Cotton Flea Beetle (*Podagrica puncticollis* Weise) Over-Seasoning Strategy in a Hot Dry Tropical Environment of Ethiopia

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Abstract

The field survey was started early in the main rainy season and during off-season of 2016 in Metema district to determine the over-seasoning strategy of cotton flea beetle. The cotton fields, sorghum fields, sesame fields and non-crop habitats (woodlots, patches of alternative hosts, crop field border edges, fallow lands and grasslands) nearby to cotton fields were assessed intensively in this study. During dry season, a site of 10m x10m of each habitat type was reserved randomly to sample number of aestivating beetles. On each sampling date, a 1m^2 sampling unit of leaf litter was collected from the reserved site of each habitat. Soil sample was taken to determine the depth at which the insect aestivate during the off-season. The highest number was recorded in the early dry months (January and February). The highest average number of aestivated beetles per m^2 of leaf litter was recorded in the *S. setigera* (14.8) tree, while the least in sorghum grown fields (0.65). The adults of cotton flea beetles also survived the dry season at highest densities underneath loose barks at the upper parts of the trunk of standing trees mainly on loose barks of *S. setigera* (up to18.8 adult beetles). The cotton flea beetle survived between 10 and 30 cm depths of soil in the aestivation sites from January to May usually in areas like woodlots and field border borders nearby cotton fields, and also within the cotton fields. These findings provided benchmark information for devising sustainable management tactics for cotton flea beetle.

Keywords: Aestivation, Aestivating sites, Cotton flea beetle, Over-seasoning, Population

Introduction

Cotton is susceptible to more kinds of insects, diseases and soil-borne pests, and because cotton is a broadleaved plant that must be harvested cleanly, weeds can cause greater damage (ICAC, 2006). According to Mathews and Tunstall (1994), more than 1326 species of insects cause damage to cotton plants at different stages of its development. More than five hundred (500) insect species and fifty pathogens are known to attack cotton in sub-Saharan Africa (Ivan *et. al.*, 2011). In Ethiopia, more than 57 insects and mite species are recorded on cotton, although only a few of them are economically important and include cotton flea beetle. For instance, among the four species of cotton flea beetles (Alticinae), *Podagrica puncticollis* reported in Ethiopia is the dominant species and causes extensive losses annually (Gentry, 1965, IAR, 1972, Ermias *et. al.*, 2009). Flea beetles cause the greatest damage by feeding on cotyledons, stems, and foliage (Hines and Hutchinson, 1997). Although, Tekeba (2005) reported *P.*

puncticollis was less important than bollworms.

The infestation of cotton-by-cotton flea beetle increased over time in Metema district (IPMS, 2008, Abebe, 2015) as a result cotton production is at an alarming risk of collapse unless concerted efforts are made to manage it. This requires knowing the survival strategy of the cotton flea beetle in places like Metema where the rainy season is interrupted by up to nine months of dry period. The dry period survival strategy of the cotton flea beetle in Ethiopia may be through aestivation in different habitats. Aestivation is a recurring state of summer dormancy, typically characterized by suppressed reproduction and/or growth that facilitate extended survival during harsh conditions (Reisen *et. al*., 1977). It is known that many insects, including those inhabiting tropical regions, undergo seasonal dormancy aestivation (Denlinger, 1986).

Chrysomelidae in warm countries are reported to inter aestivation under the bark of native trees or introduced and adapted species like Eucalyptus. Aestivation is sometimes very short in temperate countries and longer in tropical places with a long dry season (Beccari, 1952). In a temperate environment where flea beetles are common, they are favored by stable, warm spring weather and hampered by alternating periods of hot and cold temperatures with intermittent rains (McKinley, 1992). This needs to be confirmed for cotton flea beetle in the dry cotton-growing areas in Ethiopia. Considering that most flea beetles are of temperate origin, studying the survival strategy of flea beetles on different host plants is essential. Such work is very limited for flea beetles under Ethiopian conditions. This will serve as a guide to both scientists and extension workers who have contact with Malvaceae farmers.

Despite the economic importance of the cotton flea beetle, its over-seasoning strategy is not yet well known in Ethiopia especially in Metema district where cotton is the main commodity. Generally, the study of the ecology of the cotton flea beetle is a precondition for the development of appropriate management methods. Therefore, the main goal of this study was to determine the over-seasoning strategy of cotton flea beetle in cotton-producing areas of Metema district.

Materials and Methods

Assessment of over-seasoning strategy of cotton flea beetle

A field survey was conducted in early periods of the main rainy season and off-season from January through May 2016 in Metema district in North Gondar Zone of the Amhara National Regional State. The study was conducted in three kebeles, namely Genda Wuha, Kumer-Aftit and Meka. The habitats considered include cotton, sorghum and sesame fields, non-crop habitats nearby cotton fields including woodlots, field border borders with patches of alternative hosts, fallow lands, and grasslands. Habitats around river banks and close to cotton fields were also examined. In the 2016 dry season, a plot of 10m x10m of each habitat type was delineated randomly in each sampled kebele and examined for aestivating cotton flea beetles. Woodlots were delineated randomly 50m from the edge of an adjacent cotton field, whereas grasslands, alternative host plants patches, fallow lands, field borders, cotton, sesame and sorghum fields were reserved randomly throughout the field. Leaf litter samples were collected two times monthly from January to May. On each sampling date, a $1m^2$ sampling unit of crop residue or leaf litter was randomly collected from the reserved site of each habitat type at each kebele.

