFW) (g): It was recorded by cutting the plants at the soil surface after harvesting and weighing.

Shoot Dry Weight (SDW): After determining SFW, from the same samples, SDW was measured by oven drying in a forced air circulation oven at 80^0C until a constant weight was obtained

Root Fresh Weight (RFW) (g): Both included roots and stolen parts of stem remaining underground were dug out and weighed to determine RFW.

Root dry weight (RDW) (g): From RFW samples, the RDW was determined after first air-dried and further dried in a ventilated oven at 80 ^{0}C till a constant weight was obtained.

Percentage dry weight (PDW): PDW was determined as the ratio of dry weight of shoot and root to total weight X100.

Moisture content (MC): MC was determined as total weight **–** dry weight

Percentage moisture content (PMC): PMC was calculated as the ratio of moisture weight to total weight multiplied by 100.

3.4. Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) using SAS Computer software version 9.2 (SAS, 2008) and MSTATC software's. Mean separation was carried out using Least Significant Difference (LSD) at 5 percent level of significance.

4. RESULTS AND DISCUSSIONS

Experiment I: Effect of Earthing up and harvesting time on the management of Sweet potato Weevil

4.1.1 Effect of earthing up and harvesting time on number of damaged sweet potato tubers at Chano Dorga

Analysis of variance showed significant ($p<0.05$) interaction effect of earthing up and harvesting time with regard to number of tubers damaged by sweet potato weevil at harvest (Table 1 and Appendix table 4). The results obtained indicate that three times earthing up and prompt harvesting significantly gave the lowest number of damaged tubers (25 damaged tubers per plot). The next best treatment was obtained from two times earthing up and prompts harvesting (33.66 damaged tubers per plot). On the other hand, significantly highest numbers of damaged tubers were recorded from the interaction between farmer's practices and two months delayed harvesting (218.3 damaged tubers per plot) followed by no earthing-up (farmers' practices) and one month delayed harvesting (181.6 damaged tubers per plot).

In this experiment three times earthing up and prompt harvesting reduces number of tuber damage from 218.3 to 25 tubers per plot. This is because hilling up prevented soil cracking that help adult weevil movement to reach the tubers underground for egg lying. Emana (1994) opined earthing-up of soil around the plant three times at monthly interval starting from the second month after planting significantly reduce the infestation of sweet potato weevil to sweet potato tubers as this practice hills up soil cracking thereby preventing the adult weevil to reach the tubers underground for egg laying. The same author demonstrated that such practice could protect sweet potato tubers from sweet potato weevils for more than six months. On the other hand, interaction of farmers practices with two months delayed harvesting gave high number of damaged tubers per plot (218.3) followed by farmers practice with one month delay harvesting (181.6). This is because weevils might undergo several life cycles which probably increased the weevil population, in the presence of tubers as a food that might ultimately lead to heavy damage of sweet potato tubers. Sherman and Tamashiro

(1954), Sutherland (1986b), and CIP (1997) reported the relationship between damage caused by sweet potato weevil and harvesting time. According to their findings, infestation of sweet potato by sweet potato weevil increase as harvesting time delayed. Emana (1990) also demonstrated that delayed harvesting enhance the activity of sweet potato weevils. These works suggest that prevention of soil cracking by earthing up the area around the plant and harvesting the crop at right time are an important method of reducing weevil damage.

Table1. Effect of earthing up and harvesting time on number of sweet potato tuber damage by sweet potato weevil per plot at Chano Dorga

		Earthing up				
		E1	E2	E3	E4	Mean
Harvesting time	H1	63^{g}	33.33^{i}	25^{j}	131^{d}	63.4^{Z}
	H2	101^{e}	58^{g}	36.66^{i}	181.6^{b}	94.5^{Y}
	H3	145^{c}	83.33^{f}	43.66^{h}	218.3^{a}	122.5^{X}
	Mean	103.2^{B}	58.6^{C}	35.11^{D}	177^{A}	93.5
		CV% =4.12		$LSD_{0.05}$ =6.52		

Means followed by the same letter within a table are not significantly different at 5% level of significance for interaction effects. Note: E = Earthing-up, E_1= one times earthing- up, E_2= two times earthing-up, E_3= three time earthing-up, E_4= farmers practice, H = harvesting time, H_1= prompt (immediately) harvesting, H_2= One month delayed harvesting, H_3= two months delay harvesting, (value with capital letters indicates the significance of main effect and small letters indicates the significance of interaction effect (α = .05)

4.1.2 Effect of earthing up and harvesting time on percent damage of sweet potato tubers at Chano Dorga

Similarly, **a**nalysis of variance for the percentage damaged tubers showed significant ($p<0.05$) interaction effect of earthing-up and harvesting time (Table 2 and Appendix Table 6). Three times earthing-up and prompt harvesting gave significantly lowest percentage damaged tuber (6.9%) where as maximum and significant percentage damaged tuber (89.4%) was obtained from farmer’s practices integrated with two months delay harvesting The next best treatment was obtained from the combination of three times earthing-up and one month delay harvesting (12.2%).

In this study highest mean percentage damage of tuber with weevil damage was recorded from interaction of farmers practices with two month delayed harvesting which was about 89.4%, where as the lowest percent (6.9%) damage of tubers with weevil damage was obtained from the treatment of three times earthing-up and prompt harvesting. This compared to the farmers practices with three times earthing up and prompt harvesting significantly reduced tuber infestation by sweet potato weevil. This was because prevention of soil cracking by earthing up the area around the plant prevented the tuber from weevil damage. This is in agreement with result of Palaniswami and Mohandas, (1994) in that five time earthnig up between 50 and 90 days after planting, at 10 days interval, significantly reduce the weevil damage to the tubers. Tuber damage due to the insect was generally more sever during the dry season (Sutherland, 1986b). Sweet potato weevils are particularly serious problems under dry condition because the insect reach tubers more easily cracks that appear as the soil dries out. Telli and Salunkhe (1994) reported that weevils generally failed to penetrated wet soils but can penetrate dry soils.

Table 2. Interaction effect of earthing and harvesting time on percent damage of tuber per plot (%) at Chano Dorga

		Earthing up				
		E1	E2	E3	E4	Mean
Harvesting time	H1	28.6^{g}	15.2^{j}	6.9^{k}	56.3^{d}	26.7^{Z}
	H2	40.5^{f}	24.5^{h}	12.2^{j}	70.2^{b}	36^{Y}
	H3	61.3^{c}	46.3^{e}	21.2^{i}	89.4^{a}	54.5^{X}
	Mean	44.2^{B}	27.2^{C}	13.9^{D}	71.7^{A}	**39.4**
		CV%=4.9		$LSD_{0.05}$=9.26		

Means followed by the same letter within a table are not significantly different at 5% level of significance for interaction effects. Note: E_1= one times earthing- up, E_2= two time earthing up, E_3= three time earthing up E_4= farmers practice and H_1= prompt (immediately) harvesting, H_2= One month delayed harvesting, H_3= two months delay harvesting (value with capital letters= main effect and small letter& $LSD_{0.05}$=9.26= interaction effect)

4.1.3 Effect of earthing up and harvesting time on marketable and unmarketable sweet potato tuber yield (t/ha) at Chano Dorga

Marketable sweet potato tuber was found significantly different ($p<0.05$) due to the interaction effect of earthing-up and harvesting time (Table 3 and Appendix table5). Maximum marketable tubers (15.63 t/ha) were harvested when three times earthing-up was combined with prompt harvesting, followed by three times earthing-up and one month delayed harvesting (14.4 t/ha). On the other hand, significantly lowest marketable tuber yield was recorded from the interaction effect of farmer's practices (no earthing-up) and two months delay harvesting (1.18t/ha)

In this experiment three times earthing up and prompt harvesting increases tuber yield from 1.18 to 15.63 t/ha. This implies that yield of marketable tuber were significantly affected by the interaction of earthing up and harvesting time. This might be that earthing up the soil around the plant prevents the formation of soil crack and which hindered the damage by sweet weevils. This confirms with result of Emana (1990) in that earthing up of soil around the plant three times at monthly intervals starting from the second month after planting significantly reduce the infestation of sweet potato weevil to sweet potato tubers as this practice hills up soil cracking thereby preventing the adult weevil to reach the tubers underground for egg laying. This finding is in consistency with the finding of IITA (1975) this confirmed that tubers with in the soil are less likely to be infested by the weevils. This indicated that low infestation of sweet potato weevil resulted in high marketable yield of sweet potato tuber in this study.

