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Review Paper

The effects of major pests of banana in Tanzania and their managements in relation to climate change

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Abstract

Pests have played a major role in reducing banana yields in Tanzania. Despite the fact that banana is important as staple food and cash crop, a 30 to 100% yield decline has been reported in the country due to weevil and parasitic nematodes. This review aimed at discussing the effects and management options for major banana pests in relation to climate change using online resources. The review identified the consequences due to climate change as increased pest's development and range alteration, interference of the temporal and geographical pest harmonization, increased damage potential from alien species, promotion of minor pest to major pest, loss of host-plant resistance and failure of biological control, these affects agricultural production. This suggests that, management options should be altered depending on the changes occurring in agricultural systems, in order to ensure sustainable solution to both weevil's and parasitic nematode's challenges.

Keywords: Cosmopolites sordidus, environmental conditions, Rodopholus similis, Pratylenchus goodeyi, Pratylenchus coffeae, yield decline.

Introduction

General Background: Pests have played a major role in reducing banana (bananas and plantains) production in Tanzania[1-3]. However, banana crop has remained the first staple food and the main source of carbohydrate consumed by over 4.0 million people in Kagera, Arusha, Kilimanjaro and Mbeya[4,5]. The production of this crop holds a great promise for income generation and food security to smallholder farmers, due to its ability to produce fruits throughout the year[6,7]. The crop is linked with cultural heritage to some ethnic groups such as the Haya, the Chagga and the Nyakyusa[8-10]. It is estimated that the crop provides smallholder farmers with highest annual income of about US$1,244[11,12]. Despite of banana's economic and social importance, its production has declined to less than 7t/ha[13-15]. The decline is attributed to emergence of banana pests[2,3,16,17].

Climate change is reported to alter the biotic and abiotic conditions and destroy ecological barriers, thereby affecting the distribution of parasites and their hosts [18,19]. The alteration leads to range expansion or range contraction and this process continues, affecting agricultural production[20-24]. Other consequences due to climate change are reported to be accelerated pest development, disruption of the temporal and geographical harmonization of pests, increased damage potential from alien species, loss of host-plant resistance and failure of biological control[25-27]. Therefore the status and economic importance of different pests will vary depending on the agro-ecosystem and climate changes[28,29]. This justifies the truth that, a minor pest of today is a major pest in the future[27,30].

Management of these pests has remained a serious challenge for banana smallholder farmers due to the effects of climate change. Thus, understanding the influence of climate change on major and minor pest population dynamics, crop phenologies is an important factor for proper management decision making. This review therefore, aimed at discussing the effects and the management of major banana pest in relation to climate change. The information gathered will help in banana pest management decision and identify research areas.

Major banana pests

In Tanzania, major banana pests that are considered of economic importance are banana weevils (*Cosmopolites sodidus*)[2,16,31] and nematodes (e.g. *Rodopholus similis, Pratylenchus goodeyi* and *Pratylenchus coffeae*)[2,3,32]. Far back in the 1970's it was reported that banana weevils and parasitic nematodes have been the major cause of banana yield decline[13]. These pests are reported to reduce banana yields by 30 to 100%[33-36].

However, there are minor pests like Mole rat *(Tachyoryetes splendens*) which is one of the most devastating underground rodents that attack roots and corms of banana[37]. Baboons feed on banana fruits more frequently leading to yield reduction[38], and Silvering Thrips (*Hercinothrips bicinctus* Bagn.) which damages the fruits.

Corm weevil *(Cosmopolites sordidus):* The banana and plantains corm borer, (*Cosmopolites sordidus*) (Germar) (Coleoptera: Dryophthoridae), is the leading insect pest of the crop in Tanzania[16,15,31]. Huge counts of banana weevil have been documented in many regions of Tanzania, such as Kagera, Arusha, Kilimanjaro and Mbeya regions[3]. The pest is thought to be native in the Indo-Malaysian region[39,40] .*Cosmopolites sordidus* is narrowly oligophagous, adults are active during the night and attracted to the banana plants by volatiles proceeding from fresh and decaying banana material[41]. The pest is commonly associated with crop residues and banana mats since it prefers corm odours[42,43]. *Cosmopolites sordidus* larvae can infest any stage of development of a plant, feed and develop inside the shoot by forming galleries or tunnels. Symptoms due to *C. sordidus* are yellowing of leaves, pseudostem weakness, reduced bunch formation and development, or presence of defective bunches. Serious weevil attacks may lead to massive toppling of bananas.