Soil sample with stubble or cotton stalk was taken from the cotton fields, nearby field border borders and woodlots to extract the insect and determine the depth at which the insect aestivate during the off-season. Soil samples were taken from three sites at each representative kebele once a month from January through to the end of June. The soil samples were collected with soil auger from each experimental area at depths of 10, 20 and 30 cm. Samples collected were bagged and returned to Gende Wuha research station of the Gondar Agricultural Research Center to check for the presence of aestivating adults after air-drying and soaking the soil in water by using floatation technique to separate the insect from the soil.

In woodlots, *Sterculia setigera, Acacia seyal* and *Acacia polyacantha* are common in cotton-based farming system. Searching of aestivating cotton flea beetle population was carried out through carefully examined the leaves, bark (near to the ground), cracks and hollows in standing or felled trees. This was done from January through to June 2016 both in wet and off-season periods of a year. All cotton flea beetle found in the different habitats and from each sampling unit were counted. Axe, blade, knife, machete, hoe, spade, soil auger, aspirator, hand lens and paper bags were used for cutting, digging, collecting and identifying samples.

Observations were made to know whether the adult cotton flea beetle is active or not during the dry season as well as on the emergence of flea beetle from the soil during the rainy season. The field observation was complemented by growing cotton plants (Delta Pine-90) in five plastic pots and placing them in the open field at Gende Wuha station of the Gondar Agricultural Research Center from January through July 2016. Recording of cotton flea beetles emergence was started immediately five days after cotton seedling emergence. The emerged adults were collected by aspirators and counted.

Data collection

Through field observation, data were collected on: time and condition when cotton flea beetle infestation starts and extends, time cotton flea beetle population and damage decreases in the cotton farms, observation on the behavioral response of the cotton flea beetle at the end of the cotton cropping season, time/ condition when the cotton flea beetle leave the cotton crop, areas/habitat preference of the cotton flea beetle at the end of the cotton cropping season, number of cotton flea beetle per habitats during the off-season and number of cotton flea beetle trapped by trap plants.

Data analysis

Data were analyzed through descriptive statistics to generate summaries and tables. Specifically, data collected on soil experiment of over-seasoning strategies were subjected to analysis of variance using SAS statistical software version 9.10 (SAS, 2003).

Results

Aestivation in leaf litters

The number of aestivated adult cotton flea beetles recorded under the leaf litters or residues of all studied habitats was highest in early dry months (January through February), and then the number decreased as the dry period progressed. The highest average number of 7.5 beetles per m^2 of leaf litter was found aestivated under leaf litters in cotton grown fields in January and the lowest was 0.65 aestivated beetles per m^2 in sorghum grown fields, in January (Figure 1).

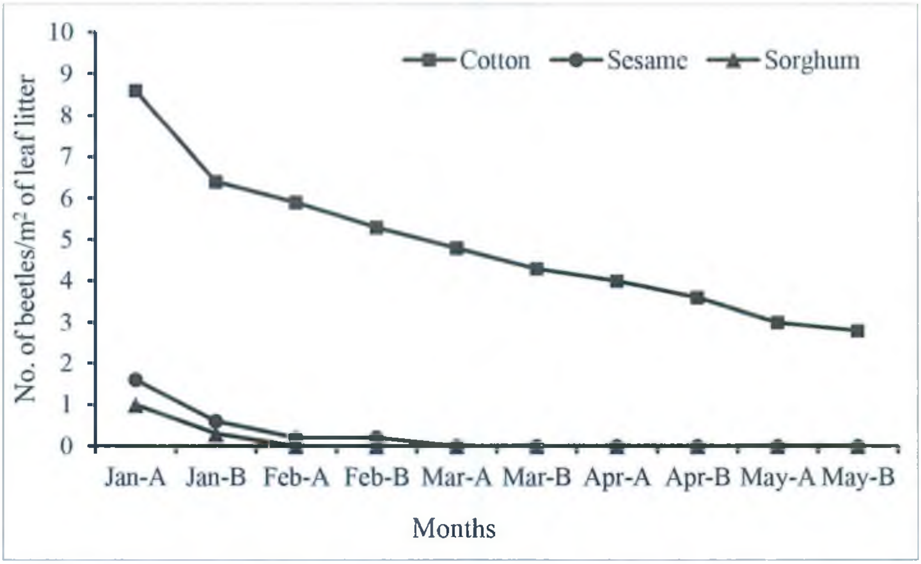

Figure 1. Numbers of aestivating cotton flea beetle adult recorded twice in each month under leaf litters of the previous year major crop fields during January through May, 2016 at Metema.

Among the major alternative host plant species, the highest average number of aestivated adult flea beetles per m^2 of leaf litters was found in *Hibiscus* sp. (8.25) followed by *Corchorus* sp. (6.15) and *Abutilon* sp. (4.4) in January (Figure 2). From the beginning of February to the end of May the survived beetles consistently decreased indicating that there may be natural controlling factors affecting the survival of aestivating cotton flea beetles.

