Journal of Entomology and Zoology Studies 2020; 8(1): 765-770

Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

JEZS Journal of Entomology and Zoology Studies

E-ISSN: 2320-7078
P-ISSN: 2349-6800
JEZS 2020; 8(1): 765-770

Received: 10-11-2019
Accepted: 12-12-2019

Gebissa Yigezu
Haramaya University, College of Agriculture and Environmental Sciences, School of Plant Sciences; P.o. Box: 138, Dire Dawa, Ethiopia

Mulatu Wakgari
Haramaya University, College of Agriculture and Environmental Sciences, School of Plant Sciences; P.o. Box: 138, Dire Dawa, Ethiopia

Corresponding Author:
Gebissa Yigezu
Haramaya University, College of Agriculture and Environmental Sciences, School of Plant Sciences; P.o. Box: 138, Dire Dawa, Ethiopia

Local and indigenous knowledge of farmers management practice against fall armyworm (*Spodoptera frugiperda*) (J. E. Smith) (Lepidoptera: Noctuidae): A review

Gebissa Yigezu and Mulatu Wakgari

Abstract
Fall Armyworm (FAW) (*Spodoptera frugiperda*) is a polyphagous insect pest. It is a dangerous pest that attacked more than 80 plant species commonly maize, sorghum, and rice. It caused a major economic loss on these important cultivated crops in Sub-Saharan African countries where the yield losses of maize estimated up to $US13 billion per annum after 2018. It posed a threat to food security, nutrition, and livelihoods. The management practices of this pest by synthetic pesticides also affected human health, natural enemies and the environment negatively. The farmers practiced different management which was varied across countries, regions, and places. These practices were safe for the environment and human health. However, there was no adequate documented information on the indigenous knowledge of farmers in different places and across countries. Therefore, this review paper has emphasized on local and indigenous knowledge of farmers against FAW. The farmers applied different locally available knowledge such as handpicking, killing of larvae, adding soil to plant whorls, drenching tobacco extracts, destroying ratoon host crops, early planting, deep plowing to kill pupae, placing sand or ash in the whorls, burn stubbles after harvesting of infested crops, intercropping and sowing multiple varieties and rotation of maize with non-host crops. This work is to encourage subsistence farmers of developing countries to exchange their various local knowledge and experiences in the management of the notorious FAW especially in maize production.

Keywords: Cultural practices, fall armyworm**,** indigenous knowledge, management, push-pull

Introduction

Fall Armyworm (FAW) (*Spodoptera frugiperda*) is a polyphagous insect pest native to tropical and subtropical regions of America [1]. It attacked more than 80 plant species [2], particularly the family of graminaceae throughout America [3]. It commonly feeds on maize, sorghum, and rice. Frequently it also caused injuries to alfalfa, barley, buckwheat, cotton, clover, oat, millet, peanut, ryegrass, wheat, sugar beet, sudangrass, soybean, sugarcane, timothy, tobacco, cabbage, onion, pasture grasses, tomato, and potato if not well managed [2, 4]. It caused major economic losses on these important cultivated crops. FAW could be one of the most damaging crop pests in America [5]. In Brazil, it also caused yield losses of maize up to 34% [5, 6].

The FAW prevailed in African and Asia continent after 2016 [7]. Currently, it was devastating 47 African countries and 19 Asian countries. Cameroon, Egypt, Mayotte, Reunion, Swaziland were among the countries that restricted the distribution of FAW [4]. This pest is a dangerous pest. It could migrate from country to country with a high potential further spread because of its natural distribution capacity, sporadic, migratory behavior and trans-boundary trade. It has also a number of generations per year and the moth could fly up to 100 km per single night. The caterpillars of FAW feed on leaves, stems and reproductive parts of host plants [1]. FAW preferred maize to many other crops in Africa [8]. The gravid females of FAW prefer young maize plants that are 30 to 60 centimeters in height for oviposition. The small caterpillars feed on leaves of young maize plants [9]. The young larvae consume leaf tissue from one side initially by leaving the opposite epidermal layer intact. The larger larvae act as cutworms. It caused entirely sectioning the stem base of maize plantlets, skeletonized leaves and heavily windowed whorls that loaded with larval frass. The FAW larvae could attack maize plants during vegetative and reproductive or flowering phase. It could also bore into the maize ears, stems, and cobs [10].