Influence of climate change on weevil pest

For insects like weevil, the capability to complete their life cycle is a product of victorious adaptation to their host plants and to the climatic settings in which they are found[44]. Their survival, reproduction, abundance and dissemination are highly influenced by the environmental conditions[44,45]. Different factors such as feeding materials, altitude, rainfall distribution, temperature, banana cultivars and volatiles, soil status and types, banana management practices and farming systems influences weevil prevalence[46-49]. Temperature is reported to be the dominant factor for weevil's life cycle completion[46,50-52]. It affects both the duration of the weevil life cycle and adult activities, which in turn disturb the economic impact of this pest and the way in which it is controlled[52]. This agrees with a report by FAO[53] that, banana growing areas in Ecuador displayed the highest number of generations per annum due to provisional of better conditions for the development of C. sordidus in terms of temperature. Close synchrony of the weevil's life cycle, plant phenology and agro-ecological zone determines the magnitude of crop damage[46,54]. Therefore, understanding the interaction between weevil, banana plant and environmental conditions is of prime importance in designing proper management options.

Effects of banana weevil

The banana weevil's (*Cosmopolites sordidus*) damage is unique and can be identified straight by observation of the galleries in the rhizome of banana plant[55]. The damage is caused by larvae feeding inside the corm producing tunnels, resulting in reduced nutrient and water uptake, premature leaf senescence and reduced bunch filling[56,57]. The galleries deteriorate the plant and arrange for entry points for secondary pests, which quicken the decomposition of the rhizome tissues, and toppling[56]. It has been reported that, yield losses due to banana weevil increases with crop cycle[56]. In severe cases, through sucker death, toppling and snapping, the pest can cause banana yield losses of up to 100%[34,35,43].

Management of banana weevil in relation to climate change

For effective management of weevil, the understanding of its biology is inevitable; this is because their life cycle's are temperature dependent[58]. It has been reported that, the most damaging stage of banana weevil is the larvae stage which takes place in the corm[56,57]. Adult weevils are free living and feeds on plant tissues or crop debris with negligible damage[59]. Therefore management options should define the weevil stage to be targeted, the geographical location and environmental conditions. This is because management methods are likely to vary from one ecological-system to another and reflect the importance and pest status. Moreover, no single method is effective in managing the pest therefore, an integrated strategies for the management of the weevil is required. The following are some of the management options for banana weevil based on life stage of the weevil.

Management of adult weevil: i. Crop sanitation, i.e. devastation of crop residues, reducing the number of suckers removal of mulches around the mat area has been reported to lower banana weevil damage by removing adult refuges and breeding sites[16,57,60]. ii. Use of pheromone trap[61]. iii. Local trapping using pseudostem[62,63].

Management of larvae: i. Remove the entire plants after harvest, cut the corm and pseudo-stems of harvested plants into small pieces and scatter them to dry[16,59,64]. ii. For establishment of a new field use seedlings from healthy fields to avoid transfering larvae[65]. iii. Hot-water treatment[58,65].

Management of both adult weevil and larvae: i. Crop rotation with non host crops[66]. ii. Ensure proper fertilization, irrigation and weed removal[67,68]. iii. The use of resistant cultivars[69,70].

Therefore, more researches are needed on biological behaviors of adult and larvae of this pest under dynamic agro-ecological conditions for the purpose of providing site specific management recomendations.

Nematodes: Nematodes (parasitic and non-parasitic) are small, worm-like members of the animal kingdom adopted to live in almost every habitat[71-74]. Plant-parasitic nematodes spend either all or part of their life in the soil[71,74,75]. *Radopholus similis* (endo-parasite), *Pratylenchus goodeyi* (endo-parasite) and *Pratylenchus coffeae* (endo-parasite) are among the major banana nematode pest reported to cause significant yield losses in Tanzania[3,73,74,76,77]. Generally *Radopholus similis* is reported to be the most damaging specie across all banana growing regions in East Africa[2,75]. The specie was first reported by Cobb in 1891 in New South Wales in necrotic tissues of *Musa sp*. from Fiji[74,78].

Pratylenchus goodeyi is indigenous to Tanzania but *Pratylenchus coffeae* was first reported in Zanzibar islands in 1999 and confined to the humid lowlands[76,79]. Plant-parasitic nematodes have stylets, spear-like mouthparts that pierce cells and allow nematodes to feed on their hosts[71]. Nematodes have limited movement, but can be spread over long distances through flooding, equipment, shoes, infected roots and suckers[74,80].

Symptoms due to nematodes infestation are black or purple necrosis of epidermal or cortical tissue of roots, cavities formation, stunted growth, reduced size and number of leaves, yellowing or greenish-yellow bands along the leaf blades and reduced bunch weight[71,81]. Infected plants are also prone to wilting during moderately hot days, distortion of roots and sometimes bifurcation occurs after heavy nematode infections[82].

Effects due to nematodes

Damage inflicted by nematodes depends on factors, such as their population density, the virulence of the species, host resistance or tolerance, climate, water availability, soil conditions, soil fertility, and the presence of other pests and diseases[73,83,84]. Yield losses of more than 50% are reported to be the result of nematode infestation[2,73,75]. Such losses are attributed to, weakened root systems, limited nutrient and water uptake, toppling of plants before harvest[73,75,85]. The infestations due to nematodes are compromise plant resistance to other soil-borne plant pathogens[86], which enter the plant tissues through areas damaged by nematodes leading to loss in resistance in some banana genotypes[73,87].

