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WILL ON-GOING CLIMATE VARIABILITY & CHANGE CONTINUE IMPACTING ON APHID (*Aphis craccivora* Koch) INSECT PEST AND ON THE COMMON BACTERIAL BLIGHT (*Xanthomonas axonopodis pv. phaseoli*) DISEASE INCIDENCE IN FIELDS OF BEAN (*Phaseolus vulgaris* L.) FOUND IN KALEHE TERRITORY, EASTERN DRCONGO?

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ABSTRACT

Bean production is constrained by the infestation of arthropod pests, among which aphid (Aphis craccivora Koch, Homoptera: Aphididae).Also, bean is also face various threats from diseases such as the common bacterial blight (CBB), caused by Xanthomonas axonopodis pv. phaseoli Smith (Xap) and Xanthomonas axonopodis pv. phaseoli var. fuscan Burkholder (Xapf) . The pest is one of most economically important insect pest causing devastating damage while the is the most serious biotic constraint of common bean (Phaseolus vulgaris L.) production and productivity in Kalehe territory, eastern DRCongo. The incidence of the disease/pest, and its association to agronomic practices and environmental factors remained mainly undermined (undocumented), in Kalehe territory. The understanding of the intricate interactions between environmental factors and disease/pest dynamics, can boost/enhance pest management practices for improved efficiency and sustainability. Bean field surveys were conducted in main growing villages of Kalehe territory from 2019 to 2024 across main cropping seasons and environments to determine the linkage between climatic factors distribution and the incidence of aphids and CBB and analyses its association with socioeconomic and biophysical factors suspected by farmers are key drivers . Bean fields were surveyed in villages located at different altitudes in three villages of Kalehe territory. These three villages were randomly selected for inspection among 15 key bean growing villages of the territory, that are found along main road Bukavu-Goma. The field survey was conducted to explore the link between meteorological parameters and aphid population density and CBB. Plants were inspected in farmers' fields to count the number of aphids and assess bacterial blight incidence (%). Weekly field inspections documented aphid levels alongside concurrent meteorological data. Linear regressions were used to evaluate these relationships. Generalized linear models were used to explore perception of farmers about key drivers responsible for the fluctuation of the pest/disease. The results of the study survey revealed that aphids w ere present in all study areas throughout the year with a fluctuating population density in which the highest density was concentrated on marshlands/lowlands. The results indicated that climatic factors were among the best predictors of aphid population dynamics. Aphid infestation varied annually and seasonally.

Peak density aligned with specific growth stages, indicating temporal variability. In some years, population dynamics appeared to be response to environmental factors. Also, results revealed that the overall mean incidence of the disease oscillated across years, altitude, plant growth stages, and cropping seasons from 5 to 100%. The study investigated the effect of climatic factors on the CBB incidence and aphid population density.T here was complex relationship between meteorological parameters and pest population dynamics. The population density of aphids showed significant ($P<0.05$) differences among the study months, years, villages and cropping seasons. There was a marked increase in aphid population density from March to June and from October to November each year when increased/heavy precipitation was observed and a swift decrease in September and January and in dry seasons when rainfall was of low intensity. The variance (coefficient of determination R2) associated with different regression indicating the level of influence of climatic factors in aphid population density across years and locations. Positive and negative relations ($P<0.05$) with monthly rainfall and average minimum/maximum temperatures were observed, although not consistent in all 5 years. Using generalized linear model (GLM) regression analysis type, some independent variables (altitude, cropping season, planting date, seed source, variety type, plant density,) were found to have significant ($P<0.05$) effects on the aphid population density and bacterial blight incidence (%). It is likely that climatic, environmental and biophysical characteristics of the respondents influence ($P<0.05$) the level of knowledge of the farmers about key drivers of fluctuations in the population density of aphids and oscillations of bacterial blight. The results of this survey indicate ($P<0.05$) that planting bean should comply cropping calendar as well implementing and adopting best agronomic practices such as using climate smart varieties, planting improved tolerant varieties, crop rotation to reduce the negative impact of the variability in climatic factors on pests and diseases and the resultant impact on yield ($P<0.05$). Furthermore, it is recommended that effective and feasible integrated management options need to be developed against pests and diseases to boost the production and productivity of the crop and minimize effects of biotic agents on yield. It is likely that climate change will continue affecting pest aggressivity /disease virulence, natural enemy regulation and yield loss of beans. Other contributing factors should be investigated further for better advising farmers on strategies to cope up with ongoing climate changes in interaction with other anthropogenic and environmental factors.

