DEVELOPMENT OF EFFECTIVE INTEGRATED MANAGEMENT PACKAGE OF SWEET POTATO WEEVIL

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DEVELOPMENT OF EFFECTIVE INTEGRATED MANAGEMENT PACKAGE OF SWEET POTATO WEEVIL

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This is to certify that the thesis entitled "**Development of effective integrated management package of sweet potato weevil**" submitted to the Department of Entomology, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN ENTOMOLOGY**, embodies the results of a piece of bonafide research work carried out by **Nurjahan Nipa**, Registration No. **12-04959** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I, further certify that any help or source of information, received during the course of this investigation has been duly acknowledged.

Dated: June, 2018

Dhaka, Bangladesh

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DEDICATED

TO

MY BELOVED PARENTS and

GRANDPARENTS

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The Auther

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ABSTRACT

The present study on integrated management package of sweet potato weevil infesting sweet potato was conducted during rabi season (Nov-2017 to Mar-2018) in the experimental field of Department of Entomology at Sher-e-Bangla Agricultural University, Dhaka. The variety of sweet potato BARI Mistialu-8 was used as test crop. The experiment consisted of six treatments and one untreated control, they are T_1: Sex pheromone trap + Earthing up one time + Mulching (straw) + One irrigation, T_2: Sex pheromone trap + Earthing up two times + Two light irrigation , T_3: Sex pheromone trap + Earthing up three times + Three light irrigation, T_4: Earthing up two times + Sevin 85WP @ 3g\L of water at 15 days interval (2 times application), T_5: Earthing up two times + Diazinon 10G @ 15 kg\ha (one time soil application), T_6: Earthing up two time + Fenthion 2ml\L of water, T_7: Untreated control. The experiment was laid out in Randomized Complete Block Design (RCBD) with three (3) replications. The result revealed that sex pheromone trap with earthing up three times and three light irrigation (T_3) showed the best control measure against sweet potato weevil compared to other treatments. Highest number of sweet potato weevil adult was found in T_7 (9.46 weevil/plot) and highest damage result was observed in T_7 (15.4%). Whereas the lowest number of adult weevil was observed in T_3 (0.392 weevil/plot) and lowest damage was noticed in T_3 (5.04%). At 15 days early harvest, in consideration of infestation level of storage tubers in number and weight basis, the lowest infestation was recorded from T_3 (3.68% and 5.68%), whereas the highest infestation (12.24% and 12.98%) was observed in T_7. At optimum days harvest, for infestation level of tubers in number and weight basis, the lowest infestation was recorded from T_3 (4.49% and 6.48%), whereas the highest infestation (13.55% and 14.15%) was observed from T_7 treatment. After 15 days from optimum harvest, in case of infestation level of tubers in number and weight basis, the lowest infestation was recorded from T_3 (5.32% and 6.92%), whereas the highest infestation (16.35% and 17.04%) was observed from T_7 treatment. Besides, highest deformed tuber was found in T_7 (11.960%) and lowest in T_3 (2.362%). The highest yield was recorded from T_3 (41.87 t/ha), whereas, the lowest from T_7 (30.28 t/ha) treatment. These findings illustrated that, the Sex pheromone trap with earthing up three times and three light irrigation (T_3) treatment was more effective for controlling of sweet potato weevil.

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SOME COMMONLY USED ABBREVIATIONS

FULL WORD	ABBREVIATION
Agro-Ecological Zone	AEZ
Bangladesh Bureau of Statistics	BBS
Co-efficient of variation	cv
Days After Sowing	DAS
and others	*et al.*
Etcetera	etc
Food and Agriculture Organization	FAO
Journal	J.
Least Significance Difference	LSD
Muriate of Potash	MoP
Sher-e-Bangla Agricultural University	SAU
Soil Resources Development Institute	SRDI
Triple Superphosphate	TSP

CHAPTER I

INTRODUCTION

Sweet potato [*Ipomoea batatas* L.] is one of the most important food crops in developing countries, where over 95% of the world's production occurs (CIP, 1996; Hijmans *et al.*, 2001). Sweet potato is currently ranked as the seventh most important crop in the world with a total production of 103 million tons in 2013 (FAO, 2015). It is grown both for home consumption and to supplement house hold income by sale to local market and urban areas. Over the last two decades the role of sweet potato innutrition and food security of the developing countries has changed significantly. The major countries producing sweet potato continued to witness decline in the use of sweet potato as a staple food, but increased its use in animal feed and making industrial starch. Meanwhile, sub-Saharan Africa added over one million hectares to sweet potato cultivation (FAO, 2005). The technological information developed in the sweet potato research has enabled the producers to enhance the productivity and quality.

In addition, with agreement on the millennium development goals by the United Nations, the international community has given renewed emphasis to alleviating poverty, hunger, malnutrition, disease, and other dimensions of under-development. Sweet potato is a excellent source of fiber, vitamins B_6, E and C. It is good for heart and also helps in controlling blood sugar due to low glycemic content. Sweet potato has strong immunity and anti-inflammatory properties, good for digestion and also helps in preventing cancer. Sweet potato is very widely adapted throughout temperate and tropical zones over almost 80 degrees of latitude and from sea level to over 2000 m altitude. Sweet potato grows best in regions of 750-1250 mm of rainfall per annum but, it responds well to irrigation in more arid regions, perhaps because of the increase in sunshine. The most suitable soils are well-drained, sandy loams or tropical peats but sweet potato can be grown on fairly poor soils if the ground is well cultivated. Heavy soil should be avoided as the tubers tend to be badly shaped and difficult to lift. There is almost no fresh storage of roots. Farmers practice in ground storage and piece meal harvesting (Smit and Matengo, 1995). Over 95 percent of the global sweet potato crop is produced in developing countries, it has considerable unrealized potential.

There are a few key needs that are facing farmers in all major sweet potato producing countries, but there are other very important needs specific to certain regions. The needs that scored highest in all or most of the major sweet potato producing areas in developing countries include production of quality planting material, management of sweet potato weevil (SPW), *Cylas formicarius* (Fab.) and development of high β-carotene content in tubersto address vitamin A deficiency (Fuglie, 2007). Sweet potato weevil, *Cylas* spp (Coleoptera: Curculionidae) is the most destructive insect pest of sweet potato, *Ipomoea batatas* (L.) in Zanzibar (Saleh and Mohammed, 2001). Although the extent of damage caused by sweet potato weevils has never been quantified in Zanzibar, (Chalfant *et al.*, 1990) reported that losses often reach 60 to 100 percent in low input agricultural systems. Surveys which have been conducted elsewhere in Tanzania indicate that, sweet potato weevil is the major insect pest of sweet potato crop in almost all major sweet potato growing areas (Kapinga, 1992).

Sweet potato weevil is by far the most destructive pest of the sweet potato plant. It has become widely dispersed, mainly in tropical and subtropical regions of the world, and recently has been found in higher latitude areas as well. The establishment of *C. formicarius* in Muroto (Japan) shows that it can tolerate low temperatures in winter to some extent, though it is a tropical and subtropical insect (Kandori *et al*., 2006). In India, on farm surveys revealed 25-45% yield loss in Orissa, 5-50% in Bihar, 4-50% in Kerala due to SPW (Pillai *et al*., 1987). The SPW is the major insect pest of sweet potato in the North Eastern Hill Region of India, where, farmers cultivate this crop in the altitudes ranging between 600-1600 m (above mean sea level) (Rajase khara *et al*., 2006). Though several eradication programmes for this pest were taken up in some countries, still *C. formicarius* appears to be one of the major insect pests in the sweet potato producing countries worldwide. Management strategies for the SPW took a pragmatic change, soon after the discovery of female sex pheromone by Heath et al. The weevil can be managed by Integrated Pest Management (IPM) strategy, which includes host plant resistance, biotechnological approaches, cultural methods, biological control, use of semiochemicals, botanical and chemical pesticides etc. Often producers rely on chemical control but it causes frequent pest outbreak, pesticide resistance, contamination of the environment and pest resurgence. Earthing-up, late harvesting, intercropping and pheromone trap were found to be more effective in the management of *C. formicarius.*

Integrated Management package has emerged as an important approach of pest control strategy and has least disruption of agro-ecosystem.

Many of the farmers are showing their interests in cultivation of sweet potato in Rajshahi, including char areas, for a higher demand of the crop with good market price. Low production cost and easy cultivation process made the farmers eager in its cultivation and for this reason its cultivation has increased considerably in char areas of the region. The DAE and other government and non-government organizations concerned have taken necessary measures to make the sweet potato cultivation a success in the region.

The sandy lands and the riverbeds (chars) are suitable for the sweet potato cultivation. So, people of the Ganges and Brahmaputra basins and the remote char areas are habituated in the farming widely besides consuming it. Production cost of the crop is very low, as it requires less fertilizer and irrigation. Nutritive value of the crop is similar to rice and its taste is delicious. It contains vitamin A and C and expected mineral elements, which are absent in rice. It is also enriched with protein, carbohydrate, calcium, iron, carotene and vitamin B_1 and B_2, which are essential for human body. An adult person needs 13 grams of vitamin A per day it can be fulfilled after consuming only a single sweet potato.

People of Philippines and Papua New Guinea consume sweet potato as the alternative of rice while in USA and Japan it is used as food widely. Different types of tasty foods like halua, payesh, bread, pauruti, biscuit, pastry and cake could be made through processing the indigenous potato. If the people are habituated to sweet potato consumption the nation can reduce its dependence on rice to a greater extent, Steps should be taken to make the people aware in this regard. Importance should be given to providing adequate training and agri-loans among the farmers. There is an enormous scope of boosting both acreage and yield of the indigenous crop through the best uses of the existing natural resources. The objectives of this research are mentioned belows,

- To develop integrated management packages of sweet potato weevil.
- To know the intensity of infestation of sweet potato weevil.
- To relate the impact of irrigation and harvesting time interval on the infestation of sweet potato weevil.

CHAPTER II

REVIEW OF LITERATURE

Sweet potato weevil is considered as the most serious pest of sweet potato around the world because it causes damage in the fields, in storage, and is of quarantine significance. Its strikingly colorful appearance and extremely long rostrum (beak) has made the species inherently of interest to the entomologists. However, Sweet potato weevil is often considered to be the most serious pest of sweet potato since losses ranging from 5% to 97% were reported in areas where the weevil occurs. Vine damage or weevil density, and tuber damage are somewhat positively correlated. However, the plants showed some reparative ability, with the relationship between vine damage and yield non-linear, and sometimes insignificant. The major form of damage to sweet potato is caused by mining of the tubers by larvae; infested tuber is often riddled with cavities, spongy in appearance, and dark in color. Furthermore, simultaneously with the damage caused directly by tunneling, larvae also cause damage by indirect infestation with soil-borne pathogens. Even low levels of feeding can create a chemical reaction that imparts a bitter taste and terpene odor to the tubers. Among the several damage caused by the pest its larvae can also mine the vine of the plant, causing it to darken, crack, or collapse. The adults often feed on the tubers, creating numerous small holes that measure about the length of its head. However, damage caused by the adults is less severe because of its less access to the tuber compared to larval stage. As a result adult sometimes feed on the foliage of the plant.

TACTRI (2014) reported that Sweet potato weevil is the most destructive pest of the sweet potato plant. The severity of infestation is area specific and often varies but weevils nevertheless cause severe damage to plantations. Taiwan Agricultural Chemical and Toxic Substances Research Institute Council of Agriculture revealed that the damage caused by sweet potato weevil reduced sweet potato production in Taiwan by 1–5%, while the damage in extensive commercial produced fields was up to 18%.

Smit *et al* (2001) revealedthat trapping experiments in Uganda with decyl (*E*)-2-butenoate and dodecyl *(E)*-2-butenoate components of the female sex pheromones of the African species of sweet potato weevil, *Cylas puncticollis* and *C. brunneus*, respectively. They used four on-station trials of season-long mass-trapping of both species of weevil in 0.5 ha sweet potato plots with 100 jerry can traps ha^{-1} (50 traps for each species placed alternately), populations of male weevils were reported to reduce up to 89%, compared to un-trapped control plots. Differences in tuber infestation levels were recorded between mass-trapped and untreated control plots, and no significant differences in the proportions of female weevils that were mated were observed.

The distribution of *Cylas* spp. weevils varies between regions, *C. formicarius* is the most widespread, being the only species found in Philippines, Indonesia and Thailand and in the Pacific countries such as Papua New Guinea. In East Africa, three species have been reported *C. formicarius, C. puncticollis* and *C. brunneus*, the former two species being the most common and the latter two being restricted to Africa (Lenne, 1991 and Smit *et al.*, 2001). There are only two records of occurrence of *C. formicarius* in Africa: Msabaha in coastal Kenya and Natal Province in South Africa. In 1997 Smit found that in Kenya and Uganda *C. puncticollis* and *C. brunneus* are of equal importance. *C. formicarius* is widely distributed, it occurs in Africa, Asia, the Caribbean, in parts of North and South America and the Pacific, *C. puncticollis* is confined to Africa (Moyer *et al.*, 1989).