Influence of climate change on nematode pest

Plant-parasitic nematode incidence, population densities and associated damage on banana plant, has been reported to be influenced by climate change[27,87]. Song et al.[88] reported temperature as the most important determining factor for nematode abundances under different ecological conditions. This agrees with Bakonyi et al.[89] who observed that increase in temperature affected soil nematode species diversity, community structure, trophic structure and species dominance. Temperature affects development and behavior of plant parasitic nematodes[74,90], each species having optimum temperature for movement, metabolic rates, penetration, feeding, survival and reproduction[91-93].

Other factors reported to influence nematode pest are the introduction of new banana cultivars and the intensification of cropping systems in the face of climate change[87,94,95]. Moreover, changes in water regimes influence nematode's abundance, community structure and the duration of nematode parasitic event, i.e. their reproduction, infection phase and the disease outcome[83,88].

Management options for nematodes in relation to climate change

Management of parasitic nematode has remained a serious challenge for banana smallholder farmers in Tanzania due to lack of improved integrated pest management techniques, limited use of quality inputs, inadequate access to value-added cultivars and poor pest diagnostics approaches. *Pratylenchus goodeyi* and *Pratylenchus coffeae* are lesion nematode whereas *Radopholus similis* burrowing nematodeare bothmigratory endo-parasite in all life stages[71,74,87].

Management practices: i. The nematode load in the soil can be reduced with crop rotation[74,82,89]. ii. Fallowing for six months[71,82]. iii. Exposure of banana planting material to direct sunlight for a period of two weeks[71]. iv. Cover crops that are not susceptible to the nematode, such as *Crotalaria spp*., *Raphanus sativus* and *Tagetes patula* can be sown[82]. v. The use of disease-free planting materials[28,74]. vi. The use of chicken and cattle manure at rate of 40 MT ha^{-1}or more in combination with chemical fertilizers is reported to suppress parasitic nematodes[82,89]. vii. Hot water treatment; the infected plants are dipped in a hot water bath for about 30 minutes at 53-55^{o}C, this eliminates almost all nematodes without harming the plant[71,81,95]. viii. The use of resistant banana cultivars[71,74,95]. ix. De-suckering; it has been reported that nematode densities and associated root necrosis and damage are higher in roots of banana suckers than in mother plants[90], this suggests that de-suckering reduces nematode building up for the next crop cycle. x. Improvement of soil conditions by applying good agronomic practices reduces the population density of parasitic nematodes; McSorley et al.[94] and Wang and Hooks[95] reported that in perennial cropping systems there is a great opportunity of establishing parasitic nematode's natural enemies than in annual systems where there are continuous soil disturbances. xi. The use of quarantine systems, there must be an authorization for the transport of suckers and rhizomes between local production areas to restrict the spread of nematodes[82]. xii. Intercropping, banana farms can be intercropped with crops such as vegetables, coffee (*Coffea arabica),* maize (*Zea mays*) and cassava (*Manihot esculenta*)[82].

Therefore, researches should focus on modelling all management aspects like host plant resistance, biological control, chemical control and cultural practices based on temperature in order to ensure sustainable solution to parasitic nematode's challenges. Again, due to differences in adaptation, plant parasitic nematodes require different management strategies for their effective control, researches should focus on identification of specific control measures.

Conclusion

Tanzania as other banana producing countries is faced by climate change impacts. Solution to solve pest challenges is possible through concerted efforts by the researchers, farmers, Government, and non-Governmental organizations.