Keywords: Bean, Pests, Fluctuations, Diseases, Epidemics, Linkages, Drivers, Climate Change, Drcongo.

1. INTRODUCTION

Bean is one of the most important food legumes cultivated and consumed worldwide. It belongs to the genus Phaseolus, with pinnately compound trifoliate large leaves. The crop played an integral part in the lives of many, not only by being rich in nutrients(proteins) but also used as a source of livelihood for millions of people, particularly in eastern DRCongo (Munyuli et al.2008). Common bean (*Phaseolus vulgaris* L.) occupies an important place in human nutrition. The dietary fibre part of the carbohydrate reduces cholesterol and prevents colon cancer, while 18-30% dry weight of common beans is protein. It also contains vitamin B and minerals (namely calcium, copper, magnesium, and zinc) and sometimes referred to as a near perfect food (Munyuli et al.2008).

The crop is grown under very diverse climatic conditions in tropical and subtropical zones. Likewise, bean is the most widely grown legume crop in eastern DRCongo, in terms of economic importance. The cultivated area has been rapidly increasing from year to year, especially in because of migration of populations due to insecurity in neighboring villages/territories of eastern DRCongo. The average yield of bean at farmer level, oscillate between 0.2 and 1.2 t/ha (while the potential at research stations is above 1.5-3t/ha). The difference in yield is due to various abiotic and biotic factors including pests and diseases (Munyuli et al.2009).

Although, bean is an important legume crop cultivated due to its high nutritional value and ability to fix atmospheric nitrogen. However, the crop production faces numerous challenges, including various diseases and insect pests that can significantly impact yield and quality. Common bean production is limited due to different biotic and abiotic factors (Munyuli et al. 2009). Among the abiotic constraints are inadequate total rainfall, erratic rainfall distribution, periodic water stress, heat variability, during the crop critical growth as a result of climate change. Low soil fertility, shortage or excess of minerals and extreme lower pH of soil are also the abiotic factors that limit common bean production .

Climate change is a broad range of global phenomena created predominantly by burning fossil fuels, which add heat-trapping gases called greenhouse gases to Earth’s atmosphere (Debelo 2020). Agricultural production is heavily reliant on the Earth ’ s climate, affecting the growth and development of crops, the spread of pests and pathogens, and the availability of water (Hartl et al.2024) .Climate change poses a number of additional problems for agriculture and, thus, for biodiversity. (Raven & Wagner 2021). Climate change already challenges people’s livelihood globally and it also affects plant health (Gullino et al.2022). The climatic impact on agriculture will be heterogeneous and ambiguous and vulnerability will vary between crops and regions and with people’s socio-economic conditions including inequality and oppression and because people involved in agriculture tend to be poorer compared with their urban counterparts (Tikadar & Kamble 2023, Hartl et al.2024).

Climate change may percolate to pest management at a macro level through compositional changes in which species attack commodities through distributional changes or what commodities are grown in a region (and thus processed in that area). However, climate change may also result in altered microclimates at food facilities, which can be tied to increased generation times, elevated damage and contamination potential, greater abundance of species, and greater need for external inputs(Gerken & Morrison 2022).

Climate change is widely recognized as a critical global challenge with far-reaching consequences. It affects pest species by altering their population dynamics, actual and potential distribution areas, as well as interactions with their hosts and natural enemies(Szyniszewska et al.2024). Climate change thus has potentially important implications for multiple areas of the pest risk analysis process (Szyniszewska et al.2024). The dynamic nature of climate change, with its complex interactions and uncertainties, can make it difficult to predict and assess the future risks posed by pests accurately. While climate can influence the distribution and abundance of pests and hosts alike, its significance will vary depending on the situation (Szyniszewska et al.2024).

