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Research Article

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Interaction of the fluctuation of the population density of sweet potato pests with changes in farming practices, climate and physical environments: A 11-year preliminary observation from South-Kivu Province, Eastern DRCongo

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Abstract: Sweetpotato is a major food security crop grown in eastern Democratic Republic of Congo. Its production is however limited due to high prevalence of pests and diseases among other abiotic and biotic factors. A study was designed to aid understanding the knowledge of farmers about pests and their perception about climate variability impacts, as well as documenting the phenology of sweetpotato pests (pest population dynamics) in relationship with weather factors. The paper aimed at determined which climatic factors may be used as best predictors of the different status of pest populations (declines, outbreaks). Farmer based data was obtained using a semi structured questionnaire administered to several of farmers. Population dynamics of sweetpotato pests were monitored year-round from 2005 to 2015 in South Kivu province, eastern DRCongo. Field monitoring (visual counts) observations (population dynamic of different soil–dwelling and surface dwelling arthropods visiting sweetpotato fields) combined with a survey of farmers' knowledge on sweetpotato pests and their practices in the management of these pests in South-Kivu Province were conducted for 11 years. Monitoring (with field observations and counts) was carried out in fields under different farming practices (monocropping and inter-cropping) in sites located at different altitudes. Similarly, data for climatic factors, for the same period, were collected from Lwiro Research center. Regression models were applied to understand the linkages between environmental factors (rainfall and temperature) and pest population dynamics.

The results indicated that different varieties (local and improved ones) of sweetpotato are grown three times (3 seasons) per annum under various cropping systems (sole crop, mixed crops) in various agroecological zones at different altitudes. Various arthropod species visit the crop at its different stages of development including classically known pests (*Acraea acerata*, *Cylas* spp.) or as vectors of diseases (*Bemisi tabaci*, *Aphis* spp.). The results indicated a high fluctuation in the population density of different pests. The change in the population dynamics were characterized by gradual increase in the populations during rainy seasons followed by decline during dry seasons (hot months of the year). Significant ($P<0.05$)

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differences were observed in the population dynamics between sole sweetpotato and mixed sweetpotato intercropping. There was a synchronization of multiple pest generations (biannual, multiannual cycles of reproduction) built up with early rains.
The results indicate that rainfall and maximum temperature were critical to the survival and population built up of the pest population. High rainfall in the previous months caused increases in the population density in the subsequent months within a year. The population dynamic (seasonal occurrence) over months and years was likely to coincide with favorable feeding and breeding conditions available within sweetpotato biotopes when temperatures were sufficiently high or after heavy rainfall. For some species, maximum temperature and dry seasons were associated with declines in the pest populations whereas for other species, heavy rainfall was associated with subsequent outbreaks (high populations) in the following months of the years. It is likely that perturbations in temperature/rainfall patterns may cause serious changes in the pest population, therefore favoring the build-up of multiple generations within a year, thus. Rainfall and maximum temperatures were reliable predictors of key pest species. In fact, regressions analyses indicated that there were significant relationships ($P<0.01$) between the fluctuation of the population density of different pest species and the variability of climatic factors (mean monthly maximum/minimum temperature, average rainfall).
The population density of different insect pest species varied according to cropping system and to altitude. For example, a significant relationship ($P<0.001$) was observed between adult aphid population density and average maximum temperature whereas *Cylas* spp. correlated significantly ($P<0.05$) with rainfall at high and mid altitudes in both sole and mixed crops. The population density of *Acraea acerata* was not related to variability in rainfall because the species seemed to occur in number in crops (mono cropping and mixed crops) in marshland areas in June-July and December-February. The virus pressure (measured as the number of leaves symptomatically showing virus attack) followed the population density of whiteflies and aphids. Population trends of other arthropod groups (millipedes, beetles) were not affected by crop variety (clones) or by the altitude or the climate variability but more by the farming practice (mixed or monoculture) implemented by the farmer. It is possible that the resistance or tolerance of some varieties (bio-fortified/vitamin-rich/orange flesh varieties) may be reduced in the future under changing climatic conditions of crop growing in the region with Maximum temperature as the key driver of changes in the population density. The ability to predict the severity of pest populations from mean monthly rainfall/temperature data will provide a significant input into the development of IPM programme for sweetpotato pest species. The data indicates that building resilient sweetpotato crops will require the consideration of various approaches. It is likely that climate change may affect both the pests and vector-diseases and therefore the yield of the crop in eastern DRCongo. Such situation may endanger food security of small scale farmers in the future. Further investigations would be better focus on the understanding on the interacting of climatic, anthropogenic, environmental and soil factors on the pressure of sweetpotato pest in different agro-ecological zones of DRCongo.

Keywords: Sweetpotato, Pest population dynamics, Climate change and variability, Forecasting, Farming practices, Crop resilience, Yield reduction, Altitude, Agroecological zones, Kivu, eastern DRCongo

1 Introduction

Agriculture is a vital sector in the Democratic Republic of Congo (DRCongo). Revolution in DRCongo agricultural policies is highly recommended because this sector has very high potential of growth and income generation. Agriculture provides direct employment to more than 50% of the Congolese population and accounted in average of 40% of total GDP which produces the largest percentage of total value added. Sectoral Gross Domestic Product (GDP) contributions in the Democratic Republic of Congo (DRC) include agriculture (55%), industry (11%) and services (34%). Favorable agroclimatic diversity and high level of rainfall is likely to favor the development of huge agricultural potential in DRCongo. Agroclimatic conditions of the DRCongo strongly favor the cultivation of various crops including e.g. palm, rubber, coffee, cocoa, banana, cassava, potato, sweetpotato. Presently, DRCongo has about 80 million hectares of arable land but out of this only 8-10% is under cultivation (Munyuli 2016). Sweetpotato is cultivated across DRCongo but high consumption of the crop is found in the eastern part of the country, mainly in North and South Kivu provinces (Figure 0A and 0B).

South-Kivu province is located in the Eastern part of Democratic Republic of Congo. Agriculture in this province is still unproductive and less exploited because of inconsistent and uncoordinated agricultural policies.

However the province (located in highlands of the country) has the potential to grow various kind of crops. Currently, farmers are engaged in the production of food and staple crops (such as soya bean, sorghum, banana, cassava, beans, maize, peas, potato, Irish potato, rice, sweetpotato) and vegetable crops (tomato, onion, eggplant, cabbage, cucurbits, amaranths), fruit crops (e.g. mango, avocado, tangerine, citrus, guava, orange, pineapple) and industrial crops (e.g. coffee, tea, palm oil, cotton). With recent epidemic wars, and rising insecurity, the agricultural sector is currently disorganized. Farmers are almost abandoned. The government no longer supports or assist farmers. Several NGOs are currently helping farmers through their organizations. Some farmers have identified demand and invested their time in some lucrative farming activities. Hence, some crop cultivation is currently considered as lucrative agribusiness for farmers: tomato, sweetpotato and potato cultivation (Munyuli 2016).

The cultivation and productivity of sweetpotato is subject to various abiotic and biotic constraints. Recent surveys indicate that farmers are complaining about rising yield loss. Factors incriminated in this situation include climate change and variability, emerging pests and diseases (Munyuli 2016).

Farmers are convinced that for pests and diseases, they may use chemical and non-chemical pesticides. However, they are not sure of what to do about climate variability. Preliminary field surveys were conducted and climate change and pests were raised as key food production constraints by farmers. Therefore, it was necessarily to conduct an investigation in order to confirm farmers' allegations about pests and climate change. Hence, monitoring surveys were designed and data has been collected. In this paper, preliminary observations are presented.

Although agriculture is the back born of livelihood in most farmers from eastern DRCongo; however, the current productivity of crops is subjected to various constraints and stresses. Among key constraints highlighted by farmers include pests, diseases, lack of improved and pest-tolerant seeds/varieties, soil infertility, soil erosion, general land and environmental degradations, lack of access to market and post-harvest processing facilities, basic rural infrastructure degradation. The impact of these stresses is more visible in regions with high security risks because rebel movements and activities (raping women, kidnapping) disturb farming activities.

Climate change, with expected long term changes in rainfall patterns and shifting temperature zones, is expected to have negative effects on agriculture (Munyuli et al. 2013). DRCongo's agriculture, which is the mainstay of the country's economy constituting more than half the nation's gross domestic product (GDP) and generates more the big portion of the foreign exchange earnings, is mainly rainfed and heavily depend on rainfall (Munyuli 2016). This dependence makes the country particularly vulnerable to the adverse impacts of climate change despite its richness in natural resources. Literature showed that the scope (geographic coverage), frequency and magnitude of climatic changes and environmental degradation, such as deforestation, and soil erosion, have been increasing from time to time in DRCongo (Munyuli et al. 2013).

The potentially adverse effects of climate change on the Congolese's agricultural sector are of a major concern because of this dependence. Long-term climate change can be associated with changes in rainfall patterns and variability, and temperature, which can increase the country's frequency of both droughts and floods (Munyuli et al. 2013). These climatic hazards, particularly drought, are becoming the major forces challenging the livelihoods of most farmers. Though the country is rich in natural resources, the problem of food insecurity at provincial and national level remains a concern, because of the severity of food production constraints in some territories. In addition, the food markets do not function correctly, thus the level of vulnerability of farmers to this kind of shock is increased (Munyuli et al. 2013).

The rural population, for whom agriculture is the primary source of food, direct and/or indirect employment and income, may be more affected due agriculture's vulnerability to climate changes. As the sector is the largest consumer of water resources, variability in water supply has a major influence on health and welfare of the agriculture dependent poor. Vulnerability analysis across the country is likely to indicate that the exposure, sensitivity and adaptive capacity of people may vary from territory to Province. Previous reports indicates that South-Kivu Province is among the most vulnerable Province of DRCongo because of the higher frequencies of drought, floods, and landslides (Munyuli 2016). Also in South-Kivu Province, there are few to no institutions dealing with environmental change and climate related hazards. Also the province is characterized by a lack of basic infrastructures and technologies that can be used by the population to cope with these hazards.

Vulnerability to climatic change is highly correlated with environmental degradation. The level of poverty and living status of farmers determines their vulnerability to and adaptation to climatic changes. An increase in the frequency of climate related hazards may lead households to lower expected incomes, which in turn may cause a fall below the poverty threshold level (Munyuli 2016).

Adaptation to climatic changes requires a combination of various individual responses at the household and farm levels and assumes that farmers have access to information, alternative practices and technologies available in their area. It may also involve changes in agricultural management practices, nature conservation practices, and change in land-use decision making in response to changes in climatic conditions for an agrarian community. Adaptation to different hazards vary from household to households and province (territory) to province (territory), based on the ability of the existing support system to increase the resilience of affected individuals. One of the objectives of this assessment was to generate primary information from the farming communities of south-Kivu province related to climate change and variability and its impact on crop productivity (particularly sweet-potato).

The general conclusion from assessments made by the intergovernmental panel on climate change (IPCC) is that both the mean temperature and the frequency of extreme weather events such as heat spell, dry spell, storms and flooding, could increase in the nearest future (Azerefegne et al. 2001; Bale et al. 2002; Braun et al. 1999) The development of insects is strongly affected by temperature, moisture and related abiotic stresses (extreme weather events). There exist therefore interplay between vegetation susceptibility and insect performance (Munyuli 2013). Consequently, climate change has the potential to alter the frequency and intensity of pest outbreaks, both in agricultural and forest ecosystems (Brunke et al. 2009; Coley and Markham 1998; Evans et al. 2002; Harrington et al. 2001). Assessments of the risk of insect outbreaks and damage in response to climate change are required in order to develop appropriate local pest management strategies.

The occurrence of climate changes is evident from an increase in global average temperature, changes in the rainfall pattern and extreme climatic events. These seasonal and long term changes would affect the fauna, flora and population dynamics of insect pests. These abiotic parameters are known to have direct impact on insect population dynamics through modulation of developmental rates, survival, fecundity, voltinism and dispersal (Hódar and Zamora 2004; Konvicka et al. 2003; Morgan 1996; Porter et al. 1991; Zhou et al. 1995). Among the climatic factors, temperature is an important factor. Higher temperature may cause changes in the pest population dynamics. Therefore, climate change would result in changes in the population dynamics of insect pests.

Thus, temperature rise plays a pivotal role in insect population dynamics. The occurrence of climate changes is evident from increase in global average temperature, changes in the rainfall pattern and extreme climatic events (Konvicka et al. 2003; Morgan 1996).

Pest population outbreaks occur due partly to climate driven population fluctuations. Climate variation affects the occurrence, distribution and population dynamics of crop pests because body temperatures of many insects approximate ambient conditions and breeding (habitat) sites of different species are directly or indirectly affected by precipitation. Temperature governs most biological rates including blood feeding, reproduction, and larval development, whereas precipitation determines the quantity and quality of habitats for egg hatching and larval development and therefore adult population size.

Climate variation affects all life stage processes of the insect at multiple spatio-temporal scales. Seasonal cycles create periods of the year with favorable conditions for population reproduction and growth, whereas variation among years determines inter-annual changes in population size (Azerefegne et al. 2001; Bale et al. 2002; Braun et al. 1999; Brunke et al. 2009; Harrington et al. 2001; Hódar and Zamora 2004).

In the development of pest management strategies, a detailed knowledge of the influence of abiotic factors on the biology of pest insects is essential (Coley and Markham 1998; Evans et al. 2002). Weather and climatic conditions are known to significantly affect the population dynamics of insect pests. Knowledge of abiotic conditions, such as temperature, day length, rainfall and relative humidity can be used as important components in forecasting and predicting the severity of insect pest populations. Environmental factors operate together in an interactive manner in natural ecosystems. Temperature and moisture are considered to be the most important climatic factors affecting life history processes of insects and population dynamics (Harrington et al. 2001; Hódar and Zamora 2004; Konvicka et al. 2003; Morgan 1996; Porter et al. 1991; Zhou et al. 1995). Also weather conditions, increased natural enemy pressure, and a decline in plant quality, are factors that may cause decline in pest populations in the field.

Climate models provide forecasts that predict climate variation, ecosystem dynamics and productivity. Temperature sum requirements and thermal thresholds affect the activity and development of pests throughout the year and can be used for modelling the effect of weather on the development of pest population (Harrington et al. 2001; Hódar and Zamora 2004; Konvicka et al. 2003; Morgan 1996; Porter et al. 1991; Zhou et al. 1995).

The ecology, biology and taxonomy of sweetpotato pests is less documented in eastern DRCongo. Some species are generally not found in the field during some months of the year while other are more abundant. Some species are active during cooler months of the years while others have peaks during the hot months of the year. Pest species encountered on different varieties were likely causing the same type of injury on leaves, flowers, vines and tubers of all cultivated varieties although there was a tolerance of some local varieties. Hence, the setting of tubers was likely to be influenced by attack of different pests.

In root and tuber crops, severe outbreaks are common and are believed to be strongly influenced by climatic conditions, although this has never been proven under local conditions in eastern DRCongo. The status of different pests are not yet established, although some of them are considered as serious pests of sweetpotato in east Africa. *Acraea acerata* outbreaks are observed during the semi-dry months to dry months of the year. However, year to year, the seriousness of attacks are different. Also, the natural enemies (parasitoids, predators), which are attacking the pests are not documented. This study was done to determine the spatio-temporal distribution of pests in sweetpotato plants, and to monitor the monthly, annually and seasonal abundance of the pests in sweetpotatoes. This knowledge is necessary to learn the best means of monitoring populations (by growers and pest advisors and extensions, in addition to researchers) and to develop possible means of alerting farmers and controlling the pests. Such information is important for designing a suitable intervention and successful integrated pest management (IPM) strategy (Munyuli 2000).

Pest management and control through insecticides is costly for the farmer and also has associated ecological and toxicological hazards. Therefore, an integrated pest management (IPM) programme is to be adopted by farmers. Monitoring and forecasting pest abundance should ideally be an essential component of any IPM system (Munyuli 2000).

Studies concerning the population dynamics of sweetpotato pests are rare to absent in eastern DRCongo and those that do exist tend only to investigate and document epidemiological aspects only. Phenological behaviour of the pest population dynamics during rainy and dry seasons are largely unknown in eastern DRCongo. Here, is reported investigation on abundance pest population over 11 years in relation to meteorological data. Insect numbers are related to weather conditions in an attempt to establish their importance in causing fluctuations and injuries to crops.

Sweetpotato is a major food security crop grown across the 6 different agroecological zones of South-Kivu Province (Munyuli 2000). Its production is however limited due to a number of constraints including high prevalence of pests and diseases. Other limiting factors include declining soil fertility, unpredictability of weather factors, soil erosion, and loss of local varieties. Environmental degradation (land degradation, climate variability) is likely exacerbating negative impacts of pests and diseases. However, best environmental parameter predictors of change in the population density of pests are unknown under local conditions, yet they are needed for best forecasting warning mechanisms. In addition, the current level of knowledge of the different pests by farmers is not documented, yet such information may help to develop appropriate strategies to monitor and empower farmers to control pests.

The impact of climate change on sweetpotato production is expected to be high. With climate change and variability, the traditional sweetpotato growing highlands are rapidly growing warmer in eastern DRCongo. Moreover, the rapidly increasing population and consequent diminishing of land availability in these highland zones have forced farmers to migrate to the lower, warmer and drier areas. While pests are a major constraint in crop production in many parts of Africa including eastern DRCongo, little is known about farmers' knowledge and management practices. In addition, little is known about farmers' perceptions about climate change impacts (Munyuli et al. 2013) on sweetpotato.

Pests are currently causing significant damages and economic losses in different varying environmental conditions in eastern DRCongo (Munyuli, personal observation). In additions, differences in pest and disease pressures contribute significantly to inconsistencies in performance of sweetpotato clones in various environments. Sweetpotato production in eastern DRCongo is considered to be vulnerable to ongoing climate variability. Adaptation is generally suggested to maintain sweetpotato productivity. Therefore, better understanding of farmers' knowledge of climate change and of pest management strategies status are among the pre-requisites for the successful management of such adaptation. Sweetpotato is among the top-ranking cash crops in South-Kivu Province. Major bottlenecks to increased productivity in sweetpotato in eastern DRCongo are often the occurrence of various pest species, which lead to severe yield and quality losses. It has been predicted that global warming may further intensify pest range expansion and abundance (pest population densities).