FAW was severely incident on young crops and begun infesting the crops at the age of 20-22 days. Neonate larvae fed the leaves by scrapping of chlorophyll, which led to a silvery transparent membrane initially that ultimately resulted in white elongated patches. Later instars created 'windowpane' on leaves by leaving moist sawdust-like frass near funnel and upper leaves. Mature larvae characterized by white inverted 'Y' shaped capsule on the head and have four distinct black spots on the eighth abdominal segments [10]. It feeds mostly in the whorls of young plants and caused severe damage when crops are in the age between 42 to 56 days after planting [8, 10]. However, the severity level may vary the damage to crops occurs in all phenological stages [11].

In developing countries of Africa, the FAW has major economic and environmental implications. The costs of management, losses of grain yield, hunger or food insufficiency, losses of quality and quantity of crops, and risks of chemical pesticides on health and environments are the major ones. The estimated percentage yield losses of maize across African countries as reported by various authors indicated variations. For instance, in Ghana (22%) and Zambia (67%) [12], Ethiopia (32%) and Kenya (47%) [13], Zimbabwe (11.57%) [14] and Namibia (57%) [15].

The estimated potential impacts of FAW on Africa's maize yield losses lied between 4.1 and 17.7 million tons annually, out of the total expected production of 39.3 million tons. The capital losses in terms of money also estimated to be 1,088 to 4,661 US$ million annually, of the total expected value of US$ 10,343 million [16]. In Sub-Saharan African countries alone, the yield loss of maize is estimated to $US13 billion per annum after 2018, thereby threatening the livelihoods of millions of poor farmers [17]. These findings of the two authors indicated that yield losses caused by FAW increased from year to year. It posed a threat to food security, nutrition, and livelihoods, human health and environments negatively [8, 12]. The response of extensive, indiscriminate and unguided use of synthetic pesticides caused losses of natural enemies and predators of FAW [18]. FAW also developed resistant to many of the effective synthetic insecticides and caused difficulty of finding new other pesticides [19]. In addition, the potential increment of secondary pest population outbreaks following the application of synthetic pesticides was found considerable [20].

Mismanagement of crops and crop pests strongly influenced the production and profitability of any crop enterprise. Therefore, there is a real need to manage crops from FAW effectively and efficiently to ensure the sustainability of any agriculture based enterprise. Locally, farmers use different management practices across countries, regions, and places which has no negative impact on the environment and human health. However, these farmers' best practices and experiences were not systematically documented and made available to farmers in different countries. Even if introduction of FAW to Africa is very recent, the farmers adopted different cultural management practices. In general, currently FAW is major maize production limiting constraint in major parts of Africa to which farmers are attempting to adopt various cultural practices. Therefore, this review is aimed at searching, documenting, summarizing and selecting best indigenous knowledge and practices to make available to farmers and farming stakeholders at large.

Importance of Indigenous Knowledge and Practices of Farmers

Indigenous knowledge of farmers encompasses the relationship of peoples with the spiritual, natural environment, use of natural resources, social organizations, values, institutions and laws which was a basis for scientific systems radically [21, 22]. It provides the basis for problem-solving strategies for local poor and underutilized resource communities. The traditional ways of agriculture is based on sustainability in long terms rather than maximizing yield in short terms, which is safe for environmental health [21].

Traditional peoples used indigenous knowledge which they acquire by nature that is safe to physical and socioeconomic environments of an agroecosystem [23]. Indigenous practices of farmers are considered as the kingpin of society, knowledge, and experience shared among farmers that usually passed from generation to generation. However, in Africa, the FAW introduced in 2016 and most of the farmers lack indigenous knowledge to manage it culturally [21].

In recent times, climate change has had observable impacts on the aspects of agriculture. Subsequently, plant protection, now a day, has become a serious matter, due to changes in climate, ecology, and biology of different insect pests [24]. These attributes caused the pest control mechanisms more difficult and complex. Climate change will change the biology, geographic distribution, the timing of life cycles, population dynamics, natural habitats, as well as structure and composition ecosystems of FAW [25, 26].