Table 3.Interaction effect of earthing and harvesting time on marketable tuber yield of sweet potato (t/ha) at Chano Dorga

		Earthing up				
		E1	E2	E3	E4	Mean
Harvesting time	H1	6.69^{c}	9.38^{b}	15.63^{a}	3.43^{e}	8.78^{X}
	H2	5.15^{d}	6.67^{c}	14.40^{a}	2.42^{ef}	7.16^{Y}
	H3	1.62^{g}	5.93^{cd}	10.07^{b}	1.18^{fg}	5.20^{Z}
	Mean	5.01^{C}	7.32^{B}	13.36^{A}	2.49^{D}	7.05
	CV% =7.61			$LSD_{0.05}$ =1.235		

Means followed by the same letter within a table are not significantly different at 5% level of significance for interaction effect. Note: E_1= one times earthing- up, E_2= two time earthing up, E_3= three time earthing up E_4= farmers practice and H_1= prompt (immediately) harvesting, H_2= One month delayed harvesting, H_3= two months delay harvesting (value with capital letters= main effect and small letter& $LSD_{0.05}$ =1.235= interaction effect)

The lowest unmarketable yield were recorded from the interaction of three times earthing-up and prompt harvesting, which was 0.566 t/ha, while interaction of farmers practices with two month delay harvesting which was about 6.38 t/ha (Figure1). In this result earthing up the soil around the plant three times at monthly intervals starting from one month after planting with prompt harvesting highly reduced unmarketable yield. In general, three times earthing-up accompanied by prompt harvesting significantly minimize the damage of sweet potato tuber by sweet potato weevil.

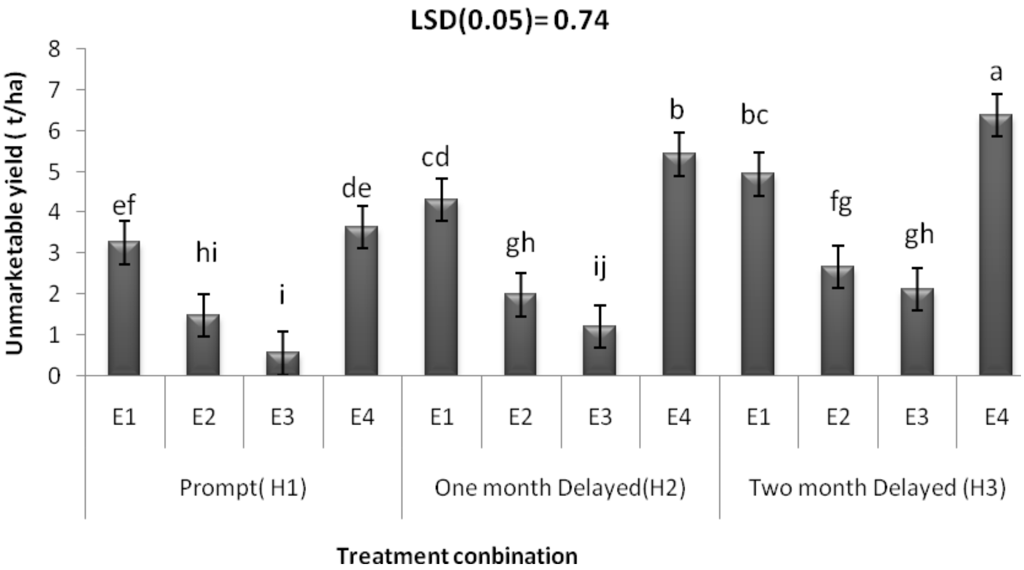

Figure 1. Interaction effect of earthing up and harvesting time on unmarketable tuber yield of sweet potato (t/ha) at Chano Dorga

4.1.4 Effect of earthing up and harvesting time on sweet potato tuber yield loss at Chano Dorga

Analysis of variance showed significant (p<0.05) interaction effect of earthing-up and harvesting time with regard to percent yield loss of sweet potato tubers at harvest (Figure 2 and Appendix table7). The result showed that three times earthing-up and prompt harvesting gave significantly lowest yield loss (8.68 %) and farmers' practices with two month delay harvesting gave significantly highest yield loss (88.11%) of sweet potato tubers per plot. This indicates that the current practices of farmers' in sweet potato cultivation subjects the crop to 79.43% preventable yield loss by practices earthing-up and prompt harvesting alone.

The lowest percentage yield lose due to sweet potato weevil was obtained from the interaction of three time earthing up and prompt harvesting while the highest was from farmers practices with two month delayed harvesting was recorded. This may be during early harvesting crop escapes from weevil damage. This in line with report of Smith (1997) from Uganda which confirm that damage by sweet potato weevil linearly increase with the delayed of harvesting time beyond the physiological maturity of the crop because as harvesting time delayed the weevils may go under several life cycle which significantly increase the weevil population which ultimately lead to heavy damage. Smith (1997) also demonstrated that larvae tunnel through vines and tubers, which result in significant quality loss and possibly a direct yield reduction. This is in relation with report of Slathers *et al*. (2003) in that low levels of infestation can reduce tuber quality and marketable yield because infested plants produce unpalatable terpenoids in response to weevil feeding. Sutherland (1986a) reported that loss of tuber weight occurred as a result of shrinkage due to loss of water through feeding and oviposition cavity made by the weevil as tuber was severely infected.

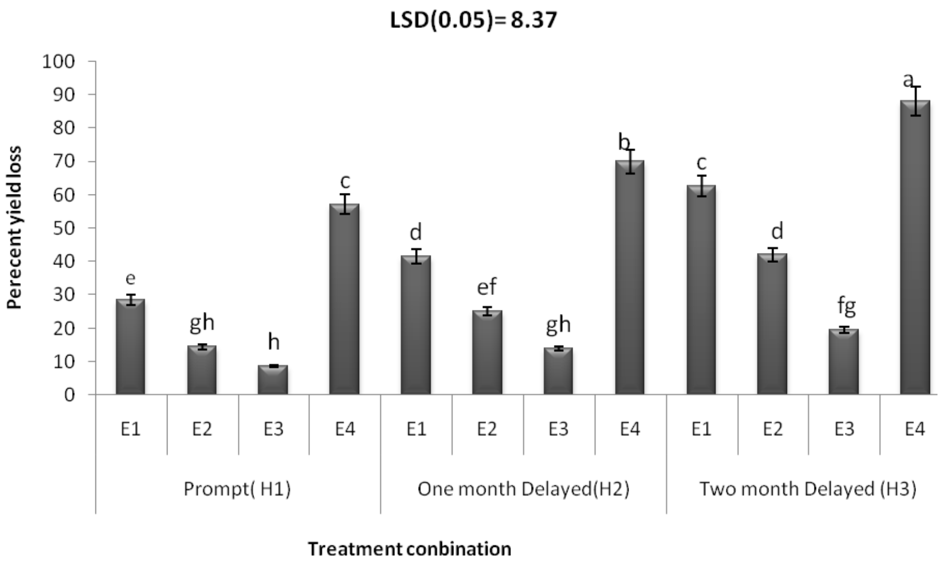

Figure 2 Interaction effect of earthing up and harvesting time on percent yield loss per plot due to weevil damage at Chano Dorga

4.1.5. Effect of earthing up and harvesting time on population density of weevils at Chano Dorga

Sweet potato weevils count was found significantly different ($p<0.05$) due to the different treatment combinations (Table4 and Appendix Table 9). Significantly minimum numbers of weevils were obtained from plots that received three times earthing-up and prompt harvesting (29.77) followed by two times earthnig-up and prompt harvesting (51.66). On the other hand, significantly highest weevil populations were recorded from farmer's practices integrated with two month delayed harvesting (185.3)

Minimum infestations of sweet potato weevils were recorded from interaction of three times earthing-up and prompt harvesting indicating the positive contribution of earthing-up and harvesting time. This is might be because of the fact that frequent earthing up disturbed the life cycle of the weevil apart from hindering the movement of the adult weevils via cracks. On the other hand, no earthing-up integrated with two month delay harvesting gave highest mean population of weevils. This is because weevil undergo several life cycles without obstacle during a prolonged storage period which increasing their population. This finding is in agreement with Smith (1997) from Uganda who reported damage by sweet potato weevil linearly increase with the delay of harvesting time beyond the physiological maturity of the crop because as harvesting time delays the weevils may go under several life cycle which significantly increase the weevil population). The other reason may be the conduciveness of the environmental condition; the area is hot spot for sweet potato weevil infestation. This is in relation to report of Allard et al. (1991), in that sweet potato weevils are particularly a serious problem under dry conditions, because the insects, which cannot dig, can reach tubers more easily through cracks that appear in the soil as it dries out. According to report of Emana (1990) the site is known for its hot spot for sweet potato weevils.