Global warming and climate change trigger major changes in diversity and abundance of arthropods, geographical distribution of insect pests, population dynamics, insect biotypes, herbivore plant interactions, activity and abundance of natural enemies, species extinction, and efficacy of crop protection technologies (Debelo 2020).

With a changing climate, over time, there is the potential for pests to further expand (in the suitable and favourable areas) and their distribution and becoming increasingly severe pests in certain areas (Berzitis et al.2014). Climate change is predicted to have a significant impact on the geographic distribution of various flora, fauna, and insect species by expanding, contracting, or shifting their suitable climate environment (Ejaz et al.2023). Climate change is expected to alter species interactions , especially between native (common) and invasive species and many invasive insect pests are vectors that transmit plant diseases (Zhu et al.2023)linking the dynamics of insect vector performance to species interactions in transmitting pathogens under climate warming will help to improve plant disease predictions(Zhu et al.2023).

Climate change has already impacted ecosystems and species and substantial impacts of climate change in the future are expected. Species distribution modeling is widely used to map the current potential distribution of species as well as to model the impact of future climate change on distribution of species. Mapping current distribution is useful for conservation planning and understanding the change in distribution impacted by climate change is important for mitigation of future biodiversity losses (Shrestha & Bawa 2014).

Factors such as global warming, frequent droughts, changing atmospheric carbon dioxide (CO2) concentrations, weather disruptions, and other climate-related variables, however, continue to challenge crop yields. These abiotic factors also influence pest biology, performance, population dynamics, and their interactions with plants and natural enemies, all of which are critical factors in determining crop yield. Increased pest populations and frequent outbreaks due to weather disruptions and climate-related changes can negatively impact crop productivity and availability, ultimately threatening food security (Subedi et al. 2023).

Climate change significantly contributes to shifts in the geographical range of pests and diseases (Santos et al.2024). Climate(weather) changes could profoundly affect the status of insect pests of crops. These may arise not only as a result of direct effects on the distribution and abundance of pest populations but also indirect effects on the pests' host plants, competitors and natural enemies (Sangle et al.2015).Some pests which are already present but only occur in small areas, or at low densities may be able to exploit the changing conditions by spreading more widely and reaching damaging population densities(Sangle et al.2015).

Rising temperatures facilitate the introduction and establishment of unwanted organisms, including arthropods, pathogens, and weeds (hereafter collectively called pests) (Gullino et al.2022). The growth of plants and insects occurs only above a minimum temperature threshold (Taylor et al.2018). In insects, the growth rate depends on the temperature above the threshold up to a maximum. In plants the growth rate above the threshold generally depends on the availability of sunlight (Taylor et al.2018).

Global warming is already affecting the bionomics, fitness and distribution range several arthropod species in the world (Jaramillo et al.2009). The global surface temperature is projected to increase from 1.8°C lower scenario to 4°C maximum scenario in 2050s. In eastern DRCongo, the temperature is expected to be increased with the maximum scenario mainly because of progressive degradation of natural forests (habitats). When temperature is increasing at an alarming rate, water loss occurs through evapo-transpiration and results in reduction of soil moisture content with increase in relative humidity. Increasing temperature until the optimum level for bacterial strains, and increasing relative humidity creates suitable condition for the development of CBB epidemics in susceptible common bean varieties. However, at higher temperature, above the optimum level for bacterial blight development, especially above 30°C, the heat tolerant, disease resistant and drought resistant varieties adapt to high temperature and lower soil water content . The drought resistant and disease resistant common bean varieties develop several adaptation mechanisms that allow the plant survival during hot and dry conditions .

The high temperature causes water deficit due to excessive transpiration that could adversely affect the development and function of its reproductive organs (Munyuli et al 2023). In drought resistant varieties, tissue water content is kept high by restricting excessive vegetative growth and a large reduction in water potential. The reduction in leaf water potential due to water stress is linearly correlated with reductions in shoot extension rate and leaf water content.

The reduction in shoot growth due to stress contributes to a build-up of water-economizing traits, such as specific leaf weight and succulence index. Drought stresses induce genotypic variation of shoot biomass accumulation, pod, seed number, and biomass partitioning index. In general, drought resistance mechanisms can include drought escape; drought avoidance, and drought tolerance.