With global warming (Munyuli et al. 2013) the number of generations of different pests are expected to increase 2 to 5 times per year, and such situations is likely to further increase pest related yield losses. Hence, there is a need to think of new innovative sweetpotato production systems that are resilient to future pest situations and outbreaks. To attain such an objective, it is important to model potential changes in pest population status and predict the likely yield damage that may be associated with the change in pest population density and the resultant damages (yield loss) before proposing new breeding adaptation strategies. The success of adaptation strategies require baseline surveys (farmers' knowledge of climate change and pest management).

2 Objectives

(i) To understand farmers' knowledge of existing insect pest problems and their management practices.
(ii) To document farmers' perceptions of climate change effects and knowledge of sweetpotato pest management in South-Kivu provinces (eastern DRCongo).
(iii) To describe the population fluctuation patterns of sweetpotato pests, and then to determine the major factors affecting the population processes
(iv)To investigate linkages between variability of climatic factors and the fluctuation of the population density of different pests at different sites

3 Hypotheses

(i) Knowledge of farmers of pests and of best pest management practices may be very poor.
(ii) The level of knowledge of farmers about climate change and its impacts on sweetpotato pest population outbreak may be poor in South-Kivu provinces (eastern DRCongo).
(iii) Fluctuations in the population density of different pests may not be associated with variability in local climatic factors (rainfall, temperature) in eastern DRCongo.
(iv)There may be no linkages between variability of climatic factors and the fluctuation of the population density of different pests at different sites in eastern DRCongo.

4 Study area

4.1 Description of characteristics on South-Kivu Province

Administratively, eight territories constitute South Kivu province (Kabare, Kalehe, Walungu, Idjwi, Mwenga, Shabunda, Fizi, Uvira). This survey was conducted from 2004 to 2015 in South-Kivu Province (see map). Population density is the highest in the DRCongo, with more than 80-120 inhabitants per square kilometer. The province of South Kivu, with an area of 69 130 square Km and having a population of 11-12 million , is located in the east of the Democratic Republic of Congo. South- Kivu is bordered on the east by the Republic of Rwanda through the Ruzizi river and by Burundi and Tanzania through Lake Tanganyika, and on the south-east by Katanga province. It is bordered on the south, west and north-west by Maniema province and on the north by North-Kivu province (Dowiya et al. 2009).

The geographical area of the province provides an exceptional range of diversity of biomes, ecosystems, and habitats. These include dry rainforests, open woodland forests, grassland savannah, and cloud and gallery forests. A network of protected areas conserves portions of the diverse ecology of in Kivu area. This forms part of the DRC's tropical rainforest landscape, which is said to store eight percent of global forest carbon. Extreme population pressure is a ubiquitous feature across the regional landscape of South-Kivu province. South-Kivu is characterized by mostly lush equatorial vegetation and terrain stretching from high mountainous and plateau areas reaching nearly 3,500 m along the western shore of Lake Kivu, and descending westward to a less densely populated lowland plateau at approximately 500 m and equatorial forest area (Munyuli 2016).

In south-Kivu province, while Uvira territory is located in the flat zones, Kabare and Kelehe territories have similar physical characteristics (geology, topography, climate, soil, hydrography, and hydrology). These two territories belong to the mountains of Kivu. These two territories are characterized by mountains with marshlands in the intersection of lowlands and highlands. The altitude of South-Kivu province is varied from 500-1000 m up to 3000 m above the sea level. The altitude of the study sites oscillated between 1400 and 2100 m for Kabare and between 1500 and 2300 m for Kalehe territory (Munyuli 2016).

The province has a temperate climate, but has more of a tropical savanna and warm summer Mediterranean climate according to the Köppen climate classification system. Practically, the climate of the region is diversified and is largely influenced (moderated) by wind speed regime, rainfall pattern, altitude, water (Lake Kivu) and protected areas (Kahuzi Biega National park). The climate of the study area can be classified as Tropical moderated by the altitude. The province is characterized by a bimodal pattern of two rainy seasons, occurring from March-May

Figure 0A: A map showing the study country and South-Kivu Province among the 26 Provinces of DRCongo

and September-December, followed by two short dry seasons in June-August and January-February.

Seasonality is determined by the inter-tropical Convergence Zone which oscillates north and south across the Equator and Tropic of Capricorn during the year. Rainfall is bimodal, with annual rainfall amounting between 800 mm (Ruzizi plain) and 2500 mm (mountain zones) per annum. Rainfall is averaging just over 1,600-2500 mm annually, with a minimum average of nearly 1,000 mm and a maximum of almost 2,660 mm. Average monthly temperature is about 21-23°C, but with slightly less range from cold to warm (9°C-25°C). In Bukavu, temperatures average 19.9°C, with a high of 20.5°C in September and low of 19.5°C in July. However, high variability in climatic factors is registered during more recent years. The annual average temperature is currently trending towards 25-27°C. The variability is registered in terms of date of onset of rainfall periods (the date of rainfall start), the number of days of rainfall per month and in terms of frequency of semi-dry months during the rainy seasons.

Overall the province has about five ecological zones and the different territories are located in the different agroecological zones (savannah lowland ecological zone with Uvira territory, mountain savannah zone with Kabare, Kalehe Walungu territories, lowland forest zones with Mwenga, shabunda, Fizi territories and Medium altitude savanah zone: Idjwi zone).

Soils are largely volcanic by origin and rainfall is in abundance, allowing for two extended growing seasons, primarily from September to December, and March through May. Practically, the soils of the study area mainly ferrisols, ferrasols, acrisols and nitisols. There is a declining level of fertility in these soils, especially for gardens located on slippery hillsides. In addition, soil erosion on hillside is intense in the mountain zones. Soil erosion and land degradation are key constraints to food productivity in South-Kivu Province. Together with

Carte 2. *Territoires, collectvités et principales villes du Sud-Kivu*

Figure 0B: A map of South-Kivu Province Showing the territories (Kabare, Walungu, Kalehe) where study sites were selected across the different sweet potato growing zones

sediments from soil erosion in the hilly side, pesticides from agricultural landscape increase the level of pollution of Lake Kivu in its edges, yet these margin zones are very critical for the reproduction (breeding) of many fish species. In Kalehe and Kabare territories, there exist fertile lands in marshlands found at the edge of Lake Kivu or in the lower part of hilly lands (Munyuli 2016). These marshlands play a vital role since they support cash crop production such as sweetpotato.

Agriculture provides livelihoods for the vast majority of the poor populations (73-90% of people have agriculture as their main source of income) in the study province. The vast majority of inhabitants live on the margins of poverty, having small landholdings where they carry out subsistence farming, hunting, small animal husbandry (goats, sheep, pigs, poultry, rabbits, ducks, guinea pigs), limited cattle production and some fishing, and mining. Pressures to access land for farming or other purposes are severe in the study province and a constant source of violent conflict. The average sizes of smallholdings are only about a half hectare of land due to the confluence of many factors, including strong demographic pressure, soil erosion and loss of fertility, land grabbing and speculation, and a history of intense ethnic conflict in the region (Munyuli 2016).

The climate of South-Kivu Province is favorable for the cultivation of various food and stable crops. Livestock and fishery activities are practiced in the province although animal rearing is declining in the entire region. A wide range of staple crops are grown, and are cultivated in both highland and lowland areas, with garden crops grown near small streams and water courses (in marshland areas).

The majority of the people in Eastern DRCongo engage in small-scale agriculture where bananas and plantains (Musa spp.) predominate. Banana and plantain fruits are second in importance as a source of calories after cassava in this region. In South-Kivu, farmers are growing fruit crops (avocado, mango, citrus, tangerine, pineapple), industrial crops (e.g. tea, cotton, coffee, palm oil), legume crops (peas, beans, soybeans, cereal crops), cereal crops (e.g. rice, sorghum, maize) and vegetable crops (e.g. eggplant, tomato, cabbage, amaranths, cucurbits) for their own subsistence.

Also, people of South-Kivu province have been affected by wars and civil unrest for several years. Farmers do not receive assistance any more from the government and farmers just keep trying whatever they can. Some farmers have identified some crops as key crops to increase their income. Potato, sweetpotato and vegetable productions (tomato, cabbage, onion) are the lucrative or commercial crops for farmers. However, farmers are complaining about pests and diseases attacking their sweetpotato.

4.2 Study sites

Monitoring surveys of pest population were conducted in some sites of three territories of South-Kivu Province. The study was conducted at different sites (sweetpotato major growing zones) located at different altitudes. In the territory of Walungu, the study was conducted at Kamanyola-Sange (1100 m) and Kamisimbi (1950 m). In the territory of Kabare, the study was conducted at Kabare-Cirunga (1560 m), Miti (1750 m), Mudaka (1650 m) and Katana (1580 m). In the territory of Kalehe, the study was conducted at Luzira (1850 m) and Ihusi (2180 m) sites (localities).

5 Methods

5.1 Survey of farmers' perception and knowledge of pests and impacts of climate change

Farmers' knowledge of sweetpotato pests and practices in the management of these pests was recorded from 2005 to 2015 in Kabare, Kalehe and Walungu territories (South-Kivu Province). Farmer based data was obtained using a semi structured questionnaire administered to several farmers. At the start, a well-structured interview schedule was used to collect data from 220 sweetpotato growers from Kabare, Walungu and Kalehe territories (South-Kivu Province) at the start (in 2004). Farmers were selected through a three-stage sampling technique. After interviews, villages and fields were selected in each cropping season for monitoring pest populations as recommended (Munyuli 2011).

5.2 Meteorological data collection

Meteorological data for the present study came from the nearest continuous recording weather station. Meteorological data was collected from the most trustworthy meteorological station. Meteorological (rainfall, min/max temperature) data was used as recorded by the meteorological station of Lwiro National Research Center that is located at about 45 km far away from Bukavu (the South-Kivu provincial capital). The meteorological station of Lwiro that is located at about, 20, 30, 50, 80, 100, 150 km from the different study sites. Meteorological data are expected to vary from about 250 km diameter (Munyuli et al. 2013).

5.3 Field observations, pest monitoring and insect counting and recording

Various sampling methods can be used and most likely they vary from one species (or group) to another one, but field observations and inspections were previously found to be effective in monitoring insect pests in sweetpotato rather than any other method (sweep netting, bait traps) and therefore, field inspection (observations and records counts) is an effective method (Munyuli 2011) of forecasting potential increases in pest populations in relationship to variability in local weather factors.

Monitoring was primarily carried out in the fields in the sites (localities) where sweetpotato is predominantly grown. These localities were chosen from Walungu, Kabare and Kalehe territories of the South-Kivu Province (eastern DRCongo). In each of these sites, 10 fields (of different sizes) were randomly selected among others to cover 30% of the total sweetpotato fields available in these localities. Among the selected fields for monitoring, efforts were made to select at least 50% of fields where sweetpotato was grown under monocropping system and 50% of fields containing sweetpotato mixed with other crops such as maize, cassava, banana, coffee, onions, and taro.

In each territory, sites where sweetpotato is predominantly grown were selected. Fields were preselected in each study site two weeks after plantations were established by farmers. The selected fields were monitored each month of the year. Each year, newly established fields were chosen in the same study sites since sweetpotato is grown three times each year.

During each field visit, whole plants were inspected (leaves, tubers, vines) in a 0.2ha plot selected in the middle of each field. Plants were inspected at 4 week intervals. Adults and larvae (caterpillars) were counted on all leaves. For underground pests, tubers were removed and the number of larvae (immature stages) were counted on all tubers collected from plants in the 0.2ha plot. This was done in consultation with the farmer. We paid for damage caused to the farmer for earlier harvesting process of the plants. Activity of leaf miners was diagnosed by counting the number of gales on vines and leaves. The number of leaves showing mosaic virus attacks were also counted in order to estimate the virus pressure as a result of the population built up of aphids and whiteflies. Insect specimens were carried out for advanced examination at the entomology laboratory at Lwiro Research Center.

Practically, field observations and count of the pest populations were conducted on a regular basis (using time-sheets) to monitor population dynamic of different soil–dwelling and surface dwelling arthropods visiting sweetpotato crop in different fields. Each field visit day, the current number of insect pests are counted on leaves, plant parts and on uprooted tubers. The data is collected in a 0.2ha plot that is selected in the middle of the selected farmer's field. Insect species were identified in the field following published information and guides (Ames et al. 1996; Anyanga et al. 2013; Bassey 2012; Chalfant et al. 1990; Downham et al. 2001; Jackson and Bohac 2006; Jackson et al. 2003; Korada et al. 2010; Nderitu et al. 2009; Talekar and Cheng 1987).

Each field day, the following parameters are measured:

Number of sweetpotato leaves presenting symptoms of virus infection per plot (0.2ha).

-Sweetpotato butterfly (Acraea *acerata*, Lepidoptera: Nymphalidae): Nbr of caterpillars on leaves of all plants/ plot of 0.2ha;

-Aphids, *Aphis gossypii* (Homoptera: Aphididae): Nbr of aphids counted on leaves of all plants inspected /0.2ha;

-Armyworms (*Spodoptera* spp., Lepidoptera: Noctuidae): Nbr of caterpillars counted on leaves of all plants/0.2ha;

-Eriophyid mites (*Aceria* sp., Acari: Eriophyidae): Nbr of galls on leaves, petioles-stems) counted on all plants /0.2ha;

-Whiteflies *Bemisia tabaci* (Homoptera: Aleyrodidae): Nbr of whiteflies and nymphs counted on the back of leaves of plants inspected/0.2ha;

-Striped sweetpotato weevil (*Alcidodes dentipes*, Coleoptera: Curculionidae): Nbr of larvae and pupae counted by 200 vines randomly selected in 0.2ha plot;

-Rough sweetpotato weevil (*Blosyrus* sp., Coleoptera: Curculionidae): Nbr of larvae/pupae counted inside 200 sample tubers/0.2ha;

-Sweetpotato weevils (*Cylas* spp., Coleoptera: Curculionidae): Nbr adults and larvae counted per 200 tubers/0.2ha plot.

5.4 Data analysis

Descriptive statistics (mean, percentage, frequency, correlations, and histograms) and inferential statistics (regressions) were applied to the data. Farming practices (sole, intercrop) and altitude were the independent variables while the dependent factors include the population density. Whenever necessary, all counted insects were log 10 (n + 1) transformed before statistical tests were performed (Minitab TM Release 16). Tukey ± Kramer multiple comparison tests were used to separate means. Arithmetic rather than transformed means, are given in the results. Regression analysis was applied to examine trends of climatic factors (rainfall and temperature) in relationships with pest population density dynamics during the study period. Regressions analyses were conducted when interested at detecting the relationships between pest population fluctuations and climatic factors. These regression analyses were used to select which climatic factors influenced most the population dynamics of different pest species studied.

6 Results

6.1 Knowledge of production constraints, pest species, and climate variability impacts by sweetpotato farmers from South-Kivu Province, eastern DRCongo

Sweetpotato is grown at different altitudes (800-2650 m) in different geographic topographies (flat, hilly, mountain areas) in both infertile and fertile soils and in land located in different environments (flooded zones, marshland zones, home gardens, lowlands, highlands zones). Across the different agroecological zones, different varieties (local and improved, white and orange flesh ones) are grown, in lowland (800-1000 m), medium (1100-1400 m) and highland sites (1500-2650 m).

Several improved and local varieties (e.g. Kajuru) and improved varieties (white and orange flesh ones) are grown under two cropping systems (sole crop, mixed crops). Orange flesh ones are grown in mixture with local varieties. Improved biofortified (nutrient enriched varieties) are grown more in sole cropping systems than in intercropping systems. In the intercropping systems, sweetpotato is commonly found being mixed with cassava, sorghum, banana, maize, taro, coffee.

Sweetpotato is grown as a monocrop (45% of cases) and in mixture with other crops (55% of cases). The crop is mainly a female crop. Various varieties are used, including local varieties that have been released by researchers. In some areas, improved varieties are still found. In most cases, farmers went back to traditional genotypes since improved (orange flesh, biofortified, nutrient enriched) varieties that were released some 15 years ago, are currently being decimated by new emerging pests and diseases. Farmers are unable to find varieties that are tolerant to multiple biotic and abiotic stresses. Consequently, landraces are being used even if they are not high yielding.

Various arthropod species visit the crop at its different stages of development including classically known pests (*Acraea acerata*, *Cylas* spp., *Spodoptera*) or vectors of diseases (*Bemisia tabaci*, *Aphis* spp.). Farmers have poor to medium knowledge of pests and of best control methods for each type of pest. The population density of pests was relatively high in lowlands (low altitude sites) compared with medium and highlands (high altitude sites) locations. The population density of crop pests seemed to be higher in monocropping compared with intercropping. Different varieties supported different pest populations with improved (biofortified) varieties being associated with high numbers of pests compared with local varieties.

There was a low level of knowledge of the potential impacts of climatic change on emergence of pests and on the resultant impacts on sweetpotato growth and yield. Overall, there were significant ($P<0.05$) negative/positive correlations between population density of pests and climatic factors (mean monthly maximum/minimum temperature and mean monthly rainfall). The virus pressure (measured as the number of leaves symptomatically showing virus attack) followed the population density of whiteflies and aphids. Population trends of minor arthropod pests (such as millipedes, ants) was not affected by crop variety, altitude or climate variability but was more affected by the farming practice (mixed or monoculture) implemented by the farmer.