Table 4.Interaction Effects of Earthing -up and harvesting time on population density of sweet potato weevils per plot at Chano Dorga.

		Earthing up				
		E_1	E_2	E_3	E_4	Mean
Harvesting time	H_1	57.33^{fg}	31.33^{h}	29.77^{h}	129.7^{c}	62^{Z}
	H_2	83.66^{e}	55.33^{fg}	51.66^{g}	147^{b}	84.41^{Y}
	H_3	130.7^{c}	97.66^{d}	60.33^{f}	185.3^{b}	118.5^{X}
	Mean	90.55^{B}	61.44^{C}	47.22^{D}	154^{A}	88.30
	CV% = 5.73		$LSD_{0.05}$ = 8.578			

Means followed by the same letter within a table are not significantly different at 5% level of significance for interaction effects. Note: E_1= one times earthing- up, E_2= two time earthing up, E_3= three time earthing up E_4= farmers practice and H_1= prompt (immediately) harvesting, H_2= One month delayed harvesting, H_3= two months delay harvesting (value with capital letters= main effect and small letter& $LSD_{0.05}$ = 8.578= interaction effect)

4.1.6. Simple correlation coefficient among different variables at Chano Dorga

Significant and positive correlations were observed between weevil population & unmarketable tuber yield (r=0.97**), percent yield loss (r=0.95**) & unmarketable tuber numbers (r=0.99**) (Table 5). However, marketable tuber yield was negatively and highly significantly correlated with sweet potato weevil population (r = -0.83**). Similarly, marketable tuber yield was negatively and significantly correlated with (r = -0.702**) percent yield loss. This indicates that higher number of weevils in sweet potato ecosystem is associated with increased yield loss and unmarketable tubers but decreased marketable tubers.

Table 5. Simple correlation coefficient among different variables at Chano Dorga

	UMTN	MYt/ha	UYt/ha	PYL	PCW	SPWP
UMTN	1	-0.83*	0.94**	0.986**	0.869*	0.977**
MYt/ha		1	-0.881*	-0.878*	0.702*	-0.83*
UYt/ha			1	0.94**	0.787*	0.898*
PYL				1	0.841*	0.979**
PCW					1	0.867*
SPWP						1

Note * significant and ** highly significant at 5% level at 5% level Note: UMTN=unmarketable tuber numbers, MYt/ha= marketable yield ton per hector= UYt/ha= unmarketable yield ton per hector, PYL= percent yield loss, PCW= percent colonization of weevils, SPWP= sweet potato weevil population

4.1.7. Effect of earthing up and harvesting time on number of damaged sweet potato tubers at Lante

Analysis of variance showed significant (p<0.05) interaction effect of earthing up and harvesting time with regard to number of tubers damaged by sweet potato weevil at harvest (Table 6 and Appendix table 2). The results obtained indicate that three times earthing up and prompt harvesting significantly gave lowest number of damaged tubers (8 damaged tubers per plot). The next best treatment was obtained from two times earthing up and prompts harvesting (18.5 damaged tubers per plot). The significantly highest numbers of damaged tubers were recorded from the interaction between farmer's practices and two months delayed harvesting (231 damaged tubers per plot) followed by one time earthing up and farmers' practices one with month delay harvesting (143).

In this trial three times earthing up and prompt harvesting were reduced tuber damage from 231 to 8 damaged tubers per plot. This was similar to the result obtained at the site Chano Dorga the only difference is lower number of tuber damaged tubers were recorded from the Lante. This might be due to soil factor. This is in agreement with report of O'Hare (1991) which confirms that soils with a higher clay contents tend to shrink when dry and forms cracks through which weevils can enter and reach underground tubers.

Table 6.Effect of Earthing and harvesting time on number of sweet potato tuber damage by sweet potato weevil per plot at Lante

		Earthing up				
		E1	E2	E3	E4	Mean
	H1	44^{gh}	18.5^{i}	8^{j}	103^{e}	43.5^{Z}
Harvesting time	H2	63^{f}	37.5^{h}	24^{i}	143^{c}	66.87^{Y}
	H3	195^{b}	122.5^{d}	50^{g}	231^{a}	149.7^{X}
	Mean	100.6^{B}	59.5^{C}	27.33^{D}	159.33^{A}	**86.70**
	CV%=4.18		$LSD_{0.05}$=7.99			

Means followed by the same letter within a table are not significantly different at 5% level of significance for interaction effects. Note: E_1= one times earthing- up, E_2= two time earthing up, E_3= three time earthing up E_4= farmers practice and H_1= prompt (immediately) harvesting, H_2= One month delayed harvesting, H_3= two months delay harvesting (value with capital letters= main effect and small letter& $LSD_{0.05}$=7.99= interaction effect)

The lowest tuber damage from three times earthing up and prompt harvesting might be hilling up soil cracking was prevented the adult weevil to reach the tubers underground for egg lying. This is in relate to the finding of Emana (1990) in that earthing up of soil around the plant three times at monthly interval starting from the second month after planting significantly reduce the infestation of sweet potato weevil to sweet potato tubers. So this practice hills up soil cracking thereby prevent the adult weevil to reach the tubers underground for egg laying.

4.1.8 Effect of earthing up and harvesting time on marketable and unmarketable sweet potato tuber yield (t/ha) at Lante

Marketable sweet potato tuber was found significantly different ($p<0.05$) due to the interaction effect of earthing-up and harvesting time (Table7 and Appendix table 10). The result obtained indicates that interaction of three times earthing-up and prompt harvesting gave significantly highest marketable yield of sweet potato tubers (12.4 t/ha). Next best treatment was recorded from three times earthing-up and one month delayed harvesting (9.81 t/ha). On the other hand, significantly lowest marketable yield of tubers were recorded from the interaction between farmer's practices with two months delay harvesting (0.86t/ha).

In this study three times earthing up and prompt harvesting increases tuber yield from 0.86 to 12.4. t/ha. This might be that earthing up the soil around the plant prevents the formation of soil crack and which hindered the damage by sweet weevils. This confirms with result of Emana (1990) in that earthing up of soil around the plant three times at monthly intervals starting from the second month after planting significantly reduce the infestation of sweet potato weevil to sweet potato tubers as this practice hills up soil cracking thereby preventing the adult weevil to reach the tubers underground for egg laying. That means the low infestation of sweet potato weevil in the sweet potato, resulted in high marketable and healthy tubers in this study. This finding is in consistency with the finding of IITA (1975) who confirmed that tubers with in the soil are less likely to be infested by the weevils.