Drought escape allows plants to accelerate their cell cycle with an early flowering and maturity, and rapidly relocates metabolites to seed production and away from leaves and shoot tissues . Drought avoidance is the capability to keep high tissue water potential through increased rooting depth, hydraulic conductance reduction, and radiation absorption reduction in leaves, water-loss area reduction, reduced absorption of radiation by leaf movement, and reduced surface evaporation. During higher temperature and lower moisture, the disease resistant varieties will reduce disease development due to mobilization of resources into host resistance through various mechanisms, such as reduced stomata density and conductance.

Common beans adapt stress conditions of climate change variables through production of greater accumulation of carbohydrates such as waxes, extra layers of epidermal cells, increased fiber content and pH change in their cell cytoplasm. It has been previously reported that the resistance might be increased by change of pH of plant cell cytoplasm, due to the increase in phenolic acid content, resulting in inhibition of pathogen development. Hence, the accumulation of phenolic compounds at infection site restricts the development of common bacterial blight causing bacterial strains since such compounds are toxic to bacterial strains .

Changes in climate, such as increasing temperature and reducing soil moisture(rainfall) can potentially affect disease development and crop production. Crop production in eastern DRCongo is dependent on rainfed agriculture, largely at a subsistence level. Hence, change in weather patterns, particularly rainfall amounts and distribution as well as temperature could be favourable to CBB development and can devastate common bean production (Munyuli et 2023).

Insects are poikilothermic animals and thus sensitive to climate warming. Both a-biotic (temperature, humidity, light) and biotic (host, vegetative biodiversity, crowding and diets) stresses significantly influence the insects and their population dynamics (Khaliq et al.2014). Abiotic factors can affect their ovulation, rate of fecundity, development, survival, multiplication and various immune and genetic responses(Khaliq et al.2014). In biotic stresses certain plant characters (anti-xenosis, anti-biosis), nutritional modifications, variation in flora (landscape diversity, cover crops) and insect crowding influence insect multiplication, emergence and migration(Khaliq et al.2014).

Climate change could profoundly affect the status of agricultural insect pests. Several approaches have been used to predict how the temperature and precipitation changes could modify the abundances, distributions or status of insect pests (Estay et al.2009) . Climate change alters the distribution range of many organisms and peripheral populations around the edge of the distribution range can be exposed to more severe selection pressure due to the changing environment (Kiritani 2011).

Climate change may favour pest and disease development and further exacerbate the vulnerability of smallholder farming systems to biotic constraints (Nakato et al.2023) Both the agricultural crops and the pests connected to them are greatly impacted by climate change, both directly and indirectly (Bhagarathi & Maharaj 2023) . Pest reproduction, development, survival, and dispersal are directly impacted, whereas climate change has indirect effects on pest insect relationships with their environment and relationships with other insect species, such as natural enemies, vectors, and competitors (Bhagarathi & Maharaj 2023).

Climate change involving rise in temperature and CO_2 level in the atmosphere, and other weather events such as drought and flooding, all affects the host plant resistance to pathogens (Kaur et al.2023). Climate change has the potential to alter host-pathogen interactions and ultimately pose great impact on development of disease epidemics (Kaur et al.2023).

Crop pests and crop diseases damage food crops and are a major cause of yield losses in agriculture (up to 40% crop loss globally). Climate change has been found to be an important determinant of the abundance, distribution and level of activity of these crop pests and the pest-related diseases they carry (Nguru& Mwongera 2023).

The occurrence of climate changes is evident from increase in global average temperature, changes in the rainfall pattern and extreme climatic events (Karuppaiah & Sujayanad 2012). These seasonal and long term changes would affect the fauna, flora and population dynamics of insect pests. The abiotic parameters are known to have direct impact on insect population dynamics through modulation of developmental rates, survival, fecundity, voltinism and dispersal (Karuppaiah & Sujayanad 2012). Among the climatic factors, temperature is an important factor (Karuppaiah & Sujayanad 2012). Climate change can influence the abundance of insect herbivores through direct and indirect mechanisms (Robinson et al.2017).