References

1. Swennen, R., Blomme, G., VanAsten, P., Lepoint, P., Karamura, E., Njukwe, E., Tinzaara, W., Viljoen, A., Karangwa, P., Coyne, D. and Lorenzen, J. (2013). Pages 85-104 in: Agroecological intensification of farming systems in the East and Central African Highlands. Eds: B. Vanlauwe, P. van Asten and G. Blomme. Routledge Publishers, Oxon, UK and New York, USA. ISBN: 978041553273-0 (2013).
2. Treverrow, N., Peasley, D. and Ireland, G. (1992). Banana weevil borer, a pest management handbook for banana growers. Banana Industry Committee, New South Wales Agriculture, NSW, Australia.
3. Kilimo Trust (2012). Analysis of the Banana Value Chains in Tanzania and Uganda. Consumption, Productivity and Challenges. VCA report in improving the banana value chain in the EAC Region.
4. Spilsbury, J., Jagwe, J., Wanda, K., Nkuba, J., & Ferris, R. S. B. (2004). Evaluating the marketing opportunities for banana and its products in the principal banana growing countries of ASARECA. ASARECA monograph, No. 7.
5. SAGCOT (2014). Integrated Pest Management Plan (IPMP). Southern Agricultural Growth Corridor of Tanzania (SAGCOT) Investment Project. Prime Minister's Office, Government of Tanzania.
6. Makundi, R. H. and Massawe, W.A. (2010). Community-Based Rodent Pest Management in Kilimanjaro Region, Tanzania. Technical Report December 2010. Pest Management Centre, Sokoine University of Agriculture & National Rodent Control Centre- Ministry of Agriculture, FoodSecurity and Cooperatives.
7. Nayar, N. M. (2010). The Bananas: Botany, Origin, Dispersal. *Horticultural reviews*, 36(3), 117-164. .
8. Simmonds, N.W. (1966). Bananas. 2nd edition. Longmans, London.
9. Maruo, S. (2007). Development of the plantain-based culture of the Nyakyusa of Southern Tanzania. *African Study Monographs*, 34, 21-38.
10. Maruo, S. (2002). Differentiation of subsistence farming patterns among the Haya banana growers in northwestern Tanzania. *African Study Monographs*, 23(4), 147-175.
11. Kilimo Trust (2012). Analysis of the Banana Value Chains in Tanzania and Uganda. Consumption, Productivity and Challenges. VCA report in improving the banana value chain in the EAC Region.
12. Numbeo, (2018). Food Prices in Tanzania. https://www.numbeo.com/cost-of-living/country_result.jsp? country=Tanzania. *Newsletter*.
13. Bujulu, J., Uronu, B. and Cumming, C.N.C., (1983). The Control of Banana Weevils and Parasitic Nematodes in Tanzania. *East African Agricultural and Forestry Journal*, 49(1-4), 1–13. doi:10.1080/00128325.1983.11663418.
14. FAOSTAT (2014). Food and Agricultural Commodities Production/Countries by Commodity. Accessed date; 31 October, 2018.
15. Nkuba, J., Tinzaara, W., Night, G., Niko, N., Jogo, W., Ndyetabula, I., Mukandala, L., Privat, N., Niyongere, C., Gaidashova, S., Ivan, R., Opio, F. and Karamura, E. (2015). Adverse impact of Banana Xanthomonas Wilt on farmers' livelihoods in Eastern and Central Africa. *African Journal of Plant Science*, 9, 279-286.
16. Gold, C.S., Pena, J.E., and Karamura, E.B. (2001). Biology and integrated pest management for the banana weevil Cosmopolites sordidus (Germar) (Coleoptera: Curculionidae). *Integrated Pest Management Reviews*, 6, 79–155.
17. Makundi, R.H. and Massawe, W.A. (2010). Community-Based Rodent Pest Management in Kilimanjaro Region, Tanzania. Technical Report. December 2010. Pest Management Centre, Sokoine University of Agriculture & National Rodent Control Centre-Ministry of Agriculture, FoodSecurity and Cooperatives.
18. Dobson, A., Kutz, S., Pascal, M. and Winfree, R. (2003). Pathogens and parasites in a changing climate. In: Hannah L and Lovejoy T, Eds. Climate change and biodiversity: synergistic impacts. Advances in applied biodiversity science. Center for Applied Biodiversity Science, Conservation International Washington, DC; 4: 33-38.
19. Hoberg, E.P. (2005). Coevolution and biogeography among Nematodirinae (Nematoda: Trichostrongylina) Lagomorpha and Artiodactyla (Mammalia): exploring determinants of history and structure for the northern fauna across the Holarctic. *Journal of Parasitology*, 91, 358-69.
20. Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.M., Hoegh-Guldberg, O. and Bairlein, F. (2002). Ecological responses to recent climate change. *Nature*, 416, 389–395. doi:10.1038/416 389a.
21. Parmesan, C. and Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*; 421, 37–42
22. McSorley, R., Wang, K.H. and Church, G. (2007). Suppression of root-knot nematodes in natural and agricultural soils. *Applied Soil Ecology*; 39, 291-298.
23. Chemura, A., Kutywayo, D., Mahlatini, P., Nyatondo, U. and Rwasoka, D. (2013). Assessing the impact of climate change on the suitability of rainfedflu-cured tobacco (*Nicotianatobacum*) production in Zimbabwe. 1st Climate Science Symposium of Zimbabwe. Cresta Lodge, Harare: MSD/UNDP/UNOCHA; pp. 1–14.

24. Kambrekar, D.N., Guledgudda, S.S., Katti, A. and Mohankumar, (2005). Impact of climate change on insect pests and their natural enemies. *Karnataka J. Agric. Sci*; 28(5), 814-816.

25. Burdon, J.J., Thrall, P.H. and Ericson, L. (2006). The current and future dynamics of disease in plant communities. *Annual Review of Phytopathology*; 44, 19-39.

26. Garrett, K.A., Dendy, S.P., Frank, E.E., Rouse, M.N. and Travers, S.E. (2016). Climate change effects on plant disease: genomes to ecosystems. *Annual Review of Phytopathology*; 44, 201–21.

27. World Bank (2009). Agricultural Development under a Changing Climate: opportunities and Challenges for Adaptation. Agriculture and Rural Development & Environment Department. Joint Discussion Paper.