Moreover, the indiscriminate use of chemical pesticides in the agricultural field caused the development of pest-resistant, affected insect pollinators, natural enemies of crop pests, farm communities and lead to environmental degradation *via* polluting the soils and water. As the soil deteriorates, it is able to hold less water, causing farmers to strain already depleted water reservoirs [27].

Chandola *et al.* [28] reported that indigenous practices of pest management are effective without having a deteriorating effect on the environment and cheap. In general, the application of indigenous knowledge in agriculture minimizes the disturbance of the ecosystem by agrochemicals without losing the natural services of ecosystems and thereby sustaining plant growth, crop production and protection against crop pests. Intensification of indigenous knowledge among farmers through provision awareness, training, and information might be boosting its application particularly in tropical Africa [29]. Indigenous knowledge used by all farmer categories are varied based on application and attainability. Some of them are dominant, easily accessible, and safe for man, animals and thus promotes social cohesion due to the mechanism of their dissemination. There is also inefficiency in the dissemination of some indigenous knowledge methods. Integrating the important practices of farmers with contemporary research enabled the farmers to compete and respond to global opportunities and challenges. Grzywacz *et al.* [30] reported that the solution of crop protection where synthetic pesticide is unavailable, expensive and hazardous to the environment should emphasize on harnessing biological resources that are locally available, such as endemic natural enemies and indigenous pesticidal plant materials.

Indigenous Knowledge of Farmers and Their Management Practices against Fall Armyworm

The current method in practice in Ethiopia against FAW is cultural where 15% of the farmers practiced handpicking and killing of the larvae. The farmers of Kenya added soil to plant whorl, drenching tobacco extracts to damage plants, handpicking, and killing [13]. Kansiime *et al*. [31] reported that farmers in Zambia practiced handpicking of eggs, crushing of larvae and adding ash/sand to crop whorls. The farmers also destroy ratoon host crops [32]. The use of conventional tillage could disturb and reduce FAW than conservational tillage, but had negative side effects on soil [33] in contrary to the report of Megersa and Tamiru [18]. Early harvesting of maize ears allowed the escaping of FAW that could develop in the later season [34]. Therefore, late harvesting after maize is highly matured is better than early harvesting. Handpicking of egg masses and larvae, deep plowing to kill pupae in the soil and placing sand or ash in the whorls reduced the yield losses that occurred in the infested farms by FAW [7, 35]. Burning stubbles or crop residues after harvesting on infested fields could destroy the unhatched eggs, larvae, pupae and adults [36]. The FAW infested and caused severe damage to the late planted crops compared with the early planted. The cultural practices such as land preparation, harvesting before high pest population buildup, avoiding new crop planting during a heavy outbreak reduced yield losses due to FAW. The most relevant indigenous stem borer management was also adapted for FAW. The indigenous methods include the use of wood ash, cocoa pod that also increased P, K, Ca and Mg status of soil and pH [37- 40]. The farmers also practiced the combination of ash with conventional insecticides such as Mocap (ethopropos), Sevin, Gamalin or Kerosene and ash with water or Kerosene. They apply in the leaf whorl of the plant [37, 39].

Sole maize cropping systems offer a favorable environment for FAW to spread fast [41]. Sowing crops along with intercropping and multiple varieties of plants on the same farms land at the same time could increase the diversity of crops and reduced the rate of oviposition by confusing the FAW female moth, thereby helping in reducing the level of its infestation. Rotating maize with non-host crops such as sunflower and bean may be useful to minimize the invasion of FAW [42]. Push-pull technology that was developed against stem borers is also effective in the management of FAW. The technology comprises intercropping maize with drought-tolerant green leaf desmodium, (*Desmodium intortum* Mill.) and planting Brachiaria cv Mulato II as a border around farms by intercropping. Protection of maize is provided by semiochemicals that are emitted by the intercropped crop that repel (push) FAW, while those released by the border crop attract (pull) them [8]. Midega *et al*. [43] also reported that the climate-adapted push-pull could reduce more than 80% of FAW infestation and increased yield by 2.7 times when compared with the mono-cropping of maize plants. The leaf area of maize treated with sugar reduced damage by 35% and its infestation rates by 18%. This was mainly because of the fact that the applied sugar attracted and concentrated the natural enemies of FAW populations as reported from Honduras [44].