Pests and diseases are a major cause of low productivity in crops and livestock worldwide and particularly in sub-Saharan Africa where there are few resources to invest in protection in the form of pesticides, vaccines (Farrow et al.2011). A number of pest and disease outbreaks are triggered by climatic factors. For some biotic stresses the general seasonal conditions are most important while for others the timing of rainfall or dry spells within a season is crucial when they coincide with susceptible periods of plant or animal growth(Farrow et al.2011). There are several biotic and abiotic production constraints on common bean (*Phaseolus vulgaris* L.) . Diseases, insect pests, low soil fertility and periodic water stress are the major constraints(Hailu et al.2015).

The major diseases of common bean in the tropical regions (most important diseases hindering common bean), that should be targeted for management are common bacterial blight (CBB) caused by *Xanthomonas axonopodis pv. phaseoli*, halo blight caused by *Pseudomonas syringae pv. phaseolicola*, bacterial brown spot caused by *Pseudomonas syringae* *pv. syringae*, rust caused by *Uromyces appendiculatus*, anthracnose caused by *Colletotrichum lindemuthianum* , angular leaf spot caused by *Pseudocercospora griseola* Crous U, Brown and other viral and root rot diseases. These diseases are frequently occurring and widely distributed in bean fields and are destructive agents of common bean production causing heavy yield loss and decreasing seed quality (Hailu et al.2015, Kijana et al.2017).

The top disease of common bean in eastern DRCongo , is common bacterial blight (CBB), caused by *Xanthomonas axonopodis pv. Phaseoloi* (Smith) and *Xanthomonas axonopodis pv. phaseoloi var. fuscans* (Burkholder) (Buruchara et al. 2010, Mwangombe et al.2007, Legesse 2016). Because common bacterial blight is a warm weather and higher humidity disease, it can cause the greatest damage at warm temperature of 28°C to 32°C . The bacteria survive at the temperature ranges of 25°C to 35°C in the field on infected seed and plant debris .

Also, the low productivity is mainly due to several biotic and abiotic production constraints. Consequently bean production fluctuates annually with an erratic harvest determined by biotic and the abiotic stresses. Among the abiotic constraints, drought at different growth stages of the crop cycle is a major yield constraining. Among the biotic constraints, CBB is the most disastrous disease of bean. It has been reported in almost all growing regions across the Eastern and central Africa and is deemed to be the most devastating biotic factor, resulting in significant loss of yield and degradation of seed quality.

Because CBB is polycyclic (has numerous infection cycles during the cropping seasons), infection can happen at any time throughout the growing season if the conditions are right for it (20—23°C). The disease epidemics may cause up to 5-100% yield losses. Hence, it is therefore considered as one of the most important foliar diseases of bean in eastern DRCongo. Depending on susceptibility of common bean varieties and environmental conditions, CBB may cause yield losses ranging between 5% and 100% (Munyuli et al 2007) .

There are different species of insect pests and diseases that contribute to the low yield of the crop throughout its stages of development. Among these insect pests, thrips, borers, and aphids. Among diseases, there are anthracnose, bacterial blight, angular leaf spot,.. These are some of the of the biotic constraints for bean production.

Among the most dominant insect pests, aphid, is one of the most damaging insects in of bean crops(Buruchara et al. 2010) . Most varieties types are susceptible to aphid attacks. Aphid (*Aphis craccivora* L., Hemiptera: Aphididae) stands out as a major threat, causing substantial economic losses in many bean growing villages in eastern DRCongo. The population dynamics of aphids are influenced by a multitude of factors, including the prevailing environmental conditions, host plant characteristics, and natural enemies (Kishor et al.2023) . Of these factors, environmental weather conditions play a pivotal role in shaping aphid populations by affecting their reproduction, development, dispersal, and survival.

Suitable weather factors play the main role in pest spread and infestation (Bakry & Abdel-Baky, 2023). To develop an efficient IPM program for a pest, it is necessary to understand insect bio-ecology, including population dynamics in various climatic conditions, which may affect the insect life cycles and its damage (Bakry & Abdel-Baky, 2023). From an ecological point, determining the factors that affect insect biodiversity is a fundamental topic and necessary, as well as, from a practical view, forming a base to estimate the economic injury levels (Bakry & Abdel-Baky, 2023).