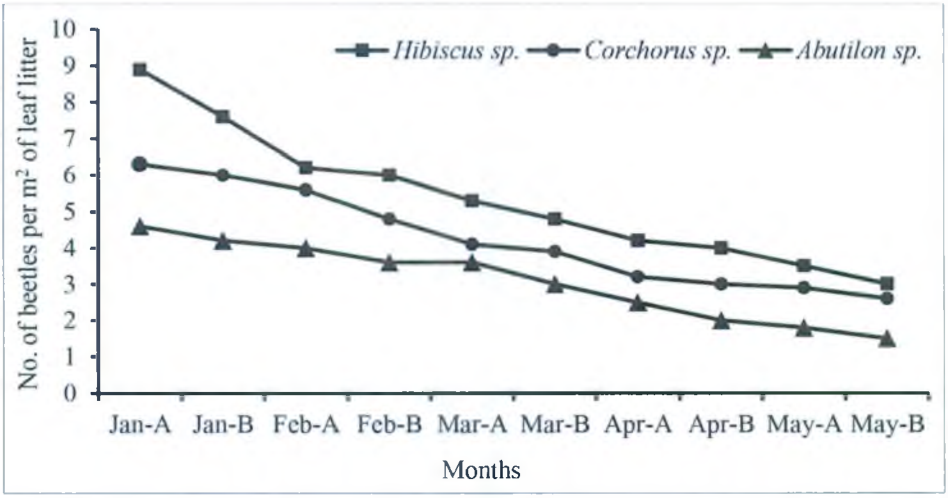

Figure 2. Numbers of aestivating cotton flea beetle adults recorded twice in each month under leaf litters of major alternative host plant species nearby previous year cotton fields during January through May, 2016 at Metema

Hibiscus sp., *Corchorus* sp. and *Abutilon* sp. were found commonly in or around cotton fields harboring higher numbers of adult cotton flea beetle. Thus, these alternative host plants patches nearby cotton fields support the over-seasoning of cotton flea beetle. Nearby dried leaf litters of alternative host plants, as well as stumps, field border borders, or edges with withered dicotyledon leaves or debris of weeds, are also favorable habitats for the cotton flea beetle survival during the dry season.

The population densities of aestivating beetles under leaf litters which were assessed in the field border borders, fallow, and grasslands nearby cotton-grown fields are presented in Figure 3. In January, 5.3 beetles per m^2 of leaf litter were found aestivated in field border borders, while 3.15 beetles per m^2 of leaf litter in fallow land whereas, 0.8 beetles per m^2 of leaf litter aestivated in grassland in January. The population densities in May declined to 2, 0.6, and 0 in cotton field borders, fallow and grasslands, respectively.

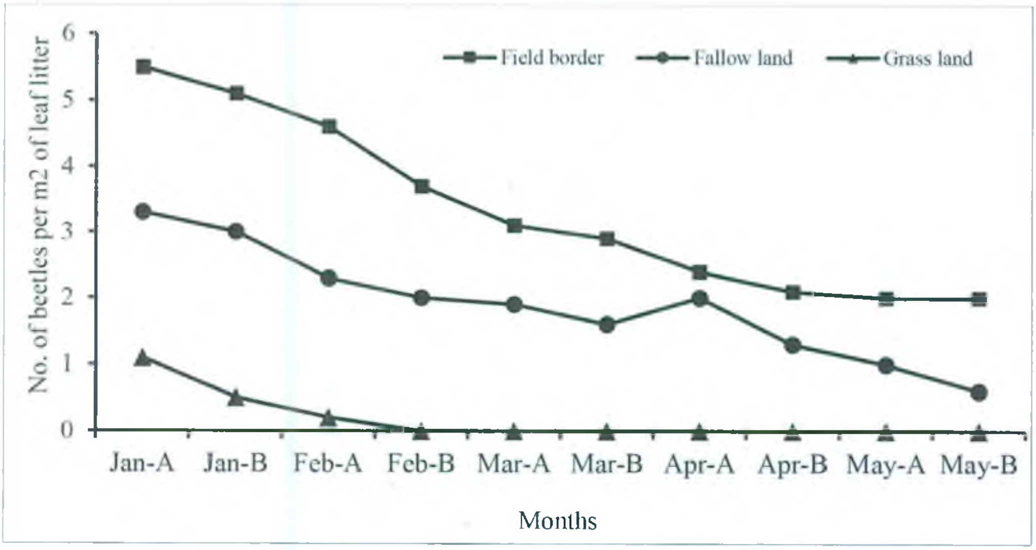

Figure 3. Numbers of aestivating cotton flea beetle adults recorded twice in each month under leaf litters of field borders, fallow and grasslands nearby previous year cotton fields during January through May, 2016 at Metema.

The leaf litters of field border borders and fallow lands hosted a significant population of aestivating adult cotton flea beetle and served as suitable aestivating sites for this insect pest next to cotton fields. Commonly these habitats harbor a lot of alternative host plants of cotton flea beetle during the main cotton growing season. The minimum number of adult beetles was noted under leaf litters of grasslands, sesame, and sorghum grown fields may be due to reduced aestivation success. The population trend of aestivating adults of cotton flea beetle under leaf litters of the different tree species or woodlots showed that the highest average number of aestivating adult beetle per m^2 of leaf litters was found in leaf litters of *S. setigera* (14.8) and *A. seyal* (7.05) and the lowest (3.05) under leaf litters of *A. polyacantha* in January (Figure 4). The aestivated beetle population decreased and reached the lowest level in May on the three species. More adult cotton flea beetles aestivated in *S. setigera* present nearby cotton fields throughout the dry months as compared to the other studied habitats.