2.1 Description, Diversity, Biology and Distribution of *Cylas formicarius*

2.1.1Description of *Cylas* spp.

Sweet potato weevils is in the genus *Cylas* (Coleoptera: Apionidae) (Chalfant *et al*., 1990; Smit, 1997a). Contains three species namely *Cylas brunneus* (Olivier), *Cylas puncticollis* (Boheman) and *Cylas formicarius* (Fabricius) (Wolfe, 1991). Adult weevils are elongated smooth and shine with ant like snouted beak but species can be differentiated by size and colour (Smit, 1997a). *C. formicarius* are small with a bluish black abdomen and a red thorax, *C. puncticollis* are black and large *C. brunneus* are small either black or brown (Wolfe, 1991).

2.1.2 Diversity of sweet potato weevils

Parker *et al.* (1990), stated that both *C. puncticollis* and *C. brunneus* are the most common species in East Africa. On the other hand, *Cylasformicarius* is the main pest species in Asia, the United States and Oceania, but in Africa it has been found in Natal, South Africa and on the coast in Kenya.

2.1.3 Biology of sweet potato weevils

Ames *et al.,* (1996) found that all three species have a similar life history. The adult female lays eggs singly in cavities excavated in vine or in roots, preferring the latter. The egg cavity is sealed with a protective, gray fecal plug. The developing larvae tunnel in the vine or root. Pupation takes place within the larvae tunnels. A few days after reclusion, the adult emerge from the vine or roots because the female weevil cannot dig, she finds soil cracks. Alternate host of sweet potato weevils are *Ipomoea* spp. Weeds.

2.1.3.1 Eggs

Otto *et al.,* (2006) revealed that, Eggs are deposited in small cavities created by the female with her mouthparts in the sweet potato root or stem. The female deposits a single egg at a time, and seals the egg within the oviposition cavity with a plug of fecal material, making it difficult to observe the egg. Eggs will hatch after three to seven days depending on the environmental conditions.

From Schmutterer (1969), the egg is oval, and yellowish-white.

2.1.3.2 Larvae

From Allard (1990), The larvae have head, thorax and abdomen. The head is pale brown with darker brown mandibles, one pair of ocelli (stemmata), each containing two contiguous pigment spots.

Otto et al., (2006) found that, The thorax is divided into prothorax and mesothorax whereby mesothoracic spiracle located on a lobe very close to the prothorax. The abdomen is whitish, legless, slightly curved, approximately 10 millimeters length maximum width two millimeter scuticle speculate. Larvae have three instars, first larval instar, second larval instar, and third larval instar. Total larvae period varies from 10 – 25 days.

2.1.3.3 Pupae

Otto *et al*., (2006), found that the pupa of sweet potato weevil is white and approximately six millimeters in length; pronotal width one meter, cuticle glabrous. The head and rostrum are provided with setiferous tubercles, one pair between the eyes at base and two pairs on the rostrum. The posterior pair are being close to the eyes and the anterior behind the middle. Pupation occurs inside the vine or root and takes eight days for adults to emerge.

2.1.3.4 Adults

The pest is black, with a faint, metallic blue luster, and not with a distinctly shiny, copper-like sheen, body length is eight millimeters. The length of male antennal club is equal to or greater than combined length of all preceding segments. Eyes close together in dorsal view; distance between eyes is about one sixth of minimum width of rostrum.

From Ames *et al.,* (1996), At an optimal temperature of 27-30^0 C, *C. formicarius* completes development (from egg to adult) in about 33 days. Adult longevity is two to three months and females lay between 100 and 250 eggs in this period.

Okonyo (2013) found that the male and female adult sweet potato weevils can be told apart by the shape of their antennae. The antennae of the males are straight while those of the female are round or club-shaped. Under favorable conditions, sweet potato weevils can produce 13 generations a year and can live for three to four months.

2.1.4 Distribution

According to Parker *et al*. (1990), the sweet potato weevil is one of the major pests of sweet potato worldwide. Three species have been identified in Africa. Their distribution in Africa is being surveyed and it appears that all the three species have a similar life history, making all of them difficult targets for conventional pest control measures.

Nderitu *et al.* (2009) found that, among the three, *C. formicarius* is an important pest in India, South East Asia, Oceania, the United States and the Carribean.

2.1.5 Mode of action of sweet potato weevil

Although different subspecies of sweet potato weevils can be found in different geographical locations, their modes of action remain the same (Capinera, 2001). Sweet potato weevils generally cause serious damage to all parts of sweet potato plant throughout their life cycle, from egg to adult. When laying eggs, female weevils excavate cavities and create egg-laying punctures in the roots. The eggs are laid below the surface of the roots and covered with dark color excrement from the female adults (Capinera, 2001). As a result of the unsightly punctures, the appeal of the roots and market price of sweet potato become greatly reduced, resulting in major economic losses.

Hatching will generally occur in a week after oviposition by females. Hatched larvae will start making tunnels inside tubers and feed inside galleries (Onwueme and Charles, 1994). The tunnels inside the tubers of sweet potatoes will be filled with excrement from the larvae. As the larvae feed, the sweet potato will impart a bitter flavor and terpene odor, making it unsuitable for the consumption of human or livestock. The presence of terpenoid reduces the marketable yield and root quality of sweet potatoes (Uritaini *et al*., 1974). Mining of sweet potato tubers by larvae is the principal cause of sweet potato damage. The tuber becomes spongy in appearance, riddled with cavities, and dark in color (Uritaini *et al*., 1974). Beside that, larvae also mine into the vines of sweet potato, causing it to darken, crack, and collapse. Apparent symptoms of weevils infestation will be yellowing of the vines but this usually only occur after heavy infestation (Uritaini *et al.,* 1974). Larvae tunneling inside the tubers will indirectly facilitate the entry of soil borne pathogens, which can cause further damage from secondary infections by fungi and bacteria (Onwueme and Charles, 1994). In addition, the larvae will cause damage to the vascular system, which then reduces the number and size of future storage roots. Subsequently, adults will start emerging and will start feeding on leaves, vines, tender buds, and storage roots of sweet potato by punctuating the surface. Since most of the infestations generally occur below the soil level, these problems can go undetected until harvesting season arrives. Observations from the different regions of sweet potato plantations summarize the factors that can contribute to sweet potato weevil infestation. This information is important as a preventive measure against future infestation.

2.2 Economic Importance of Sweet Potato Weevils

Sweet potato weevil is one of the most important biotic factors limiting sweet potato production in Africa (Chalfant et al., 1990; Pfeiffer, 1982; Smit and Matengo, 1995). Sweet potato is the sixth most important food crop in the world (Vietmeyer, 1986) and both adults and larvae cause serious damage to leaves and stems. Adults attack the leaves of sweet potatoes, but the larvae are more injurious boring into the stems and causing serious mortality to seedlings (Daiber, 1994).

Wolfe (1991), described that adults of all three *Cylas* species feed on the epidermis of vines and leaves, scraping oval patches off petioles, young vines and leaves. Yield loss is seldom serious. Adults also feed on the external surfaces of roots causing round feeding punctures which can be distinguished from oviposition sites by their greater depth and the absence of a faecal plug. The developing larvae tunnel in the vines and roots causing significant damage. Frass is deposited in the tunnels. In response to the damage, the root produces terpenes which render the infested root part inedible (Sato *et al.,* 1981).

According to Allard *et al*. (1991), serious larval infestations disrupting sweet potato nurseries in Ethiopia, on established plants, the larvae feed in the tubers and stems producing larvae tunnels and later, pupal chambers stem damage is believed to be the main reason for yield loss, although damage to the vascular system caused by feeding, larvae tunnel secondary rots reduce the size and number of roots. In Eastern Africa both *C. puncticollis* and *C. brunneus* can be found infesting the same root. When a root is exclusively infested by *C. puncticollis*, the core of the root might still be untouched; *C. brunneus* larvae seem to tunnel further inside the root. First severe infestations render the crop unpalatable and therefore inedible to humans. Pest damage usually continues during storage, therefore infested tubers cannot be stored for a long time. In conjunction with other coleoptera pests, sweet potato weevil can completely destroy sweet potato plantations (Geisthardt and van, 1992). Weevil feeding on storage roots induces terpenoid production that makes even slightly damaged root unpalatable (Uritani *et al*., 1975; Sato et al., 1981). Thus low weevil densities may cause devastating crop losses of up to 60 -100% (Chalfant *et al.,* 1990).

2.3 Vine planting and Management of Sweet PotatoWeevils

2.3.1 Vine planting

Time of planting has been identified as one of the most important factors affecting growth, yield and quality of roots (Nedunchezhiyan and Byju, 2005). In Malaysia, higher root yield was noticed during drier growing season (January to July) compared to wet season (August to December) (Zaharah and Tan, 2006). In India, sweet potato is grown throughout the country, utilizing monsoon rain during kharif, (June-August), and with supplemental irrigation during rabi (October-December). The major area under sweet potato is planted during kharif season, though rabi planted sweet potato enjoys warm sunny days and cool nights with moderate rainfall conductive for higher root yield. Investigations carried out at different regions of India on the optimum time of planting revealed that rainfed crops should be planted immediately after onset of monsoon (Nedunchezhiyan and Reddy 2006) whereas dry season crops should be planted in October- November (Nath *et al*., 2006) for higher storage root yield. In India, it is observed that the tuber yield of sweet potato is comparatively more during rabi than kharif season (Nawale and Salvi 1983; Nedunchezhiyan and Byju, 2005). In Taiwan, high yields of sweet potato were obtained when the mean daily temperature was maintained around 22ºC for the 1st 60 DAP (Sajjapongse, 1989). In Korea, as per the demand of sweet potatoes, transplanting time is advanced from May-June to March-April and the harvesting time is advanced from September-October to June-August with the modification of cultural requirements (Jeong, 2000).

Irrigation

Sweet potato vines are succulent and fragile and if sufficient moisture is not available in the soil immediately after planting it dries up. Hence, sufficient soil moisture at the time of planting is to be ensured for proper sprouting and establishment of vines. Sweet potato is mostly grown under rainfed conditions. Hence, planting is carried out on rainy day or immediately after rain. It is also grown in dry season under protective irrigation. Under such conditions, if sufficient moisture is not available after planting, irrigation need to be provided on alternate days initially for the first fortnight and thereafter once in 7-10 days. Trials conducted in the sweet potato growing areas have conclusively proved the beneficial effect of irrigation. Sweet potato required on an average of 2 mm of water per day in the early parts of the growing season and gradually increased to 5-6 mm of water/day prior to harvest (Gomes and Carr 2003). Biswal (2008), found that when soil moisture was high or the soil was compacted sweet potato had luxuriant vegetative growth with little or no tuberization of root. Excessive irrigation should be avoided as poor aeration may cause poor storage root induction or development (Chua and Kays 1981).

Indira and Kabeerathumma (1988), imposed water stress for 20 days to sweet potato grown in lysimeter during early growth phase (10-30 days), root development phase (30-50 DAP) and root maturity phase (75-90 DAP) and observed significant reduction in root yield for the stress induced during early growth phase. Stress induced during root development phase however slightly improved the yield while stress during root maturity phase resulted in a slight reduction in yield. Martin (1988), stated that sweet potato could not tolerate dry conditions at planting. According to Yassen and Thompson (1988) irrigation increased the number of root and total marketable yield. According to Goswami *et al*. (1995), three irrigations at root initiation, early bulking and late bulking stages were most favourable for higher number of roots/vine, root bulking rate and dry matter content resulting in higher root yield (278 t ha-1).

Cultural control

According to Stathers *et al.* (2005) different successful cultural practices used in experiments conducted in East Africa, Taiwan, Philippines, Vietnam, America, India, Cuba and Indonesia. Cultural practices aimed at preventing infestation proved to be effective way of reducing weevil damage.

a) Field sanitation

Smit and Matengo (1995) studied on the farmers cultural practices in Kenya and suggested that crop protection workers should concentrate their research and extension efforts on crop sanitation and the avoidance of adjacent planting of successive crops.

From Stathers *et al.* (2005) removal and destruction (through burning or feeding to livestock) of infested vine and root carries infestation. If vines are left in the field to maintain soil fertility, care should be taken to ensure they are dead or dry and not able to sprout and then provide food for weevils. If peace meal harvesting of the crop is practiced, care should be taken to remove and destroy any infested roots that are found.