Major insect pests experienced by farmers in sweetpotato (% households) included sweetpotato butterfly (*Acraea acerata* , Lepidoptera: Nymphalidae) = “Bisholero” (local language), the sweetpotato Weevils (*Cylas* spp., Coleoptera: Curculionidae)-“ Mivunyu Y’ebijumba” (local language), the rough sweetpotato weevil (*Blosyrus* sp., Coleoptera: Curculionidae), the striped sweetpotato weevil (*Alcidodes dentipes*, Coleoptera: Curculionidae), the aphids (*Aphis gossypii*, Homoptera: Aphididae) = ”Buhula” (local language), the eriophyid mites (*Aceria* sp., Acari: Eriophyidae), the whiteflies (*Bemisia tabaci*, Homoptera: Aleyrodidae) = “Buhuka bweru” (local language), the armyworms (*Spodoptera* spp., Lepidoptera: Noctuidae) = “Nyalwifunya” (local language); and various other species (ants, ground beetles, grasshoppers, etc). These insect species occur in other tropical regions (Ames et al. 1996; Anyanga et al. 2013; Bassey 2012; Chalfant et al. 1990; Downham et al. 2001; Jackson and Bohac 2006; Jackson et al. 2003; Korada et al. 2010; Nderitu et al. 2009; Talekar and Cheng 1987).

Farmers indicated that sweetpotato is one of the staple / cash contributing significantly to the total agricultural income. The majority (75.8%) of farmers were not able to identify correctly the different pest species. Less than 10.4% could describe correctly the pests’ common names. The description was given by colour, by mode of flying, by type of action or damage, by hour and moment of attack, by type of plant part that is attacked by the pest, or by the way the plant damage appeared. Some farmers were not able to distinguish damage due to pests or diseases or rains, especially for improved (orange flesh) varieties.

Some farmers perceived that the damage caused by whiteflies (*Bemisia tabacci*) was negligible during long rain seasons whereas the sweetpotato butterfly (*Acraea acerata*) was mentioned to occur with high levels during the semi-dry to dry months of the year (December-February, June-August). Interestingly, 80.5% farmers were able to show (indicate, demonstrate) the damaged (infested) part of the plant although they were not able to determine which pest species was involved. In some case, the species (the stage of the life cycle of the insect) were named in the local language.

Farmers were aware of the climate changes in their own understanding levels. Most farmers perceived climate change as the rainfall irregularity (variability) and excessive heat or excessive speed of winds. Sometimes, farmers indicated that repeated floods, violent winds, landslides, soil erosion, and deforestation in the upper hillsides were the best indicators of climate change in the villages.

Farmers linking of climate change to pest emergency was not clear: in some cases, they linked emergency of pests to recent wars; in other cases, as the consequence of utilizing varieties (sweetpotato vines) that were distributed by humanitarian agencies and development organizations. For farmers from Kamanyola, these development agencies were bringing the so called improved varieties and strongly advised adoption. Farmers indicated that in the first year of planting, these so called improved varieties were performing well; however, in the second and third plantation years, they became susceptible to pests and diseases and most often, new diseases and pests emerged for which current pesticides cannot control.

Farmers suspected that recently distributed vines of so called improved and vitamin rich varieties came with pests and diseases for which they knew no methods of control. The level of damage caused by new pests and diseases to sweetpotato may be more exacerbated with rising soil infertility, lack of crop diversification, disappearance of local landraces, and rainfall irregularity (and temperature increase), especially in lowland zones.

Localities complaining more of sweetpotato pests and diseases are those where massive campaigns for vine distribution occurred between 2001 and 2005, under projects related to food security strengthening in post war provinces in eastern DRCongo. According to farmers, these varieties were imported from outside and directly distributed to them without being pre-tested by researchers from CRSN-Lwiro or INERA-Mulungu. Late plantation of sweetpotato increased the susceptibility of the crop to variability of rainfall and this resulted in continuous pest infestation. In addition, potential losses due to pests and diseases were estimated to be relatively high in lowland (low altitude) sites and relatively low in highlands. Also, farmers indicated that intercropped sweetpotato was not associated with dramatic yield losses as compared to sole sweetpotato.

Farmers perceived that (i) insect pests and millipedes (45% of respondents), (ii) climate change and variability (42%), (iii) poor quality of varieties (38%) and (iv) soil infertility (35%) were the leading production constraints in eastern DRCongo (Figure 1a). In addition, 45-55% of farmers believed that weather change (climate variability) and insect pest attacks were key factors responsible for post-harvest losses (Figure 1b). Farmers perceived that sweetpotato weevils (*Cylas* spp.), whiteflies (*Bemisia tabaci*) and aphids (*Aphis gossypii*) were the major and consistent pest of sweetpotato across the study sites and altitudes (Figure 2). However, in terms of incidence, most (80%) farmers believed that sweetpotato weevils and whiteflies (Table 1) occurred in higher numbers, thus these two species were more incriminated in causing serious injuries to sweetpotato. Across the different study sites, the majority (51-74%) of sweetpotato farmers were doing nothing to control these pests (Table 2).

Most farmers perceived that increase/decrease in temperature/ rainfall affected slightly (Figure 3a)

Table 1. Perceived incidence of sweet potato insect pests (% of respondents)

	Territories and study site names							
Territory	**Kabare**	**Kabare**	**Kabare**	**Kabare**	**Walungu**	**Walungu**	**Kalehe**	**Kalehe**
Study site	Cirunga	Miti	Mudaka	Katana	Kamanyola-Sange	Kamisimbi	Luzira	Ihusi
Insect Pests								
Sweet potato weevils (*Cylas* spp.)	88.11	85.78	85.44	45.45	53.12	50.43	68.99	87.90
Sweet potato butterfly (*Acrae acerata*)	53.43	74.23	76.55	88.56	29.29	50.55	62.61	57.81
Whiteflies (*Bemisia tabaci*)	91.67	74.45	15.12	55.76	26.66	24.11	47.67	34.66
Sweet potato hornworm (*Agrius convulvuli*)	18.61	69.76	19.11	37.98	18.56	6.22	28.44	23.77
Armyworm (*Spodoptera* spp.)	6.09	3.89	18.67	62.45	18.55	65.33	28.55	65.67
Others (ants, millipedes,...)	26.54	38.91	24.90	33.43	6.32	9.57	23.87	17.92

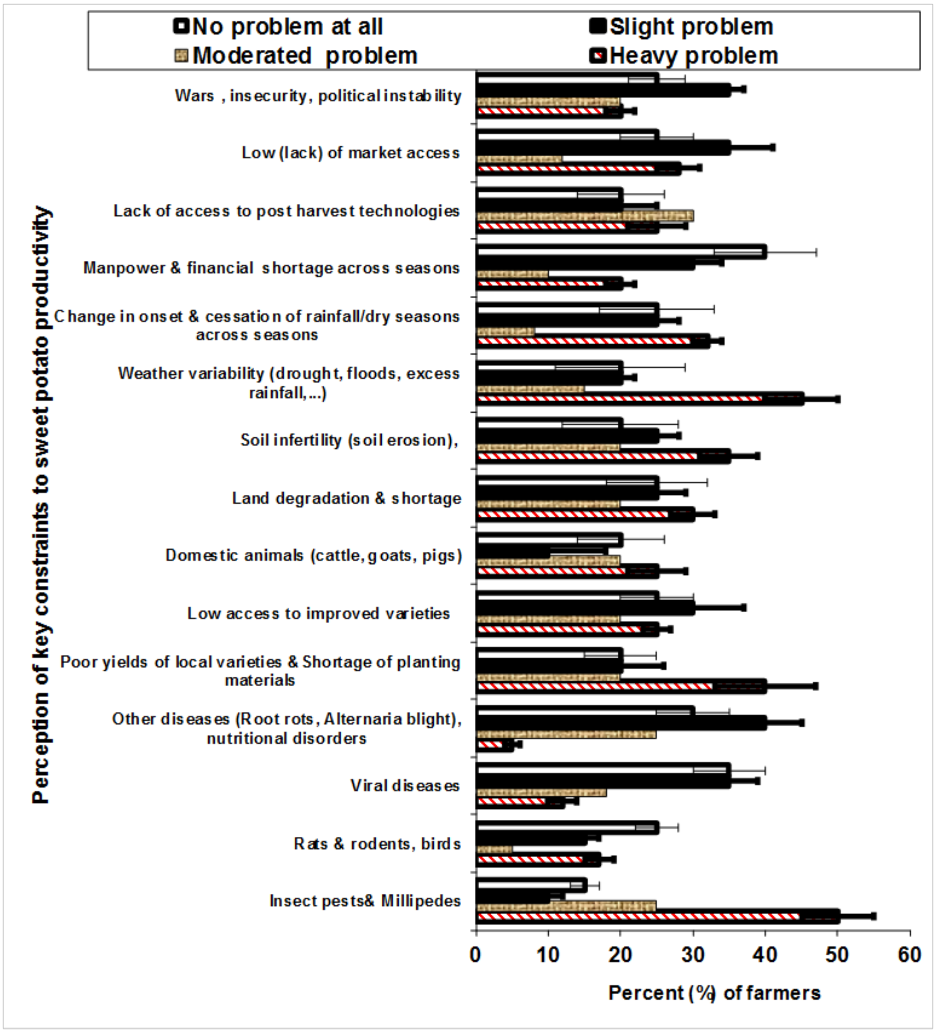


Figure 1a. Farmers 'perception (belief) of the magnitude (scale level) of key constraints to sweet potato productivity in South-Kivu Province, eastern DRCongo

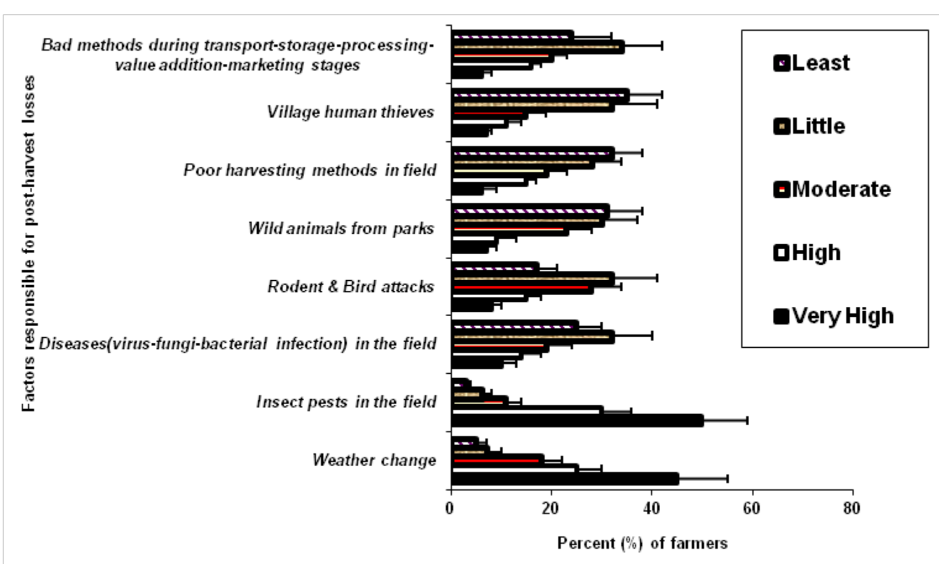


Figure 1b. Farmers' perceptions about factors responsible for post-harvest losses in sweet potato

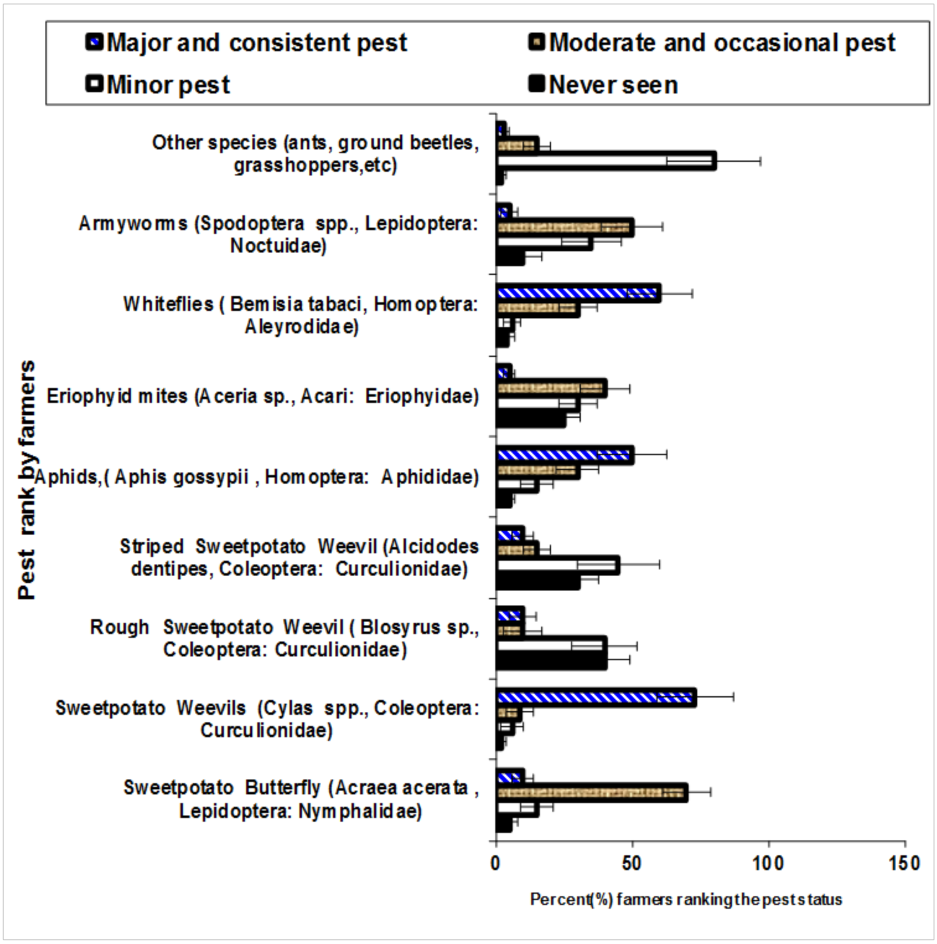


Figure 2. Major insect pests experienced by farmers in sweet potato (% households) : Ranking of Pests in terms of pest status (prevalence) from questionnaire response from major crop growers of South-Kivu Province

Table 2. Control methods for the most important insect pests of sweet potato (% households)

Study territory	Kabare	Kabare	Kabare	Kabare	Walungu	Walungu	Kalehe	Kalehe
Study sites (villages)	Kabare-Cirunga	Miti	Mudaka	Katana	Kamanyola-Sange	Kamisimbi	Luzira	Ihusi
Application of synthetic chemical insecticides	0.34	4.21	3.33	4.12	2.12	1.67	0.23	2.89
Application of ash powder, insecticidal plant powders	6.45	10.21	7.13	18.11	0.11	7.45	7.45	7.45
Regular monitoring, hand-picking of pests	4.23	5.34	0.41	1.37	0.34	0.54	1.34	0.55
Seeking/planting tolerant varieties, crop rotations, selection of good varieties	11.3	15.6	10.46	17.1	7.99	4.81	2.54	4.11
Early harvesting,	0.67	0.81	4.65	2.54	16.12	9.42	10.43	9.34
Mulching, re-hilling , earthing vines, ,	13.11	5.23	6.32	4.12	4.12	0.02	2.65	0.76
Establishing in plots scaring manequins	0.21	2.22	0.34	8.91	0.44	0.65	2.89	0.34
Setting rodent traps	5.59	3.14	2.21	5.12	2.56	0.34	6.76	0.67
Applying (combining) various practices (IPM)	6.21	1.15	1.04	2.54	1.45	0.65	1.45	0.22
None (doing nothing at all)	51.67	52.05	64.1	36.01	64.7	74.19	64.31	73.7

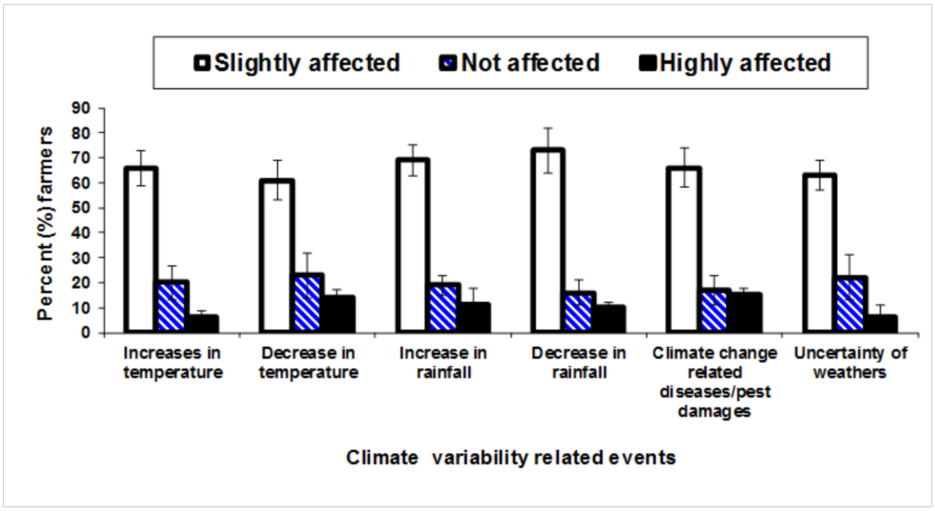


Figure 3a. Do the climate change related common natural hazards and catastrophes (floods, drought, heavy precipitation, winds) affects sweet potato growth, yield and production in South-Kivu Province, eastern DRCongo? Error bars represent standard errors (SE)