Table 7.Interaction effect of earthing up and harvesting time on marketable tuber yield (t/ha) at Lante

	Earthing up				
	E1	E2	E3	E4	Mean
H1	5.81[d]	8.96[b]	12.4[a]	3.14[f]	7.49[X]
H2	4. 66[e]	6. 96[c]	9.81[b]	1.74[g]	5.77[Y]
H3	3.4[f]	5.3d[e]	9 .07[b]	0.86[g]	4.68[Z]
Mean	4.69[A]	7.07[B]	10.29[C]	1.93[D]	**5.98**
CV%=4.9		$LSD_{0.05}$=5.35			

Means followed by the same letter within a table are not significantly different at 5% level of significance for interaction effects. Note: E_1= one times earthing- up, E_2= two time earthing up, E_3= three time earthing up E_4= farmers practice and H_1= prompt (immediately) harvesting, H_2= One month delayed harvesting, H_3= two months delay harvesting (value with capital letters= main effect and small letter= interaction effect, $LSD_{0.05}$=5.35= interaction effects)

The significantly lowest unmarketable yield (0.8 t/ha) were recorded from the interaction effects of three times earthing-up and prompt harvesting where as interaction of farmers practices with two month delayed harvesting gave significantly highest (23.1t/ha) unmarketable yield (Figure3). This is because earthing up the soil around the plant three times at monthly intervals starting from one month after planting with prompt harvesting were highly reduced unmarketable yield. In general, three times earthing-up accompanied by prompt harvesting significantly minimize the damage sweet potato weevil to sweet potato tubers

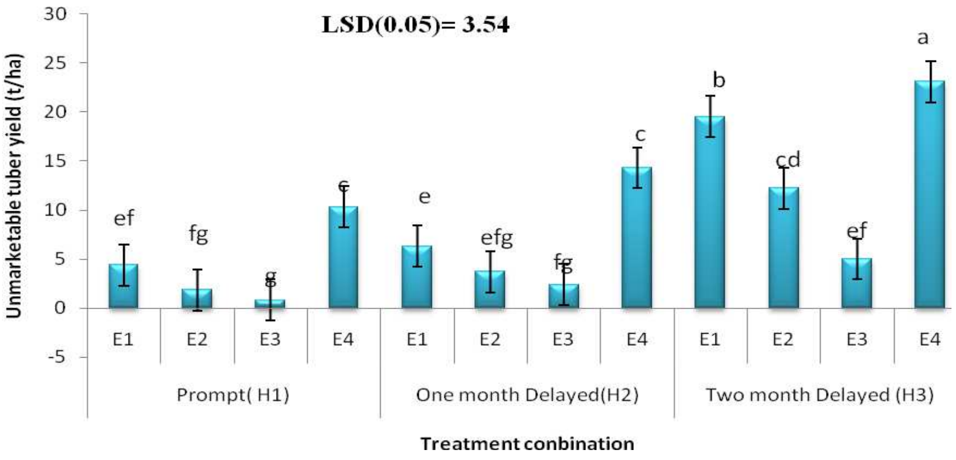

Figure 3 Interaction effect of earthing up and harvesting time on unmarketable tuber yield (t/ha) at Lante

4.1.9. Effect of earthing up and harvesting time on sweet potato tuber yield loss at Lante

Percent yield loss of sweet potato tubers were found significantly different ($p<0.05$) due to the interaction effect of earthing-up and harvesting time (Figure4 and Appendix table 11). The result obtained indicates that three times earthing-up and prompt harvesting gave the lowest percent yield loss (3.26%)of sweet potato tubers) and farmers practices with two month delayed harvesting gave highest yield loss (87.37%) of sweet potato tubers.

The minimum yield lose due to sweet potato weevil was obtained from the interaction of three time earthing up and prompt harvesting while the highest was from farmers practices with two month delayed harvesting was recorded. This was because, during early harvesting crop escapes from heavy weevil infestation. This is in line with report of Smith (1997) from Uganda which confirm that damage by sweet potato weevil linearly increase with the delay of harvesting time beyond the physiological maturity of the crop because as harvesting time delayed the weevils may go under several life cycle which significantly increase the weevil population which ultimately lead to heavy damage.

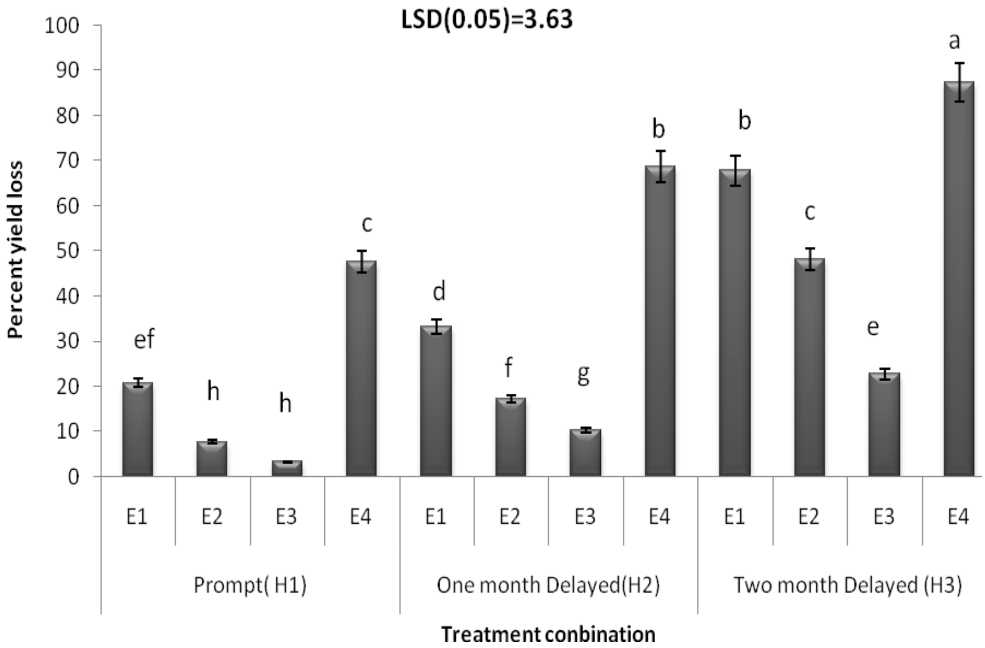

Figure 4 Interaction effect of earthing up and harvesting time on percent yield loss due to weevil damage per plot at Lante

Smit (1997) also demonstrated that larvae tunnel through vines and tubers, which result in significant quality loss and possibly a direct yield reduction. This is in relation with report of Slathers *et al*. (2003) in that low levels of infestation can reduce tuber quality and marketable yield because infested plants produce unpalatable terpenoids in response to weevil feeding. Sutherland (1986a) reported that loss of tuber weight occurred as a result of shrinkage due to loss of water through feeding and oviposition cavity made by the weevil as tuber was severely infected. Complete infestation of the tubers and sever attacks were observed as the harvesting delayed more than two month in farmers practices and one time earthing up of the soil around the plant. This was evidenced by the observation of externally pierced, internally mined, shrinked and dried tuber from harvesting delayed more than two month. On established plants the larvae feed in the tubers and stems, producing larval tunnels and later, pupal chambers. Stem damage is believed to be the main reason for yield loss, Therefore, direct feeding of the adult and mining of the larvae also directly contributed to reduced tuber weight apart from facilitating the loss of water from the tubers (Allard *et al*., 1991).

4.1.10 Effect of earthing up and harvesting time on population density of *Cylas puncticollis* at Lante

Analysis of variance showed significant ($p<0.05$) interaction effect of earthing-up and harvesting time with regard to population density of sweet potato weevils (Table8 and Appendix table 8). The result obtained indicates that two times earthing-up and prompt harvesting gave significantly the lowest number of sweet potato weevils (21), whereas significantly the highest sweet potato weevils from combination of farmer's practices with two month delayed harvesting (128.5).

Table 8. Interaction effects of earthing and harvesting time on population density of sweet potato weevils per plot at Lante.

		Earthing up				
		E_1	E_2	E_3	E_4	Mean
Harvesting time	H_1	45^{g}	21^{h}	39.5^{g}	74.5^{e}	45^{Z}
	H_2	79^{de}	73^{e}	66^{f}	95.5^{c}	78^{Y}
	H_3	109^{b}	93.5^{c}	83.5^{d}	128.5^{a}	103.62^{X}
	Mean	77.66^{B}	62.5^{C}	63^{C}	99.5^{A}	**75.66**
	CV% = 4.59			$LSD_{0.05}$ = 6.243		

Means followed by the same letter within a table are not significantly different at 5% level of significance for interaction effects. Note: E_1= one times earthing- up, E_2= two time earthing up, E_3= three time earthing up E_4= farmers practice and H_1= prompt (immediately) harvesting, H_2= One month delayed harvesting, H_3= two months delay harvesting (value with capital letters= main effect and small letter= interaction effect, $LSD_{0.05}$ = 6.243= interaction effect)

The lowest numbers of sweet potato weevils were recorded from interaction of three times earthing-up and prompt harvesting. This indicates that the interaction effect of earthing up and harvesting time was significantly affected weevil population. This is might be earthing up frequency was disturbed at one stage of life cycle of the weevil. On the other hand, farmers practice with two month delay harvesting gave highest mean population of weevils. This is because weevil undergo several life cycles during a prolonged storage period which increasing their population This in agreement with Smith (1997) from Uganda also reported that damage by sweet potato weevil linearly increase with the delayed of harvesting time beyond the physiological maturity of the crop because as harvesting time delays the weevils may go under several life cycle which significantly increase the weevil population. The other reason may be environmental condition, because hot area is hot spot for sweet potato weevil infestation. This in relation to report of Allard *et al*., (1991), in that sweet potato weevils are a particularly serious problem under dry conditions, because the insects, which cannot dig, can reach tubers more easily through cracks that appear in the soil as it dries out. According to report of Emana (1990) the site is known for its hot spot for sweet potato weevils.