28. Jacobsen, K. (2009). Host status of twelve commonly cultivated crops in the Cameroon Highlands for the nematode Pratylenchusgoodeyi. *International Journal of Pest Management*; 55(4), 293-298. DOI: 10.1080/09670 870902890140.

29. Bergé, J.B., and Ricroch, A.E., (2010). Emergence of minor pests becoming major pests in GE cotton in China: What are the reasons? What are the alternatives practices to this change of status?. *GM Crops*, 1(4), 214-219.

30. War, A.R., Taggar, G.K., War, M.Y. and Hussain, B. (2016). Impact of climate change on insect pests, plant chemical ecology, tritrophic interactions and food production. *International Journal of Clinical and Biological Sciences*, 1(2), 16-29.

31. Mbwana, A.A.S. and Rukazambuga, N.D.T.M. (1999). Banana IPM in Tanzania. Pp. 237-245 in Mobilizing IPM for sustainable banana production in Africa. (E. Frison, C.S. Gold, E.B. Karamura and R.A. Sikora, eds). Proceedings of a workshop on banana IPM, Nelspruit, South Africa, 23-28 November 1998, INIBAP, Montpellier, France.

32. Sikora, R.A., Bafokuzara, N.D., Mbwana, A.S.S., Oloo, G.W., Uronu, B., Sheshu, and Reddy, K.V. (1989). Interrelationship between banana weevil, root lesion nematode and agronomic practices, and their importance for banana decline in the United Republic of Tanzania. *FAO Plant Protection Bulletin No*., 37(4), 151-157.

33. Sengooba, T. (1986). Survey of banana pest problem complex in Rakai and Masaka Districts in Uganda. Namulonge, Uganda: Namulonge Research Station; August 1986: Preliminary trip report.

34. Koppenhofer, A.M., Seshu, Reddy, K.V., and Sikora, R.A. (1994). Reduction of banana weevil populations with pseudostem traps. *International Journal of Pest Management*; 40, 300-304.

35. Speijer, P.R., KaJumba, C. and Ssango, F. (1999). East African highland banana production as influenced by nematodes and crop management in Uganda. *International Journal of Pest Management*; 45, 41-49.

36. Wairegi, L.W.I., Van Asten, P.J.A., Tenywa,M.M. and Bekunda, M.A. (2010). Abiotic constraints override biotic constraints in East African highland banana systems. *Field Crops Research*, 117, 146-153

37. Makundi, R.H. and Massawe, W.A. (2010). Community-Based Rodent Pest Management in Kilimanjaro Region, Tanzania., Technical Report. December 2010. Pest Management Centre, Sokoine University of Agriculture & National Rodent Control Centre- Ministry of Agriculture, FoodSecurity and Cooperatives.

38. Naughton, T.L. (1998). Predicting patterns of crop damage by wildlife around Kibale National Park, Uganda. *Conservation Biology*; 12, 156–169.

39. Zimmerman, E.C. (1968). Rhynchophorinae of southeastern Polynesia. *Pac. Insects*; 10, 47–77.

40. Clausen, C. P., Bartlett, B. R., De Bach, P., Goeden, R. D., Legner, E. F., McMurtry, J. A., ... & Rosen, D. (1978). Introduced parasites and predators of arthropod pests and weeds: a world review [Biological control, economic plants]. Agriculture Handbook-US Dept. of Agriculture (USA). no. 480.

41. Mwaitulo, S., Haukeland, S., Sæthre, M.G., Laudisoit, A. and Maerere, A.P. (2011). First report of entomopathogenic nematodes from Tanzania and their virulence against larvae and adults of the banana weevil Cosmopolites sordidus (Coleoptera: Curculionidae). *International Journal of Tropical Insect Science*; 31(03), 154–161. doi:10.1017/s1742758411000294.

42. Cerda, H., Lopez, A., Sanoja, O., Sanchez, P., and Jaffe, K. (1996). Atracccionolfactiva de Cosmopolites sordidus Germar (1824) estmuladopor volatiles originados en Musaceas de distintasedades y variedadesgenomicas. Agronomia Tropica; 46: 413-429.

43. Gold, C.S., Night, G., Ragama, P.E., Kagezi, G.H., Tinzaara, W. and Abera, A.M.K. (2004). Field distribution of banana weevil (Cosmopolites sordidus (Germar)) adults in cooking banana stands in Uganda. *Insect Science and its Application*; 24, 242–248.

44. Bale, J.S., Masters, G.J., Hodkinson, I.D., Awmack, C., Bezemer, T.M., Brown, V.K. and Whittaker, J.B., (2002). Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. *Global Change Biology*, 8(1), 1–16 doi:10.1046/j.1365-2486. 2002.00451.x

45. Agrios G. (1997). Plant Pathology. 4th Edition. California, USA, Academic Press.

46. Njau, N., Mwangi, M., Gathu, R., Mbaka, J. and Muasya, R. (2011). Banana weevil (Cosmopolites sordidus) reduces availability of corms for seedling production through macropropagation technology. *Journal of Animal & Plant Sciences*; 12(1), 1537-1542.