Mono-cropping of host plants of FAW offers a favorable environment for its dispersal to a new environment rapidly. Most subsistence farmers in Africa deter or kill pests *via* maize intercropping, handpicking and killing of caterpillars, application of wood ashes and soils to leaf whorls [45]. For instance, 39% of Kenya`s farmers practiced handpicking for FAW management [13].

Restricting transportation of infested plant materials to uninfected new areas and crop rotation with non-host crops like sunflower, bean and other varieties reduced pest pressure [46]. Intercropping, conservation agriculture, proper weed management, use of manure, compost, companion cropping, agroforestry, diversify food, shelter and alternative food sources for natural enemies could reduce the ability of FAW larvae to move between host plants [8, 18]. Tambo *et al*. [47] also reported that early planting, crop rotations, frequent weeding, and the push-pull approach were practiced by farmers against FAW in Africa.

Optimizing the time of crop planting and rotations helps the target crops to escape from FAW pest pressure. Such approaches work by creating asynchrony between the pest and critical crop growth stages [8]. The benefits of cultural and landscape management approaches often arise from the interplay of environmental factors across a range of spatial scales that disrupts and manage the pest at multiple stages throughout its life cycle [48, 49]. Cultural and ecological management practices are highly compatible with host plant resistance and biological control approaches [8]. The combination of pesticide application and handpicking of FAW larvae produced the highest yield gain by 125 percentages [47].

The subsistence farmers of Africa often lack the biological and ecological information that are necessary to develop better pest management through experimentation. Indigenous pest management knowledge is site-specific and should be the basis for developing integrated pest management (IPM) techniques [45]. Host plant resistance, biological control, application of chemical pesticides and landscape management options can be implemented as part of an effective Integrated Pest Management (IPM) strategy against Fall Armyworm (FAW). This practice is relevant for smallholders who lack financial resources to purchase improved seed, pesticides and other relatively expensive agricultural inputs in Africa [48, 50].

The cultural or landscape management practices that improve plant health to better withstand pest attack; also improve soil management and crop nutrition. It also includes optimizing and timing of crop planting and rotations to escape pest pressure. Manipulating the time of host plant by early planting and crop rotations helps to create asynchrony between the pest and critical crop growth stages [48, 49]. Cultural and ecological management options are highly compatible with host plant resistance and biological control approaches. In East Africa, farmers who fully implemented the Push-pull approach reduced FAW infestation and crop damage by 86%, with a 2.7-fold increase in yield relative to neighboring fields that did not implement the approach [43]. The method provided a suitable environment for the proliferation of predators and parasitoids of FAW [51].

The farmers also practiced mechanical methods such as deep plowing to expose pupae to predators and solar heat during land preparation, early monitoring to take early management action and mass trappings by pheromone traps to suppress moth populations. These resulted in reduction in egg laying by the moths and killed the hatching larvae [46]. Morales [52] also synthesized that preventative approach taken by traditional farmers is more effective, but lacks integration of ecological theory and cooperation among social and biological scientists to support mechanisms that advance their knowledge.

Summary, Conclusion and Future Directions

Fall armyworm is a polyphagous insect pest that devastates mostly maize, sorghum, and rice. It caused both yield and economic losses. To tackle this problem, many of the African farmers practiced their local knowledge against this pest. Different local practices of farmers were reviewed which is considered safe to the environment, effective and cheap. Indigenous knowledge of farmers is also the basis for problem-solving strategies for local poor and underutilized resource communities and scientific knowledge development. This indigenous knowledge is traditionally associated with the adaptive strategies to natural, physical, socio-economic environments of an agro ecosystem. In general, the application of indigenous knowledge in agriculture minimizes the disturbance of the ecosystem by agrochemicals. It also protects natural ecosystems services thereby sustaining crop production and reduces crop pest pressure.

Indigenous knowledge required integration methods of farmers' practices across countries to make it effective and efficient in application to ensure the sustainability of agricultural development. Incorporating such important and safe practices in crop protection is the best option to minimize the hurdle posed by agrochemicals on health and environments. The farmers' cultural practices such as handpicking, killing of larvae, placing sand or ash in plant whorls, drenching tobacco extracts, destroying ratoon host crops, early planting, deep plowing to kill pupae, burning stubbles after harvest of infested crops, intercropping and sowing multiple varieties and maize crop rotation with non-host crops managed FAW.