4.1.11. Simple correlation coefficient among different variables at Lante

Positive correlations were observed among marketable tuber numbers & marketable tuber weight (r=0.98**), unmarketable tuber numbers & unmarketable tuber weight (0.95**), unmarketable tuber numbers & sweet potato weevil population (0.95**) and percent yield loss & unmarketable tuber weight (r=0.97**) (Table9). These indicating that direct relationship between sweet potato tuber damage and weevil population. This is in line with the report of Sutherland (1986b) in that weevil population and percent damage of sweet potato tuber is directly related with time. Smit (1997) also reported that weevil damage increases linearly with increases in harvesting time.

However, marketable tuber weight was negatively and highly significantly (r = -0.97**) correlated with sweet potato weevil population (Table9). Similarly, marketable tuber number was negatively and significantly (r = -0.96**) correlated with percent yield loss. This indicated that marketable yield and yield loss was directly correlated when one increased the other reduced. These suggest that application of three times earthing up the soil around the plant are extremely increasing the marketable yield of sweet potato tuber and significantly reduce insect infestation while farmers practices with no earthnig up significantly increased weevil infestation with tuber damage of sweet potato.

Table 9. Simple correlation coefficient among different variables at Lante

	MTN	MTW	UMTN	UTW	PYL	PCW	SPWP
MTN	1	0.98**	-0.98**	-0.94**	-0.96**	-0.82*	-0.97**
MTW		1	-0.98**	-0.95**	-0.97**	-0.85*	-0.94**
UMTN			1	0.95**	0.97**	0.84*	0. 95**
UTW				1	0.98**	0.89*	0.97**
PYL					1	0.88*	0.97**
PCW						1	0.85*
SPWP							1

Note * significant and ** highly significant at 5% level Note: MTN=marketable tuber numbers, MTW= marketable tuber numbers= UMTN= unmarketable tuber number, UTW= unmarketable tuber weight, PYL= percent yield loss, PCW= percent colonization of weevils, SPWP= sweet potato weevil population

Experiment II: Evaluation of sweet potato varieties against sweet potato weevil at Humbo and Bele

4.2. 1. Root pulling resistance (kg) at 60 days after planting

Root pulling resistance of different sweet potato varieties were presented in Table 10 and Appendix Table 12. The results obtained indicate that varieties PIPI and Ukerewe, at Humbo and Beletech, Damota and Temesgen at Bele significantly (P<0.01) showed the highest pulling resistance implying that these varieties set their tubers deeper than the rest which helped them to resist weevil infestation as the contact between the weevil and the tubers either denied and/or become difficult. Varieties such as Eujumula, Awassa-83 and Koka-12 were intermediate both in terms of tuber pulling resistance and weevil infestation.

This result is in agreement with Emana (1990) in that he demonstrated that varieties which set their tuber deeper are resistant to sweet potato weevil. This confirms with finding of Edmond (1971) in that deep tuber forming sweet potato cultivars were less affected by weevils. This in line with report of Allard *et al*. (1991) in that selecting deep-rooting cultivars, with long necks between the tubers and the stems are less susceptible because the adult weevil cannot burrow downwards more than 1 cm. Cocker ham and Deen (1947) suggest the importance of physical traits, like tuber depth, arrangement, tuber size and shape, of sweet potato cultivars playing important role in conferring resistant to *Cylas ssp*. in the field. Tesfaye (2002) also demonstrated that varieties with deeper tubers suffer less from the attack of sweet potato weevils which was also demonstrated by the current work. This suggest that it might be advantageous to select cultivars that set their tuber deeper are resistant to sweet potato weevils

Table 10. Mean root puling resistance (Kg) of sweet potato varieties grown at Humbo and Bele

	Root puling	Resistance
Varieties	Humbo	Bele
Awassa-83	18.00^{c}	22.00^{cde}
Belela	9.00^{i}	17.00^{fgh}
Beletech	12.97^{e}	28.83^{ab}
Boreda	Not ob	10.50^{j}
Damota	7.17^{i}	29.00^{ab}
Dubo	5.03^{jk}	16.33^{fgh}
Eujumula	9.37^{i}	29.00^{ab}
Falha	Not ob	$15.33g^{ghi}$
Kero	14.67^{d}	19.17^{efg}
Koka-12	17.00^{c}	27.60^{b}
Kudade	10.50^{ghi}	19.33^{efg}
Kulfo	11.33^{fg}	$18.53e^{fg}$
Mayai	16.57^{c}	25.17^{bcd}
Ordollo	Not ob	25.67^{bc}
PIPI	23.07^{a}	32.67^{a}
Resisto	9.67^{hi}	10.77^{ij}
Temesgen	11.17^{fgh}	28.43^{ab}
TIS9068.7	10.03^{ghi}	24.33^{bcd}
Tulla	12.17^{ef}	13.17^{hij}
Ukerewe	20.60^{b}	20.67^{def}
CV%	8.68	13.07
LSD	1.6	4.68

Means followed by the same letter within a column are not significantly different at 5% level of significance.

4.2. 2. Percentage dry weight and moisture content

Percent dry matter and moisture contents of different sweet potato varieties were presented in Table 11 and Appendix Table 13. The results obtained indicate that Kero, Mayai and TIS-9068.7 at Humbo and Boreda and Eujumula at Bele significantly ($P<0.01$) showed the highest dry matter content implying that the weevils found difficult to tunnel the tubers of these varieties and ultimately rendered them resistant. However, varieties such as Kulfo, Temesgen, PIPI, Eujumula, Damota and Belela were intermediate both in terms of dry matter content and weevil infestation.

This result is in line with the result obtained by Joshi, and Bishwo, (2004) in that clones with high dry matter content were significantly reduce the infestation by insect pest. This also confirms with current work Table (10) in that varieties with high dry matter contents lower the infestation weevil. These suggest that highest dry matter content implying that the weevils found difficult to tunnel the tubers of these varieties and ultimately rendered them resistant. This experiment try to see the sweet potato weevil resistant varieties come-up with the conclusion that varieties Kero, Mayai and TIS-9068.7 were significantly reduces weevil infestation.

Table 11. Mean percent dry weight and moisture content of sweet potato varieties grown at Humbo and Bele.

	Humbo		Bele	
Varieties	PDW	PMC	PDW	PMC
Awassa-83	17.41^{gh}	82.58^{ab}	8.28^{h}	91.7^{a}
Belela	21.66^{de}	78.34^{cd}	21.49^{cde}	78.51^{def}
Beletech	24.44^{cd}	75.56^{ef}	18.01^{f}	81.98^{c}
Boreda	Not ob	Not ob	24.00^{bc}	76.33^{fg}
Damota	23.36^{de}	76.63^{de}	19.76^{edf}	80.23^{cde}
Dubo	Not ob	Not ob	21.17^{cdef}	79.16^{cdef}
Eujumula	26.24^{c}	73.75^{f}	25.41^{b}	74.59^{g}
Falha	Not ob	Not ob	22.75^{bcd}	77.25^{efg}
Kero	43.513^{a}	56.15^{h}	29.72^{a}	70.27^{h}
Koka-12	Not ob	Not ob	20.57^{de}f	79.41^{cdef}
Kudade	16.50^{gh}	82.82^{ab}	18.86^{ef}	81.14^{cd}
Kulfo	33.63^{b}	66.37^{g}	20.12^{def}	79.88^{cde}
Mayai	46.00^{a}	54.00^{h}	14.19^{g}	85.80^{b}
Ordollo	Not ob	Not ob	21.58^{cde}	78.41^{def}
PIPI	21.15^{ef}	78.85^{cd}	20.67^{def}	79.32^{cdef}
Resisto	16.40^{h}	83.60^{a}	20.66^{def}	79.33^{cdef}
Temesgen	23.28^{de}	76.72^{de}	21.33^{cde}	78.66^{def}
TIS9068.7	45.73^{a}	55.26^{h}	18.89^{ef}	81.10^{cd}
Tulla	17.78^{gh}	82.22^{ab}	21.75^{cde}	78.25^{def}
Ukerewe	19.31^{fg}	80.68^{bc}	21.44^{cde}	78.55^{def}
CV%	8.62	2.99	9.5	2.49
LSD	2.82	2.73	3.22	3.27

Means followed by the same letter within a column are not significantly different at 5% level of significance.
Note: PDW= percent dry weight, PMC= percent moisture content.