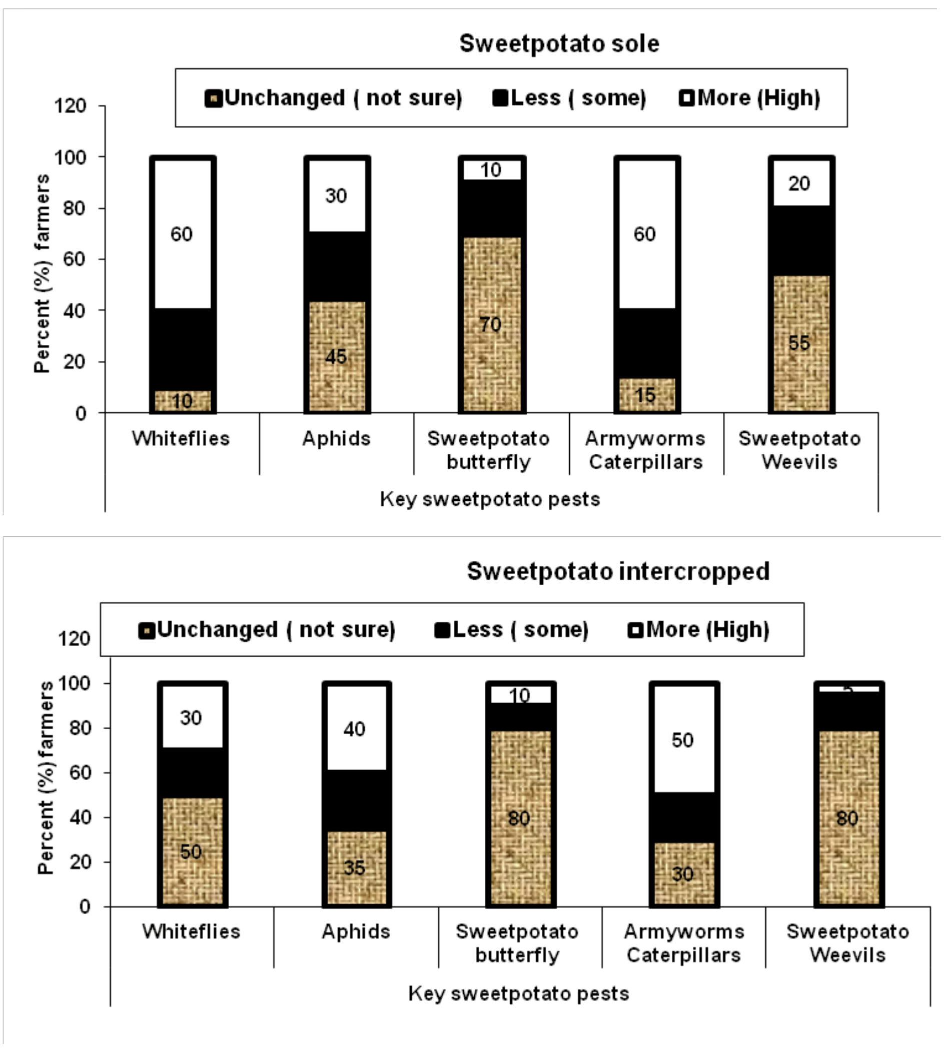


Figure 3b. Perception of farmers (%) reporting the change in the pest population density 10 years (2005-2015) ago as compared to the current situation (2015). These are perceived changes in abundance, pressure and damages caused by key pests to various sweet potato varieties. The perception is based on historical experience in struggling with sweet potato antagonists in the region

sweetpotato yield and productivity; indicating that yield loss could not necessarily be associated with variability in climatic factors. Under intercropping systems, most farmers (80%) perceived the status (in terms of abundance) of sweetpotato weevil and sweetpotato butterfly remained unchanged over the last 10 years. Similarly, under monocropping systems, 70% of farmers perceived that the status sweetpotato butterfly has remained unchanged over the last 10 years (Figure 3b).

6.2 Trends in characteristics of local climatic factors

Concerning the average monthly rainfall across years and months in the study area, data showed large variation. The high fluctuation in rainfall, spatially and temporally, increased the difficultly for reaching comprehensive relationships between the monthly rainfall amounts and annual rainfall amounts. Overall, rainfall patterns during the 11 years of the study were highly unpredictable (long period of dry weather or of heavy rainfall).

Weather conditions between dry and rainy seasons (months) differed greatly, year after year, during the course of the study. Generally, September-May was cold and rainy, whereas June-August was unusually warm and dry. Sometimes, there was warm weather at the start of the rainy season, then it gradually changed to cold and rainy weather in October-November. The length of dry or rainy seasons varied less between years. Weather conditions in September were warmer than normal. The mean temperature was slightly lower than normal in November but unusually high in July-August.

From 2005 to 2015, there were marked variations in the temperature and precipitation pattern. Some years experienced above normal rainfall, much as years with extremely low rainfall were not numerous or dominant. Rainfall shows a fluctuating trend about the mean from year to year, month to month; however there was a marked increase in the magnitude of years of below average rainfall since 2010 to 2015. While the rainfall pattern showed a fluctuating pattern from year to year, temperatures (maximum) slightly increased steadily by almost 0.01°C to 0.15°C over the past 11 years. Over time and space, the trend in climatic factors show a slight decline in rainfall amounts and increasing temperatures (average monthly minimum/maximum temperature). However, the trend in annual rate of rainfall decline needs to be further investigated.

6.3 Patterns of pest population dynamics: general observations

To better understand the overall dynamics of the pests over an 11-year period, the average number of pest caught/ counted was plotted against the year. There were significant differences in the number of pests collected from one year to the next (P<001; $F_{(1,10)}$=5.78, ANOVA test). Readily apparent was the gradual increase in the population densities over years. Equally apparent were the sudden and drastic effects of years (months) of high temperatures and the consequential effects in the following years (months). At this juncture, it is likely that pest populations may continue increasing over years with rise in the temperatures and uneven rainfall amount, regime and intensity. This situation may be exacerbated with general rural environmental degradation and with the poor farming practices currently implemented by farmers (e.g. use of degenerated varieties, use of non-certified for origin and sensitive varieties, and declining fertility levels of soils). Although pests were not a big issue in sweetpotato cultivation in the 10-20 past years, in the future, pests and diseases may worsen the productivity of sweetpotato despite high yielding and vitamin rich varieties being deployed in rural areas. Climate change impact on crop pests is a reality in eastern DRCongo and the lack of pests and diseases-tolerant and high yielding varieties, coupled with continuing decline in soil fertility levels and soil erosions, will continue putting rural communities at high famine risk.

6.4 Trends in pest population density over years

The curves of changes in the population density had various shapes for the different pest species. They show fluctuations with peaks offset in time between years and between months. The population dynamics of pests seemed to be similar across years, with two to several peaks of density per year, occurring during the rainy season, and the lowest density recorded during dry seasons. The scarce populations observed during dry seasons may be related to fluctuation in current climatic conditions.

Overall, for most pests studied, the variation curves for the different pests show three main peaks, with shifts in time and amplitude differences between years and months. In some months of the year the number (population density) was low, probably because of the variation in maximum temperatures. For some pest species, the population density fluctuated significantly (P<0.01) over months and years. For example, sweetpotato weevil had three major peaks across years. However, its population density was low and slightly unchanged between 2005 and 2010. The population density became relatively more important from 2010 to 2015. There was a decrease in 2010 followed in 2011 by an increase in the population density. The population density of the pest reached remarkable values in 2012. From 2013, the population was nearly zero until June 2014.

Coincidentally, during the 11 years of pest monitoring, individuals were sampled on almost the same dates in all study sites. There was one very prominent observation throughout the years of monitoring: major peaks of pest activity always occurred 1-2 weeks after peaks in climatic factors (rainfall, temperatures) during the rainy season. During dry seasons, the trend was not clear. The initial peak of pest activity occurred consistently regardless of the cropping system. However, this trend was not of the same magnitude across study sites and, age of the potato plants. For a few pest species, the change in the population dynamics occurred during the first 5 years of monitoring.

The 2014-2015 data showed very large peaks in the pest population during the months of the rainy season, with several subsequent smaller peaks of activity during dry seasons. For the sweetpotato butterfly, data from the 2005-2010 revealed very small peaks during March-May of each year, and much smaller peaks during September-December. The 2010-2012 data showed slight peaks in the dry months (June-July), and an even smaller peak in August, but subsequent peaks were of much longer durations during the start of rainy seasons.

There appeared to be some patterns in the spatio-temporal abundance of pests with high peaks in numbers occurring mostly during rainy seasons, corresponding with the time of growth and tuber forming of the crop. It was clear that high pest populations congregated and feed more on sweetpotato plants during rainy seasons than during dry seasons across the years. Lack of sufficient rainfall caused very low populations. There were clear relationships between pest populations and rainfall such that there was an increase in pest numbers in response to rainfall amount.

The population dynamics changed from large bursts of activity to more evenly distributed activities throughout months, seasons and years. The population density of most pests had similar survival trends even during unusual weather (high temperatures, abnormal rainfall, wetter/hotter months) although one would expect a drastic decline (a death). Pest population in fields located at low or high altitudes followed the same pattern and magnitude of activity. Obviously, cooler temperatures favored feeding and oviposition habits and fecundity for underground pests such the weevil. Also warm weather were likely favoring other species feeding behavior and population built-up. It was observed in this study that plant damage by the pests was more severe at lower altitude than at higher and cooler elevations.

Overall, temporal dynamics of the population dynamics were found to be temperature-dependent activities. Hence, both temperature and annual rainfall affected bionomic, phenology and population density of the pest each year through synchronization of egg hatching periods for the pests and allowing larvae and adults to peak when food (leaves of sweetpotato) is abundant in the field.

It is likely that some of these pests are well established in the region since change in their population density dynamics across months occurred over all sampling years. For example, Aphid population showed a very large peak population during long rainy seasons, with subsequent smaller peaks of activity during the short rainy season. Whiteflies showed slight peaks at the start of the rainy seasons and an even smaller peak in September of each year, but subsequent peaks were of much longer duration.

Hence, the population dynamics changed from a single large burst of activity to more evenly distributed activity throughout the course of the year. Plant damage by aphids may be more severe at higher, cooler elevations. Sweetpotato weevil trend revealed a very small peak at the beginning of the long dry season (June-August) and a much smaller peak during the short dry season of January-February although subsequent peaks were of the same magnitude. Sweetpotato butterfly caterpillar population were evenly distributed across years and months. They showed a clear cyclical activity corresponding to its adult population peaks over years.

6.5 Regression analyses exploring multiple dependency of pest population density fluctuations to climatic factors under intercropped sweetpotato systems (mixture of sweetpotato with other crops such as cassava, banana, coffee)

The effects of climate variability on pest population remain largely un-studied in DRCongo. However, climate change may also play a role in the fluctuation of the pests. The data indicated that variations in pest population density (slow rise/decrease, drops, and peaks) were closely interconnected with variability in climatic factors (slow rise/decrease, drops and peaks in rainfall and maximum temperature amounts) on a monthly basis within the same year. The different pest population densities were characterized by different trends.

Thus, the fluctuation in the population density was dependent on the distribution of rainfall and temperature across the year. Continuing fluctuation of the population density of the pests may be due to the continuing impact of climate variability by influencing (offsetting/bursting) and favoring reproduction or breeding conditions for the pest, as most bionomics of various insects are rain-temperature dependent. In fact, across years, increases in monthly rainfall are followed by outbreaks of the pest populations in the following month within the same seasonal period. Hence, peaks in population density of the pests were closely matched to peaks in climatic factors in high altitude sites.

The results of the multiple regression reveal that the fluctuations of the population density of pests were significantly ($P<0.05$) dependent on the increase in rainfall/ temperature in the study area.

Under multiple regression analyses, climatic factors (monthly mean temperature, monthly rainfall) were significantly correlated with monthly population fluctuations. The highest peaks in population density in some months and years coincided, in some cases, with the peaks (highest/lowest points) in climatic factors. Whenever, correlation analysis revealed significant positive correlation between monthly pest population fluctuations and climatic factors (mean temperature/ rainfall) suggesting that monthly increases in the mean maximum temperature and monthly rainfall favored increases in population size of the pests.

In contrast, significant negative correlations between monthly population fluctuations and climatic factors suggested that cold days might disfavor increases in population size of the pests. However, only 10-20% of the fluctuation in the population density in the current month of the years could be attributed (accounted for) to variability in climatic factors during previous months of the years. In some cases, there were weak correlation with climatic factors and this may be attributed to the fact that it takes some time for the rain to cause an increase in food resources for the pest obtained through favoring breeding conditions, which would then be available for build-up of the pest population.

It is likely that in this study, the population building up throughout successive rainy/dry months was controlled by many factors not considered in this study (natural enemies, soil composition and structure, type grown in the neighborhood, degree of tolerance- susceptibility of the variety grown to pests and diseases and the creation of favorable survival conditions within microhabitat where the crop is grown, etc.)

Trends in the relationship of different species to climatic factors are presented in Figures 4-11. Trends in virus pressure (number of leaves showing symptoms of virus infection) are also presented in Figure 12. Data presented in these figures are means of 6 study sites and varieties. In the study sites, all varieties that were grown were local genotypes. In a few cases (Mulungu, Miti), improved varieties (orange flesh ones) that were found in the field were previously released by agricultural research systems (INERA) and locally named by farmers. From these Figures, it can be observed that population density of different pest species fluctuated differently from year to year.

According to multiple regression models there were significant ($P<0.05$) relationships between the fluctuation of pest population densities and climate parameters (rainfall, temperature). An increase in climatic factors (temperature, rainfall) was likely to be associated with a corresponding increase in the pest population densities.

The population fluctuation of *Acraea acerata* was significantly and positively related to year of sampling ($T=2.44$, $P=0.025$) and maximum temperature ($T=6.93$, $P<0.001$); and negatively related to rainfall ($T=-4.08$, $P<0.001$). This result implies that an increase in the maximum temperature increased also the population density of *Acrae acerata*. However, increases in rainfall amount reduced the population density of *Acraea acerata*. All predictors explained only 18.15% of the variability in the fluctuation of the population density of *Acraea acerata*.

Over time, the fluctuation in the population density of *Cylas* spp. was related to: (i) negatively to minimum temperature ($T=-5.18$, $P<0.001$), and (ii) positively related to both month of the year ($T=4.19$, $P<0.001$), rainfall ($T=3.43$, $P<0.001$) and maximum temperature ($T=9.84$, $P<0.001$). The total determinant coefficient of these three climatic factors was 19.56%, indicating that these climatic factors can explain most of the variation in the fluctuation of the population of Cylas spp.

The aphid population density dynamics over time was significantly and positively related to month of the year ($T=4.40$, $P<0.001$), maximum temperature ($T=6.56$, $P<0.001$), and minimum temperature ($T=2.68$, $P=0.008$). The overall variance explained by the predictors was of 38.81%. The whitefly population density dynamics was positively related to month of the year ($T=2.40$, $P<0.001$), rainfall ($T=8.45$, $P<0.001$), minimum temperature ($T=2.59$, $P<0.001$) and maximum temperature ($T=10.88$, $P<0.001$). The overall

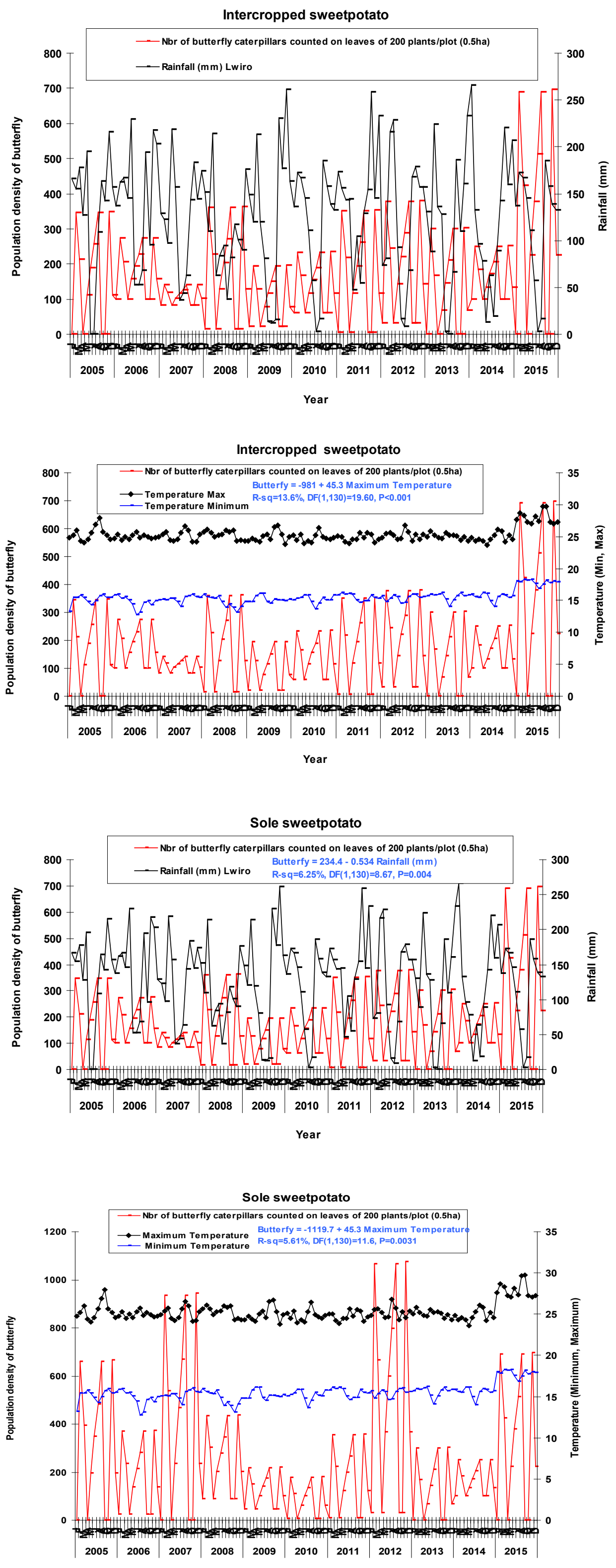


Figure 4: Fluctuation of the population density of sweet potato butterfly pest in relationship with variability in climatic factors (rainfall, temperature) under intercropping and mono-cropping systems in Kivu, eastern DRCongo