Komi (2000) repoted that removal of alternate host plants like *Calys tegiasoldanella*, *C. hederacea* and *Ipomoea indica* reduced the sweet potato weevil infestation in Japan. Removal of volunteer sweet potato plant and wild morning glories as these may be alternative hosts (Sato *et al.*, 1981).

Geisthardt and Van (1992), stated that crop rotation with other crops for two to three seasons appears to be the most effective method of preventing infestations of weevils.

In a large ecosystem area or community burying can help to reduce sweet potato weevil infestation. Infested storage roots must be buried >15 cm underground (Stathers *et al.*, 2005).

b) Hilling up

Allard *et al.* (1991), reported that collection of soil around the base of plants to prevent or fill soil cracks. This practice not only protects the plants from weevil attack but can also result in increased crop yield.

Palaniswami and Mohandas (1994) reported that, Re-ridging the crop at tuber formation stage prevents the weevil from laying the eggs and the entry of the grubs into the tuber. The efficacy of re-ridging in sweet potato crop, as a cultural practice for reducing weevil incidence was investigated over two seasons at Vellayani, Kerala, India. Five re-ridgings between 50 and 90 days after planting, at 10 days interval, significantly reduce the weevil damage to the tubers.

Deep planting into the hill, and planting into the furrow and earthing up after six weeks offers protection against weevils (Macfarlane, 1987).

c) Mulching

Geisthardt and Van (1992) described that application of dry leaves on the soil to keep it moist, prevent cracks and provide a more favourable place for natural enemies. Care should be taken to make sure the weevils cannot feeds or develop on the mulching material.

According to AVRDC (1987), mulching with rice straw or black plastic reduced the infestation by SPW in the root zone. The availability of mulch is a problem especially in dry-lands coupled with higher temperatures. Termites are a problem during summer as they completely devour the dried grasses and other shrubs in dry lands.

d) Early harvesting

Ebregt *et al*. (2005), studied that harvesting two weeks earlier reduce the loss due to weevil from greater than 30 percent to less than five percent.

From Powell *et al*. (2001) reported that, early harvesting of the crop is practiced to ensure that infested roots are removed and destroyed. Vines left in the field should not be allowed to sprout and then provide food for weevils.

From Stathers *et al*. (2005), timely harvesting to remove the largest storage root most at risk from weevil attack and subsequent hilling up of the soil around the remaining root to prevent weevils from accessing the root through cracks in the soil.

e) Flooding

Otto *et al*. (2006) reported that flooding of the field for more than 48 hours kill the weevil larvae present in roots that have been left in the field. Flooding of fields between two consecutive sweet potato crops may reduce the immediate source of weevil from the field. Sweet potato weevils can be controlled by flooding of fields before planting (Stathers et al., 2003).

Talekar (1987) reported that flooding of infested field for at least 48 hours after completing harvest drown weevils and induces rotting of the left over plant materials and thereby reduces weevils‟ densities from one planting to the next. This is an option in areas where rotation is not possible.

f) Intercropping

Stathers *et al.* (2005) reported that, In Taiwan, 103 different crops were tested as intercrops for sweet potato weevil control, the best result were obtained with coriander (*Coriandrum sativum* L.).

According to Rajasekhara Rao (2005) and Rajasekhara Rao *et al.* (2006), Mixed cropping systems with sweet potato and other crops (ginger, okra, maize, colocasia and yam) are practiced by farmers in North Eastern Region of India. Low incidence of *C. formicarius* was noticed in these systems and the interaction of intercrops and several insect pests of tuber crops, including sweet potato weevil, in these multiple cropping systems.

g) Use of clean planting material

Allard *et al.* (1991) described the following techniques that have been used in the management of sweet potato weevils. Planting only in fields that have had no weevil infestations within the last 12 months and preferably more than 1 km away from any infested land; planting resistant or tolerant cultivars; selecting deep-rooting cultivars, with long necks between the roots and the stems (which are less susceptible because the adult weevil cannot burrow downwards more than one centimeter); planting early-maturing cultivars which can escape serious damage; earthing up of plants (hilling), particularly those cultivars with the tendency to push out of the ground; removal of all plant debris and volunteer plants after harvest; re-ridging approximately 30 days after planting as this places the roots deeper and out of reach of the weevils; planting non-infested material; and use of intercropping.

Weevils tend to lay eggs in the older woodier parts of the sweet potato vine, so if the tender tips are used for planting they are less likely to be infested by weevils (Nair, 2006).

h) Mixed cropping

Some farmers practice mixed cropping systems with sweet potato, rice, cowpea, maize, ginger, and yam to reduce the incidence of sweet potato weevils. Pillai *et al.* reported that intercropping sweet potato with colocasia, rice, or cowpea resulted in up to tenfold reduction in the infestation of sweet potato weevil (4.8–11.54 weevils per kg of tubers) compared to mono crop of sweet potato (217.5 weevils per kg of tubers) in Kerala, India.
Besides, effective crop rotations also resulted in lower tuber damage (ranged from 7 to 9%) compared to monoculture of sweet potato (52%) (Pillai *et al.*, 1986). Crop rotation method was found to be effective in controlling weevil infestation as the number of weevils captured by sex pheromone traps in areas with monoculture of sweet potato exceeded exponentially compared to pheromone traps in areas planted with sweet potato rotated with potato (Alcarez *et al.*,1996).
Additional steps such as elimination of crop residues will also increase the effectiveness of IPM. For instance, a field sampling in Cuba showed that 0.7 tones of crop residues per hectare could harbour approximately one million weevils. Aside from this, new sweet potato plantings are also recommended to be separated from older fields (approximately 1 km) as the risk of weevil infestation increases with the age of sweet potato fields. This distance length was chosen as the estimated dispersal ability of the weevils from invading a new plantation (Alcarez *et al*., 1984). In Japan, alternative crops were suggested to farmers to be planted between sweet potato plantations, for example, yam (*Dioscorea japonica*), "senryo" (*Chloranthus glaber*), and edible sunflower (Reinhard, 2000).

2.3.2 Biological control

2.3.2.1 Parasitoids

Maeto and Uesato (2007), reported a new species of braconid, *Braconyasudai* from the south-west islands of Japan. It is a solitary idiobiontectoparasitoid of the larvae of the West Indian sweet potato weevil, *Euscepespost fasciatus,* and the sweet potato weevil, *C. formicarius*, both feeding on *Ipomoea batatas* (L.).

Palaniswami and Rajamma (1986), reported the *Bracon idsrhaconotus* and *Bracon* sp. and an unidentified hymenopterous parasitoid on the larvae of sweet potato weevil.

Jansson and Lecrone (1991), reported *Euderus purpureas*, aneulophid parasitizing on *C. formicarius* in Southern Florida. Nevertheless, the success of all these parasitoids at field conditions is doubtful since they are recorded in a very few numbers.

2.3.2.2 Predators

Lagnaoui *et al.* (2000), stated that the use of ants against weevils is another component of the control strategy adopted for the sweet potato weevil in Cuba. Two species of predatory ants, *Pheidole megacephala* and *Tetramorium guineense* (Pheidoleguineensis), are common inhabitants of banana plantations. Rolled banana leaves were used as "temporary nests" to transport the ants from their natural reservoir to sweet potato fields, where they prey upon weevils and other insects. Set up ant colonies in the field 30 days after planting with 60- 110 nests has reduced weevil infestation from three to five percent.

Allard *et al.* (1991), described that the subterranean habitat 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 dense foliage of sweet potato. The eggs are also well protected as they are laid within vines, or in tubers and egg cavity are sealed with a fecal 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.

2.3.2.3 Entomopathogenicnematodes

Entomopathogenic nematodes (EPN) have beneficial interaction with sweetpotato within the roots and are promising for the control of sweet potato weevils (Jansson and Lecrone, 1997). Among different species, Heteror habditis was found to be most effective, infective and pathogenic than Steiner nematids (Mannion and Jansson, 1992). According to Jansson *et al.* (1991), Heteror habditid nematodes were more pathogenic to pupae, than were Steiner nematid nematodes. Weevil adults were the least susceptible to nematode infection. The number of applications of bacteriophora did not significantly reduce numbers of *C. formicarius* but consistently reduced damage to sweet potato tubers. Also bacteriophora, is more infective than Steiner nematids carpocapsae (All strain). Subsequent field tests showed that one application of bacteriophora has found effective at protecting sweet potato tubers from weevil damage. This nematode persisted for over 130 and 250 days after application in two separate experiments, respectively. Nematode application rate had no effect on densities of *C. formicarius* or damage caused suggesting that a single application early in the growing season is adequate. Weevil damage to plants treated with insecticides is intermediate to that on nematode-treated and untreated plants weevils (Jansson and Lecrone, 1997). 2.3.2.4 Entomo pathogenic fungi According to Su (1991a), most effective entomo pathogenic fungi infecting sweet potato weevil has been identified as Beauveria bassiana (Bals.) Vuill, which can be applied as a foliar spray or in combination with pheromone trap, for its successful infection and dispersal. Spraying of *B. bassiana* solution (isolated from *C. formicarius*) at a concentration of 1.6x104 conidia ml-1 at planting and rootstock formation, and broadcasting soybeans containing *B. bassiana* into the rows at planting controlled *C. formicarius* effectively. Su (1991b), indicated that application of *B. bassiana* isolated from honey bees at a concentration of 1x106 conidia ml-1 at planting and rootstock formation also gave the best results. The success of infection of *B. bassiana* on sweet potato weevil is dependent on the type of soil. Yasuda et al. (1992), experimented on thirteen different soils were pernicious to sweet potato weevil out of eighty soils collected from central and southern Taiwan because when they were added to the row at planting, mortality caused to the sweet potato weevil by *B. bassiana* was >80%. Environmental factors also govern the successful infection of sweet potato weevil by entomo pathogenic fungi. Low relative humidity (<43%) and low temperatures below (<15^{o}C) were not conducive for *B. bassiana* infection of adults of sweet potato weevil. Yasuda (1995) developed an auto-infection system consisting of a modified sex pheromone trap and a bottle with exit holes containing conidia of *B. bassiana* (9.3x1010 g-1 medium) successfully tested to control *C. formicarius* in Japan. Male weevils were attracted to the system by the action of pheromone and exited the bottle were found infected with B. bassiana.

According to Yasuda et al. (2004), Formulations of *B. bassiana* conidia in a 10% corn oil mixture showed more superior infectivity in both sexes of *C. formicarius* than the formulation of conidia.

Low cost and effective technology of production of *B. bassiana* at a cottage industry level to control sweet potato weevil was successfully established and adopted by many farmers in Cuba (Lagnaoui *et al.,* 2000).

Use of the fungus is particularly attractive because it relieves farmers from the high cost of chemical pesticides. Incubation of entomo pathogenic fungi in different growth media results in production of several metabolites with insecticidal activity. Squamulosone (aromadendr-1(10)-en-9-one) was isolated in large quantity from the plant *Hyptis verticillata* and incubated with the fungus *Curvularia lunata* in two different growth media (potato dextrose broth and beef extract medium) (Collins *et al*., 2001).

C. lunata is well known for its efficient 11a-hydroxylation of steroids (Holland and Reimland, 1985; Chen and Wey, 1990) and also has been used to transform a number of terpenes (Azerad, 2000). *B. bassiana*, the fungus which is responsible for the muscardine disease in insects, was also known to affect the bioconversion of many substrates including alkaloids, steroids and terpenes. This strain, formerly known as *B. sulfurescens* or *Sporotrichum sulfurescens* has been used to effect the reduction of various carbonyl compounds (Davies *et al*., 1989). *B. bassiana* is also known to selectively hydroxylate non-activated carbon atoms (Lamare *et al*., 1991; Holland, 1992). Incubation of cadina-4, 10 (15)-dien-3-one with *B. bassiana* results in the production of nine novel sesquiterpenes which are effective against *C. formicarius* (Buchanan *et al*., 2000). Labo-Lima (1990) conducted bioassays to evaluate the pathogenicity of the fungal pathogens *M. anisopliae* and *Beauveriabassiana* against *C. puncticollis*. Mortality rates obtained were encouraging for further research on the control of *C. puncticollis* with these fungi.

2.3.3 Chemical Control

Allard *et al.* (1991) stated that sweet potato weevil is a difficult target for conventional pest control measures as the larvae feed in the storage roots in the found, 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, nor of the other stages found within the plant tissue.

In Ethiopia, insecticidal screening trials tested the use of foliar sprays applied three months after planting, followed by four applications at fortnightly intervals, and also root dipping prior to planting. Deltamethrin and pirimiphos methyl gave good control of sweet potato pests (Allard, 1990).