4.2. 3 Marketable and unmarketable tuber yield (q/ha)

Table 12. Mean weight of marketable and unmarketable yield (q/ha) of sweet potato varieties grown at Humbo and Bele

Varieties	Humbo		Bele	
	MY(q/h)	UMY(q/h)	MY(q/h)	UMY(q/h)
Awassa-83	64.33^{ef}	21.33^{ef}	94.49^{efg}	30.10^{a}
Belela	41.73^{gh}	12.07^{h}	64.62^{hi}	2.50^{i}
Beletech	63.47^{ef}	11.85^{h}	85.28^{efgh}	7.59^{gh}
Boreda	Not ob	Not ob	101.59^{de}	5.23^{ghi}
Damota	35.16^{h}	17.00^{g}	126.37^{c}	14.72^{cd}
Dubo	Not ob	Not ob	92.96^{efg}	8.33^{fgh}
Eujumula	54.70^{fg}	22.63^{ed}	138.07^{bc}	14.01^{d}
Falha	Not ob	Not ob	94.98^{efg}	11.80d^{ef}
Kero	178.05^{a}	21.00^{ef}	163.03^{a}	13.14^{ed}
Koka-12	Not ob	Not ob	78.66^{fgh}	2.80^{i}
Kudade	39.72^{gh}	24.56^{cd}	89.13^{efg}	24.72^{b}
Kulfo	76.39^{de}	9.67^{i}	51.90^{i}	18.54^{c}
Mayai	130.57^{c}	18.31^{g}	123.60^{cd}	22.83^{b}
Ordollo	Not ob	Not ob	85.79^{efgh}	23.23^{b}
PIPI	77.77^{de}	24.81^{c}	163.40^{a}	11.94^{edf}
Resisto	86.11^{d}	20.36^{f}	80.28^{efgh}	2.60^{i}
Temesgen	73.47^{de}	24.19^{cd}	135.83^{bc}	4.94^{hi}
TIS-9068.7	152.94^{b}	18.30^{g}	99.61^{ef}	5.21^{ghi}
Tulla	62.50^{ef}	28.75^{b}	75.64^{gh}	14.40^{d}
Ukerewe	77.72^{de}	35.89^{a}	153.46^{a}	9.17^{efg}
CV%	15.47	7.69	13.03	19.84
LSD	15.53	1.97	22.61	4.06

Means followed by the same letter within a column are not significantly different at 5% level of significance.
Note: MY (q/h) = marketable yield quintal per hectare, UMY (q/h) = unmarketable yield quintal per hectare)

Marketable yield of different sweet potato varieties were presented in Table 12 and Appendix Table 15. The results obtained showed that varieties Kero, TIS-9068.7, Mayai at Humbo and varieties PIPI, Kero and Ukerewe at Bele, significantly (P<0.01) showed the highest marketable yield with low weevil infestation. Varieties such as Resisto, Eujumula and

Temesgen were found intermediate both in terms of marketable yield (q/h) and weevil infestation.

In this experiment, highest marketable yield (q/ha) were recorded from varieties like Kero, TIS-9068.7, Mayai, PIPI, Kero and Ukerewe than other varieties. This is probably high dry matter content and root pulling resistance because these varieties were showed with high dry matter content and root pulling resistance with low weevil infestation (Table9&10). This confirms with finding of Edmond (1971) in that deep tuber forming sweet potato cultivars were less affected by weevils. Pillai and Kamlam (1977) reported that deep rooting sweet potato with a long “neck” are less susceptible to weevil attack this implying that these varieties set their tubers deeper than the rest which helped them to resist weevil infestation. Addis and Tesfaye (1995) also confirmed that those that varieties with deeper tubers suffer less from the attack of sweet potato weevils which was also demonstrated by the current work. In generally, varietiey Kero, TIS-9068.7, Mayai, Resisto, PIPI and Ukerewe are improved in marketable yield and insect resistant obtained in this trial. These resistance factors that allow the roots to escape insect damage also can be exploited in IPM programs.

4.2. 4. Sweet potato weevil population densities and percent tuber damage per plot at Humbo and Bele

Sweet potato weevil infestation and percent damage of different sweet potato varieties were presented in Table 13 and Appendix Table 16. The results obtained indicate that Mayai, Koka-12, TIS-9068.7 and Kero at Humbo and Damota, Kero, Resisto, TIS-9068.7, Temesgen and PIPI at Bele significantly ($P<0.01$) showed the lowest numbers of weevil density and percent tuber damage. Varieties such as Ukerewe, Temesgen, Beletech, were found to be intermediate in both parameters.

In current study lowest weevil infestation and percent damage were recorded from varieties like , Koka-12, TIS-9068.7, Kero Damota, Kero, Resisto, TIS-9068.7, Temesgen and PIPI this may be cultivars or genotypic variation and environment factors. Sweet potato weevils are particularly serious problems under dry condition because the insects can reach tubers more easily though cracks that appears as the soil dries out , which confirms with finding of

Telli and Salunkhe (1994) in that weevils generally unsuccessful to penetrated wet soils but can penetrate dry soils which ultimately lead to heavy damage.

Table 13. Mean of sweet potato weevil densities and percent tuber damage sweet potato varieties grown at Humbo and Bele

Varieties	Humbo		Bele	
	SWP	PDW	SWP	PDW
Awassa-83	56.34^{a}	0.24^{d}	38.66^{a}	0.24^{a}
Belela	40.64^{c}	0.23^{d}	26.33^{c}	0.04^{fg}
Beletech	19.00^{fg}	0.15^{f}	23.00^{cd}	$0.08d^{efg}$
Boreda	Not ob	Not ob	18.66^{de}	0.046^{efg}
Damota	40.00^{c}	0.32^{b}	5.33^{j}	0.10^{ced}
Dubo	Not ob	Not ob	15.00^{efg}	0.08^{defg}
Eujumula	33.33^{d}	0.29^{c}	14.33^{efg}	0.090^{defg}
Falha	Not ob	Not ob	14.33^{efg}	0.11^{cd}
Kero	15.00^{gh}	0.10^{g}	8.00^{ij}	0.076^{defg}
Koka-12	11.33^{hi}	Not ob	12.66^{gh}	0.093^{edf}
Kudade	59.33^{a}	0.38^{a}	18.33^{ef}	0.22^{a}
Kulfo	45.33^{a}	0.11^{g}	26.00^{c}	0.26^{a}
Mayai	10.00^{i}	0.12^{g}	34.00^{b}	0.15^{c}
Ordollo	Not ob	Not ob	10.66^{ghi}	0.21^{ab}
PIPI	43.33^{bc}	0.24^{d}	14.00^{fg}	$0.07d^{efg}$
Resisto	29.00^{e}	0.19^{e}	8.33^{hij}	0.033^{g}
Temesgen	26.00^{e}	0.24^{d}	13.00^{g}	0.036^{fg}
TIS-9068.7	13.66^{gi}	0.10g	14.00^{fg}	0.046^{efg}
Tulla	41.66^{bc}	0.31^{bc}	33.00^{b}	$0.16b^{c}$
Ukerewe	21.66^{f}	0.31^{bc}	11.66^{ghi}	0.056^{defg}
CV%	9.73	8.63	15.47	31.5
LSD	4.06	0.023	4.59	0.058

Means followed by the same letter within a column are not significantly different at 5% level of significance.
Note: SWP= sweet potato weevil population per plot, PDW= percent damage by sweet potato weevils.