Since all insects are poikilothermic, environmental temperatures and other factors have a clear impact on insect development and infestation rates . Therefore, an occurrence of any climate fluctuations may have a substantial impact on a pest population dynamics and status. There is always an interactive relationship that may be positive or negative between any insect and its plant hosts (Bakry & Abdel-Baky, 2023). Common Bacterial Blight (CBB) is one of the major diseases and the most important constraint to common bean production. When environmental conditions are favourable for the pathogen during long periods of warm and humid weather causing reductions CBB becomes the most destructive in both yield and seed quality.

Climate change could have an impact on the disease epidemiology by influencing both common bean growth and the pathogen reproduction of the CBB (Hailu et al.2015). Change in rainfall pattern, soil moisture, soil temperature, and soil fertility has direct impact on the disease epidemiology by influencing host plant growth and susceptibility; pathogen reproduction, spread, survival, activity and host-pathogen interaction (Hailu et al.2015).

Common bacterial blight disease (CBB) causes severe yield and seed quality losses on common bean worldwide. Information about CBB distribution and pressure is important in designing effective control strategies (Tugume et al.2019). Climatic changes have become one of the major challenges for mankind and the natural environment. Climate change directly affects the reproduction, development, survival, and dispersal of pests and indirectly impacts the interactions between and within insect species, including predators, competitors, and mutualists, and interactions with their environment (Munyuli et al.2022).

In addition, indirect effects can occur through the influence of climate on the insect's host plants, natural enemies and interspecific interactions with other insects (Kishor et al.2023) . The effect of climatic and weather factors (daily mean maximum air temperature, daily mean minimum air temperature and mean monthly rainfall) has a significantly high effect on the total live population of aphids during consecutive years of bean cultivation, although some times, these factors vary from year to year.

In recent years, there has been growing interest in investigating the impact of meteorological conditions on aphid populations, as it provides valuable insights into their population dynamics and can guide the development of targeted control measures. Climate may have a major impact on aphid migratory rates, reproduction, and survival. Aphid population rates and the density on their hosts are influenced by abiotic variables such as temperature, relative humidity, and rainfall. The range, activity, and number of natural enemies—which are crucial for controlling crop pests that consume herbivores, are in turn, impacted by climate change (Kishor et al.2023).

Increased average temperature may cause interactions between predators and prey to be disrupted. Substantial impact of climatic conditions on the population density and infestation incidence percentages of *Aphis craccivora* Koch (Homoptera: Aphididae) can be observed with climate variability. Insects' daily basic activities are directly impacted by warming. There has been a significant correlation between the total daily air temperatures for aphid development and the number of aphid peaks. When the combined impact of meteorological factors and aphid incidence is calculated, it is likely that weather parameters can contribute to the above 10-30% the change in incidence of the pest and in the number of generations during the cultivation cycle of bean (Munyuli et al.2022).

Previousl studies explored the relationship between weather parameters and the abundance, distribution, and behavior of aphids on bean fields. These investigations highlighted the importance of climate variables (temperature, humidity, rainfall, and wind speed) in shaping the population dynamics and infestation patterns of aphids (Munyuli et al. 2007, Munyuli et al.2009).

In the major common bean producing areas(Mengesha Yetayew 2018) , CBB is a growing and year round threat of bean diseases. Large epidemics of CBB disease have frequently occurred in Kalehe territory leading to massive yield losses. In fact, the amount of yield loss depends on the intensity of the disease, environmental conditions and the degree of susceptibility of the cultivars grown(Mengesha Yetayew 2018). A range of 10–100% yield loss is recordable due to CBB on susceptible cultivars in some areas of astern DRCongo.

Understanding the population dynamics of aphids and its interactions with the environment is crucial for developing effective pest management strategies. Although there is no empirical evidence determining whether the disease was introduced from abroad or was indigenous to the country, it is assumed that it was introduced with imported seeds of cultivars through the mechanisms of varieties exchanges in eastern and central Africa. Currently, the area suitable for bean production in eastern DRCongo is partially limited diseases along with lack of tolerant/ resistant varieties suitable for short and long growing seasons under current on going climatic changes .