47. Rannestad, O.T., Sæthre, M. and Maerere, A.P. (2011). Migration potential of the banana weevil Cosmopolites sordidus. *Agricultural and Forest Entomology*; 13, 405–412.

48. Mwaitulo, S., Haukeland, S., Sæthre, M.G., Laudisoit, A. and Maerere, A.P. (2011). First report of entomopathogenic nematodes from Tanzania and their virulence against larvae and adults of the banana weevil Cosmopolites sordidus (Coleoptera: Curculionidae). *International Journal of Tropical Insect Science*; 31(03). 154–161. doi:10.1017/s1742758411000294.

49. Were, E., Nakato, G.V., Ocimati, W., Ramathani, I., Olal, S. and Beed, F. (2015). The banana weevil, Cosmopolites sordidus (Germar) is a potential vector of Xanthomonas campestrispv. Musacearum in bananas. *Canadian Journal of Plant Pathology*; 37, 1-8.

50. Inward, D.J., Wainhouse, D. and Peace, A. (2012). The effect of temperature on the development and life cycle regulation of the pine weevil Hylobiusabietis and the potential impacts of climate change. *Agricultural and Forest Entomology*; 14(4), 348–357. doi:10.1111/j.1461-9563.2012.00575.x.

51. Tonnang, E.Z.H., Carhuapoma, P., Juarez, H., Gonzales, J.C., Sporleder, M., Simon, R. and Kroschel, J. (2013). Insect Life Cycle Modeling: A Software Package for Developing Temperature-Based Insect Phenology Models with Applications for Regional and Global Analysis of Insect Population and Mapping. *International Potato Center, Lima, Peru*; 193.

52. Inward, D.J. (2018). The influence of a changing climate on development and life cycle in the pine weevil, Hylobiusabietis. Newsletter forest research. https://www. forestresearch.gov.uk.

53. FAO (2016). Ecuador's Banana Sector under Climate Change. An economic and biophysical assessment to promote a sustainable and climate-compatible strategy. *Food and Agriculture Organization of the United Nations Rome.*

54. Bale, J.S., Masters, G.J., Hodkinson, I.D., Awmack, C., Bezemer, T.M., Brown, V.K. and Whittaker, J.B. (2002). Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. *Global Change Biology*, 8(1), 1–16 doi:10.1046/j.1365-2486. 2002.00451.x

55. Dassou, A.G., Carval, D., Dépigny, S., Fansi, G. and Tixier, P. (2015). Ant abundance and Cosmopolites sordidus damage in plantain fields as affected by intercropping. *Biological Control*; 81, 51–57. doi:10.1016/j.biocontrol.2014.11.008.

56. Rukazambuga, N.D.T.M., Gold, C.S. and Gowen, S.R. (1998). Yield loss in East African highland banana (Musa spp., AAA-EA group) caused by the banana weevil, Cosmopolites sordidus Germar. *Crop Protection*; 7, 581–589.

57. Masanza, M., Gold, C.S., Van Huis, A., Ragama, P.E. and Okech, S.H.O. (2005). Effect of crop sanitation on banana weevil Cosmopolites sordidus (Germar) (Coleoptera: Curculionidae) populations and crop damage in farmers' fields in Uganda. *Crop Protection*; 24, 275-283.

58. Gold, C. S., & Messiaen, S. (2000). The banana weevil Cosmopolites sordidus Musa pest fact sheet No 4 INIBAP. Montpellier, France.

59. Treverrow, N., Peasley, D. and Ireland, G. (1992). Banana weevil borer, a pest management handbook for banana growers. Banana Industry Committee, New South Wales Agriculture, NSW, Australia.

60. Masanza, M. (2003). Effect of crop sanaitation on banana weevil Cosmopolites sordidus (Germar) populations and associated damage. Ph.D Thesis, Wagenigen University; pp 164.

61. Budenberg, W.J., Ndiege, J.O. and Karago, F.W. (1993). Evidence for volatile male produced pheromone in banana weevil Cosmopolites sordidus. *Journal of Chemical Ecology*; 19, 1905-1916.

62. Mitchell, G.A. (1978). The Estimation of Banana Borer Population and Resistance Levels. Windward Banana Research and Development Technical Bulletin 2.

63. Tinzaara, W., Gold, C.S., Kagezi, G.H., Dicke, M., Van Huis, A., Nankinga, C.M., Tushemereirwe, W. and Ragama, P.E. (2005). Effects of two pheromone trap densities against banana weevil, Cosmopolites sordidus, populations and their impact on plant damage in Uganda. *Journal of Applied Entomology*; 129, 265-271.

64. Abera, A.M.K. (1997). Oviposition preferences and timing of attack by the banana weevil (Cosmopolites sordidus Germar) in East African highland banana (*Musa spp*.). M.Sc. thesis, Makerere University. Kampala, Uganda.