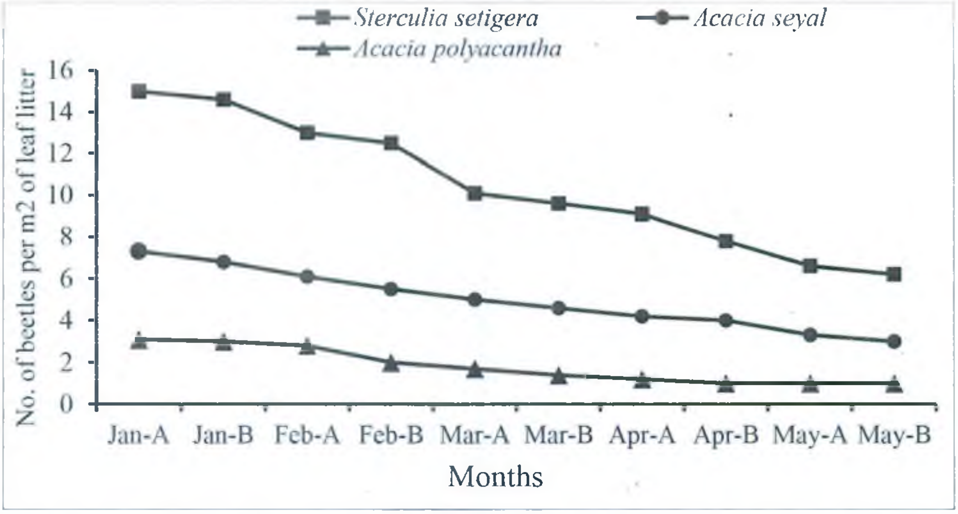

Figure 4. Numbers of aestivating cotton flea beetle adults recorded twice in each month under leaf litters of trees nearby previous cotton fields during January through May, 2016 at Metema.

Aestivation of adult cotton flea beetle along different soil depths

Significant differences ($P < 0.01$) were observed among treatments in numbers of aestivated cotton flea beetle adults recorded monthly at soil samples taken from each aestivating site (Table 1). At 10 cm depth of soil, the highest number (12.33) of adult beetle beetles per sampled soil was recorded in the soil sample taken from woodlot followed by cotton field (7.66 beetles per sampled soil) in January. The number of beetles per sampled soil was lower at 20 cm depth of soil followed by the soil sample taken from field borders (5.66 beetles) at 10 cm depth. However, the least number (2.66) of adult beetles per sampled soil was recorded in the soil samples taken from field borders, which was statistically similar with cotton fields (3 beetles per sampled soil) at 20 cm depth of soil during January. There were no significant differences in the number of aestivating cotton flea beetle adults recorded, at 30 cm soil depth, across the three aestivating sites, in January.

At the peak of the dry season (May), statistically, the highest numbers of (7.66 and 7.4) beetles per sampled soil were recorded at 30 cm depth in woodlot and field border, respectively. In the early wet month (June), the population of beetle was declined almost along the depths and the maximum number (4.2 per soil sampled) was recorded in the woodlot at 30 cm depth (Table 1).

Table 1. Numbers of aestivating cotton flea beetle adults recorded monthly at three soil depths in three aestivating sites during dry period from January through May and early wet season (June) of 2016 in Metema.

Aestivating sites	Soil depth(cm)	Number of aestivating beetles per soil sample (Monthly)					
		January	February	March	April	May	June
Cotton field	10	7.66[b]	5.33[d]	4[f]	3[e]	2[f]	2.1[f]
	20	3[e]	3.66[e]	8[d]	7.33[ab]	5[cd]	2.5[ef]
	30	0[f]	1.66[f]	3[g]	6[c]	6.6[ab]	3.33[bcd]
Field border	10	5.66[d]	8.33[c]	6.3[e]	4.4[d]	3[ef]	2.66[def]
	20	2.66[e]	5[d]	9[c]	8[a]	5.8[bc]	2.9[cde]
	30	0[f]	2.33[f]	4.1[f]	7.2[ab]	7.4[a]	3.96[ab]
Woodlot	10	12.33[a]	12.66[a]	10.33[b]	6.66[bc]	4.1[de]	3.4[bc]
	20	6.33[c]	10.66[b]	11.3[a]	7.8[a]	6.1[bc]	4[ab]
	30	0[f]	2[f]	4.66[f]	6.9[b]	7.66[a]	4.2[a]
CV (%)		8.28	7.58	8.55	7.35	12.5	13.03

Means sharing the same letter are not significantly different according to Least Significant Difference (LSD) test at 5% level of significance.

Aestivation of adult cotton flea beetle in woodlots

In the early months of the dry season (January), the highest number (18.8 and 10.6) of aestivated adult cotton flea beetle were found under the loose barks of *S. setigera* and *A. seyal* trees, respectively, and the lowest number 4.3 was recovered under loose bark of *A. polyacantha*. Similar results were obtained between February and May. During the early and later months of the wet season (June-September), there were no aestivated adult beetles in the barks of the woodlots and actively feeding adults were recorded on the leaf and twigs of *S. setigera*. Until the end of November very few beetles were recorded in the barks of the trees whereas, in December, the number started increasing under the bark of *S. setigera* and *A. polyacantha* (Figure 5).