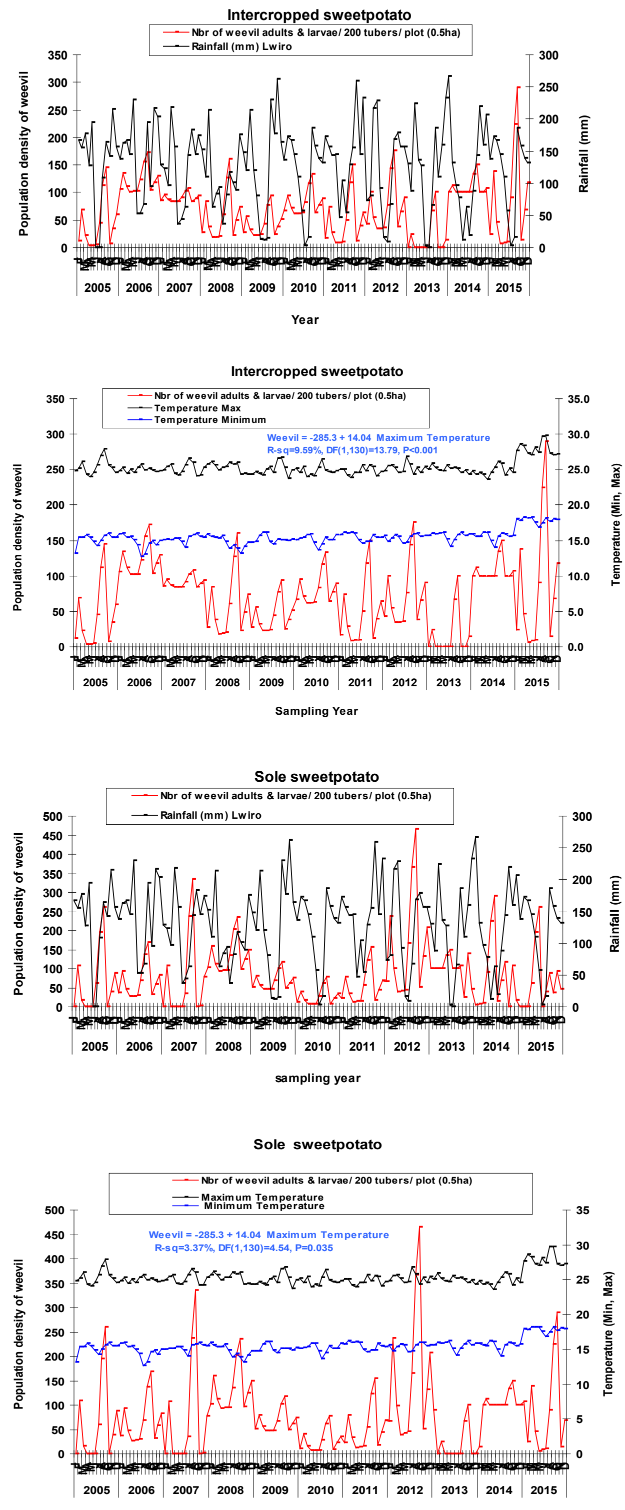


Figure 5: Fluctuation of the population density of sweet potato weevil (Cylas spp) pest in relationship with variability in climatic factors (rainfall, temperature) under intercropping and mono-cropping systems in Kivu Province, eastern DRCongo

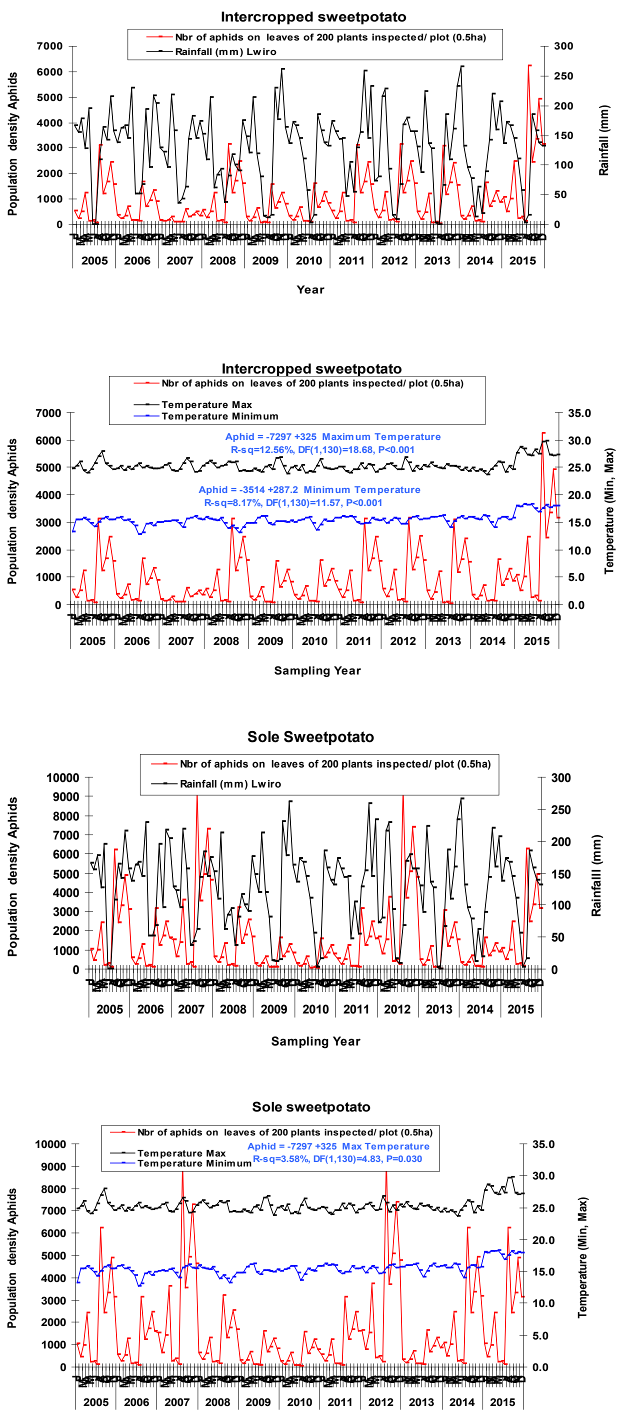


Figure 6: Fluctuation of the population density of the aphid pest in relationship with variability in climatic factors (rainfall, temperature) under intercropping and mono-cropping systems in Kivu Province, eastern DRCongo

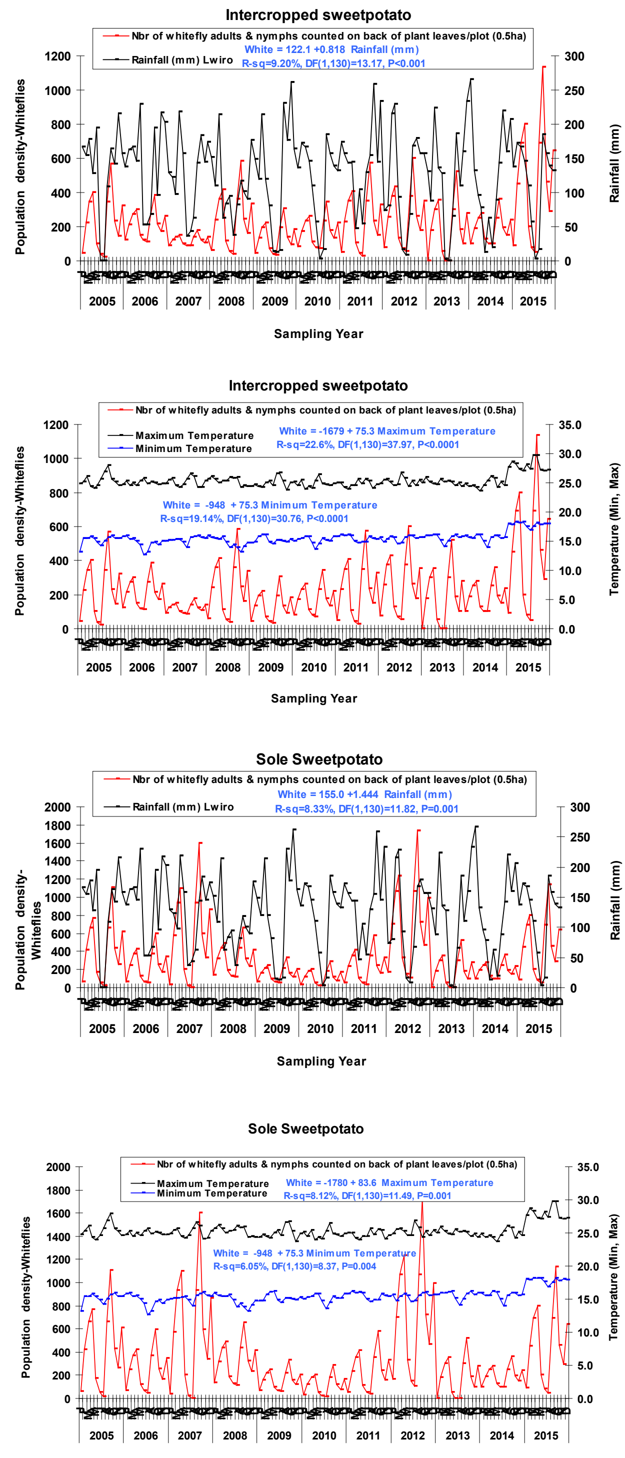


Figure 7: Fluctuation of the population density of whiteflies (Bemisia tabaci) in relationship with variability in climatic factors (rainfall, temperature) under intercropping and mono-cropping systems in Kivu Province, eastern DRCongo

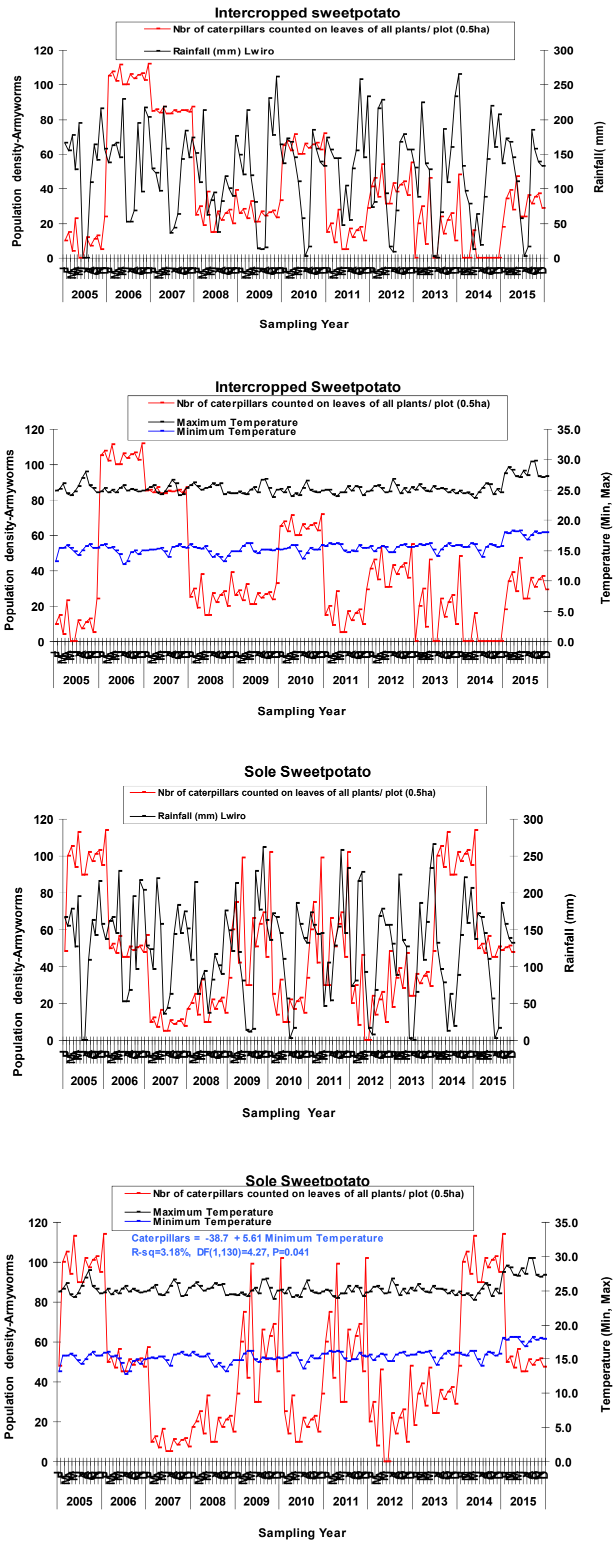


Figure 8: Fluctuation of the population density of armyworms pest in relationship with variability in climatic factors (rainfall, temperature) under intercropping and mono-cropping systems in Kivu Province, eastern DRCongo

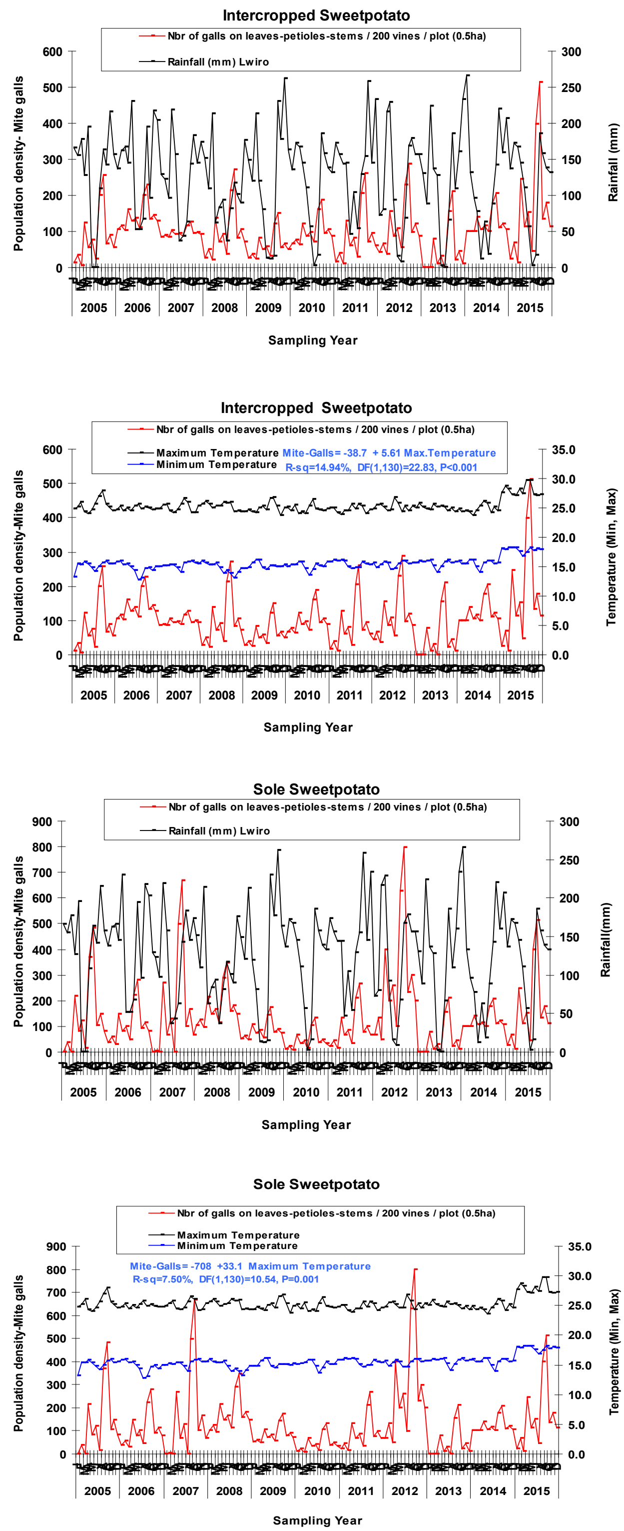
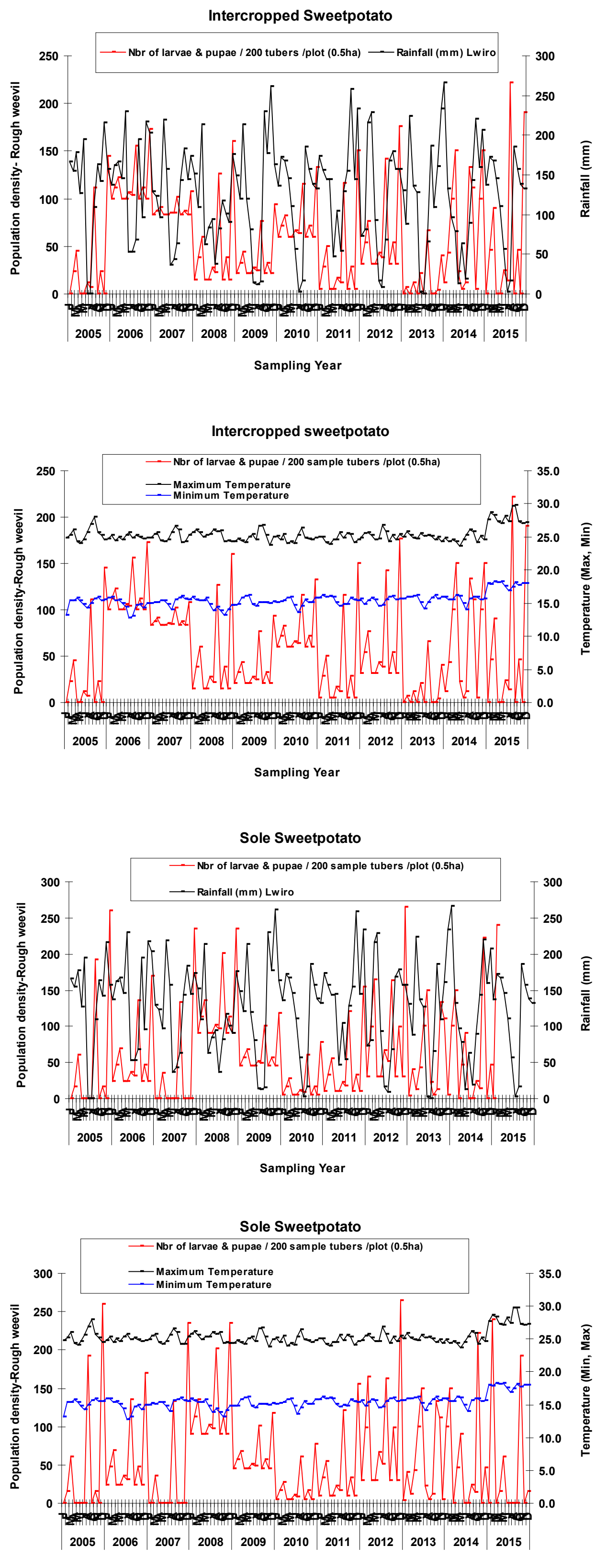