Recommendations for the use of 19 insecticides for the control of sweet potato weevils are provided by Kasasian (1978).

Rajamma and Pillai (1991) studied on several insecticides were tested for the management of sweet potato weevil by using them after planting, either by foliar spray or basal granular applications and found showed that 0.05% fenthion or endosulfan spray at monthly intervals with or without running or soil application of carbofuran or phorate granules each 1 kg a.i. ha-1 45 days after planting days after planting are all effective in reducing infestation by *C. formicarius* resulting in greater marketable tuber yields.

Some of the insecticides are also used for vine dipping for successful control of sweet potato weevil. Fenvalerate, permethrin and deltamethrin each 0.003% are the most effective insecticides to *C. formicarius* (Rajamma, 1990).

Teli and Salunkhe (1994), tried dipping cuttings in insecticide solution before planting and spraying the crop one month after planting, and further three times, at three week intervals, subsequently with cypermethrin or fenvalerate each 375 g a.i. ha-1, was most effective in reducing damage caused by the insect. Similar works on the use of several other insecticides to achieve better control of sweet potato weevil are available (Mason *et al*., 1991; Sinha, 1994).

Misra *et al*. (2001), reported that combination of vine dipping of 0.05% monocrotophos and three foliar sprays with 0.05% endosulfan proved very effective than that of basal application of phorate granules followed by vine dipping of 0.05% monocrotophos. Soil drenching at 50 and 80; 60 and 90; and 50, 65 and 80 days after planting were equally effective in suppressing the incidence and intensity of weevil damage (Palaniswami and Mohandas, 1996). Among the single soil drenching, application on the 65th day was assessed to be the most effective against the weevil.

Palaniswami *et al.* (2002), reported that endosulfan, fenthion and fenitrothion each at 0.05% applied as soil drench at 50 and 80 days after planting were effective against *C. formicarius* and their residues in tubers at harvest were lower than the detectable levels. Chlorpyrifos and fensulfothion granules are more toxic to sweet potato weevil adults than the other insecticides, while their persistence was about 10 months (Hwang and Hung, 1991).

2.3.4 Host Plant resistance

Rajasekhara (2002, 2005), stated that plant resistance provides a pivotal role in the management of insect pests. The physical attributes of the tuber namely, the shape, length, neck length, color of the skin, flesh color and thickness plays in important role in preference by *C. formicarius* apart from the inherent nutritional quality of the sweet potato plant and tuber. Round tubers are preferred by more than elongate and spindle-shaped ones.

Teli and Salunkhe (1996) reported that round and oval tubers of sweet potato were more infested in the field by *C. formicarius* than long stalked, spindle and elongate ones. Pink and red colored tubers are considered less susceptible than white and brown colored ones. Cultivars with thin foliage and lobed leaves with purple coloration at emergence were found less susceptible.

Stathers *et al.* (2003) reported that plant resistance in sweet potato to environmental stress is underway in many parts of the world to fulfil the requirements of farmers situated in arid and semi-arid tropics. Only a limited success has been achieved, because of the inconsistent expression of the resistance (Rajasekhara, 2002). Drought stress may increase the activity of oviposition stimulant present in the genotypes because weevils deposited more eggs on drought-stressed plants (Mao *et al.*, 2004).

Harrison *et al*. (2003), described that some of the plant metabolites are produced and influenced by environment, which would have a bearing on resistance or tolerance. The analyses showed that the levels of resin glycosides and caffeic acid vary between sweet potato genotypes and within genotypes among years or areas of production and have shown insecticidal activities (Jackson and Peterson, 2000). This may indicate a relationship between the quantity of these two compounds and the antibiosis of sweet potato.

According to Singh *et al.* (1993), host plant nutritional parameters are also believed to affect incidence of sweet potato weevil. The relationship between potash and silica in sweet potato stems is negatively correlated with *C. formicarius* infestation. Nitrogen and potassium influence the storage root- surface chemistry of sweet potato genotypes which have a bearing on resistance to sweet potato weevil (Marti *et al*., 1993).

Rajasekhara (2002) reported that selection of sweet potato genotypes with decreased volatile attractants (kairomones) and/or increased deterrents may significantly facilitate developing resistance to sweet potato weevil. Plant resistance can also be induced through alterations in nutritional regimes of the crop. A triterpenol acetate was identified in the root surface on a sweet potato weevil susceptible genotype „Centennial", but not in more resistant genotype (Nottingham *et al*., 1989).

Wilson *et al.* (1988), demonstrated that a methylene chloride surface extract of the periderm of tubers of the susceptible Centennial stimulated oviposition of *C. formicarius* elegantulus. Nottingham *et al*., (1987) also showed that ovipositional stimulant resided in the tuber periderm, not in the core of the tuber.

Allard *et al.* (1991), researched on breeding and evaluating sweet potato germplasm for resistance. The development of insect- resistance is seen as a viable component of integrated pest management programmes. Mechanisms of resistance to sweet potato weevil in sweet potato include antibiosis, antixenosis (non – preference) and escape (for example, long and thin storage roots set deep in the soil and scattered within growing hills). Resistance characters identified as under polygenic inheritance include fleshy root density, dry matter and starch content, root depth, vine thickness and tuber chemistry.

Anota and Odebiyi (1984) found no evidence that nitrogen, starch, dry matter, or moisture content played a role in tuber resistance of five resistant sweet potato cultivars tested in Nigeria, but carotene content was identified as a major factor. No oviposition preference for tubers or vines was apparent. There was a lower survival rate in all life stages, smaller body weights and a longer developmental period of *C. puncticollis* raised on resistant cultivars. Two orange fleshed and 18 white fleshed cultivars evaluated in the field for resistance to *C. puncticollis*. Cultivars (TIS 3053 and TIS 3030) exhibited the least root damage, whereas Cultivars (TIS 2532, TIS 3017 and TIS 3030) showed the least shoot damage (all white – fleshed) (Hahn and Leuschner, 1981). Cheng (1981) identified 14 sweet potato lines resistance to *C. puncticollis*, but their yields were lower than those of the majority of susceptible lines (Cheng, 1981). Screening of 700 cultivars of sweet potato in Nigeria revealed low resistance levels to *C. puncticollis* (Hahn and Leuschner, 1981).

Shakoor *et al.* (1984), identified seven resistant sweet potato lines, including KSP 20, KSP1K, SP 19 and KSP 20 following screening of 93 accessions of diverse origin. In trials conducted in the Philippines by Petro et al. (1986), local cultivars Karingkit and Kadulaw gave the highest yields, whereas the improved cultivars tested exhibited undesirable agronomic characteristic and susceptibility to *C. puncticollis.*

2.3.5 Pheromonal control

According to Downham *et al*. (2001), the behaviour in both the laboratory and the field indicate that there is probably a sex pheromone for *C. puncticollis*, as is the case for *C. formicarius*. In rearing rooms, gregarious clumping behavior has been noted, as well as the obvious attraction of males towards the females. In the field, males are predominantly found under the foliage, presumably seeking females. Simple laboratory tests have shown that males are attracted to females. The feasibility of using virgin, unmated females as baits for males in simple traps was investigated in Kenya (Allard, 1990).

Heath *et al.* (1986), stated that precise decision tool to assess the time of sweet potato weevil incidence on sweet potato, suggest the use of sex pheromones (boehmeryl acetate). Soon after the identification of female sex pheromone of *C. formicarius,* the course of weevil management in different parts of sweet potato growing countries around the world changed dramatically. The success of sweet potato weevil control in these countries is unequivocally assigned to the sex pheromone. The sex pheromone, alone contributed to significant reductions in weevil populations and tuber damage, which resulted in greater marketable storage root yield.

According to Yasuda *et al.* (1992), the sex pheromone (Z)-3-dodecen-1-ol (E)-2-butenoate, proved to be a successful mating disruptant for the control of *C. formicarius* (Mason and Jansson, 1991; Yasuda, 1995; Yasuda et al., 1992). It is also used to trap both sexes of sweet potato weevil. With 100 mg of sex pheromone, the attraction was 60.88%. Entrapment of weevils differs significantly during different parts of the day.

Yasuda *et al.* (1992) reported that pheromone traps installed close to the ground trapped more males than those set above the ground. Most of the males approached the traps by walking. Different types of traps used for monitoring and mass trapping. When the sex pheromone discovered and synthesized, various designs and types of traps used for the weevil management viz. Light, sticky, water, plastic funnel live trap etc. Talekar and Lee

(1989) reported that female sex pheromone identified in *C. formicarius elegantulus* was also active in *C. formicarius*. According to Li (1998), sweet potato weevil sex pheromone traps each 30 hectares with a distance of 15 m between traps reduced the tuber damage by 10.1% and controlled the sweet potato weevil up to 53.1-58.2% in China.

Pillai *et al.* (1996), reported that trap containing synthetic sex pheromone (100 traps per hectare) is highly effective for mass trapping the male sweet potato weevil which significantly reduced population build-up, consequently resulted in greater marketable tuber yield. Pheromone traps each 40 per hectare reduced sweet potato tuber damage by 65% by sweet potato weevil and use of chlorpyrifos each two kilogram's active ingredient per hectare in addition to the pheromone reduced the damage by an extra 10% over the pheromone treatment (Hwang and Hung, 1991).

Yasuda *et al.* (2004), described that integration of sex pheromone traps with insecticides or entomo pathogenic fungi are practiced successfully. Development of a new pheromone formulation to increase exposure time to insecticide for control of the sweet potato weevil. The attracted males located and tried to mate with the ball. They were thereby efficiently exposed to the insecticide for a longer time. The concentration of the new formulation was extremely low compared to the conventional formulations, and therefore, lowers the cost of application. The formulation was a combination of sex pheromone, butenoate, and an insecticide impregnated into blue ball made of the diatomaceous soil. The male weevils were attracted to the visual stimulation in addition to the sex pheromone (Smit *et al*., 2001).

2.4 The Future of Sweet Potato Crop

Advancements in molecular biology tools including Next Generation Sequencing have provided multiple advantages in the understanding and study of economically important crops. Currently, the International Potato Center (CIP), the main research organization working on root crops, is collaborating with the University of Ghent to determine the sequence the whole genome of *Ipomoea batatas* cv. Huachano using Solid complete genome shotgun sequencing. The lack of whole genome sequencing data of sweet potato has hindered DNA fingerprinting, development of molecular markers, and genetic analyses of this crop. DNA fingerprinting is important in many crop species for the identification of crops to protect the rights of plant breeders. Monden *et al*. (2014) had conducted DNA fingerprinting based on the two active retrotransposon families (Line-type LIb and LTR-type Rtsp-1) in sweet potato, which exhibited high insertion polymorphisms, by using the MiSeq sequencing platform. The polymorphism of these insertion sites was very high (91.4%) and the insertion sites, which are cultivar-specific, were successfully converted into amplified region markers. The markers helped in the precise identification of sweet potato cultivars.

Tao et al. conducted a transcriptomic study on sweet potato to further understand the molecular mechanism and gene expression in different tissues at different developmental stages as well as the biotic and abiotic stress responses in sweet potato. From this study, a large number of genes were found responding to drought, salt, heat, and osmotic stress such as those encoding metallothionein (MT), aquaporin (AQP), and abscisic acid responsive elements binding factor (AREB). Understanding the expression patterns of these genes could possibly lead to a stronger crop in the near future. Prior to this, two other sweet potato transcriptomes were sequenced by the International Potato Center and the Guangdong Academy of Agricultural Sciences of China using the Roche-454 pyrosequencing technology (Schafleitnerand Tincopa, 2010) and the Illumina/Solexa RNA-Seq technology (Wang *et al*., 2010) respectively. These studies have led to new paths in collating differentially expressed genes in the different tissues at the different development stages. This will also allow better understanding of the different genes involved in the pathways and provides information for further modification in gene expression to improve the quality of the crops.