65. Gold, C.S., Night, G., Abera, A. and Speijer, P.R. (1998a). Hot-water treatment for control of banana weevil, Cosmopolites sordidus Germar (Coleoptera: Curculionidae) in Uganda. *African Entomology*; 6, 215-221.

66. Seshu, Reddy, K.V., Koppenhöfer, A.M. and Uronu, B. (1993). Cultural practises for the control of the banana weevil. In Gold, C.S. & Gemmil, B. (Eds.) Biological and Integrated Control of Highland Banana and Plantain Pests and Diseases. Proceedings of a Research Coordination Meeting in Cotonou, Benin: IITA; 140-146.

67. Ssali, H., Mcintyre, B.D., Gold, C.S., Kashaija, I.N. and Kizito, F. (2003). Effects of mulch and mineral fertiliser on crop, weevil and soil quality parameters in highland banana. *Nutrient Cycling in Agro-ecosystems*; 65, 141-150.

68. McIntyre, B.D., Gold, C.S., Ssali, H. and Riha, S.J. (2003). Effects of mulch location on banana weevil, soil and plant nutrients, soil water and biomass in banana fields. *Biology and Fertility of Soils*; 39, 74-79.

69. Kiggundu, A., Vuylsteke, D. and Gold, C.S. (1999). Recent advances in host plant resistance to banana weevil, Cosmopolites sordidus Germar. Pp 87-96 in Mobilizing IPM for sustainable banana production in Africa. Proceedings of a workshop on banana IPM held in Nelspruit, South Africa; 23-28 (E. Frison, C.S. Gold, E.B. Karamura and R.A. Sikora, eds.). INIBAP. Montpellier, France.

70. Kiggundu, A. (2000). Host plant reactions and resistance mechanisms to banana weevil, Cosmopolites sordidus (Germar) in Ugandan Musa germplasm. Unpublished M.Sc. thesis. Orange Free State U. South Africa; pp 98.

71. Bridge, J., Fogain, R. and Speijer, P. (1997). The Root Lesion Nematodes of Banana, Musa Pest Fact Sheet No. 2.

72. Pests and Diseases of American Samoa, Banana Nematodes (2004). American Samoa Community College Community & Natural Resources Cooperative Research & Extension. Pests and Diseases of American Samoa Number 9.

73. Coyne, D.L., Nicol, J.M. and Claudius-Cole B. (2014). Practical plant nematology: a field and laboratory guide. 2nd edition. SP-IPM Secretariat, International Institute of Tropical Agriculture (IITA), Cotonou, Benin.

74. Mitiku, M. (2018). Plant-Parasitic Nematodes and their Management: A Review. *Journal of Agricultural research and technology*; DOI: 10.19080/ARTOAJ.2018. 16.555980.

75. Gowen, S.R., Fogain, R. and Quénéhervé, P. (2005). Nematode parasites of bananas, plantains and abaca. Pp 431-460 in Luc, M., R.A. Sikora, and J. Bridge (eds). Plant- Parasitic Nematodes in Subtropical and Tropical Agriculture, 2nd Edition. C.A.B. International, Wallingford, UK.

76. Rajab, K., Salim, S. and Speijer, P. (1999). Plant-parasitic nematodes associated with musa in zanzibar. *Afr. Plant Protect*; 5, 105–110.

77. Wuyts, N., Lognay, G., Verscheure, M., Marlier, M., De Waele, D. and Swennen, R. (2007). Potential physical and chemical barriers to infection by the burrowing nematode Radopholussimilis in roots of susceptible and resistant banana (Musa spp.). *Plant Pathology;* 56, 878–890.

78. Nelson, S.C., Ploetz, R.C. and Kepler, A.K. (2006). Species profiles for Pacific Island Agroforestry: Musa species (banana and plantain). www. traditionaltree.org.

79. Gowen, S.R. and Quénéhervé, P. (1990). Nematode parasites of bananas, plantains and abaca. *Plant Parasitic Nematodes in Subtropical and Tropical Agriculture*. Pp. 431-460. M. Luc, R.A Sikora and J. Bridge (eds). CAB International.

80. Stirling, G. R., & Pattison, A. B. (2008). Beyond chemical dependency for managing plant-parasitic nematodes: examples from the banana, pineapple and vegetable industries of tropical and subtropical Australia. *Australasian Plant Pathology*, 37(3), 254-267.

81. Osei, K., Mintah, P., Dzomeku, B.M., Braimah, H., Adomako, J., Mochiah, M.B., Asiedu, E., Darkey, S. and Danso, Y. (2013). Nematode pests of plantain: A case study of Ashanti and Brong Ahafo regions of Ghana. *Journal of Soil Science and Environmental Management*; 4(1), 6-10.

82. Daneel, M.S. and De Waele, D. (2017). Nematode Pests of Banana. Book chapter 16 in Fourie et al. (eds.), Nematology in South Africa: A View from the 21st Century, Springer International Publishing Switzerland; DOI 10.1007/978-3-319-44210-5_16.