Figure 9: Fluctuation of the number of mite –gall induced in relationship with variability in climatic factors (rainfall, temperature) under intercropping and mono-cropping systems in Kivu Province, eastern DRCongo



Figur 10: Fluctuation of the population density of rough weevil pest in relationship with variability in climatic factors (rainfall, temperature) under intercropping and mono-cropping systems in Kivu Province, eastern DRCongo

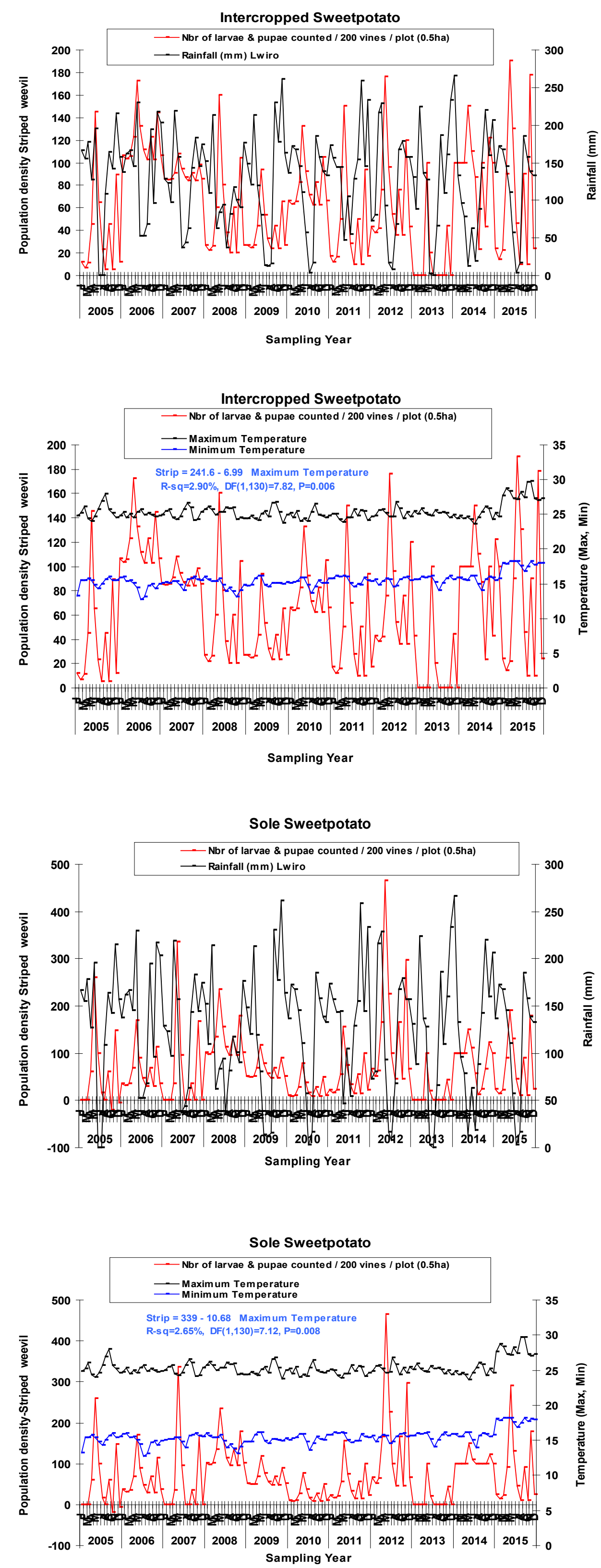


Figure 11: Fluctuation of the population density of striped weevil pest in relationship with variability in climatic factors (rainfall, temperature) under intercropping and mono-cropping systems in Kivu Province, eastern DRCongo

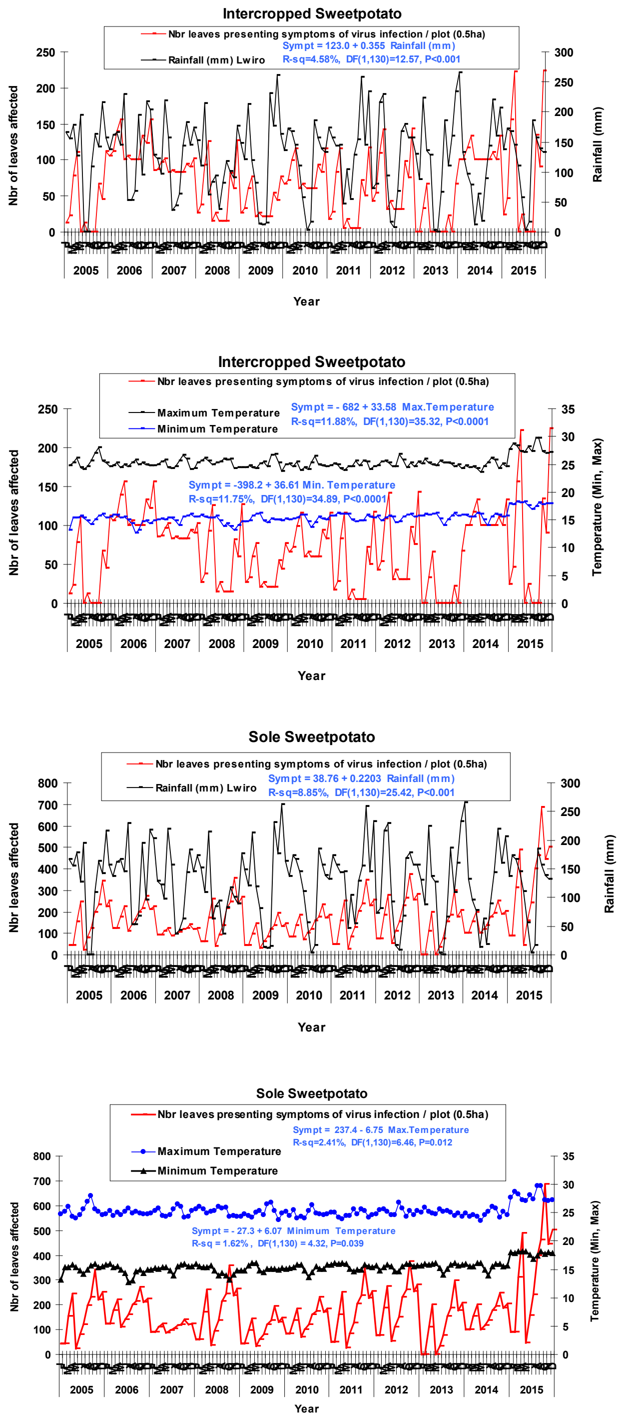


Figure 12: Fluctuation of the sweet potato virus disease pressure in relationship with variability in climatic factors (rainfall, temperature) under intercropping and mono-cropping systems in South-Kivu Province, eastern DRCongo

variance that was explained was 40.42%. Over time, the fluctuation of the population density of armyworms was significantly and negatively related to sampling Year (T=-9.62, P<0.001). The overall variance explained was 19.28%. The fluctuation of the density of galls caused by Eriophyid mites was positively related to month of the year (T=7.70, P<0.001) and maximum temperature (T=8.71, P<0.001). The overall variance explained was 24.45%.

The population density fluctuation of rough sweetpotato weevil (*Blosyrus* sp.) larvae/pupae was negatively related to year (T=-3.28, P<0.01), month of the Year (T=6.57, P<0.001), Maximum Temperature (T=2.24, P=0.025). The overall variance explained was of 11.20%. The population density fluctuation of striped sweetpotato weevil larvae/pupae was positively related to minimum temperature (T=5.26, P<0.001) and negatively related to year (T=-3.67, P<0.001), month of the year (T=2.04, P<0.001), rainfall (T=-3.91, P<0.001), and maximum temperature (T= -5.91, P<0.001). The overall variance explained was of 8.58%.

The virus pressure (number of sweetpotato leaves presenting symptoms of virus infection) was positively related to month of the year (T=14.12, P<0.001), rainfall (T=4.21, P<0.001), maximum temperature (T=6.47, P<0.001), and minimum temperature (T=4.37, P<0.001). The overall variance explained was of 47.46% (Table 3). The plants may be more exposed to virus transmission with increase in the number of days with temperatures favorable for insect activity and of virus spread. Hence, correlations with antecedent climate factors provided opportunity to forecast pest population density (whiteflies, aphids) and therefore sweetpotato virus infection.

6.6 Regression analyses exploring multiple dependency of pest population density fluctuations to climatic factors under monocropping (sole sweetpotato) systems

The fluctuation of the population density of sweetpotato butterflies was positively related to Sampling year (T=2.24, P=0.025), and maximum temperature (T=6.93, P<0.001), and negatively related to rainfall (T=-4.08, P<001). The overall variance explained was of 18.15% (Table 3). The population density of the sweetpotato weevils (*Cylas* spp.) was negatively related to minimum temperature (T=-3.05, P<0.001) and positively related to Year (T=2.07, P<0.001), month of the Year (T=3.85, P<0.001) and maximum temperature (T=4.63, P<0.001). The overall variance explained was of 9.51%

Table 3. Multiple regressions to test the influences of climatic factors (Year of data collection, Month of the year, Monthly rainfall, Maximum &Minimum temperatures) on the dynamics of the population density of sweet potato pests and virus infection pressure (number of sweet potato leaves presenting symptoms of virus infection in the field) from 2005 to 2015, South-Kivu Province, eastern DRCongo

A. Intercopped sweet potato (mixture of sweet potato with other crops such as cassava, Banana, coffee)

Terms	Coef	SE Coef	T-Value	P-Value	R^2 (%)
Nbr of Sweet potato butterfly (*Acraea acerata* , Lepidoptera: Nymphalidae) caterpillars counted on leaves of 200 plants/plot (0.5ha)					
Constant	-10544	4324	-2.44	0.015	
Year	4.89	2.18	**2.24**	**0.025**	
Month of the Year	1.86	1.64	1.14	0.256	
Rainfall(Mean monthly Rainfall in mm)	-0.3919	0.0961	**-4.08**	**0.000**	
Maximum Temperature (Mean Monthly)	41.66	6.01	**6.93**	**0.000**	
Minimum Temperature (Mean Monthly)	-8.62	8.04	-1.07	0.285	18.15
Nbr of sweet potato weevils (*Cylas* spp., Coleoptera: Curculionidae) adults & larvae / 200 tubers / plot (0.5ha)					
Constant	-1139	1552	-0.73	0.463	
Year	0.434	0.782	0.55	0.579	
Month of the Year	2.468	0.589	**4.19**	**0.000**	
Rainfall(Mean monthly Rainfall in mm)	0.1183	0.0345	**3.43**	**0.001**	
Maximum Temperature (Mean Monthly)	21.25	2.16	**9.84**	**0.000**	
Minimum Temperature (Mean Monthly)	-14.96	2.89	**-5.18**	**0.000**	19.56
Nbr of adult aphids (*Aphis gossypii*, Homoptera: Aphididae) counted on leaves of all plants inspected /plot (0.5ha)					
Constant	-59602	27366	-2.18	0.030	
Year	25.4	13.8	1.84	0.066	
Month of the Year	141.8	10.4	**13.65**	**0.000**	
Rainfall(Mean monthly Rainfall in mm)	1.138	0.608	1.87	0.062	
Maximum Temperature (Mean Monthly)	249.8	38.1	**6.56**	**0.000**	
Minimum Temperature (Mean Monthly)	0.008	50.9	**2.68**	**0.008**	38.81
Nbr of whitefly (*Bemisia tabaci*, Homoptera: Aleyrodidae) adults & nymphs counted on back of plant leaves / plot (0.5ha)					
Constant	-7234	4662	-1.55	0.121	
Year	2.57	2.35	1.09	0.274	
Month of the Year	7.78	1.77	**4.40**	**0.000**	
Rainfall(Mean monthly Rainfall in mm)	0.875	0.104	**8.45**	**0.000**	
Maximum Temperature (Mean Monthly)	70.53	6.48	**10.88**	**0.000**	
Minimum Temperature (Mean Monthly)	22.48	8.67	**2.59**	**0.010**	40.42
Nbr of armyworms (*Spodoptera* spp ., Lepidoptera: Noctuidae) caterpillars counted on leaves of all plants/ plot (0.5ha)					
Constant	9559	984	9.72	0.000	
Year	-4.769	0.496	**-9.62**	**0.000**	
Month of the Year	0.051	0.373	0.14	0.891	
Rainfall(Mean monthly Rainfall in mm)	0.0275	0.0219	1.26	0.209	
Maximum Temperature (Mean Monthly)	1.21	1.37	0.88	0.378	
Minimum Temperature (Mean Monthly)	1.97	1.83	1.08	0.282	19.28
Nbr of galls caused by Eriophyid mites (*Aceria* sp., Acari: Eriophyidae) that are counted on leaves-petioles-stems/200 vines/plot (0.5ha) each sampling day					
Constant	-48	2256	-0.02	0.983	
Year	-0.29	1.14	-0.25	0.802	
Month of the Year	6.587	0.856	**7.70**	**0.000**	
Rainfall(Mean monthly Rainfall in mm)	0.0523	0.0501	1.04	0.297	
Maximum Temperature (Mean Monthly)	27.33	3.14	**8.71**	**0.000**	
Minimum Temperature (Mean Monthly)	-1.19	4.20	-0.28	0.776	24.45

Nbr of Rough Sweet potato weevil (*Blosyrus* sp., Coleoptera: Curculionidae) larvae & pupae counted per 200 sample tubers / plot(0.5ha)					
Constant	5297	1618	3.27	0.001	
Year	-2.674	0.815	**-3.28**	**0.001**	
Month of the Year	4.035	0.614	**6.57**	**0.000**	
Rainfall(Mean monthly Rainfall in mm)	0.0100	0.0360	0.28	0.780	
Maximum Temperature (Mean Monthly)	5.05	2.25	**2.24**	**0.025**	
Minimum Temperature (Mean Monthly)	-1.40	3.01	-0.46	0.643	11.20
Nbr of striped sweet potato weevil (*Alcidodes dentipes*, Coleoptera: Curculionidae) larvae & pupae counted by 200 vines randomly selected in a field plot of 0.5ha size					
Constant	5722	1498	3.82	0.000	
Year	-2.768	0.755	**-3.67**	**0.000**	
Month of the Year	1.160	0.568	**2.04**	**0.042**	
Rainfall(Mean monthly Rainfall in mm)	-0.1300	0.0333	**-3.91**	**0.000**	
Maximum Temperature (Mean Monthly)	-12.32	2.08	**-5.91**	**0.000**	
Minimum Temperature (Mean Monthly)	14.66	2.79	**5.26**	**0.000**	8.58
Number of sweet potato leaves presenting symptoms of virus infection per filed-plot(0.5ha)					
Constant	-4304	2694	-1.60	0.111	
Year	1.68	1.36	1.24	0.216	
Month of the Year	16.56	1.02	**14.12**	**0.000**	
Rainfall(Mean monthly Rainfall in mm)	0.2521	0.0599	**4.21**	**0.000**	
Maximum Temperature (Mean Monthly)	24.25	3.75	**6.47**	**0.000**	
Minimum Temperature (Mean Monthly)	21.88	5.01	**4.37**	**0.000**	47.46
B. Sole Sweet potato (Monocropping of sweet potato)					
Nbr of Sweet potato butterfly (*Acraea acerata*, Lepidoptera: Nymphalidae) caterpillars counted on leaves of 200 plants/plot (0.5ha)					
Constant	-10544	4324	-2.44	0.015	
Year	4.89	2.18	**2.24**	**0.025**	
Month of the Year	1.86	1.64	1.14	0.256	
Rainfall(Mean monthly Rainfall in mm)	-0.3919	0.0961	**-4.08**	**0.000**	
Maximum Temperature (Mean Monthly)	41.66	6.01	**6.93**	**0.000**	
Minimum Temperature (Mean Monthly)	-8.62	8.04	-1.07	0.285	18.15
Nbr of sweet potato weevils (Cylas **spp., Coleoptera: Curculionidae) adults & larvae / 200 tubers / plot (0.5ha)**					
Constant	-5638	2628	-2.15	0.032	
Year	2.74	1.32	**2.07**	**0.039**	
Month of the Year	3.842	0.997	**3.85**	**0.000**	
Rainfall(Mean monthly Rainfall in mm)	-0.0672	0.0584	-1.15	0.251	
Maximum Temperature (Mean Monthly)	16.91	3.65	**4.63**	**0.000**	
Minimum Temperature (Mean Monthly)	-14.88	4.89	**-3.05**	**0.002**	9.51
Nbr of adult aphids (*Aphis gossypii*, Homoptera: Aphididae counted on leaves of all plants inspected /plot (0.5ha)					
Constant	257525	53248	4.84	0.000	
Year	-134.5	26.8	**-5.02**	**0.000**	
Month of the Year	248.4	20.2	**12.29**	**0.000**	
Rainfall(Mean monthly Rainfall in mm)	0.80	1.18	0.67	0.500	
Maximum Temperature (Mean Monthly)	222.4	74.1	**3.00**	**0.003**	
Minimum Temperature (Mean Monthly)	458.6	99.0	**4.63**	**0.000**	28.76
Nbr of whitefly (*Bemisia tabaci*, Homoptera: Aleyrodidae) adults & nymphs counted on back of plant leaves / plot (0.5ha)					
Constant	37893	9804	3.86	0.000	
Year	-20.33	4.94	**-4.11**	**0.000**	
Month of the Year	13.75	3.72	**3.70**	**0.000**	
Rainfall(Mean monthly Rainfall in mm)	1.355	0.218	**6.22**	**0.000**	
Maximum Temperature (Mean Monthly)	90.3	13.6	**6.63**	**0.000**	
Minimum Temperature (Mean Monthly)	48.6	18.2	**2.67**	**0.008**	23.38