Aside from this, development of orange-fleshed sweet potato with high level of beta-carotene is seen as a strategy to improve the nutritional status of millions of children in developing or underdeveloped countries. However, conventional breeding of orange-fleshed sweet potatoes are difficult due to their genetic complexity, thus marker-assisted breeding tools must be developed to assist in their breeding. A study was conducted to determine the quantitative trait loci (QTL) for starch, beta-carotene, and dry matter content in sweet potato (Cervantes-Flores, *et al.,* 2010). The identification of QTL was based on the hexaploid sweet potato mapping population that resulted from a cross between Beauregard and Tanzania sweet potato cultivars in USA. QTL analysis in two parental maps revealed 12 QTL for starch content, 8 QTL for beta-carotene, and 13 QTL for dry matter content in storage root. The results improve our understanding of these important traits in sweet potato, which are important for the development of marker-assisted breeding tools to increase sweet potato breeding efficiency (Cervantes *et al*., 2008).The development of transgenic sweet potato with foreign genes that confer additional properties such as insect resistance is important to reduce economic losses due to pest infestation. The progress of breeding sweet potato with weevil resistance is slow due to scarcity of sweet potato varieties that display significant resistance levels, hindering progress in this area (Stevenson *et al*., 2009). Most of the early works focused on the transformation of sweet potato with proteins that decrease sweet potato digestibility for insects. Newell et al. transformed sweet potato with mannose binding snowdrop lectin and cowpea trypsin inhibitor. Both transgenic sweet potatoes showed a moderate increase in resistance of sweet potato weevil. In a separate work, Cipriani *et al*. transformed soybean Kunitz type trypsin inhibitor and rice cysteine proteinase inhibitor into sweet potato. However, the transformation works, which focused on proteinase inhibitors, were abandoned due to concerns regarding nutritional impact of the proteins on human diet and after observing a small increase in weevil resistance against the proteinase inhibitors (Mwanga *et al*., 2011).

A number of studies have supported the high efficiency usage of *Bacillus thuringiensis* in controlling different pests including sweet potato weevils. Garcia et al. transformed the stems and leaves of sweet potato with agrobacterium tumefaciens carrying nptII and *Bacillus thuringiensis* (Bt) endotoxin gene. The plants were then tested for resistance against sweet potato weevil under controlled conditions. Their results showed that the transgenic sweet potato carrying Bt gene had higher resistance compared to control plants (weevil damage on the normal sweet potato was five times higher compared to transgenic). The transformation of crops with *Bacillus thuringiensis* cry proteins showed promising results in pest control through the expression of insecticidal compounds. Moran et al. conducted a study to transform Cry3A gene into sweet potato roots to fend against sweet potato weevil, *Cylas formicarius*. The transformed sweet potatoes were able to express Cry3A protein but this research was discontinued, as the control of *Cylas formicarius* with Cry3A was not promising. Ekobu *et al*. conducted an experiment to evaluate the toxicity of Cry proteins to *Cylas puncticollis* and *Cylas brunneus*. They showed that three Cry proteins: ET33/34, Cry7Aa1, and Cry3Ca1 had LC_{50} below

1 μg/gram diet, thereby proved that these transformed sweet potatoes can be used against weevil infestation.

Other biotechnological approaches have also shown promising results on pest control, including introduction of small RNA viruses that interfere with weevil life cycle (Hilder and Boulter, 1999), spider venom toxins (Trung *et al.*, 2006) and RNA-mediated interference (Ibrahime *et al*., 2011). RNA-mediated interference promotes posttranscriptional gene silencing and has been used in insect management and virus disease resistance development in sweet potato. For example, Kreuze *et al.*conducted an experiment to develop sweet potato with RNA silencing-mediated resistance to sweet potato chlorotic stunt virus. They found that 50% of the tested transgenic events showed mild or no symptoms of infection of the virus and the accumulation of the virus in the transgenic sweet potato was significantly reduced. In all, the understanding of the biology of sweet potato weevil infestation is essential so that specific preventive method can be designed. Numerous strategies and techniques have been used in the different regions; however, until recently, they only serve to suppress the potential damages by the weevils without addressing the underlying problem. The momentum in biotechnology research field has given the sweet potato industry a promising future. Despite the absence of transgenic weevil resistance sweet potato in the market, hopefully, the various research teams currently working on this can release the long-awaited transgenic sweet potato to consumers soon.

2.5 Constraints to Sweet Potato Weevil Management

Stathers*et al*. (2005) indicated that pesticides kill natural enemies that under natural circumstances quite effectively control weevil populations, and can also present health, risks for human and animals. In some countries planting materials are dipped into on synthetic pesticide before planting, which can delay pest infestation for several months, however, most pesticides are expensive and highly toxic therefore dipping is only likely to be economical for large scale commercial root production or vine multiplication nurseries. Other varieties escape weevil damage because their storage roots mature quickly and can be harvested early. Breeders have spent many years trying to develop varieties that are resistant to the weevil. So far they have not been successful (Stevenson *et al*., 2009). However, varieties that form root relatively deep in the soil are less attacked because the weevils cannot easily reach the roots to lay eggs (Kays *et al.*, 1993). Chemical control is not effective because the weevils are protected for, at least part of their life cycle by their development within roots or stems, where they are not easily reached by pesticides (Mason *et al.*, 1991).

Kabi *et al*. (2001) recorded that the larvae feed on storage root in the ground or inside the woody base of the stems. This means with the possible exception of systemic insecticides, which are costly and pose risk of residual contamination of the roots there is no effective chemical control of all stages of the pest found within the plant tissues. This subterranean habitat also makes the insect less accessible to predator and parasitoids but increases the impact of pathogens and nematodes, natural enemies which requires a protected, cool and humid environment for survival and reproduction (Stathers *et al.*, 2005).

CHAPTER III

MATERIALS AND METHODS

The present study regarding integrated management package of sweet potato weevil infesting sweet potato was conducted during rabi season (November 2017 to March 2018) in the experimental field at Department of Entomology, Sher-e-Bangla Agricultural University, Dhaka. Required materials and methodology are described below under the following sub-headings.

3.1. Location

The experiment was conducted in the experimental farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. The location of the experimental site was 23074/ N latitude and 90035/ E longitude and an elevation of 8.2 m from sea level (Anon., 1989).

3.2. Climate

The climate of the study site was under the subtropical climate, characterized by three distinct seasons, the Rabi from November to February and the Kharif- I, pre-monsoon period or hot season from March to April and the Kharif- II monsoon period from May to October (Edris *et al*., 1979). The monthly average temperature, relative humidity and rainfall during the crop growing period were collected from weather yard, Bangladesh Meteorological Department and presented in Appendix I. During the experimental period the maximum temperature (27.1^{0}C) and highest rainfall (30 mm) was recorded in the month of February 2018, whereas the minimum temperature (12.4^{0}C) and no rainfall was recorded in the month of January 2018.

3.3. Soil

Soil of the study site was silty clay loam in texture belonging to series. The area represents the Agro Ecological Zone of Madhupur tract (AEZ-28) with pH 5.8- 6.5, CEC-25.28 (Haider *et al*., 1991). The selected plot was medium high land and the soil series was Tejgaon (FAO, 1988).

3.4. Land Preparation

The land was ploughed or dug to a depth of about 20 cm and harrowed to pulverize the soil. Mound method, ridge and furrow method, bed method and flat method are practiced in sweet potato cultivation in different localities. It is preferable to plant sweet potato on mounds in areas experiencing problems of drainage. In sloppy lands, ridge and furrow system is recommended for the control of soil erosion. The higher yield recorded when planted on mounds is probably be due to better soil aeration permitted by mounds and less tendency for soil compaction. In Bangladesh, higher yields were reported with trench planting followed by ridge and flat method of planting in alluvial soils under irrigated conditions (Bhuiyan *et al*., 2006). The experimental plot was opened in the first week of November 2017 with a power tiller, and was exposed to the sun for a week, after which the land was ploughed three times followed by laddering to obtain desirable tilth. The corners of the land were spaded and later clods were broken into smaller pieces. After ploughing and laddering, all the stabbles and uprooted weeds were removed and then the land was ready. The field layout and design of the experiments were followed immediately after land preparation.

Plate 1.Cleaning the experimental field

Plate 2. Preparation of land

Plate 3. Bed preparation

3.5. Manure and Fertilizer

The fertilizers N, P, K in the form of Urea, Triple Super Phosphate (TSP), Muriate of Potash (MP) respectively and as an organic manure, Cowdung were applied. The entire amount of organic manure, TSP, MP and half amount of Urea were applied as basal dose during the final land preparation. Rest amount of Urea was applied 60 days after planting of vine in the side of row. The dose and method of application of fertilizers are shown in Table (BARI). Fertilizer name Amount/ha Cowdung (ton) 8-10 Urea(kg) 160-250 TSP(kg) 150-170 MP(kg) 150-250.

Plate 4. Applying manure and fertilizer

3.6. Vine Collection

Vines of sweet potato used in this experiment were collect from Tuber Crop Research Centre (TCRC), Bangladesh Agricultural Research Institute (BARI), Joydebpur. The variety name was BARI Mistialu-8.

Plate 5. Vine for planting

3.7. Design of Experiment

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The experimental field was divided into three blocks maintaining 1m block to block distance and each block was subdivided into 7 plots for 7 treatments maintaining 3 m x 2 m plot size. Thus the total number of plots was 21. The plot to plot distance was 0.5 m was kept to facilitate different intercultural operations.

3.8. Planting

The sweet potato vines were planted in the experimental field on 21st November, 2017.

Plate 6. Planting vine on the field

3.9. Treatments of the Experiment

Therewere six treatment combinations and one untreated control tested under the present study. These are as follows :

T_1: Sex pheromone trap + Earthing up one time + Mulching (straw) + One irrigation

T_2: Sex pheromone trap + Earthing up two times + Two light irrigation

T_3: Sex pheromone trap + Earthing up three times + Three light irrigation

T_4: Earthing up two times + Sevin 85WP @ 3g\L of water at 15 days interval (2 times application, 40 and 55 days after vine planting)

T_5: Earthing up two time + Diazinon 10G @ 15 kg\ha (1 time soil application, 40 days after vine planting)

T_6: Earthing up two time + Fenthion 2ml\L of water (40 days after vine planting)

T_7: Untreated control

At least one time earthing-up was commonly done for each treatment

3.10. Intercultural Operations

Various intercultural operations such as gap filling, weeding, earthing up, irrigation etc. were accomplished for better growth and development of the sweet potato.

3.10.1. Irrigation

The experimental field was irrigated with light water in every alternate day starting from just after planting of vines and continued up to 20 days. Following irrigation were done at 30 days , 60 days and 90 days after vine planting in the field.

Plate 7. Irrigation

3.10.2. Gap filling

The planted vines in the experimental plot were kept under careful observation. Very few seedlings were damaged after planting and that vines were replaced by new vines from the stock.

3.10.3. Weeding, earthing up and mulching

To protect the crop from weeds, at least two weedings followed by earthing up have to be given between 15 and 30 and 35 and 60 days after planting (Nedunchezhiyan and Ray, 2010).

Plate 8. Earthing up and weeding

Plate 9. Mulching

3.11. Harvesting

Harvesting of sweet potato was done in three steps from 5 selected vines in the plot. First harvest was done at 15 days early optimum harvest time, seconnd harvest was done at optimum time i.e. 130 days after vine planting and third harvest was done after 15 days from optimum harvest to assess sweet potato weevil infestation and there effect on yield.

Finally per hectare yield was calculated by converting yield of harvested sweet potato /per vine.

Plate 10. Harvesting of sweet potato

Plate 11. Healthy Sweet potato

Plate 12. Infested sweet potato

3.12. Data Collection

The data on the following parameters were recorded at different time intervals as given below:

- Number of Sweet potato weeevil in sweet potato field :

Sweet potato weevil was monitored and then listed down per plot.

- Plant damage percentage :

Vines of per plot monitored and the number of damaged plant portion was counted.

- Number and weight of healthy and infested tuber:

Harvesting was done in tree time. In every time number and weight of tuber per vine per plot was noted.

- Deformed tuber percentage :

Deformed tuber weight was measured.

- Yield of tuber (t/ha) :

Total tuber weight was measured and then it was converted for hectare.

- Vine length (cm):

After harvesting vine length was measured.

3.13. Calculation

3.13.1 Determination of storage tubers infestation in number. Harvested was done in three different time. All the storage tubers were counted from 5 randomly selected plants from rows of each plot and examined. The healthy and damaged storage tubers were counted and the percent storage root infestation was calculated using the following formula:

% tuberinfestation $=\frac{\text{Number of infested storage tubers}}{Totalnumberofstoragetubers} \times 100$

3.13.2 Determination of storage tubers infestation in weight

All the storage tubers were counted from 5 randomly selected plants from middle rows of each plot and examined. The healthy and damaged storage roots were weighted and the percent storage tuber infestation was calculated using the following formula:

% infestation $= \frac{\text{Weight of infested storage tubers}}{TotalWeightofstoragetubers} \times 100$

Plate 13. Determine the infested tuber weight

3.14.9. Sweet potato weevil *Cylas* spp.

Description and biology: Three species of the genus *Cylas* are pests of sweet potato; they are commonly called sweet potato weevils. All three species- *Cylas formicarius*, *C. puncticollis*, and *C. brunneus*-are found in Africa. *C. formicarius* is present in Asia and in parts of the Caribbean. The elongated ant-like adults of the three species can be distinguished from each other. *Cylas puncticollis* is the easiest to distinguish because the adult is all black and larger than the other two. *C. formicarius* has a bluish black abdomen and a reddish brown thorax. *C. brunneus* adults are small and not uniform in coloring. The most common type can easily be confused with *C. formicarius*. In all species, the eggs are shiny and round. The legless larvae are white and curved, and the pupae are white.