The integration of these indigenous knowledge required exhaustive review of the methods practiced across African farmers. These practices varied from location to location and pests to pests. Summarizing the techniques and synthesizing them in way that can be available to large number and broad areas of farmers and farming communities' plays great role in the advancement of FAW management. It also equally important for researchers and scientists involved in developing integrated FAW management. These cultural practiced employed by African farmers are compatible with the core components of IPM namely use of resistant crop varieties and biological control.

Therefore, research on FAW management should be developed based on indigenous knowledge and local conditions. In addition, in developing countries such as Africa, the subsistence farmers lack experience and exposure to the principles of the biological management that needs training and awareness creation. Implementation of effective management options requires farmers' awareness and cooperation among themselves in a region and also support of governments and other stakeholders' including strengthening of farmers' extension services.

References

1. FAO (Food and agricultural organizations of the United Nations). FAO Advisory Note on Fall Armyworm (FAW) in Africa. Key messages in: FAO Advisory Note on Fall Armyworm (FAW) in Africa. Rome, Italy, 2017, 1-30.
2. Pashley DP. Host associated genetic differentiation in fall armyworm (Lepidoptera: Noctuidae): A sibling species complex? Annals of the Entomological Society of America. 1986; 79:898-904.
3. Ashley TR, Wiseman BR, Davis FM, Andrews KL. The fall armyworm: a bibliography. Florida Entomologist. 1989; 72:152-202.
4. CABI (Colorado Association of Business Intermediaries). Fall armyworm (*Spodoptera frugiperda*). Datasheet. Spodoptera; Invasive Species Compendium. Wallingford, UK: CAB International, 2019. www.cabi.org/isc (accessed 22 July, 2019).
5. Cock MJW, Beseh PK, Alan GB, Cafá G, Crozier J. Molecular methods to detect *Spodoptera frugiperda* in Ghana, and implications for monitoring the spread of invasive species in developing countries. Sci Rep. 2017; 7:4103.
6. Lima MS, Silva PSL, Oliveira OF, Silva KMB, Freitas FCL. Corn yield response to weed and fall armyworm controls. Planta Daninha. 2010; 28(1):103-111.
7. Abrahams P, Bateman M, Beale T, Clottey V, Cock M, Colmenarez Y *et al*. Fall Armyworm: Impacts and implications for Africa, CABI, UK, 2017.
8. Prasanna BM, Huesing JE, Regina Eddy R, Peschke VM. Fall Armyworm in Africa: A Guide for Integrated Pest Management. Edn 1, CDMX: CIMMYT, Mexico, 2018, 1-107.
9. Belay D. Genetic variability and gene flow of the fall armyworm *Spodoptera frugiperda* (J.E. Smith) in the western hemisphere and susceptibility to insecticides. Ph. D thesis, University of Nebraska – Lincoln, USA, 2011.
10. Dhar T, Bhattacharya S, Chatterjee H, Senapati SK, Bhattacharya PM, Poddar P *et al*. Occurrence of fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) on maize in West Bengal, India and its field life table studies. Journal of Entomology and Zoology Studies. 2019; 7(4):869-875.
11. Villa-Castoreña MA, Catalán-Valencia EA. Determinación de estadioslarvales de *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) para la construcción deun modelo de predicción. *Folia Entomol*. Mex. 2004; 43:307-312.
12. Day R, Abrahams P, Bateman M, Beale T, Clottey V, Cock M *et al*. Fall armyworm: impacts and implications for Africa. Outlooks Pest management. 2017; 28:196-201.
13. Teshome Kumela, Josephine Simiyu, Birhanu Sisay, Paddy Likhayo, Esayas Mendesil, Linnet Gohole *et al*. Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (*Spodoptera frugiperda*) in Ethiopia and Kenya. International Journal of Pest Management, Int. J Pest Manag. 2018; 65(1):1-9.
14. Baudron F, Zaman-Allah MA, Chaipa, I, Chari, Newton. Understanding the factors influencing fall armyworm (*Spodoptera frugiperda* J.E. Smith) damage in African smallholder maize fields and quantifying its impact on yield. A case study in Eastern Zimbabwe. Crop Protection. 2019; 120:141-150.
15. FAO (Food and agricultural organizations of the United Nations). The Republic of Namibia: Fall armyworm impact and needs assessment. Rome, Italy. Licence: CC BY-NC-SA 3.0, IGO, 2018b, 1-52.
16. Rwomushana I, Bateman M, Beale T, Beseh P, Cameron K, Chiluba M *et al*. Fall armyworm: impacts and implications for Africa, CABI; Evidence Note Update, 2018. (accessed July 2019).
17. Harrison RD, Christian Thierfelder, Frédéric Baudron, Peter Chinwada, Charles Midega, Urs Schaffner *et al*.

Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. Journal of Environmental Management. 2019; 243:318-330.
18. Megersa Kebede, Tamiru Shimalis. Outbreak, Distribution and Management of fall armyworm, *Spodoptera frugiperda* J.E. Smith in Africa: The Status and Prospects. American Journal of Agricultural Research. 2019; 4:43.
19. Jarrod T, Hardke, Gus M, Lorenz B, Rogers Leonard. Fall Armyworm (Lepidoptera: Noctuidae) Ecology in Southeastern Cotton. Journal of Integrated Pest Management. 2015; 6(1):1-8.
20. Tscharntke T, Karp DS, Chaplin-Kramer R, Batáry P, DeClerck F, Gratton C *et al*. When natural habitat fails to enhance biological pest control–Five hypotheses. Biological Conservation. 2016; 204:449-458.
21. Kazmi T, Chaudhry AG, Ahmed A, Khan SE. Farmers Beliefs about Indigenous Farming Practices and Sustainable Agricultural Development. Pakistan J. Agric. Res. 2014; 27(1):51-57.
22. IUCN (Indigenous peoples and conservation initiatives). Indigenous peoples and sustainability: Cases and actions. Amsterdam, 1997, 1-364.
23. Bonny BP, Vijayaragavan K. Evaluation of indigenous knowledge systems of traditional rice farmers in India. J. Sust. Agric. 2001; 18(4):39-51.
24. Pradhan K, Zigme Y, Avishek S, Vara PC. Identification and Documentation of Indigenous Technological Knowledge (S) Regarding Pest Control Methods in Agriculture. International Journal of Agriculture Sciences. 2017; 9(38):4580-4584.
25. Ram, Mange. Motherhood International Journal of Multidisciplinary Research & Development. 2016; 1(2):37-42.
26. Das T, Pierce DW, Cayan DR, Vano JA, Lettenmaier DP. The importance of warm season warming to western U.S. streamflow changes. Geophysical Research Letters. 2011; 38(23):1-5.
27. Pace K. Indigenous Agriculture and Sustainable Food, 2015. https://sustainablefoodcenter.org/latest/gardening/indigenous-agriculture-and-sustainable-food
28. Chandola M, Rathore S, Kumar B. Indigenous pest management practices prevalent among hill farmers of Uttarakh and Manish. Indian Journal of Traditional Knowledge. 2011; 10(2):311-315.
29. Mkindi G, Ndakidemi P, Mbega A, Ernest R. Roles of insect pollinators, natural enemies and farmers' knowledge on improving bean production in tropical Africa. J Bio. and Env. Sci. 2017; 11(4):229-239.
30. Grzywacz D, Stevenson PC, Mushobozi WL, Belmain SR. The use of indigenous ecological resources for pest control in Africa. Food Security. 2014; 6:71-86.
31. Kansiime MK, Mugambi I, Rwomushana I, Nunda W, Lamontagne- Godwin J, Rware H *et al*. Farmer perception of fall armyworm (*Spodoptera frugiderda* J.E. Smith) and farm- level management practices in Zambia. Pest Manag Sci. 2019; 75:2840-2850.
32. All JN. Fall armyworm (Lepidoptera: Noctuidae) infestations in no-tillage cropping systems. Florida Entomologist. 1988; 71:268-272.
33. Chimweta, Moreblessing, Nyakudya, Innocent Wadzanayi, Jimu, Luke *et al*. Fall armyworm [*Spodoptera frugiperda* (J.E. Smith)] damage in maize: management options for flood-recession cropping smallholder farmers. International Journal of Pest Management. 2019, 1-13. https://doi.org/10.1080/09670874.2019.1577514.
34. Mitchell ER. Relationship of planting date to damage by earworms in commercial sweet corn in north central Florida. Florida Entomologist. 1978; 61:251-255.
35. Capinera JL. Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Insecta: Lepidoptera: Noctuidae). Entomology and Nematology, Natural Enemies, University of Florida, 2014. (Accessed 23 December, 2019).