The distribution and importance of the disease and its association with cultivation practices, geographic variables and climatic-environmental factors has not been analyzed and determined in the major growing areas of eastern DRCongo. Thus, as the disease has become a recurrent problem in major bean growing villages in eastern DRCongo. A survey is useful to gain insights into the distribution and relative importance of the disease, and to understand how to better manage the disease under the current on-going climate changes.

Insect populations are prone to respond to global changes through shifts in phenology, distribution and abundance. However, global changes cover several factors such as climate and land-use, the relative importance of these being largely unknown (Luquet et al.2019). Climate and land-use changes have strong effects on aphid populations, with important implications for future agriculture (Luquet et al.2019).

Understanding the relationship between disease incidence and severity under various cropping systems (Mulumba et al. 2012), cultivation techniques and environmental factors will assist in pinpointing the most crucial factors and concentrate efforts on creating sustainable management strategies under on going climate changes.

In particular, in Kalehe territory (South-Kivu Province, eastern DRCongo), there is still lacks information and knowledge on the prevalence and incidence of the disease, the significance and consequences of various agronomic techniques, environmental conditions, and other biophysical factors on the epidemiology of the disease (Mwangombe et al.2007).

Therefore, the purpose of this study was to ascertain the occurrence, distribution, incidence of the disease and the population density of aphids under current variability in climatic factors, and to determine the level of knowledge of farmers about causes of fluctuation in the population density of aphids and bacterial blight disease incidence in connection with farming techniques, agro-ecological parameters and socioeconomics characteristics of the farmers in Kalehe territory.

Common bean production is being constrained by a number of diseases in associations with cropping areas, cultural practices, environment and climatic facotrs (Degu et al.2023). Climate can limit distributions directly by influencing survival and fecundity, or indirectly through its effects on interacting species, including food sources, natural enemies and competitors. Phytophagous insects and their host plants are useful model systems for testing the effects of climate and biotic interactions on species distributions .

Temperature has a direct influence on insect activity and rate of development. The rate of development is based on the accumulation of heat measured in physiological rather than chronological time. The seasonal phenology of insect numbers, the number of generations, and the level of insect abundance at any location are influenced by the local environmental factors at that location .

Temperature is a crucial environmental factor affecting the development rates and reproductive capacity of aphids. Both high and low temperatures can have significant impacts on the population growth and dispersal of aphids. Similarly, humidity levels can influence aphid survival, fecundity, and movement. Wind speed and direction can play a role in the dispersal of aphids, facilitating their movement between different host plants and fields. Rainfall patterns can affect aphid colonization and survival, as population level effects may arise from the behavioral responses of biocontrol agents to rainfall (Munyuli et al.2023).

Due to the importance of aphids a major pest in bean cultivation, it is necessary to understand better how weather factors may regulate its population density dynamics throughout the crop, year, season and villages. There is currently limited information with rigorous published scientific studies in Kalehe territory on richness and diversity of pests (including aphid) and their natural enemies, concerning their ecology and population density dynamics.

The present report is an update of the currently available information on ecology and population density dynamics. the study aimed to help in the development of integrated management strategies for aphid pest in the main bean growing areas of Kalehe territory. The present work aimed to investigate aphid ecological aspects, population density, population dynamics, infestation level and the effect of weather conditions, i.e., temperature and rainfall, on the pest population density and population dynamics in eastern DRCongo.

Data gaps include predicting changing distributions for stored product insects under climate change, translating macro climate changes into microclimate changes at food facilities, and rigorously investigating how IPM tactic efficacy varies under changing climate(Gerken & Morrison 2022).

Knowing the effect of temperature and rainfall amount on disease development, number of generations and resistance expression of common bean varieties (both local and improved ones) can help to better plan and implement appropriate resilience strategies of climate change for the management of bean pests and diseases in the field conditions in the current ongoing ever-changing climate (Munyuli et al.2008) . The response of CBB development to increased temperature and reduced moisture needs field investigations in linkage with other biophysical and socio-economic drivers(factors). Variability in climatic factors is expected to cause changes in the epidemiology of pests and diseases.