Plate 14. Photograph showing sweet potato weevil larvae

Damage:

Damage symptoms are similar for all three species. Adult sweet potato weevils feed on the epidermis of vines and leaves. Adults also feed on the external surfaces of storage roots, causing round feeding punctures, which can be distinguished from oviposition sites by their greater depth. The developing larvae of the weevil tunnel in the vines and storage roots, causing significant damage. Frass is deposited in the tunnels. In response to damage, storage roots produce toxic terpenes, which render storage roots inedible even at low concentrations and low levels of physical damage. Feeding inside the vines causes malformation, thickening, and cracking of the affected vine.

Sweet potato weevils generally cause serious damage to all parts of sweet potato plant throughout their life cycle, from egg to adult. When laying eggs, female weevils excavate cavities and create egg-laying punctures in the roots. The eggs are laid below the surface of the roots and covered with dark colour excrement from the female adults (J. L. Capinera, 2001). As a result of the unsightly punctures, the appeal of the roots and market price of sweet potato become greatly reduced, resulting in major economic losses.

Plate 15.Infested sweet potato with weevil

Plate 16. Inner portion of Infested sweet potato

CHAPTER IV

RESULTS AND DISCUSSION

The study was conducted for developing integrated management package to control sweet potato weevil. Data was recorded on relative abundance of sweet potato weevil, effect of different management practices, healthy and infested storage roots of sweet potato and their infestation level and also yield contributing characters and yield of sweet potato. The analysis of variance (ANOVA) of the data on different parameters has been presented in Appendix II-IX. The results have been discussed and presented under the following headings and sub-headings:

4.1 Abundance of sweet potato weevil in sweet potato field

To count the relative abundance of sweet potato weevil the data was collected several times. For each treatment five times data was collected. In per collection two hour data is noted, where 5 vines per was monitored.

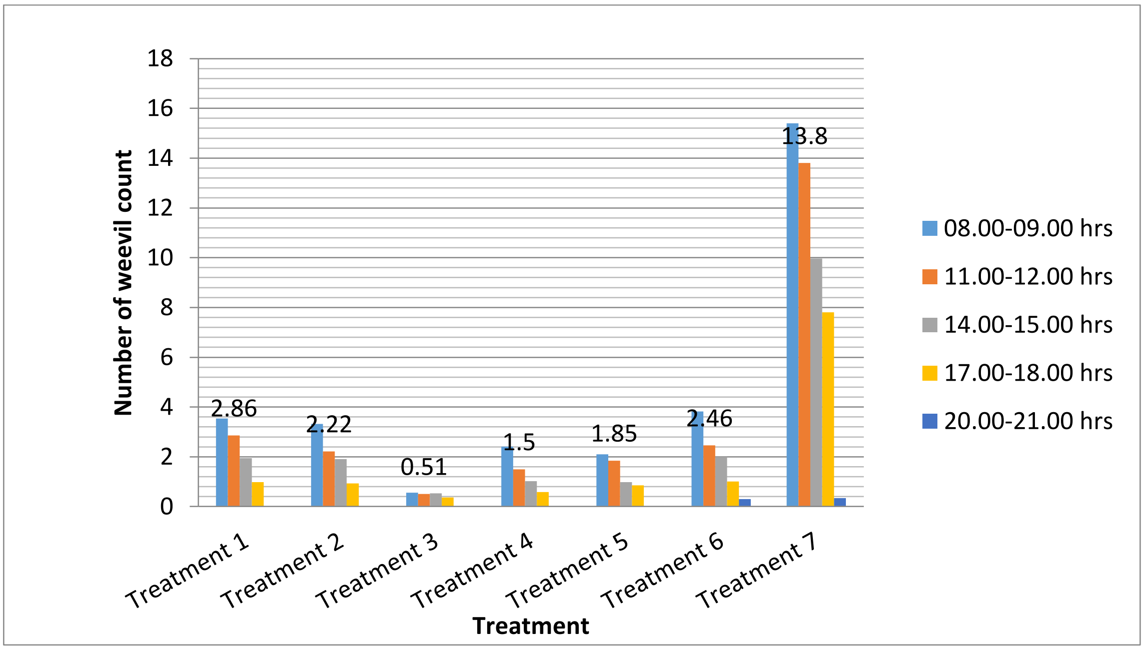

Figure 1. Abundance of sweet potato weevil in sweet potato Field

This figure revealed that lowest number of sweet potato weevil was count in T_3 (Sex pheromone trap + Earthing up 3times + Three light irrigation) which was followed by T_4 (Earthing up 2 times + Sevin 85WP @ 3g/L of water at 15 days interval 2 times), T_5 (

Earthing up 2 times + Diazinon 10G @ 15 kg / ha soil application one time), T_2 (Sex pheromone trap + Earthing up 2 times + 2 light irrigation) , T_1 (Sex pheromone trap + Earthing up one time + Mulching by straw + One irrigation) and highest number of weevil was found in T_7 (Untreated control). The mean of weevil count showed good result in T_3 (0.392), followed by T_4 (1.102), T_5 (1.156), T_2 (1.676). Lowest result found in T_7 (9.46), followed by T_6 (1.918), T_1 (1.866). Here the good control result was found in T_3 and lowest in T_7.

4.2 Plant damage percentage in different treatments:

For calculation of plant damage percentage in different treatment, data was collected several time for each treatment. Five vines of a plot was monitored.

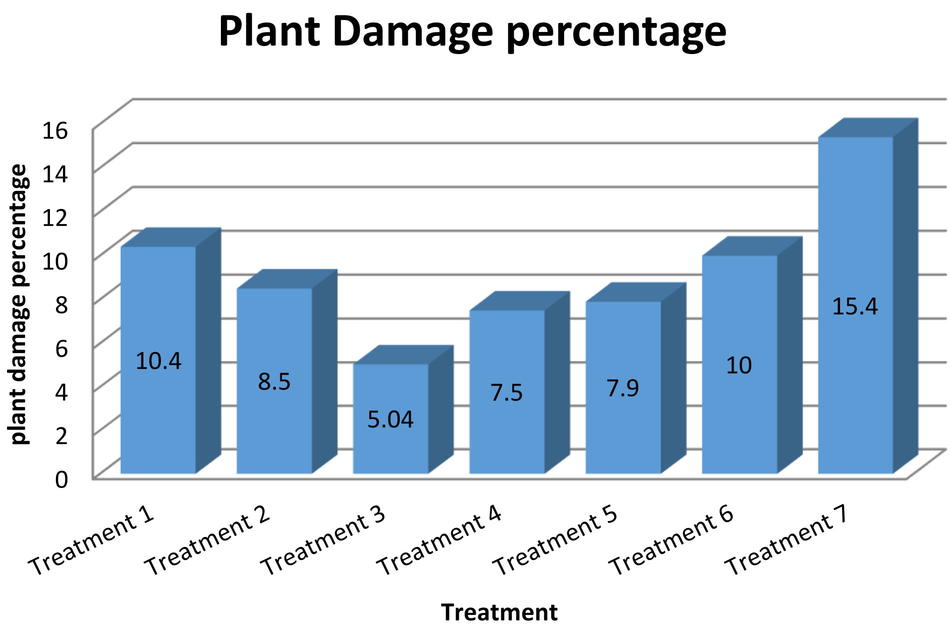

Figure 2. Plant damage percentage in different treatment

This figure showed the different management practices effect and relative damage observation, where lowest damaged was found in T_3 (5.04%), followed by T_4 (7.50%), T_5 (7.90%), T_2 (8.50). Highest damage result was observed in T_7 (15.4%), followed by T_1, T_6. From this figure highest control result seemed in T_3 and lowest control in T_7.

4.3 Tuber infestation by sweet potato weevil in different stages

4.3.1 At 15 days early harvest

Healthy, infested tuber of sweet potato in number and weight basis per vine and also percent (%) of infestation caused by sweet potato weevil at 15 days early harvest varied significantly for different treatment (Table 1 & 2).

Table 1. Sweet potato weevil incidence on tuber of sweet potato at 15 days early harvest in weight basis for different management practices

Treatments	Healthy tuber/ vine (g)	Infested tuber/ vine (g)	Infestation (%)	Infestation reduction over control (%)
T_1	683.91 a	65.51 b	8.75 b	32.59
T_2	696.47 a	56.35 c	7.48 c	42.37
T_3	713.72 a	42.96 d	5.68 e	56.24
T_4	707.12 a	48.65 d	6.45 d	50.31
T_5	701.12 a	54.68 c	7.24 c	44.22
T_6	678.24 a	69.47 b	9.29 b	28.43
T_7	608.98 b	90.84 a	12.98 a	--
$LSD_{(0.05)}$	61.74	5.936	0.748	--
CV(%)	5.08	5.46	5.09	

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 5 selected vine/plot of each treatment In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

T_1: Sex pheromone trap + Earthing up one time + Mulching (straw) + One irrigation

T_2: Sex pheromone trap + Earthing up two times + Two light irrigation

T_3: Sex pheromone trap + Earthing up three times + Three light irrigation

T_4: Earthing up two times + Sevin 85wp @ 3g\L of water at 15 days interval (2 times application)

T_5: Earthing up two time + Diazinon 10G @ 15 kg\ha (1 time soil application)

T_6: Earthing up two time + Fenthion 2ml\L of water

T_7: Untreated control

4.3.1.1 Tubers of sweet potato in weight basis

In case of tuber of sweet potato/vine in weight basis at 15 days early harvest, it was observed that the highest weight of healthy storage roots/vine was recorded from T_3 (713.72 g) treatment which was statistically similar with other treatment except T_7, while the lowest weight (608.98 g) was observed from T_7 treatment (Table 1). In case of infested tubers, the lowest weight (42.96 g) was observed from T_3 treatment which was statistically similar to T_4 (48.65 g) and closely followed by T_5 (54.68 g) and T_2 (56.35 g) treatment and they were statistically similar, while the highest weight was found from T_7 (90.84 g) treatment which was followed by T_6 (69.47 g) and T_1 (65.51 g) treatment and they were statistically similar. In consideration of infestation level of storage roots in weight basis, the lowest infestation was recorded from T_3 (5.68%) treatment which was closely followed by T_4 (6.45%) treatment, whereas the highest infestation (12.98%) was observed from T_7 treatment which was closely followed by T_6 (9.29%) and T_1 (8.75%) treatment and they were statistically similar. In case of reduction over control the highest value was recorded from T_3 (56.24) and the lowest value was found from T_6 (28.43) treatment.

Table 2. Incidence of sweet potato weevil on tubers of sweet potato at 15 days early harvest in number basis for different management practices

Treatments	Healthy tuber (No.) /vine	Infested tuber (No.) /vine	Infestation %	Infestation reduction over control (%)
T_1	6.32 ab	0.52 bc	7.81 bc	36.15
T_2	6.34 ab	0.41 cde	5.96 cde	51.44
T_3	6.88 a	0.28 e	3.68 e	69.87
T_4	6.66 a	0.33 de	4.75 de	61.32
T_5	6.52 a	0.48 bcd	6.62 bcd	45.89
T_6	6.34 ab	0.60 b	8.65 b	29.21
T_7	5.75 b	0.80 a	12.24 a	--
$LSD_{(0.05)}$	0.571	0.158	2.163	--
CV(%)	5.06	18.34	17.12	--

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 5 selected vine/plot of each treatment In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

T_1: Sex pheromone trap + Earthing up one time + mulching (straw) + one irrigation

T_2: Sex pheromone trap + Earthing up two times + two light irrigation

T_3: Sex pheromone trap + Earthing up three times + three light irrigation

T_4: Earthing up two times + Sevin 85wp @ 3gm\L at 15 days interval (2 times application)

T_5: Earthing up two time + Diazinon 10G @ 15 kg\ha (1 time soil application)

T_6: Earthing up two time + Fenthion \ Fenitrothrin 2ml\L

T_7: Untreated control

4.3.1.2 Tubers of sweet potato in number basis

In case of tubers of sweet potato/vine in number basis at 15 days early harvest, it was observed that the highest number of healthy tubers/vine was recorded from T_3 (6.88) treatment which was statistically similar with other treatment except T_7, while the lowest number (5.75) was observed from T_7 treatment (Table 2). In case of infested storage roots, the lowest number (0.28) was observed from T_3 treatment which was statistically similar to T_4 (0.33) and T_2 (0.41) closely followed by T_5 (0.48) treatment, while the highest number was found from T_7 (0.80) treatment which was followed by T_6 (0.60) and T_1 (0.52) treatment and they were statistically similar. In consideration of infestation level of storage roots in number basis, the lowest infestation was recorded from T_3 (3.68%) treatment which was statistically similar to T_4 (4.74%) and T_2 (5.96) and closely followed by T_5 (6.62%) treatment, whereas the highest infestation (12.24%) was observed from T_7 treatment which was closely followed by T_6 (8.65%) and T_1 (7.81%) treatment and they were statistically similar. In case of reduction over control the highest value was recorded from T_3 (69.87) and the lowest value was found from T_6 (29.21) treatment. Ebregt *et al.*, (2005) stated that harvesting two weeks earlier reduce the loss due to weevil from greater than 30 percent to less than five percent.