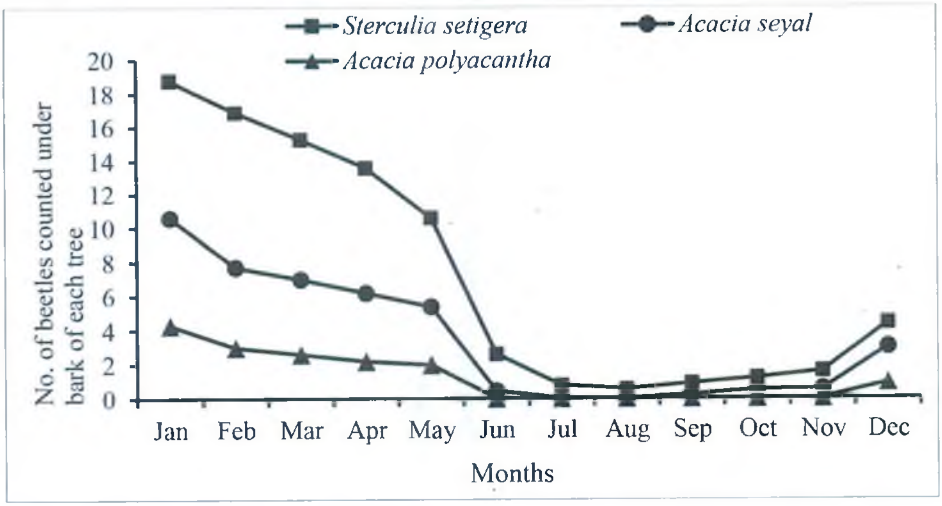

Figure 5. Numbers of cotton flea beetle adults recorded monthly under loose barks of trees nearby previous cotton fields during dry and main cropping seasons from January up to December 2016 at Metema.

Termination pattern of aestivation of cotton flea beetle as influenced by presence of host plant

By planting cotton plants as traps to lure cotton flea beetle during the dry spell it was observed that few beetles were collected per cotton plant in a pot experiment, while almost none in the reaming months (March to May) of the dry season. However, at the end of the dry season, few adult beetles were observed on the potted plants (Figure 6) in June and July the mean maximum number of cotton flea beetle was 5.45 and 5.05 beetles per plant, respectively (Figure 6). Adult cotton flea beetle emergence started following the onset of rainfall in June indicating that rainfall is important to terminate aestivation.

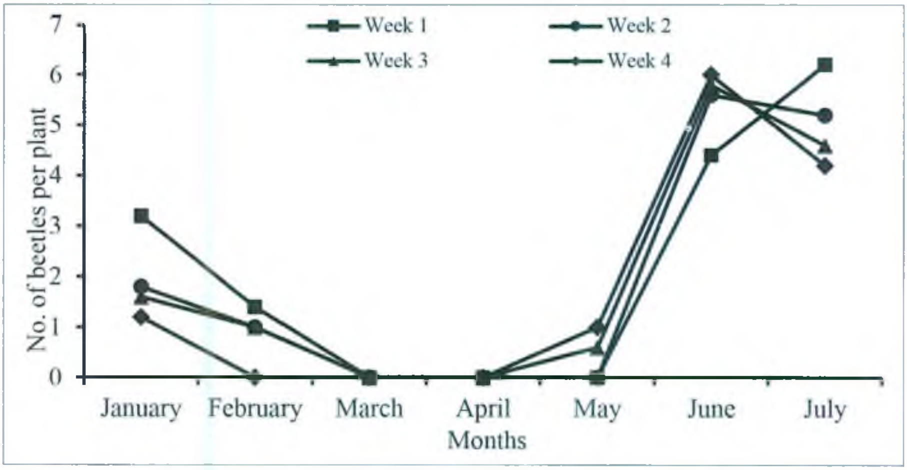

Figure 6. Numbers of cotton flea beetle adult caught in the four weeks of each month on cotton plant in pot experiment during dry season from January through May and two months of early wet season of 2016 at Metema.

In this study, adults of cotton flea beetle mainly moved to aestivating sites at the end of December while some moved to sesame, sorghum, and grasslands and stayed for a short time, and then moved to habitats favoring aestivating sites. Additionally, nearby alternative host plant patches, field borders, and fallow lands contributed to the over-seasoning of cotton flea beetles.

Aestivated population of the cotton flea beetle declined on all these hosts in June and July, and actively feeding populations were present wide-spread in new cotton fields. The first immigrants that emerged from the aestivation sites were found on a variety of plants, including the common weeds in the area, *Hibiscus vitifolius*, *H. cannabinus*, *H. articulatus*, *Abutilon figarianum*, *Corchorus olitorius* and *C. trilocularis*. During the rest of the year, cotton and other herbaceous Malvales provide abundant food and cotton flea beetle was concentrated on these hosts. Higher preference was observed to *H. vitifolius*, *H. cannabinus*, *H. articulatus*, *C. olitorius* and *A. figarianum*.