Nbr of armyworms (*Spodoptera* spp ., Lepidoptera: Noctuidae) caterpillars counted on leaves of all plants/ plot (0.5ha)					
Constant	1681	1066	1.58	0.116	
Year	-0.852	0.537	-1.59	0.113	
Month of the Year	-0.269	0.405	-0.66	0.506	
Rainfall(Mean monthly Rainfall in mm)	0.0394	0.0237	1.66	0.097	
Maximum Temperature (Mean Monthly)	-1.26	1.48	-0.85	0.397	
Minimum Temperature (Mean Monthly)	7.02	1.98	**3.54**	**0.000**	4.97
Nbr of galls caused by Eriophyid mites (*Aceria* sp., Acari: Eriophyidae) that are counted on leaves-petioles-stems/200 vines/plot (0.5ha) each sampling day					
Constant	6659	4218	1.58	0.115	
Year	-3.75	2.13	-1.77	0.078	
Month of the Year	11.26	1.60	**7.03**	**0.000**	
Rainfall(Mean monthly Rainfall in mm)	0.0280	0.0938	0.30	0.765	
Maximum Temperature (Mean Monthly)	33.78	5.87	**5.76**	**0.000**	
Minimum Temperature (Mean Monthly)	5.35	7.85	0.496	0.496	16.26
Nbr of Rough Sweet potato weevil (*Blosyrus* sp., Coleoptera: Curculionidae) larvae & pupae counted per 200 sample tubers / plot(0.5ha)					
Constant	-1761	2133	-0.83	0.409	
Year	0.89	1.07	0.83	0.410	
Month of the Year	3.740	0.809	**4.62**	**0.000**	
Rainfall(Mean monthly Rainfall in mm)	0.1133	0.0474	**2.39**	**0.039**	
Maximum Temperature (Mean Monthly)	4.83	2.97	1.63	0.104	
Minimum Temperature (Mean Monthly)	-8.11	3.97	**-2.04**	**0.041**	6.29
Nbr of striped sweet potato weevil (*Alcidodes dentipes*, Coleoptera: Curculionidae) larvae & pupae counted by 200 vines randomly selected in a field plot of 0.5ha size					
Constant	597	2434	0.25	0.806	
Year	-0.14	1.23	-0.11	0.909	
Month of the Year	1.405	0.924	1.52	0.129	
Rainfall(Mean monthly Rainfall in mm)	-0.1397	0.0541	**-2.58**	**0.010**	
Maximum Temperature (Mean Monthly)	-18.11	3.39	**-5.35**	**0.000**	
Minimum Temperature (Mean Monthly)	14.29	4.53	**3.16**	**0.002**	5.54
Number of sweet potato leaves presenting symptoms of virus infection per filed-plot (0.5ha)					
Constant	2727	1539	1.77	0.077	
Year	-1.307	0.775	-1.69	0.093	
Month of the Year	1.842	0.584	**3.16**	**0.002**	
Rainfall(Mean monthly Rainfall in mm)	0.1371	0.0342	**4.01**	**0.000**	
Maximum Temperature (Mean Monthly)	-9.78	2.14	**-4.57**	**0.000**	
Minimum Temperature (Mean Monthly)	11.87	2.86	**4.15**	**0.000**	14.00

The fluctuation of the population density of Aphids was significantly and positively related to Month of the year (T=12.29, P<0.0001), maximum temperature (T=4.31, P=0.003), minimum temperature (T=4.63, P<0.0001). The overall variance explained was of 28.76%. The fluctuation of the population density of sweetpotato whitefly (*Bemisia tabaci*) was significantly and negatively related to sampling year (T=-4.11, P<0.001), and positively related to month of the year (T=3.70, P<001), rainfall (T=6.22, P<001), maximum temperature (6.63, P<0.001), and minimum temperature (2.67, P<0.001). The overall variance explained was of 23.38%. The fluctuation of the population density of armyworms (*Spodoptera* spp.) was related to Minimum Temperature (T=3.54, P<0.001). The overall variance explained was 4.97%.

The fluctuation in the number of galls caused by Eriophyid mite was related positively to month of the year (T=7.03, P<0.001), and maximum temperature (T=5.76, P<0.001). The overall variance explained was of 16.26%. The fluctuation of the population density of rough sweetpotato weevil was negatively related to minimum temperature (T=-2.04, P=0.041) and positively related to month of the year (T=4.62, P<0.001), rainfall (T=2.39, P=0.039). The overall variance explained was of

6.29%. The fluctuation of the population density of the striped sweetpotato weevil larvae/pupae was positively related to minimum temperature ($T=3.16$, $P<0.001$) and negatively related to rainfall ($T=-0.258$, $P<0.001$), maximum temperature ($T=-5.35$, $P<0.0001$). The overall variance explained was of 5.56%.

The number of leaves with symptoms of virus infection was positively significant related to month of the year ($T=3.16$, $P=0.002$), rainfall ($T=4.01$, $P<0.001$), minimum temperature ($T=4.15$, $P<0.001$) (Table 3).

7 Discussion

7.1 Impacts of the variability in climatic factors on pest population trend and sweet-potato productivity

In this study, high inter-annual variability in rainfall and temperature were observed. The rainfall pattern exhibited cyclic pattern in peaks (low, high) of rainfall totals. The time series shows that on average there were more years of below normal rainfall than above normal. The climate of the study area was found to vary with time according to trends of seasonal and annual rainfall and temperature over time.

The results on trend analysis for both rainfall and temperature revealed variability between the periods under investigation. The slopes of the trend lines for short rains (September, October and November) and long rains (March, April and May) and dry seasons (February, June, July, and August) revealed a slight declining trend. It is likely that such variations might be attributable to a number of factors including variations in the micro-climatic conditions in the different agro-ecological zones of the south-Kivu province. These observations are common in various agroecosystems of the tropics (Hance et al. 2007; Jackson et al. 2003; Okonya and Kroschel 2013ab; Parr et al. 2014)

In this study, it was observed that rainfall was always fluctuating while maximum temperature were on the slight increase. Temperature increases for both the mean annual maximum and minimum temperatures may shorten/extend the growing season for some crops. Crops with small grains may thrive in variable climatic factors (low rainfall and high temperatures). Other crops such sweetpotato with much resilience will continue to be cultivated largely by farmers even under climatic changes provided pests and diseases are well controlled.

In this study, positive and negative correlations between climatic factors and pest populations were observed. Positive correlations between population density of pests and climatic factors indicated that any increase in temperature/rainfall amounts may always be met by a corresponding increase in the population density. However, significant negative correlations between climatic factors and population density may indicate that any reduction in climatic factors may affect negatively the population density of the pests. Overall, the decline in rainfall/temperature has had very serious consequences for pest population density built-up. It is therefore possible to forecast sweetpotato pest population density dynamics based on variability in the climatic factors (temperature mainly).

Overall, increase in maximum/minimum temperature was not necessarily associated with increase in rainfall. It is likely that currently observed variations in local climate might be an artefact of temperature rise rather than of rainfall. Long term observation and analyses of climatic factors may help in confirming this hypothesis.

It is likely that the province may experience some crop failure, mainly due to climate change and climate variability. Pest population is sensitive to climatic fluctuations especially precipitation and maximum temperature. The increase in the minimum temperature means that crops may start being exposed to longer hours of evapo-transpiration, and becoming more and more susceptible to moisture stress even during the long rainy. Therefore choice of crop planting date by farmers may become important as the local calendar may be modified.

Overall, increases in temperatures are proven to be capable of increasing demand, which in turn may increase the rate of water loss in the soil. Small changes in actual evapotranspiration may lead to huge changes field water levels and storage. The water-holding capacity of the atmosphere also increases with higher temperatures; hence even more water may be lost through evaporation. Crops that are sensitive to water availability may be grown at high risk of failure in such conditions in the future in the province. Much as sweetpotato is a resilient crop, high variability (tending to decline) in precipitation and moisture received may lead to lower yields. In climate resilient agriculture system, less sensitive crops may withstand moisture decline and produce minimum yield, despite rainfall fluctuations even years of less rain, and long dry spells.

7.2 Linkage (relationship) between climatic factors and sweetpotato pest population density

It is evident that global warming affects the bionomics of arthropods associated with crops. Climate change may change insect pest patterns. Hence, climate change may affect insect fitness and distribution in a given agro-ecological zone (Hance et al. 2007; Jackson et al. 2003; Okonya and Kroschel 2013ab; Parr et al. 2014; Sharma et al. 2002). Also, climate change (rising temperatures) may allow shifts in home range such as facilitating establishment of the pest in higher/lower altitudes where it was not found before.

Climate change may also lead to a resurgence of certain insect pests, rising temperatures may increase infestation by the pest under particular agricultural practices (monocropping versus mixed crops, continuous cropping with no rotation), creating suitable reservoirs for the pest. High population density may impact negatively on yield, quality and on the livelihood of farmers depending on the crop (Hance et al. 2007; Jackson et al. 2003; Okonya and Kroschel 2013ab; Parr et al. 2014).

It has been reported that high temperatures coupled with low wind velocities and availability of food are conditions most favorable to flight, breeding, oviposition of insect pests. These conditions often govern the number of generations that can occur in a year for a given pest species.

In this study, it was observed that the population density of pests had trends which were consistent with rainfall and temperature trends. High population densities are generally in line with temperature rainfall patterns such that highs in rainfalls correspond to highs for population density and vice versa. For some pest species (armyworm, aphids), the rainfall trend was inconsistent with the population density trend with highs for rainfall resulting in highs for population density the same with lows.

Much as relationships between climatic factors and pest population density are complex, abundant rainfall (rise/decrease in temperature) may create ideal conditions for the survival of the pest and this in turn, impacts the level of damage and pressures on the crop stage concerned (Hance et al. 2007; Jackson et al. 2003; Okonya and Kroschel 2013ab; Parr et al. 2014; Sharma et al. 2002)

Relatively higher rainfall figures may suggest an abundance of food and pest breeding sites (ideal conditions for rapid multiplication of the pest population) all month-year round. The creation of ideal conditions for rapid build-up of the populations (various generations) is likely to impact on the change in the prevalence status of the pests and hence on health status of the crop that is now being submitted to high pressure of the pest and therefore high damage, which is likely to impact on the yield.

In this study, the temperature profiles complicated the level of understanding of the influence of rainfall on sweetpotato damage and yield losses. Maximum temperatures seem to be the major driver for the pest population density since regression analyses revealed some significant correlations over time. Thus, maximum temperature probably allowed for a bounce back of pest populations. Maximum temperature may facilitate the co-occurrence of ideal conditions necessary for optimum multiplication of the pest to occur in sweetpotato field from the different agro-ecological zones studied.

The interaction of rising maximum temperature and increasing rainfall may favor for the creation of suitable conditions for the pest to rapidly build up several generations per year or per season. Thus, climate change and variability (rising temperature) may lead to occurrence of multiple generations of the pests with heavy consequences on the crop in terms of attack pressures and damages.

In the literature, it is clear that climate change and variability may influence plant performance and resilience to pest attacks, and also its interactions with other trophic levels, consequently affecting the abundance of the species (Hance et al. 2007; Jackson et al. 2003; Okonya and Kroschel 2013ab; Parr et al. 2014). Increases in the temperature are likely to be associated with the decoupling of pest population and its natural enemies, and such situation may result in higher pest numbers or more serious outbreaks of the pest in the following months of the year.

This study did not investigate the effects of a warming climate on natural enemies of the targeted pest species, yet, higher trophic levels are often disproportionately affected by drivers such as climate change and landscape habitat modification, farming practices, with specialist natural enemies (parasitoids) being affected more than generalists (predators). With rising temperature, the number of generations per year may be set to increase in even during unsuitable breeding months for the pest. Such situation has serious implications for sweetpotato production and livelihoods of growers.

Population density fluctuations may be attributed to a combination of other factors such as: heavy/light rain, strong winds, shading conditions, heat, type of neighbour crops grown, and type of vegetation surrounding the field. The exposition to adverse weather conditions is well known as a limiting factor for various crop pests. Ambient temperature and relative humidity may exhibit little/much monthly-seasonal variation for some species while for other, they are unlikely to influence fluctuations in the population density. Thus, favorable micro-climatic conditions may cause an indirect effect, since drought stress of plants is often associated with outbreaks in pest population. Overall, others factors such as natural enemies may counteract the increase of pest populations and thereafter prevent the pests from causing severe injuries (damages) during the dry/rainy seasons (months). It is worthwhile to consider interacting effects of the complexity of indigenous natural enemies as a regulator of the pest population density in sweetpotato cropping systems.

Thus, development from young stages to adult stages may be impaired by the unusual weather in sweetpotato cropping systems. On the other hand, warm weather may result in a large population built up for some pest species (whiteflies, aphids) because warm weather presumably may favor breeding ability. Hence, these species may possibly increase the risk of virus spread in field during dry and warm seasons than during rainy seasons. However, the risk of virus spread is higher in years with unusually warm dry weather. Correlating insect phenology with thermal time is of great importance for the monitoring and control of insect pests. It is likely that rainfall and temperature may be used as predictors of high/low occurrence of some sweetpotato pests in eastern DRCongo .

According to data from this study, it was unclear for the seasons (dry/rainy seasons, months, years) when the pests were reaching highly damaging levels. It may be premature to say that high population density corresponds to high levels of the crop attacks. However, the seasonal changes in weather, soil type (structure composition, reaches in nutrient), and age and host plant quality may influence the population growth of insect pests. Obviously during wet seasons, rainfall amount and intensity have a dominating effect whereas declining host quality in the dry season may limit further increase of the pest population. Natural enemies may play a significant factor although natural enemies of sweetpotato pests have not been explored in eastern DRCongo.

Overall, the data from this study indicates that climate variability (mainly maximum temperature) may be used to forecast impacts on crop production and yield (yield reduction). Yield reduction may have huge implications for livelihoods and poverty levels of farmers as it is agreed that climate change will cause more harm to poor rural communities relying more heavily on natural resources for their survival and having little capital to invest in costly adaptation strategies and/or pest and disease management.

Sweetpotato, being a major source of cash income for millions of smallholder families in eastern DRCongo, may also face the greatest challenge from climate change in the near future much as the crop is assumed to be more resilient to climatic variability. In fact, preliminary studies (Munyuli 2016, unpublished data) indicate that yield loss due to pest attacks induced by climatic factors may range between 10 and 60% depending on the type of variety cultivated. Thus, the need to develop new research strategies to combat threats such as pests and diseases. There is also a need to invest in agricultural climatic change research, and educate the public (including farmers) about climatic issues and their impacts on their lives and on crop production.

7.3 Effects of the cropping system (sole, mixed crop) and altitude on the pest population density dynamics

In this study, pairwise comparison of sites showed statistically dissimilar temporal patterns of the population density between all site combinations (sole vs intercrop: Kolmogorov–Smirnov: $Z=1.67$, $P=0.041$). Major peaks of pest activity occurred within each year. The initial peak occurred regardless of season, years, site location (altitude) and cropping system, or age of the crop.

Pest populations in both intercrop and monocrop followed the same pattern and magnitude of activity despite the fact that population density of pests was comparatively lower in intercrops than in monocrops and that pest population was higher in lowlands than in mid and highland sites.

Different responses of the pest population densities were observed for different farming practices (sole sweetpotato and intercropped sweetpotato) and altitude. This may suggest that there may be different sub-populations with distinctive feeding and nesting preferences and behaviours within.

Intercropping had a significant effect on the pest population. The population density of the pest was reduced in intercropping compared with monocropping systems. Hence, intercropping may interfere with pest feeding behaviour, breeding and host activities, subsequently reducing pest numbers. The possible explanation for this may be that pests have alternative plant host and food resources with diverse crops in the field whereas in the monocrop, they only have sweetpotato. When cassava was intercropped with sweetpotato, whiteflies preferring cassava for shading and resting habitat more than sweetpotato. However, specific mechanisms associated with intercropping with other crops (cassava, banana, coffee, maize, onion) requires additional in-depth research under local environmental conditions.

7.4 Linkage between climatic factors and virus infection pressure

It is likely that setting of the tubers was influenced by attacks and damage to the leaves since leaves play a key role in photosynthetic activities leading to growth of tubers in the soil. Although the relationship between disease pressure (number of leaves symptoms of virus infection) and pest populations was slightly complicated, the dynamic of change in the virus disease was consistently increasing over years.

Peaks in the numbers of whiteflies and aphids occurred and usually corresponded to the peaks in the population density of the pest. There was consistent change in the mean disease index between months and years across the monocrop and the intercrop fields, forming various cycles during the growth and maturity of the crop. Similar observations have been reported in Uganda and in other tropical regions (Alicia 1999; Byamukama et al. 2004; Gibson et al. 2004; Schaefers and Terry 1976; Wosula et al. 2012). Correlations with antecedent climate factors provided opportunity to forecast pest population density (whiteflies, aphids) and therefore sweetpotato virus infection (Sseruwu et al. 2015).