4.3.2 At optimum days harvest

Statistically significant variation was recorded due to different treatments for healthy, infested storage roots of sweet potato in number and weight basis per vine and also percent (%) of infestation caused by sweet potato weevil at optimum days harvest (Table 3 & 4).

Table 3. Sweet potato weevil incidence on tubers of sweet potato at optimum days harvest weight basis for different management practices

Treatments	Healthy tuber (g)	Infested tuber (g)	Infestation %	Infestation reduction over control (%)
T_1	692.77 a	76.25 b	9.92 b	30.02
T_2	717.09 a	63.76 c	8.17 c	42.38
T_3	734.07 a	50.92 d	6.48 e	54.18
T_4	726.25 a	55.64 cd	7.11 de	49.85
T_5	723.42 a	62.08 c	7.90 cd	44.08
T_6	692.79 a	76.27 b	9.92 b	30.03
T_7	627.42 b	103.45a	14.15 a	--
$LSD_{(0.05)}$	61.68	7.932	0.927	--
CV(%)	4.92	6.42	5.79	--

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 5 selected vine/plot of each treatment In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

T_1: Sex pheromone trap + Earthing up one time + Mulching (straw) + One irrigation

T_2: Sex pheromone trap + Earthing up two times + Two light irrigation

T_3: Sex pheromone trap + Earthing up three times + Three light irrigation

T_4: Earthing up two times + Sevin 85WP @ 3g\L at 15 days interval (2 times application)

T_5: Earthing up two time + Diazinon 10G @ 15 kg\ha (1 time soil application)

T_6: Earthing up two time + Fenthion 2ml\L

T_7: Untreated control

4.3.2.2 Tubers of sweet potato in weight basis

In case of storage roots of sweet potato/vine in weight basis at optimum days harvest, it was observed that the highest weight of healthy storage roots/vine was recorded from T_3 (734.07 g) treatment which was statistically similar with other treatment except T_7, while the lowest weight (627.42 g) was observed from T_7 treatment (Table 3). In case of infested storage roots, the lowest weight (50.92 g) was observed from T_3 treatment which was statistically similar to T_4 (55.64 g) and closely followed by T_2 (63.76 g) and T_3 (50.92 g) treatment and they were statistically similar, while the highest weight was found from T_7 (103.45 g) treatment which was followed by T_6 (76.27 g) and T_1 (76.21 g) treatment and they were statistically similar. In consideration of infestation level of storage roots in weight basis, the lowest infestation was recorded from T_3 (6.48%) treatment which was statistically similar to T_4 (7.11%) treatment, whereas the highest infestation (14.15%) was observed from T_7 treatment which was closely followed by T_6 (9.92%) and T_1 (9.92%) treatment and they were statistically similar. In case of reduction over control the highest value was recorded from T_3 (54.18) and the lowest value was found from T_1 (30.03) treatment.

Table 4. Sweet potato weevil incidence on tubers of sweet potato at optimum days harvest in number basis for different management practices

Treatments	Healthy tuber (No.)/vine	Infested tuber (No.)/vine	Infestation %	Infestation reduction over control (%)
T_1	6.61 a	0.68 b	9.22 bc	32.09
T_2	6.60 a	0.52 bc	7.48 bcd	44.75
T_3	7.00 a	0.34 c	4.49e	66.88
T_4	6.80 a	0.40 c	5.54 de	59.00
T_5	6.66 a	0.52 bc	7.36 cd	45.81
T_6	6.60 a	0.72 b	9.978b	26.48
T_7	5.92 b	0.934a	13.55 a	--
$LSD_{(0.05)}$	0.556	0.196	2.412	--
CV(%)	4.73	18.60	16.46	--

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 5 selected vine/plot of each treatment In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

T_1: Sex pheromone trap + Earthing up one time + Mulching (straw) + One irrigation

T_2: Sex pheromone trap + Earthing up two times + Two light irrigation

T_3: Sex pheromone trap + Earthing up three times + Three light irrigation

T_4: Earthing up two times + Sevin 85WP @ 3g\L at 15 days interval (2 times application)

T_5: Earthing up two time + Diazinon 10G @ 15 kg\ha (1 time soil application)

T_6: Earthing up two time + Fenthion 2ml\L

T_7: Untreated control

4.3.2.2 Tubers of sweet potato in number basis

In case of tubers of sweet potato/vine in number basis at optimum days harvest, it was observed that the highest number of healthy storage roots/vine was recorded from T_3 (7.00) treatment which was statistically similar with other treatment except T_7, while the lowest number (5.92) was observed from T_7 treatment (Table 4). In case of infested storage roots, the lowest number (0.34) was observed from T_3 treatment which was statistically similar to T_4 (0.40), T_2 (0.52) and T_5 (0.52) treatment, while the highest number was found from T_7 (0.934) treatment which was followed by T_6 (0.72) and T_1 (0.68) treatment and they were statistically similar. In consideration of infestation level of storage roots in number basis, the lowest infestation was recorded from T_3 (4.49%) treatment which was statistically similar to T_4 (5.56%) and closely followed by T_5 (7.36%) treatment, whereas the highest infestation (13.55%) was observed from T_7 treatment which was closely followed by T_6 (9.978%) and T_1 (9.22%) treatment and they were statistically similar. In case of reduction over control the highest value was recorded from T_3 (66.88) and the lowest value was found from T_6 (26.48) treatment.

4.3.3 After 15 days from optimum harvests

Statistically significant variation was recorded due to different treatments for healthy, infested storage roots of sweet potato in number and weight basis per vine and also % of infestation caused by sweet potato weevil after 15 days from optimum harvests (Table 5 & 6).

Table 5. Sweet potato weevil incidence on tubers of sweet potato after 15 days from optimum harvest in weight basis for different management practices

Treatments	Healthy tuber (g)/vine	Infested tuber (g)/vine	Infestation %	Infestation reduction over control (%)
T_1	713.51 a	76.95 c	9.75 c	42.86
T_2	726.04 a	70.11 cd	8.81 d	48.38
T_3	743.78 a	55.31 f	6.92 f	59.34
T_4	736.53 a	61.24 ef	7.68 ef	54.91
T_5	733.67 a	67.46 de	8.42 de	50.55
T_6	710.18 a	91.74 b	11.41 b	32.97
T_7	638.31 b	131.22 a	17.04 a	--
$LSD_{(0.05)}$	61.87	8.424	0.923	--
CV(%)	4.86	5.99	5.19	--

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 5 selected vine/plot of each treatment In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

T_1: Sex pheromone trap + Earthing up one time + Mulching (straw) + One irrigation

T_2: Sex pheromone trap + Earthing up two times + Two light irrigation

T_3: Sex pheromone trap + Earthing up three times + Three light irrigation

T_4: Earthing up two times + Sevin 85WP @ 3g\L at 15 days interval (2 times application)

T_5: Earthing up two time + Diazinon 10G @ 15 kg\ha (1 time soil application)

T_6: Earthing up two time + Fenthion 2ml\L

T_7: Untreated control

4.3.3.1 Tubers of sweet potato in weight basis

In case of tubers of sweet potato/vine in weight basis after 15 days from optimum harvest, it was observed that the highest weight of healthy tubers/vine was recorded from T_3 (743.78 g) treatment which was statistically similar with other treatment except T_7, while the lowest weight (638.31g) was observed from T_7 treatment (Table 5). In case of infested storage roots, the lowest weight (55.31 g) was observed from T_3 treatment which was statistically similar to T_4 (61.24 g) and followed by T_5 (67.46 g) and T_2 (70.11 g) treatment and they were statistically similar, while the highest weight from T_7 (131.23 g) treatment which was followed by T_6 (91.74 g) treatment. In consideration of infestation level of storage roots in weight basis, the lowest infestation was recorded from T_3 (6.92%) treatment which statistically similar to T_4 (7.68%) treatment, whereas the highest infestation (17.04%) was observed from T_7 which was closely followed by T_6 (11.41%) treatment. In case of reduction over control the highest value was recorded from T_3 (59.34) and the lowest value was found from T_6 (32.97) treatment. According to Stathers *et al*., (2005) reported that timely harvesting to remove the largest storage root most at risk from weevil attack and subsequent hilling up of the soil around the roots prevent weevils from accessing the root through cracks in the soil.

Table 6. Sweet potato weevil incidence on tubers of sweet potato after 15 days from optimum harvest in number and basis for different management practices

Treatments	Healthy tuber (No.)	Infested tuber (No.)	Infestation %	Infestation reduction over control
T_1	6.72 a	0.68 c	8.97 c	45.13
T_2	6.81 a	0.66 c	8.93 c	45.52
T_3	7.14 a	0.41 d	5.32 d	67.55
T_4	7.26 a	0.48 d	5.99 d	63.46
T_5	6.88 a	0.72 bc	9.63 bc	41.24
T_6	6.72 a	0.88 b	11.36 b	30.49
T_7	6.12 b	1.20 a	16.35 a	--
$LSD_{(0.05)}$	0.536	0.186	1.891	--
CV(%)	4.42	14.75	11.17	--

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 5 selected vine/plot of each treatment In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

T_1: Sex pheromone trap + Earthing up one time + mulching (straw) + one irrigation

T_2: Sex pheromone trap + Earthing up two times + two light irrigation

T_3: Sex pheromone trap + Earthing up three times + three light irrigation

T_4: Earthing up two times + Sevin 85WP @ 3gm\L at 15 days interval (2 times application)

T_5: Earthing up two time + Diazinon 10G @ 15 kg\ha (1 time soil application)

T_6: Earthing up two time + Fenthion 2ml\L

T_7: Untreated control

4.3.3.2 Tubers of sweet potato in number basis

In case of storage roots of sweet potato/vine in number basis after 15 days from optimum harvest, it was observed that the highest number of healthy tubers/vine was recorded from T_3 (7.14) which was statistically similar with other treatment except T_7, while the lowest number (6.12) from T_7 treatment (Table 6). In case of infested storage roots, the lowest number (0.41) was observed from T_3 treatment which was statistically similar to T_4 (0.48) and followed by T_2 (0.66), T_1 (0.68) and T_5 (0.72) treatment, while the highest number was found from T_7 (1.20) treatment which was followed by T_6 (0.88) treatment. In consideration of infestation level of storage roots in number basis, the lowest infestation was recorded from T_3 (5.32%) which was statistically similar to T_4 (5.99%) and followed by T_2 (8.93%) and T_1 (8.97), whereas the highest infestation (16.35%) was observed from T_7 treatment which was closely followed by T_6 (11.36%) treatment. In case of reduction over control the highest value was recorded from T_3 (67.55) and the lowest value was found from T_6 (30.49) treatment.

4.4 Deformed tuber percentage

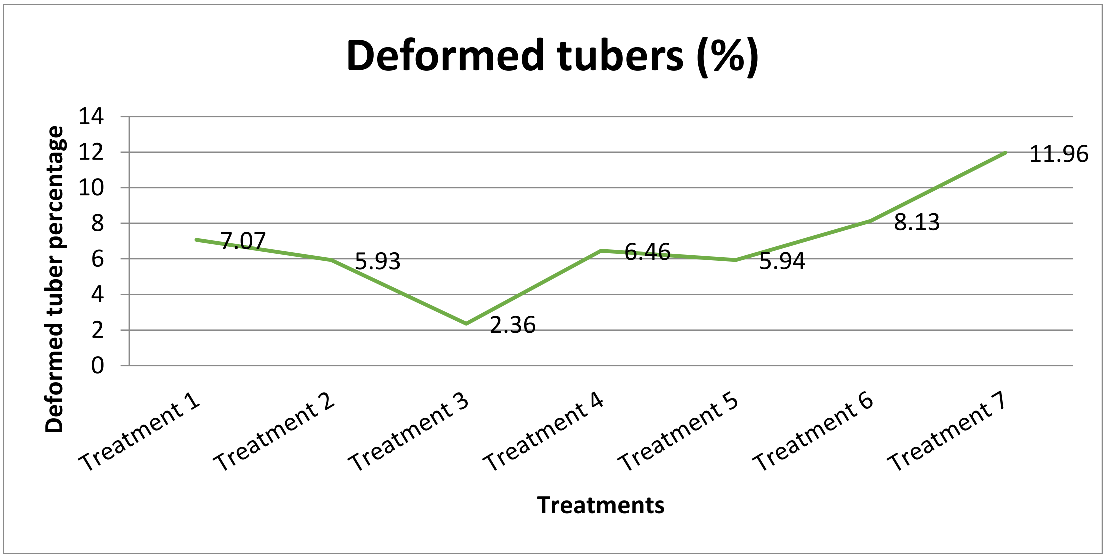

Figure 3. Deformed tuber percentage

This figure showed effect of different management practices on percent deformed tuber. In this case highest deformed tuber was found in T_7 (11.960%), which was followed by T_6(8.13%), T_1(7.086%), T_4(6.758%), T_5(5.94%), T_2(5.93%). Lowest deformed tuber is counted in T_3(2.36%).