Discussion

Leaf litter or residues at the base of cotton stubbles or stumps and in cracked soil particularly on loose soil clod provided survival sites for aestivating adult cotton flea beetle during the harsh dry season when extreme hot temperature prevails. Similarly, the bean leaf beetle, *Cerotoma trifurcata* (Forster) overwintered as adults under debris within fields or in wooded areas (Lam and Pedigo, 2000). Also, Onayemi *et al.* (2016) reported that okra stumps left in the field, well after harvesting was over, attracted a significantly higher flea beetle population compared to kenaf. The stumps acted as a continuous means of sustaining flea beetles (*Podagrica* spp.) in the field. The leaf litters of field border borders and fallow lands hosted a significant population of aestivating adult cotton flea beetle and served as suitable aestivating sites for this insect pest next to cotton fields. Commonly these habitats harbor a lot of alternative host plants of cotton flea beetle during the main cotton growing season. According to Bonnie *et al.* (2015), most flea beetle species overwinter as adults in protected places such as under leaf litter, dirt clods, or on weeds along field borders and ditch banks.

More adult cotton flea beetles aestivated in *S. setigera* present nearby cotton fields throughout the dry months as compared to the other studied habitats. Similar to our finding multiple insect pests on diverse host plants move to woodlands to over-season. For instance, Golding (1928) in Nigeria, *Dysdercus superstitiosus* reported to feed on *Sterculia* sp. between January and March but then moves to cotton (*Gossypium* sp., Malvales: Malvaceae). European corn borer was found to be more abundant in woodland close to cereal fields than in herbaceous edges or in corn fields itself (Dyer and Landis, 1997). Further, Casagrande (1975) reported that adult cereal leaf beetles, *Oulema melanopus* survive the winter in the highest densities at the edge of woodlots. In this regard, Lam (1999) indicates when flea beetles overwinter under the litter of forest-floor, the microhabitat helps them to avoid the extreme cold temperatures by acting as an insulating layer. Also, Danks (1991) stated that most insect species, ecological or behavioral means of moving to suitable overwintering sites and avoiding low winter temperatures are important to withstand the winter season. Similarly, the behavior of the aestivating cotton flea beetle moving to the ground of woodlots mainly under leaf litter of forests probably helped the insect to find a microhabitat and a protective layer, unlike what is described above, to avoid the extreme hot temperatures prevailing in the study area.

According to the results of the present survey, the adult cotton flea beetle mainly aestivated in the soil, usually in woodlots and field borders nearby to cotton fields, but also within the cotton fields. Flea beetles overwinter as adult under soil and leaf litter in brushy or woody areas surrounding the fields, rather than in grassy areas right next to fields (Schmutterer, 1969) as well as in the soil around plant debris in undisturbed areas near the field where they emerged (Mario, 2008).

The depth at which the beetles aestivate in the soil varies depending on the climate, with beetles burrowing deeper in the dry hot conditions during March, April, and May. From January until May between 10 and 30cm depths of soil seem to be more suitable for aestivation cotton flea beetle. One important over-seasoning strategy of the cotton flea beetle to survive in the dry season is the ability of adults to burrow into or hide in the soil for aestivation. Further, this behavior of the cotton flea beetle helps to avoid harsh conditions. One important feature which has allowed the Colorado potato beetle, to spread from its almost sub-tropical native range to the almost sub-arctic northern range margin in Europe (EPPO, 2006) is the capacity of adults to burrow into the soil for diapauses (e.g., Hsiao, 1988). Adult beetles destined for diapause normally migrate to the sides of potato fields, or into neighboring forest patches, where they burrow into the soil, to depths between 20 and 80 cm (Milner *et al.*, 1992). Also, De Wilde (1969) showed that for the Colorado potato beetles soil depth of 30 cm proved to be more suitable for hibernation: the mortality of the beetles was lower than at 50 cm depth. A post-hibernation analysis showed that the beetles that dug into the soil over-wintered more successfully than those that remained on the soil surface. Unlike the Colorado potato beetle higher survival of cotton flea beetle in the hot dry environment of Metema area varied with the prevailing temperature and the insect moved to lower depth to get cooler environment when the air temperature was very hot and returned close to the soil surface after rainfall is received and the surface temperature became cooler. Further, Bale *et al.* (2002)

reported that insects that spend important parts of their life histories in the soil may be more gradually affected by temperature changes than those that are aboveground simply because soil provides an insulating medium that tends to buffer the effects of temperature changes more than the air.

Most of the cultivation of crops in Metema district occurs on the dark cracking clay soils. These soils by nature are deep cracking types contributing a lot for over-seasoning of cotton flea beetle in the dry season by providing a more suitable hiding place. Thus, the survival of the cotton flea beetle is not attributed only to one factor; other factors may determine aestivating behavior and success in field conditions. Woodlots present near cotton fields played a greater role in providing a home for over-seasoning cotton flea beetles that move into cotton fields starting from the onset of rainfall in June. Similarly, Beccari (1952) indicated that the aestivation of Chrysomelidae in warm countries is generally done under the barks of native trees or exotics like Eucalyptus. Different insect species also use tree bark for over-seasoning. For instance, Castrot (1964) reported that cereal leaf beetle, *Oulema melanopa* aestivates in stubble or under the bark of trees, fencerows, or field trash until spring. Also, Boldt and Staines (1993) reported that in temperate climates, adults of Cassidines overwinter under bark besides leaf litter at the base of the host plant, or in soil. In this context, Ericson (1948) also reported that ladybird beetles hibernate in big colonies under the loose bark of trees, in tree cavities, and in buildings. Leaf curl mites find hibernation shelters in bark crevices, branch scars, and at the base of cottonwood trunks (Morris *et al.*, 1975).