83. Colagiero, M., & Ciancio, A. (2012). Climate changes and nematodes: expected effects and perspectives for plant protection. *Redia Journal of Zoology*, 94, 113-118.

84. Kamira, M., Hauser, S., Van Asten, P., Coyne, D. and Talwana, H.L. (2013). Plant parasitic nematodes associated with banana and plantain in eastern and western Democratic Republic of Congo. *Nematropica*; 43, 216-225.

85. Chitwood, D.J. (2003). Research on plant-parasitic nematode biology conducted by the United States. Department of Agriculture-Agriculture Research Service. *Pest Manag Sci*; 59, 748-753.

86. Talwana, H., Sibanda, Z., Wanjohi, W., Kimenju, W., Luambano, N., Massawe, C., Davies, K.G. and Manzanilla-López, R.H. (2016). Agricultural nematology in East and Southern Africa: problems, management strategies and stakeholder linkages. *Pest Management Science;* 72 (2): 226-245. DOI: http://dx.doi.org/10. 1002/ps.4104.

87. Coyne, D.L., Cortada, L., Dalzell, J.J., Claudius-Cole, A.O., Haukeland, S., Luambano, N. and Talwana, H. (2018). Plant-Parasitic Nematodes and Food Security in Sub-Saharan Africa. *Annual Review of Phytopathology*, 56, 381-403.

88. Song, Z., Zhang, B., Tian, Y., Deng, A., Zheng, C., Islam, M.N, …and Zhang, W. (2014). Impacts of Nighttime Warming on the Soil Nematode Community in a Winter Wheat Field of Yangtze Delta Plain, China. *Journal of*

Integrative Agriculture, 13(7), 1477–1485. doi:10.1016/s 2095-3119(14)60807-8.

89. Bakonyi, G., Nagy, P., Kovacs-Lang, E., Kovacs, E., Barabas, S., Repasia, V. and Seres, A. (2007). Soil nematode community structure as affected by temperature and moisture in a temperate semiarid shrubland. *Applied Soil Ecology*, 37, 31-41.

90. Lee, J.H., Dillman, A.R., and Hallem, E.A. (2016). Temperature-dependent changes in the host-seeking behaviors of parasitic nematodes. *BMC Biology*, 14(1), 1-17. doi:10.1186/s12915-016-0259-0.

91. Tzortzakakis, E.A. and Trudgill, D.L. (2005). A comparative study of the thermal time requirements for embryogenesis in Meloidogynejavanica and M. incognita. *Nematology*; 7(2), 313-315.

92. Thompson, J.P., Clewett, T.G. and O'Reilly, M.M. (2015). Temperature response of root-lesion nematodes (*Pratylenchus thornei*) reproduction on wheat cultivars has implication for resistance screening and wheat production. *Annuals of Applied Biology*; 167(1), 1-10.

93. Hajihassani, A. (2016). Studies of Plant Host Preferences of The Stem Nematodes, Ditylenchus Weischeri and D. Dipsaci. A Thesis Submitted to the Faculty of Graduate Studies of The University of Manitoba in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy. Department of Soil Science University of Manitoba Winnipeg, Manitoba.

94. McSorley, R., Wang, K.H. and Church, G. (2007). Suppression of root-knot nematodes in natural and agricultural soils. *Applied Soil Ecology;* 39, 291-298.

95. Wang, K.H. and Hooks, C.R.R. (2009). Plant-parasitic nematodes and their associated natural enemies within banana (*Musa spp*.) plantings in Hawaii. *Nematropica*; 39, 57-74.

96. Kardol, P., Cregger, M.A., Campany, C.E. and Classen, A.T. (2010). Soil ecosystem functioning under climate change: plant species and community effects. *Ecology*; 91(3), 767-781.

97. De Villiers, E.A., Daneel, M.S. and Schoeman, P.S. (2007). Pests. In: Robinson JC, De Villiers EA (eds). The cultivation of banana. Ingwe Print, Nelspruit; pp 194–219.

98. Moens, T.A.S., Araya, M. and De Waele, D. (2001). Correlations between nematode numbers and damage to banana (Musa AAA) roots under commercial conditions. *Nematropica*, 31, 55-66.

99. Dobson, A., Kutz, S., Pascal, M., and Winfree, R. (2003). Pathogens and parasites in a changing climate. In: Hannah L and Lovejoy T, Eds. Climate change and biodiversity: synergistic impacts. Advances in applied biodiversity science. *Center for Applied Biodiversity Science, Conservation International Washington*, DC; 4: 33-38.

100. Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.M., Hoegh-Guldberg, O. and Bairlein, F. (2002). Ecological responses to recent climate change. *Nature*; 416, 389–395. doi:10.1038/ 416389a.

101. Inward, D.J., Wainhouse, D. and Peace, A. (2012). The effect of temperature on the development and life cycle regulation of the pine weevil Hylobiusabietis and the potential impacts of climate change. *Agricultural and Forest Entomology*; 14(4), 348–357. doi:10.1111/j.1461-9563.2012.00575.x.