Table 7. Yield and yield contributing characters of sweet potato for different management practices

Treatments	Vine length (cm) at harvest	Number of tubers/vine	Weight of individual tubers (g)	Yield ot tubers (t/ha)
T_1	194.86 a	6.57 a	142.27 a	39.69 a
T_2	197.81 a	6.57 a	144.97 a	39.67 a
T_3	205.55 a	7.01 a	148.49 a	41.87 a
T_4	202.02 a	6.90 a	147.02 a	40.13 a
T_5	199.25 a	6.68 a	146.21 a	39.83 a
T_6	191.81 a	6.57 a	141.01 a	38.54a
T_7	169.55 b	5.92 b	127.01 b	30.28 b
$LSD_{(0.05)}$	19.57	0.438	12.53	3.906
CV(%)	5.67	3.74	4.95	5.68

In a column, numeric data represents the mean value of 3 replications; each replication is derived from 5 selected vine/plot of each treatment In a column means having similar letter(s) are statistically identical and those having dissimilar letter(s) differ significantly as per 0.05 level of probability.

T_1: Sex pheromone trap + Earthing up one time + Mulching (straw) + One irrigation

T_2: Sex pheromone trap + Earthing up two times + Two light irrigation

T_3: Sex pheromone trap + Earthing up three times + Three light irrigation

T_4: Earthing up two times + Sevin 85wp @ 3g\L at 15 days interval (2 times application)

T_5: Earthing up two time + Diazinon 10G @ 15 kg\ha (1 time soil application)

T_6: Earthing up two time + Fenthion 2ml\L

T_7: Untreated control

4.5 Yield contributing characters and yield

Yield contributing characters and yield of sweet potato showed statistically significant variation due to different treatment (Table 7).

4.5.1 Vine length at harvest

In consideration of vine length at harvest, the longest vine was recorded from T_3 (205.55 cm) treatment, which was statistically similar with other treatment except T_7, whereas the shortest vine from T_7 (169.55 cm) treatment (Table 7).

4.5.2 Number of tubers/vine

For number of tubers/vine, the highest number was recorded from T_3 (7.01) treatment, which was statistically similar with other treatment except T_7 and the minimum number was found from T_7 (5.92) treatment (Table 7).

4.5.3 Weight of individual tuber

In case of weight of individual tuber, the highest weight was recorded from T_3 (148.49 g), which was statistically similar with other treatment except T_7, while the lowest weight was found from T_7 (127.01 g) treatment (Table 7).

4.5.4 Yield of tuber

In consideration of yield of tubers, the highest yield was recorded from T_3 (41.87 t/ha), which was statistically similar with other treatment except T_7 and the lowest yield was found from T_7 (30.28 t/ha) treatment (Table 7).

SUMMARY AND CONCLUSION

SUMMARY

A field experiment was carried out in the experimental field of Department of Entomology at Sher-e-Bangla Agricultural University (SAU), Dhaka, to development of effective integrated management package of sweet potato weevil during the period from November 2017 to March 2018. The seven treatments were T_1: Sex pheromone trap + Earthing up one time + Mulching (straw) + One irrigation, T_2: Sex pheromone trap + Earthing up two times + Two light irrigation , T_3: Sex pheromone trap + Earthing up three times + Three light irrigation, T_4: Earthing up two times + Sevin 85wp @ 3g\L of water at 15 days interval (2 times application), T_5: Earthing up two time + Diazinon 10G @ 15 kg\ha (1 time soil application), T_6: Earthing up two time + Fenthion 2ml\L of water, T_7: Untreated control. The experiment was laid out in Randomized Completely Block Design (RCBD) with three replications. Data were recorded on insect pest incidence, vine and branch infestation, infestation of storage roots in number and weight basis and statistically significant variation was recorded for different treatment.

In case of lowest number of adult weevil was found in T_3 (0.392), followed by T_4 (1.102), T_5 (1.156), T_2 (1.676). Highest number of adult weevil found in T_7 (9.46), followed by T_6 (1.918), T_1 (1.866). In case of different management practices effect and relative damage observation, where lowest damage result found in T_3 (5.04%), followed by T_4 (7.50%), T_5 (7.90%), T_2 (8.50). Highest damage result was observed in T_7 (15.4%), followed by T_1, T_6. In case of tubers of sweet potato/vine in weight basis at 15 days early harvest, it was observed that the lowest infestation was recorded from T_3 (5.68%), whereas the highest infestation (12.98%) was observed from T_7 treatment. In case of reduction over control the highest value was recorded from T_3 (56.24) and the lowest value was found from T_6 (28.43) treatment. At optimum days harvest, the lowest infestation was recorded from T_3 (6.48%), whereas the highest infestation (14.15%) from T_7 treatment. In case of reduction over control the highest value was recorded from T_3 (54.18) and the lowest value was found from T_6 (30.03) treatment. After 15 days from optimum harvest, the lowest infestation was from T_3 (6.92%), whereas the highest infestation (17.04%) from T_7 treatment. In case of reduction over control the highest value was recorded from T_3 (59.34) and the lowest from T_6 (32.97) treatment.

In case of tubers of sweet potato/vine in number basis at 15 days early harvest, the lowest infestation was recorded from T_3 (3.68%), whereas the highest infestation (12.24%) was observed from T_7 treatment. In case of reduction over control the highest value was recorded from T_3 (69.87) and the lowest value was found from T_6 (29.21) treatment. At optimum days harvest, it was observed that the lowest infestation was recorded from T_3 (4.49%), whereas the highest infestation (13.55%) from T_7 treatment. In case of reduction over control the highest value was recorded from T_3 (66.88) and the lowest value from T_6 (26.48) treatment. After 15 days from optimum harvest, the lowest infestation was recorded from T_3 (5.32%), whereas the highest infestation (16.35%) from T_7 treatment. In case of reduction over control the highest value was recorded from T_3 (67.55) and the lowest value from T_6 (30.49) treatment.

In this case highest deformed tuber was found in T_7 (11.960%), which was followed by T_6 (8.133%), T_1 (7.076%), T_4 (6.748%), T_5 (5.940%), T_2 (5.930%). Lowest deformed tuber was counted in T_3 (2.362%).

In consideration of vine length at harvest, the longest vine was recorded from T_3 (205.55 cm), whereas the shortest vine from T_7 (169.55 cm) treatment. For number of tubers/vine, the highest number was recorded from T_3 (7.01), while the minimum number from T_7 (5.92) treatment. In case of weight of individual tuber, the highest weight was recorded from T_3 (148.49 g), whereas the lowest from T_7 (127.01 g) treatment. For yield of tubers, the highest yield was recorded from T_3 (41.87 t/ha), whereas the lowest from T_7 (30.28 t/ha) treatment.

Conclusion:

From the above discussion it can be concluded that among the different control measures Sex pheromone trap with earthing up three times and three light irrigations was the best for the controlling sweet potato weevil and also attaining highest yield of tubers**.**

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APPENDICES

Appendix I. Monthly record of air temperature, relative humidity and rainfall of the experimental site during the period from October, 2018 to January 2019

Month	Air temperature		Relative humidity (%)	Rainfall (mm)
	Maximum	Minimum		
October, 2018	26.7	16.7	80	10
November, 2018	25.8	16.0	78	00
December, 2019	22.4	13.5	74	00
January, 2019	24.5	12.4	68	00

Source: Bangladesh Meteorological Department (Climate & weather division) Agargoan, Dhaka-1207.

Appendix II. Characteristics of the soil of experimental field by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the soil of experimental field

Morphological features	Characteristics
Location	Expeimental Field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

B. Physical and chemical properties of the initial soil

Characteristics	Value
%Sand	27
%Silt	43
%Clay	30
Textural class	Silty-clay
Ph	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

Appendix III. Anova for Relative abundance of Sweet potato weevils per 10 minutes per m^2 along with different management practices.

Source	DF	SS	MS	F- ratio	P Value
Replication	2	29.861	0.1500		
Treatment	6	339.825585	56.6375975	8.03	0
Error	12	84.639	7.05325		

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix IV. Anova for the effect of different management practices on sweet potato weevils and relative damage observation.

Source	DF	SS	MS	F- ratio	P Value
Replication	2	0.296	0.1500		
Treatment	6	135.7125	22.61875	75	0
Error	12	3.619	0.3015833333		

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix V. Analysis of variance of the data on incidence of sweet potato weevil on storage roots of sweet potato at 15 days early harvest in number basis for different management practices

Source of variation	Degrees of freedom	Mean square		
		Healthy (No.)	Infested (No.)	Infestation (%)
Replication	2	0.024	0.007	1.338
Treatment	6	0.381**	0.096**	24.137**
Error	12	0.016	0.001	1204.062

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix VI . Analysis of variance of the data on incidence of sweet potato weevil on storage roots of sweet potato at 15 days early harvest in weight basis for different management practices

Source of variation	Degrees of freedom	Mean square		
		Healthy (g)	Infested (g)	Infestation (%)
Replication	2	36.800	.0741	0.014
Treatment	6	3763.029**	761.459**	17.596**
Error	12	1204.061	11.139	0.177

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix VII. Analysis of variance of the data on incidence of sweet potato weevil on storage roots of sweet potato at optimum days harvest in number basis for different management practices

Source of variation	Degrees of freedom	Mean square		
		Healthy (No.)	Infested (No.)	Infestation (%)
Replication	2	0.41	0.007	0.916
Treatment	6	0.325**	0.0127**	27.419**
Error	12	0.097	0.012	1202.431

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix VIII. Analysis of variance of the data on incidence of sweet potato weevil on storage roots of sweet potato at optimum days harvest in weight basis for different management practices

Source of variation	Degrees of freedom	Mean square		
		Healthy (g)	Infested (g)	Infestation (%)
Replication	2	22.688	9.828	0.111
Treatment	6	3969.565**	918.038**	19.683**
Error	12	1202.431	19.878	0.271

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix IX. Analysis of variance of the data on incidence of sweet potato weevil on storage roots of sweet potato after 15 days from optimum harvest in number basis for different management practices

Source of variation	Degrees of freedom	Mean square		
		Healthy (No.)	Infested (No.)	Infestation (%)
Replication	2	0.014	0.0002	0.008
Treatment	6	0.392**	0.213**	40.661**
Error	12	0.092	0.013	1.132

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix X. Analysis of variance of the data on incidence of sweet potato weevil on storage roots of sweet potato after 15 days from optimum harvest in weight basis for different management practices

Source of variation	Degrees of freedom	Mean square		
		Healthy (g)	Infested (g)	Infestation (%)
Replication	2	64.87	1.613	0.011
Treatment	6	3833.877**	1992.258**	35.241**
Error	12	1209.131	22.417	0.271

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix XI. Anova for the effect of different management practices on percent deformed tubers (%).

Source	DF	SS	MS	F- ratio	P Value
Replication	2	29.861	0.1500		
Treatment	6	7.69398305	1.2823305083	21.19	0
Error	12	0.72619	0.0605158333		

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance

Appendix XII.Analysis of variance of the data on yield and yield contributing characters of sweet potato for different management practices

Source of variation	Degrees of freedom	Mean square			
		Number basis		Weight basis	
		Vine length (cm) at harvest	Number of tubers/vine	Weight of individual tubers (g)	Yield of tubers (t/ha)
Replication	2	14.703	0.009	1.433	0.009
Treatment	6	420.515*	0.356**	159.058*	0.145**
Error	12	120.995	0.061	49.525	0.029

**: Significant at 0.01 level of significance; *: Significant at 0.05 level of significance