According to the finding of O' Hair (1991), cultivars with smaller hard crown, long tubered than set scattered tuber and tuber with high in carotenes and low starch content showed low infestation. Edmond (1971) also reported that deep tuber forming sweet potato cultivars were less affected by weevils. This in relation to the finding of Sutherland (1986) he confirmed that those varieties with deeper tubers less susceptible by sweet potato weevil as this implying that these varieties set their tubers deeper than the rest which helped them to resist weevil infestation

4.2.5 Simple correlation coefficient among different variables at location Humbo and Bale

Significant and positive correlations were observed between percent dry weight & weevil population (r=0.03*), percent of damaged tuber (r=0.80*) & unmarketable tuber yield (r=0.54*) (Table 14). However, marketable tuber yield was negatively and significantly correlated with sweet potato weevil population (r = -0.83**). Similarly, marketable tuber yield was negatively and significantly correlated with (r = -0.24**) weevil population. Root pulling resistances were also positively and significantly correlated with marketable yield (r= 0.64*), and unmarketable tuber yield (r= 0.20*) and of damaged tuber per plot (r=0.58*).

This implies that weevil's populations are associated with root puling resistance, dry weight and unmarketable tubers but decreased marketable tubers. This indicates that one variable increased the other decreased vice versa.

Table 14.Simple correlation coefficient among different variables at location Humbo and Bale

	RPR	PDW	PMC	MY	UMY	PDT	SWP
RPR	1	0.092^{ns}	0.23^{ns}	0.64*	0.20*	0.58*	0.28^{ns}
PDW		1	0.92**	0.10^{ns}	0.10^{ns}	0.02^{ns}	0.03*
PMC			1	0.13^{ns}	-0.02^{ns}	0.30*	0.13^{ns}
MY				1	0.33*	-0.29 *	-0.24*
UMY					1	0.10*	0.54*
PDT						1	0.80*
SPW							1

Note: * significant at 5% level, RPR=root puling resistance, PDW= percent dry weight= PMC= percent moisture content, MY= marketable tuber yield, UMY= unmarketable tuber yield, PDT= percent of damaged tuber, SWP= sweet potato weevil population

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The conclusion to be drawn from the field study is that interaction effect of earthing up and harvesting time have potential role in reducing sweet potato infestation by weevils. The two cultural practices have shown an immense advantage for sweet potato producers in that their integration has resulted in low infestation of sweet potato by sweet potato weevil as compared to farmer's practices (no earthing-up and delayed harvesting). Earthing up soil around plant has most important impact on reduction of sweet potato weevil infestation in field. Early harvesting play important role in reduction of weevil population in which plant escape from heavy infestation. The results reported in the present study indicated that combined effect of three times earthing up and prompt harvesting showed significant reduction of weevils infestation and highly minimized number of damaged tubers per plot; percent damaged tubers, yield loss and highly enhanced healthy tuber number and marketable tuber yield. Earthing up the soil around the plant prevents the formation of soil crack which avoid the damage by sweet potato weevils. This practice hills up soil cracking thus, preventing the adult weevil to reach the tubers underground for egg laying. This kind of cultural practice could protect sweet potato tubers from sweet potato weevils. Hence, farmers in southern Ethiopia can save their storage tubers of sweet potato, capital and environment by using these cultural management practices of sweet potato weevils. Thus, interaction effect of earthing-up and harvesting time to suppress sweet potato weevils' infestation has been successfully demonstrated. Therefore, combination of three times earthing-up and prompt harvesting appears to be a valuable component in IPM programs against this pest

Among the evaluated sweet potato varieties PIPI and Ukerewe at Humbo and Beletech, Damota and Temesgen at Bele significantly showed the highest pulling resistance which implies that these varieties set their tubers deeper than the rest which helped them to resist weevil infestation. Next to these varieties, varieties Kero, Mayai and TIS-9068.7 significantly showed the highest dry matter content which indicate that these varieties are difficult to assimilate or tunnel in to tuber by the weevils than the rest which helped them to resist weevil infestation. Finally, varieties Mayai, Koka-12, TIS-9068.7 and Kero at Humbo and Damota, Kero, Resisto, TIS-9068.7, Temesgen and PIPI at Bele significantly showed the lowest numbers of weevil density and percent tuber damage. This is probably because of high dry matter content and root pulling resistance of these varieties. In conclusion, among the varieties tested at the two locations, varieties Kero, TIS.908.7, Mayai, PIPI and Ukerewe were significantly better than the others in resisting weevil infestation. Therefore, these varieties appear to be a valuable component in IPM programs against sweet potato weevils.

5.2. Recommendation

In this study, interaction effect of earthing up (3x) and harvesting time (prompt) were found to significantly reduce sweet potato weevils' infestation, resulting in better marketable (healthy) tuber yield of sweet potato. However, it is too early to reach at a conclusive recommendation since the experiment were conducted only at two locations for one season on one variety, Awassa-83. Hence, further studies must involve other available cultivars of Sweet potato under different agro-ecologies and soil types.

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Varieties Kero, TIS.908.7, Mayai, PIPI and Ukerewe were found to significantly reduce sweet potato weevils' infestation and improved marketable tuber yield of sweet potato under field conditions at Humbo and Bele. These varieties can be part of the cultural practices of sweet potato production in Southern Ethiopia for the management of sweet potato weevil. But, it is still too early to give a conclusive recommendation since the experiment were conducted only at two locations for one season. Further, it was noted that the performance of the varieties at the two locations were not consistent. Therefore, there is a need to consider other variables over-seasons under different agro-ecologies to arrive at conclusive recommendation. Further, there is a need to work with breeders and agronomists to come up with conclusive result for sweet potato weevil management.

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7. APPENDICES

Appendix1. Mean minimum and maximum temperature (^oC) and total rain from fall from Six year data (2005-2010) at Arbaminch, Bele and Humbo

	Arbaminch			Bele		Humbo	
Months	Total rain fall (mm)	Maximum monthly Tem.(C^o)	Minimum Monthly Tem.(C^o)	Total rain fall (mm)	Maximum monthly Tem.(C^o)	Minimum Monthly Tem.(C^o)	Total rain fall (mm)
Jan	25.00	21.5	16.2	9.54	22.8	7.93	18.96
Feb	30.43	28.0	16.8	57.38	22.0	10.66	46.97
Mar	83.50	27.9	18.1	66.12	22.3	10.86	78.60
Apr	161.23	31.1	18.2	119.70	22.5	10.57	148.93
May	154.08	29.2	18.1	112.80	22.6	10.68	174.47
Jun	86.42	28.9	17.8	199.58	23.5	10.54	111.17
Jul	70.40	28.4	18.1	163.10	23.1	11.14	162.17
Aug	51.45	28.7	18.1	141.08	23.9	10.33	166.08
Sep	121.74	19.6	17.7	130.23	23.1	11.06	155.34
Oct	133.36	19.9	17.3	166.10	23.0	10.54	110.77
Nov	58.80	20.2	15.4	99.57	22.1	44.88	66.68
Dec	45.38	20.8	14.2	58.50	22.4	10.67	12.23
Total Mean	85.15	25.4	17.2	110.31	22.8	13.32	104.36

Source: National meteorological agency of Ethiopia (2005-2010)

Appendix2. ANOVA table for interaction effect of earthing up and harvesting time on damaged tuber number of sweet potato tubers in Southern Ethiopia at Lante

Source	DF	SS	MS	F Value	Pr > F
ERT	3	63907.12	21302.37	1092.64	<.0001
HRVT	2	24807.00	12403.50	636.20	<.0001
ERT*HRVT	6	519.00	86.50	4.44	0.0160
rep	1	35.04	35.041	1.80	0.2071
Error	11	214.45	19.49		
Corrected Total	23	89482.62			
		R^2=99	CV= 3.02		

Appendix.3. ANOVA table for the interaction effect of earthing up and harvesting time on sweet potato weevil's density in south southern Ethiopia at Chano Dorga

Source	DF	SS	MS	F Value	Pr > F
ERT	3	60571.64	20190.55	786.72	<.0001
HRVT	2	19425.72	9712.86	378.46	<.0001
ERT*HRVT	6	1990.94	331.82	12.93	<.0001
rep	2	0.72	0.361	0.01	0.9860
Error	22	564.61	25.66		
Total	35	82553.63			
	R^2 =99		CV= 5.73		