36. Fenta Assefa. Status of Fall Armyworm (*Spodoptera frugiperda*), Biology and Control Measures on Maize Crop in Ethiopia: A Review: International Journal of Entomological Research. 2017; 06(02):75-85.
37. Oben EO, Ntonifor NN, Kekeunou S, Abbeytakor MN. Farmers' knowledge and perception on maize stem borers and their indigenous control methods in south western region of Cameroon. Journal of Ethnobiology and Ethno medicine. 2015; 11(77):1-13.
38. Adu-Dapaah HK, Cobbinah J, Asare EO. Effect of cocoa pod ash on the growth of maize. J Agric Sci. 1994; 122:31-3.
39. Owolabi O, Adeleye, A, Oladejo, BT, Ojeniyi, SO. 2003. Effect of wood ash on soil fertility and crop yield in Southwest Nigeria. Nigerian J. Soil Sci. 2003; 13:55-60.
40. Pal LR. Effect of source and rate of nitrogen and phosphorus on yield nutrient uptake and apparent fertilizer nutrient recovery by maize in the Southern Guinea savanna. J Agr. Sci Tech. 1991; 1:21-4.
41. Assefa F, Ayalew D. Status and control measures of fall armyworm (*Spodoptera frugiperda*) infestations in maize fields in Ethiopia: A review. Journal Cogent Food and Agriculture. 2019; 5(1):1-16.
42. FAO (Food and agricultural organizations of the United Nations). Briefing Note on FAO Actions on Fall Armyworm in Africa 31 January 2018. In: Briefing Note on FAO Actions on Fall Armyworm in Africa. Rome, Italy, 2018, 1- 6.
43. Midega CAO, Pittchar J, Pickett JA, Hailu G, Khan ZR. A climate-adapted push-pull system effectively controls fall armyworm, *Spodoptera frugiperda* (J.E. Smith), in maize in East Africa. Crop Protection. 2018. 105:10-15.
44. Canas LA, O'Neil RJ. Applications of sugar solutions to maize, and the impact of natural enemies on Fall Armyworm. International Journal of Pest Management. 1998; 44(2):59-64.
45. Abate T, Van Huis A, Ampofo J. Pest management strategies in traditional agriculture: An African perspective. Annual Review of Entomology. 2000; 45(1):631-659.
46. Kinyua ZM. Interim Recommendations for Management of Fall Armyworm in Kenya. http://www.kalro.org/arlri/sites/default/files/. 2017 (accessed 15 December, 2019).
47. Tambo JA, Day RK, Lamontagne-Godwin J, Silvestri S, Beseh PK, Oppong-Mensah B *et al*. Tackling fall armyworm (*Spodoptera frugiperda*) outbreak in Africa: an analysis of farmers' control actions. International Journal of Pest Management. 2019, 1-13.
48. Martin EA, Seo B, Park CR, Reineking B, Steffan-Dewenter I. Scale-dependent effects of landscape

composition and configuration on natural enemy diversity, crop herbivory, and yields. Ecological Applications. 2016; 26(2):448-462.
49. Veres A, Petit S, Conord C, Lavigne C. Does landscape composition affect pest abundance and their control by natural enemies? A review. Agriculture, Ecosystems and Environment. 2013; 166:110117.
50. Wyckhuys K, O'Neil RJ. Social and ecological facets of pest management in Honduran subsistence agriculture: Implications for IPM extension and natural resource management. Environment Development and Sustainability. 2010; 12(3):297-311.
51. Khan ZR, Midega CAO, Bruce TJA, Hooper AM, Pickett JA. Exploiting Phytochemicals for developing a 'push–pull' crop protection strategy for cereal farmers in Africa. Journal of Experimental Botany. 2010; 61:4185-4196.
52. Morales H. Pest Management in Traditional Tropical Agroecosystems: Lessons for Pest Prevention Research and Extension. Integrated Pest Management Reviews. 2002; 7(3):145-163.