In this study, most of the aestivated adult beetles were collected under loose barks of trees especially during the hottest months and the dry season (March to May). These particular sites or parts (microhabitat) of the trees could provide cooler conditions for cotton flea beetle during the dry season. Temperature plays an important role in the localization of insects that live in tree trunks (Dajoz, 1992). Large *S. setigera* trees nearby cotton fields were found growing on cracking red and dark cotton clay soils as well as on rocky sandy loam soils mainly on the higher slopes of rivers and ditch banks. On the other hand, most of the *Acacia* sp., which were examined nearby cotton fields, were commonly on the stiff clay plains of Metema and clay soils of seasonally wet depressions (groundwater forest). The aestivated adults that emerge in June may determine the density of the establishing cotton flea beetle population in new cotton fields. In this regard, Bale (1989) reported that for many insects, survival of overwintering stages plays a major role in determining the pest status of the species in the following year, hence supporting the above suggestion for cotton flea beetle.

Conclusions and Recommendations

The study on the over-seasoning strategy of cotton flea beetle demonstrated that the aestivating adults aggregated in the residue of the aestivating sites, including cotton fields and woodlands. Similarly, significant numbers of aestivating beetle were also present under residue of alternative host plants, in dicotyledon leaf litters or debris in field borders and fallow lands in and edges of cotton fields. Additionally, only a few cotton flea beetles were aestivated in grasslands, sesame, and sorghum fields. Moreover, the cotton flea beetle aestivated from January until May, at various soil depths (10 and 30cm), probably in response to soil surface temperature and rainfall. Besides, soil type also plays an important role in aestivating of cotton flea beetle. Aestivating period of the cotton flea beetle is commonly initiated by the start of the extended dry season and leads to migration to favorable aestivation sites. The adult cotton flea beetle mainly survives the dry season in the higher densities at the patches of woodlots with particular microhabitats such as in soil, under leaf litters, and in loose barks of trees. However, the onset of rainfall plays a crucial role during the aestivation termination process. Once the cotton flea beetle appeared in fields before the establishment of the cotton crop, the alternative host species, especially Malvaceae weeds like *Hibiscus* spp. provide an early food supply to adults, thereby greatly enhancing its survival and increasing the severity of its attacks on the seedling stage of the succeeding cotton crop. On the other hand, the late-season host plant species highly support the adult cotton flea beetle to pass through the period until it aestivates / diapauses or moves to perennial trees that may be serving as host plants.

The study indicated that it is feasible to sample the aestivating populations for pest management programs. Also, these current findings offer the opportunity to apply tools of management programs effectively against the cotton flea beetle in hot-dry tropical environments that persist in cotton-producing areas of Metema, north-western Ethiopia. Further work on the role of climatic factors affecting the over-seasoning strategy of the cotton flea beetle is worth investigating to develop a prediction model and monitor population fluctuations.

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References

Abebe EA. 2015. Cotton flea beetle, *Podagrica puncticollis* Weise (Coleoptera: Halticidae) in Metema District, Northern Ethiopia: Yield loss assessment and management. *Open Access Library Journal*, 2: e1128.

Bale JS. 1989. Cold hardiness and overwintering of insects. *Agricultural Zoology Reviews*, 3: 157–192.

Bale JS, Masters GJ, Hodkinson ID, Awmack C, Bezemer TM, Brown VK, Butterfield J, Buse A, Coulson JC, Farrar J, Good JEG, Harrington R, Hartley S, Jones TH, Lindroth RL, Press MC, Symrnioudis I, Watt AD, Whittaker JB. 2002. Herbivory in global climate change research: direct effects of rising temperatures on insect herbivores. *Global Change Biology*, 8:1–16.

Beccari F. 1952. Observazioni sulla biologia del Longitarsus linaei Duft. (Col. Chrys.). *Redia*, 37: 309–325.

Boldt PE, Staines CL. 1993. Biology and description of immature stages of *Pentispa suturalis* (Baly) (Coleoptera: Chrysomelidae) on *Baccharis bigelovii* (Asteraceae). The *Coleopterists Bulletin,* 47: 215–220.

Bonnie B, Diane A, Marion M. 2015. Flea Beetles on Vegetables (Coleoptera: Chrysomelidae). Published by Utah State University Extension and Utah Plant Pest Diagnostic Laboratory. ENT-174–15.

Casagrande RA. 1975. Behavior and survival of the adult cereal leaf beetle, *Oulema melanopus* (L.). Ph.D. Thesis. Michigan State University, East Lansing, Michigan.

Castrot R. 1964. Natural history of the cereal leaf beetle, *Oulema melanopa* (Linnaeus), and its behavior under controlled environmental conditions.

Ph.D. Thesis. Michigan State University, Michigan.

Dajoz R. 1992. Insects and forests. The role and diversity of insects in the forest environment. Intercept Ltd, London. Pp. 668.

Danks HV. 1991. Winter habitats and ecological adaptations for winter survival. Pp. 231–259. In: Lee RE, Denlinger DL (eds.), *Insects at Low Temperature*. Chapman and Hall, New York.

Denlinger DL. 1986. Dormancy in tropical insects. *Annual Review of Entomology*, 31: 239–264.