Appendix4. ANOVA table for the interaction effect of earthing up and harvesting time on number of tuber with sweet potato weevil damage in southern Ethiopia at Chano Dorga

Source	DF	SS	MS	F Value	Pr > F
ERT	3	105441	35147.1	2367.05	<.0001
HRVT	2	21022.2	10511.1	707.89	<.0001
ERT*HRVT	6	4658.05	776.34	52.28	<.0001
Rep	2	40.6667	20.33	1.37	0.2751
Error	22	326.667	14.84		
Total	35	131489			
	R^2= 99%			CV= 4.12	

Appendix5. ANOVA table for the effect of earthing up and harvesting time on marketable tuber yield (t/ha) in southern Ethiopia at Chano Dorga

Source	DF	SS	MS	F Value	Pr > F
ERT	3	584.24	194.75	675.87	<.0001
HRVT	2	77.19	38.6	133.95	<.0001
ERT*HRVT	6	17.19	2.87	9.94	<.0001
Rep	2	0.43	0.22	0.75	0.4823
Error	22	6.34	0.29		
Total	35	685.39			
	R^2 = 99%		CV=7.6		

Appendix6. ANOVA table for the interaction effect of earthing up and harvesting time on unmarketable tuber yield (t/ha) in southern Ethiopia at Chano Dorga

Source	DF	SS	MS	F Value	Pr > F
ERT	3	87.155	29.05	271.74	<.0001
HRVT	2	19.265	9.63	90.10	<.0001
ERT*HRVT	6	2.367	0.393	3.68	0.0110
rep	2	0.583	0.29	2.73	0.0872
Error	22	2.35	0.106		
Total	35	111.71			
	R^2 =97%		CV=10.30		

Appendix7. ANOVA table for the interaction effect of earthing up and harvesting time on percent yield loss in southern Ethiopia at Chano Dorga

Source	DF	SS	MS	F Value	Pr > F
ERT	3	19553.1	6517.71	667.05	<.0001
HRVT	2	3393.12	1696.56	173.63	<.0001
ERT*HRVT	6	406.99	67.83	6.94	0.0003
Rep	2	25.98	12.99	1.33	0.2851
Error	22	214.96	9.77		
Total	35	23594.2			
R^2 = 99%			CV=8.49		

Appendix8. ANOVA table for the interaction effect of earthing up and harvesting time on sweet potato weevil's Population in southern Ethiopia at Lante

Source	DF	SS	MS	F Value	Pr > F
ERT	3	5435.00	1811.66	150.03	<.0001
HRVT	2	13835.58	6917.79	572.87	<.0001
ERT*HRVT	6	779.75	129.95	10.76	0.0005
rep	1	0.166	0.16	0.01	0.9086
Error	11	132.83	12.075		
Total	23	20183.33			
		R^2 =99%		CV=4.59	

Appendix9. ANOVA table for the interaction effect of earthing up and harvesting time on sweet potato weevil's population in southern Ethiopia at Chano Dorga

Source	DF	SS	MS	F Value	Pr > F
ERT	3	60571.64	20190.55	786.72	<.0001
HRVT	2	19425.72	9712.86	378.46	<.0001
ERT*HRVT	6	1990.94	331.82	12.93	<.0001
rep	2	0.72	0.361	0.01	0.9860
Error	22	564.61	25.66		
Total	35	82553.63			
	R^2 =99%		CV= 5.73		

Appendix10. ANOVA table for the interaction effect of earthing up and harvesting time on marketable tuber yield (t/ha) in southern Ethiopia at Lante

Source	DF	SS	MS	F Value	Pr > F
ERT	3	22791.84	7597.28	854.33	<.0001
HRVT	2	3199.80	1599.90	179.91	<.0001
ERT*HRVT	6	167.88	27.98	3.15	0.0476
rep	1	14.27	14.28	1.61	0.2313
Error	11	97.81	8.89		
Total	23	26271.62			
	R^2=99%		CV=4.98		

Appendix11. ANOVA table for interaction effect of earthing up and harvesting time on percent yield loss in southern Ethiopia, at Lante

Source	DF	SS	MS	F Value	Pr > F
ERT	3	10498.71	3499.57	2555.32	<.0001
HRVT	2	5568.78	2784.39	2033.11	<.0001
ERT*HRVT	6	577.22	96.20	70.25	<.0001
rep	1	0.049	0.0492	0.04	0.8527
Error	11	15.06	1.36		
Corrected Total	23	16659.83910			
	R^2 =99		CV= 3.22		

Appendix12. ANOVA table for tuber puling resistance of Sweet potato varieties grown at Humbo and Bele, southern Ethiopia

Source	DF	SS	MS	F Value	Pr > F
Trt	19	3445.53	181.34	40.32	<.0001
Rep	2	9.09	4.54	1.01	0.3686
Loc	1	3473.33	3473.32	772.2	<.0001
Trt*loc	19	1415.44	74.49	16.56	<.0001
Error	78	350.83	4.49		
Total	119	8694.23			
R^2 =95%		CV=13.01			

Appendix13. ANOVA table for percentage dry weight of Sweet potato varieties grown at Humbo and Bele, southern Ethiopia

Source	DF	SS	M S	F Value	Pr > F
Trt	19	6526.77	343.51	97.49	<.0001
Rep	2	5.144	2.572	0.73	0.4852
Loc	1	15.32	15.329	4.35	0.0403
Trt*loc	19	7068.45	372.02	105.58	<.0001
Error	78	274.84	3.52		
Total	119	13890.55			
R^2=98%			CV=9.3		

Appendix14. ANOVA table for percentage moisture weight of Sweet potato varieties grown at Humbo and Bele, southern Ethiopia

Source	DF	SS	MS	F Value	Pr > F
Trt	19	35105.64	1847.66	533.83	<.0001
Rep	2	4.21	2.107	0.61	0.5465
Loc	1	17742.16	17742.17	5126.10	<.0001
Trt*loc	19	31400.23	1652.64	477.48	<.0001
Error	78	269.96	3.46		
Total	119	84522.22			
R^2 =99%		CV=2.76			

Appendix15. ANOVA table for marketable yield (q/ha) of Sweet potato varieties grown at Humbo and Bele, southern Ethiopia

Source	DF	SS	MS	FValue	Pr > F
Trt	19	141754.5	7460.76	55.45	<.0001
Rep	2	315.04	157.52	1.17	0.3155
Loc	1	58612.29	58612.3	435.64	<.0001
Trt*loc	19	64428.15	3390.95	25.2	<.0001
Error	78	10494.35	134.54		
Total	119	275604.35			
	R^2=96%		CV=14		

Appendix16. ANOVA table for unmarketable yield (q/ha) of Sweet potato varieties at Humbo and Bele, southern Ethiopia

Source	DF	SS	MS	F Value	Pr > F
Trt	19	6039.10	317.84	84.47	<.0001
Rep	2	13.20	6.60	1.75	0.1797
loc	1	296.25	296.26	78.73	<.0001
Trt*loc	19	4432.57	233.29	62.00	<.0001
Error	78	293.49	3.76278		
Total	119	11074.6			
R^2 = 97%		**CV=** 13.89			

Appendix17. ANOVA table for percentage damage of Sweet potato varieties grown at Humbo and Bele, southern Ethiopia

Source	DF	SS	MS	F Value	Pr >
Trt	19	0.648	0.034	46.82	<.0001
Rep	2	0.000	0.0004	0.64	0.5306
loc	1	0.101	0.1015	139.22	<.0001
Trt*loc	19	0.576	0.030	41.61	<.0001
Error	78	0.056	0.000		
Total	119	1.384			
R^2 =95%			CV=19		

Appendix18. ANOVA table for sweet weevil density on Sweet potato varieties grown at Humbo and Bele, southern Ethiopia

Source	DF	SS	MS	F Value	Pr > F
Trt	19	16352.62	860.66	122.58	<.0001
Rep	2	0.350	0.175	0.02	0.9754
loc	1	1606.00	1606.008	228.74	<.0001
Trt*loc	19	9347.49	491.97	70.07	<.0001
Error	78	547.65	7.021		
Total	119	27854.12			
R2= 98%		CV=12.24			