7.5 Farmers' knowledge of insect pests

Insect pests, climate change, unimproved varieties, price fluctuations, and low market prices were highly ranked as key constraints in sweetpotato production in South-Kivu Province. Some pests were perceived as pests of high importance by farmers. Major yield losses were predominantly attributed to insect pests. The majority (70%) of farmers applied no reliable control method for pests as reported elsewhere (Bonhof et al. 2001; Ebregt et al. 2004ab; Lebesa et al. 2012; Mukanga et al. 2011; Obopile et al. 2008; Okonya et al. 2014; Tounou et al. 2013). Overall, some IPM components where applied by farmers (use of tolerant varieties, monitoring and manual removal of attacked plants in the fields). Farmers had no to little knowledge about natural enemies and their pests. In the past, pests used not be a major issue. Seasonal pest outbreaks, high prevalence and incidence in pest status, as well as emerging new pests were not recognized as climate change related phenomenon. Hence, the need in the future to develop an appropriate IPM programme with emphasis on biocontrol of pests with natural enemies (parasitoids, predators) and related biopesticides, to help farmers adequately manage pests. It is believed that effective control and increase in the resilience of sweetpotato to pest outbreaks that can be easily adopted by farmers are also likely to be sustainable and safe. The lack of knowledge of pest description called for training of both farmers and extension workers in insect pest identification, bioecology, behavior and control. Empowering farmers with correct information about insect pests is essential for the reduction of pesticide misuse and uptake of more environmentally friendly approaches like IPM. Field surveys would need follow-up in order to assess and monitor the actual field infestation rates and intensities of each insect pest species and compare the results with the responses received from farmers.

The results from the survey indicated that most farmers significantly perceived ($P<0.05$) climate change as changes in patterns of rains, seasons, daily temperature and wind speed. Climate variability was described in the following terms: delay in the onset of rains, fluctuations in rainfall pattern, reduction in number of rainy days, early end to the rainy season, increase in daytime temperatures, and violent winds.

7.6 Farmers' knowledge and perception of climatic factors impacts on sweetpotato yield and food security

Results from this study indicated that households were aware of climate variability impacts in their villages. Farmers perceived a shift in the occurrence of rainfall and its distribution over the year and space within the province of South-Kivu. In addition, farmers perceived also that there was an increasing rise in maximum temperature and an inconsistency in rainfall occurrence year to year. Farmers believed that such variability in climate could be associated with shifts in rainfall patterns in terms of quantity, intensity and frequency over decades, which had direct consequences on their livelihoods in terms of mismatch of crop planting seasons with the onset of the rainy season. As reported from other areas in Africa (Mukanga et al. 2011; Okonya et al. 2014), some farmers indicate that there is a reduction in number of rainy days per month. Some reported too much rain falling within 2 to 3 days per month and the rest of the days of the month having no rain fall. Farmers indicated that the number of rain-days appeared to be declining with time, with a shift in the occurrence of rainfall. The pattern of change revealed by farmers was very consistent with climatic factors, as illustrated in Figures 4-12.

The climatic knowledge of farmers was also investigated in this study. Perceived climate patterns and environmental changes included: rainy seasons becoming warmer or hotter and dry seasons becoming cooler, increasing flood incidence, rains coming late, rains ceasing early, increase in pests and diseases, indigenous trees and wood vegetation scarcity, wild food becoming rare, and forest cover decreasing. Also, in the different study sites visited, it was observed that rural farming communities were likely to be vulnerable to the adverse impacts of climate change and related environmental hazards (landslides, soil erosion and floods, seismic activities). Hence, (i) natural disasters (drought, earth quake, seismic activity, epidemic, flood, wild and forest fire, landslide, river bank erosion) and (ii) related climatic stresses (drought, famine, erratic rainfall, water logging, potable water shortage, increasing frequency of droughts, dry spells, shifts of the rainfall season, crop growing seasons becoming shorter, temperatures rising, rainfall amounts declining, mid-season droughts occurring more and more frequently) were perceived by farmers as common phenomenon in their villages. The interaction of seismic and volcanic activities was perceived by farmers as likely to lead to a mixture of methane and $C0_2$ gas in Lake Kivu, hence the human population was exposed to a risk of dying in case of explosion of methane gas in the lower layers of Lake Kivu.

Farmers were even able to list indicators of climate variability and change. Climate variability was understood in terms of fluctuating rainfall trends, increasing incidences of floods, unpredictable rainfall patterns, disappearance of natural assets, and failure to predict the onset of the rainy season, using traditional knowledge.

Farmers perceived that climate irregularity was reducing crop yield, heating/drying up of environment, and increasing soil erosion/fertility loss. These stresses were perceived as affecting natural plant regeneration, exacerbating drying up of wells, streams and springs, driving disappearance of trees and plants, erosion of local agrobiodiversity, rarity of wild animals in natural vegetation in the villages, and increasing and emergency of new pests and diseases, etc.

Similar perceptions of farmers about climate changes are reported from other areas in Africa and in sub-Sahara Africa (Bonhof et al. 2001; Ebregt et al. 2004ab; Lebesa et al. 2012; Mukanga et al. 2011; Obopile et al. 2008; Okonya et al. 2014; Tounou et al. 2013).

Households primarily attribute reduced crop yields to changes in rainfall/temperature patterns and increasing incidences of pests/diseases, soils erosion, and floods. The implications are that the agriculturally dependent households are at risk of food insecurity, in eastern DRCongo.

Farmer's perceptions of trends of climate change may help in better understanding existing coping strategies. Some farmers perceived that temperature was rising while precipitation is slightly declining from time to time (Mukanga et al. 2011; Obopile et al. 2008; Okonya et al. 2014; Tounou et al. 2013).

Untimely rain and frequent floods are challenging crop production in eastern DRCongo. Floods and landslides are perceived as frequent primary climate related hazards that are affecting the livelihood of farmers, particularly in areas where serious environmental degradation is advancing due to anthropogenic activities (deforestation, land degradation, soil erosion on hilly landscapes, loss of fertility level of soil, bad farming practices such as monocropping systems).

Individual's vulnerability to these environmental hazards varies based on their hazard coping capacity. Lack of systematic (modern) early warning systems against natural hazards and disasters, inflexible cropping calendars, and narrow choice of crop varieties may (among others) aggravate the vulnerability of the population. Hence, improving forecasting and dissemination of climate information, developing flood/drought resistant varieties and promoting farm-level adaptation measures like adjusting planting, implementing agro-ecological practices, and other environmental-friendly farming and nature conservation practices need to be prioritized to improve community resilience to climate change

Congolese agriculture is predominantly rainfed and hence fundamentally dependent on the vagaries of weather. Thus, it is negatively affected by climate change. Climate change is likely to adversely affect DRCongo's economy due to heavy dependence of the agricultural sector on rainfall. Fluctuation (decrease/increase) of rainfall and temperature is likely to increase the exposure of the country to frequent drought, floods, landslides, etc. Food crop production by small-holder farmers in DRCongo is particularly vulnerable to climate change and related environmental risks, given high dependence on rainfall coupled with limited adaptive capacity. In DRCongo, smallholder farmers contribute about 72% of national stable food requirements. The challenges, which farmers are facing in adapting their livelihood to the change risks, are too many.

Overall, rain dependent small-holder farmers in South-Kivu province (eastern DRCongo) are highly vulnerable to weather related shocks, which impact greatly on their food production. The levels of vulnerability vary across gender, wealth status, and agro-ecological zones. The fact that rainfed small-holder farmers face considerable hardships in adapting to the changing climate, undermines their contribution to food security in the province.

There is little effort being made by the government to assist farmers towards climate change and variability adaptation. Most farmers receive non streamlined helps (assistances) from non-governmental organizations. Despite NGOs assistance, there are still many challenges to achieve the desired outcomes. Farmers are unable to afford certain alternatives, such as those of agroforestry or natural conservation practices to fight with some other challenges related to environmental degradation (land degradation, landslides, soil erosion, rising soil infertility).

Difficulties in accessing markets, poor road infrastructure and post-harvest processing facilities, fluctuating market prices, high costs and no/late deliveries of farming inputs are among the major challenges farmers are facing in the province. This makes farming a difficult undertaking in the Kivus. There is poor research infrastructure (scarcity of meteorological stations) and absence of training-education curriculum on climate change at the University level. The capacity in research is very limited, because in the government budget, there is always no line budget for research and agriculture. This means farmers are not advised on climate and environmental issues especially because of total failure of the functionality of the national agricultural advisory and extension system.

8 Conclusion

Sweetpotatoes are an economically important crop in eastern DRCongo. Pests and diseases currently account for over 20-60% yield losses. However, combined with other factors such as anthropogenic factors, climatic variability and environmental (land) degradation, and use of poor and pest-sensitive varieties, yield losses may rise to 60-90% as recently reported by some growers (Munyuli 2016, unpublished data).

Pests may breed in fallow fields, surrounding the sweetpotato fields, and the different stages may stay there until they have little opportunity to reach the adult stage. Hence, fallow fields may serve as vector reservoirs if pest adults leave their sweetpotato sites to breed in other habitats on alternative host plants. Hence, higher risks of outbreaks of the pest in the following months may be increased with the quality of the habitat surrounding sweetpotato pest.

This study was undertaken to learn about the dynamics of pest populations by monitoring their monthly/yearly/seasonal abundance in order to predict and alert on months of likely yield reduction. The population dynamics of the sweetpotato pests fluctuated over times and years with some period of drastic changes during the course of this study. Therefore rainfall amounts and maximum temperatures may serve as a strong monitoring or forecasting tool for the different pests: It is possible to estimate the next season's population based on the previous.

Hence, in the future, weather factors (rainfall, maximum temperatures) may be used, in conjunction with pest populations, from monitoring data to predict the severity of pest populations. Such information is essential for effective IPM to improve farmer sustainability by employing targeted rather than calendar directed insecticide spraying. This information could be readily integrated into an IPM programme, involving improved cultural practices, conserving and/or enhancing biological control agents and most importantly rational pesticide use.

There was a general trend for increase in the population density of pests over years. Peaks in the population density dynamics of some species were closely associated with peaks in the rainfall and temperatures. In spite of the method used (visual counting each visit day) and given the trend in the population dynamic, it is possible that some of the studied pests may have high economic consequences. With rising temperature, multiple generation of the pests are likely to be observed in the future. Thus high population in the village may lead to high yield loss.

Findings from this study indicated that the agroecosystem complexity and farming practices (monocrop, mixed crops) also had a significant influence with high populations of pests being associated more with mono-cropping than intercropping.

Some pest populations (young larvae, caterpillars and adults) emerged and occurred during rainy seasons more than during dry seasons (El-Dessouki et al. 2014). These attempted to make multiple generations. Generation multiplication was delayed in some causes due to impending dry season. For some species, it is likely that there was synchronization of life stages with young and adults emerging with early rains or late rains of the cropping season according to the local agricultural calendar. It is possible also that the site, such as sweetpotato habitat preference of the pest, played a key role. This was elucidated by topography, the level of fertility of the soil, the soil horizon deepness, the cultivation system, the type of variety grown, the farming practice (moncrop, intercrop), and the altitude where the garden was located. Hence, these factors may influence caterpillar/larval stages and impeding or facilitating various annual (season) cycles of the pest species, such as some pest present population numbers likely causing damage to the crop of high economic losses. Control efforts should be most economically directed aiming at reducing pest population densities in sweetpotato fields

The present study showed that altitude, weather and cropping practices influence the population dynamics of pests in several ways. Weather conditions directly affect the life cycle (e.g. development of young into adults, migration, egg laying, and breeding site selection). There were also indirect weather effects since the time of emergence of crops depended on weather conditions. Rainy weather may delay sweetpotato planting dates, whereas drought results in late plantation establishment and vine emergence. In both cases, the areas of suitable sites for breeding may be reduced because late-emerging plants. The lack of respect of the agricultural calendar is therefore very critical. Sweetpotato planted in December is subject of less pest attacks compared with sweetpotato planted later in March. Planting earlier/later (as compared to the official agricultural calendar) may result in more favorable conditions for the pest population built-in interaction with climatic factors. Briefly, any change in the plantation date is may probably increase drastically virus vector populations (whiteflies and aphids).

Pest population dynamics are highly influenced by cropping practices. The tendency to sow the crops earlier may result in more favorable conditions for egg laying, and any changes in the management of the fallow fields towards a later termination could drastically increase pest populations.

Fluctuations and peaks in the population density of the sweetpotato pests were related to variability in climatic factors (rainfall, temperature). It is likely that consistent rise in temperatures and diminution in rainfall may favor breeding conditions for the buildup of various population densities (i.e. having several generations per annum) for various crop species. The more the pest numbers increase, the more crop damages will increase.

The best predictor was the temperature ($P<0.01$) with high number of *Bemisia*, *Acraea* being associated with a rise in temperature, although at high altitude. The rise in the minimum temperature is associated with an increase in number of *Cylas* spp. Across all study sites, the best predictor for sweetpotato weevil (*Cylas* spp.) was the maximum/minimum temperature. The best predictor for *Spodoptera* was the sampling year. Maximum temperature and rainfall best predicted the population density (number of generations per annum) in whiteflies. The virus pressure (measured as the number of leaves that symptomatically showing virus attack) followed the population density of whiteflies.

It is possible that the resistance/tolerance of some varieties may be reduced in the future under changing climatic conditions of crop growing in the region. The data indicates that building resilient sweetpotato crops will require the consideration of various approaches (e.g. soil infertility, climatic factors, tolerant varieties, nutritional aspects, farming practices, and habitat and landscape management to attract natural enemies). It is likely that climatic variability may affect both the status of pests and diseases and therefore lead to a resultant reduction in yield in the key crop in eastern DRCongo. There is heavy application of pesticides because farmers believe that in situations where no crop variety can resist, the best option is to intensively apply pesticides. Otherwise, if they cannot grow a crop, the alternative option is to go to work in mining sites or become member of rebel groups or plant *Eucalyptus* and abandon farming.

Farmers had a low level of pest identification. Farmers could not easily relate the level of damage in the crop to climatic variability events. There is a need to train farmers on insect pest bio-ecology, taxonomy, and behavior to improve their capabilities for controlling/managing sweetpotato insect pests in the fields. Empowering farmers with knowledge about insect pests is essential in order to enable them uptake more environmentally friendly agronomic practices such as IPM approaches. This will also enable farmers to play a key role in forecasting negative impacts (yield losses) of their crops, given the trend in weather factors. Landscape and habitat management strategies, combined with biological control (importation, rearing and releasing natural enemies) will help. Other IPM strategies, such as breeding tolerant varieties, integrated soil fertility management, conservation of local plant genetic resources, testing and validating bio-pesticide activity, while developing strategies for industrialization of natural pesticide (botanicals), is needed (Kodjo et al. 2013).

9 Recommendations

The data about the current level of knowledge of farmers about sweetpotato pests will help adapt agriculture to ongoing climate variation in eastern DRCongo. Based on findings about farmers' knowledge of the effect of climate change, some recommendations emerge. The government should increase awareness of the effects of climate change and adaptation strategies for sweetpotato farmers.

The government should increase its investment in public research institutions for making improved and tolerant varieties available for farmers as well as investigation of best and strategic IPM options for sweetpotato. Clones that are tolerant to various abiotic and biotic stresses are needed in eastern DRCongo. Peace and stability in rural area is key to encouraging farmers to remaining in their villages instead of joining rebel groups. Intercropping sweetpotato with other crops appeared to reduce the population density of pests as compared to mono-cropping systems. It is therefore advised to investigate more suitable intercropping systems that are likely to reduce the population of pests.

More breeding and screening work is needed to adapt sweetpotato varieties to climate variability and create resistance to pest attacks under current and future climate change. There is a hope for improving the livelihoods and nutrition, as well as reducing hunger and malnutrition, in eastern DRCongo through making improved sweetpotato varieties (orange flesh ones) available. These varieties should be tolerant to environmental- climatic and anthropogenic stresses (heat, drought, soil infertility etc.).

To fully understand climatic effects information on the current status of the crop pests is still needed. There is also a need to further investigate the biology, ecology, host alternation, loss assessment, management approaches, and farming practices that influence pest prevalence and level of attack. There is a need to build awareness of farmers about climate change effects on inducing negative impacts on their crops. The frequency and severity of climatic extremes are increasing and making adaptation an absolute necessity through using current information on climate variability to develop long term plans for managing pests and reducing the vulnerability of farmers to continued changes in temperature and rainfall.

Overall drivers of pest population density in complex agroecosystems, such those of eastern DRCongo, are many; but the impact of climatic factors should be acknowledged and assessed to better set appropriate strategies to effectively control pest populations in major sweetpotato growing zones.

Overall pest population may be monitored in advance of severe infestations and may therefore become a useful tool in early warning of crop yield reduction. Rainfall and maximum temperatures may be used to predict the severity of pest populations. Such information may be essential for effective IPM to reduce farmer sustainability by employing targeted rather than calendar regulated insecticide spraying. This information could be readily integrated into an IPM programme, involving improved cultural practices, conserving and/or enhancing biological control agents, and most importantly providing safer and rational pesticide use programme development. To offset the increasing costs of sweetpotato production, pest management should encompass all or some of these facets to ensure increased sustainability for sweetpotato farmers.

In the future, it may be interesting to monitor the pest population on a weekly basis, especially during higher rainfall periods since these periods foster quick pest population development. Flight activity and reproductive behavior (population built-up) for some pests may increase drastically during months of high rainfall.

Further research may investigate the interacting effects on multiple factors (climatic, soil, crop variety, farming practices, landscape habitats and environmental quality, natural enemies etc.) that determine population build-up and mortality of the pests and therefore predict more ideal conditions under which each of the studied species may become a serious nuisance for the farmer.

Lack of modern early warning systems, inflexible cropping calendars and narrow choice of crop varieties aggravate the vulnerability of rural communities, who depend on sweetpotato. Hence, improving forecasting and dissemination of climate information, developing drought resistant varieties and promoting farm-level adaptation measures like adjusting planting dates should be prioritized to improve community resilience to climate change

There is a need to find environmentally safe alternative, practicable, available and sustainable forms of control through the integrated management of the insect pest. There exists an array of insect pests that infest sweetpotato in the field at ambient temperature and relative humidity. These have complex associations with one another and can interact in a competitive manner. This trend of insect species requires multifaceted and integrated management approaches, along with climate change adaptation measures, to be able to develop and disseminate suitable and environmentally safe control measures for sweetpotato pests.

There needs to be increase public awareness about the impacts of climate change on all crops grown in eastern DRCongo. Public awareness and quality of knowledge on climate change constitute an essential background to deal with climate change and related problems. Climate change is an area that is in need of publicity to help the public make informed decisions in its adaptation and mitigation.

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