De Wilde J. 1969. Diapause and seasonal synchronization in the adult Colorado potato beetle (*Leptinotarsa decemlineata* Say). Pp. 263–284. In: *Symposium of the Society of Experimental Biology* 23. Dormancy and Survival. Cambridge University Press, Cambridge, UK.

Dyer LE, Landis DA. 1997. Influence of non-crop habitats on the distribution of *Eriborus terebrans* (Hymenoptera: Ichneumonidae) in corn fields. *Environmental Entomology*, 26: 924–32.

EPPO (European and Mediterranean Plant Protection Organization). 2006. Distribution maps of quarantine pests for Europe, *Leptinotarsa decemlineata*. ADAS, Nottingham, UK.

Ericson WN. 1948. Hibernating insects. *Journal of Insect Science*, 22:115–125.

Ermias S, Geremew T, Zeray M. 2009. Review of research on insect pests of fiber crops in Ethiopia. Pp. 93–117. In: Abraham T (ed.), *Proceeding of Increasing Crop Production through Improved Plant Protection Volume II*. Plant Protection Society of Ethiopia (PPSE), Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia.

Gentry W. 1965. Crop insects of Northeast Africa-Southeast Asia. ARS, Agricultural Hand-book No 273. USDA, Washington, D.C. Pp. 33.

Golding FD. 1928. Notes on the bionomics of cotton stainers (*Dysdercus*) in Nigeria. *Bulletin of Entomological Research*, 18: 319–334.

Hines RL, Hutchinson WD. 1997. Flea beetles. Minnesota Extension Service, Minnesota.

Hsiao TH. 1988. Host specificity, seasonality and bionomics of Leptinotarsa beetles. Pp. 581–599. In: Jolivet P, Petitpierre E, Hsiao TH (eds.), *Biology of Chrysomelidae*. Series Entomologica. Volume 42. Kluwer, Academic Publishers, Dordrecht.

IAR (Institute of Agricultural Research). 1972. Progress report for the period April 1971 to March 1972. Addis Ababa, Ethiopia: IAR. Pp. 75.

ICAC (International Cotton Advisory Committee). 2006. Cotton Development Trust of Zambia, report to the 65th ICAC Plenary Meeting in Goiania, Brazil.

IPMS (Improving Productivity and Market Success). 2008. Improving productivity and market success of Ethiopian Farmers. Seventh Progress Report.

Ivan J, Tanja G, Dinka, G. 2011. Rape stem weevil (*Ceutorhynchus napi* Gyll.) and Cabbage stem weevil (*Ceutorhynchus pallidactylus* Marsh.) (Coleoptera: Curculionidae)- Important oilseed rape pests. *Agriculturae Conspectus Scientificus*, 76(2): 93–100.

Lam W-KF. 1999. Winter survival and population dynamics of bean leaf beetle (Coleoptera: Chrysomelidae). PhD Dissertation. Iowa State University, Ames, Iowa. Pp. 115.

Lam W, Pedigo LP. 2000. A predictive model for the survival of overwintering bean leaf beetles (Coleoptera: Chrysomelidae). *Environmental Entomology*, 29: 800–806.

Mario A. 2008. Faculty research associate, Integrated Plant Protection Center, Oregon State University. Oregon State University Extension Service. EM 8947-E.

Mathews GA, Tunstall JP. 1994. Insect pests of cotton. CAB International, UK. Pp. 593.

McKinley RG. 1992. Vegetable crop pests. CRC Press, Boston, MA. Pp. 98–101.

Milner M, Kung KJS, Wyman JA, Feldman J, Nordheim E. 1992. Enhancing overwintering mortality of Colorado potato beetle (Coleoptera: Chrysomelidae) by manipulating the temperature of its diapause habitat. *Journal of Economic Entomology*, 85: 1701–1708.

Morris RC, Filer TH, Solomon JD, McCracken FI, Overgaard NA, Weiss MJ. 1975. Insects and diseases of cottonwood. U.S. Department of Agriculture Forest Service General Technical Report SO-8.

Onayemi SO, Soyelu OJ, Amujoyegbe BJ. 2016. Effects of cropping patterns on the flea beetles, *Podagrica* Spp. (Coleoptera: Chrysomelidae), in okra-kenaf intercrop system. *Journal of Agricultural and Crop Research*, 2: 40–44.

Reisen WK, Baker RH, Sakai RK, Aziz-Javed A, Aslam Y, Siddiqui TF. 1977. Observations on mating behavior and survivorship of *Culextritaenior hynchus* Giles (Diptera: Culicidae) during late autumn. *Southeast Asian Journal of Tropical Medicine and Public Health*, 8: 537–545.

SAS Institute. 2003. SAS systems for Windows, Version 9.1 Edition. SAS Institute Inc. Cary, NC., USA.

Schmutterer H. 1969. Pests of crops in Northeast and Central Africa with particular reference to the Sudan. H. Schmutterer. Gustav Fischer Verlag, Stuttgart. Cambridge University Press, U.S.A. Pp. 296.

Tekeba Y. 2005. Species composition of cotton bollworms (Lepidoptera: Noctuidae and Gelechiidae) and their management using cotton genotypes and planting dates in Metema, northern Ethiopia. MSc Thesis. Alemaya University, Ethiopia.