Despite this, the potential effects of climate change on pests and diseases remain a critical knowledge gap in Kalehe territory. To address this gap, there is need for investigations to be conducted on the potential impact of climate change on insect pest species and diseases likely being associated with bean crop.

There is a paucity of literature on studies carried out on the climate-change impact on insect pest prevalence and incidence on bean fields of Kalehe territory and sustainable adaptation strategies to overcome this. Thus, to fill this identified gap surveys were conducted to assess climate change impact on agriculture regarding insect pest population density and disease incidence in order to add new knowledge in this subject domain concerning sustainable adaptation strategies to manage pests and diseases under the on going climate change.

Knowledge of insect pest ecology and biology is important for maximizing crop protection and reducing crop losses. There is therefore a need for studies seasonal variations in the pests in contrasting environmental and agroecological areas (Mahot et al.2024) . Therefore, it is imperative to comprehend the impact of climate change on insect pests to manage them effectively and ensure sufficient food production (Subedi et al. 2023).

The objective of this study, therefore, was to assess the response of Aphid pest and CBB to variability in climatic factors as well as assessing the perception of farmers about other causes of variabilities in pest population density and oscillation in CBB. The other objective of this paper was to understand the linkage between aphid population seasonality in bean fields and to figure out abiotic factors (maximum temperature, minimum temperature, mean temperature, total monthly rainfall) regulating its populations and the temporal distribution of this pest over time and space. By providing an in-depth investigation of over-time patterns, this study fills knowledge gaps and improves the relevance of research findings to practical agricultural operations.

2. MATERIAL AND METHODS

2.1. Description of the Study survey Areas

The study was conducted in some villages of Kalehe territory (Figure-01c). Administratively, Kalehe territory belongs to the South-Kivu Province (Figure-01b) in eastern DRCongo (Figure-01a). Geographically, the territory is characterized by three various agroecologies include highlands (60%), midlands (25%), and lowlands (25%) with hilly, undulating, and rolling topographical features. For the topography, there are several planes, mountain, valley, and hill based landscapes covered by a vegetation composed of wild trees and shrubs and grasses. The altitude of the survey areas ranged from 1400 to 2700m meters above sea level (m.a.s.l.). The villages (sites of data collection) mainly differed in altitude, temperature, rainfall intensity, relative humidity and wind speed. The territory is also characterized by several historical disaster events(inundations, landsides, soil erosion,…).

The mean annual rainfall ranging between 1200 mm and 2800 mm. There are three seasons: the long rainy season runs from the months of September to January, the short rainy season from February to may and the dry season from June to August. This correspond to three cropping seasons: cropping season A (September-January and cropping season B (February-Mary) on upland and the cropping season C (June-August) in lowland/marshlands.

There several rivers flowing in the upper zones towards lowlands and Lake Kivu. The landscape is generally very sloppy. Intensive livestock are located in grasslands in the upper-side of mountains and hills while substantial cultivation is done in mid land and low lands. The soil types (ferrisols, ultisols, vertisols) are clay and red sandy clay.

Bean, soybean, groundnut, peas, maize, sorghum, potato, sweet-potato, tomato, amaranths, cucurbits, eggplants, pepper, coffee, banana, cassava, several fruit crops such as avocado, mango, citrus,.. are some major crops grown in the territory. Large cattle keeping in conducted in the mountains zones. Homegardens and multipurpose agroforestery are often combined with medical plant cultivation. Other needs in natural resources are gathered from the wild. Most household holds some small ruminants and chickens. Caviaculture is well practiced as well as fish ponds are found in the villages although the main sources of fish protein is from Fishing in rivers(swamps) and Lake Kivu. There are several suitable for cultivation of cereals and pulses in areas with heavily textured soils. These areas also support mixed crop-livestock farming systems activities.

2.2. Study Design, sampling procedure and data collection

The study was carried out from 2019 to 2024. Bean health issues survey was conducted in villages of different agroecological settings between 2019 and 2024 across the three cropping seasons (Season A, season B, season C). The selection of the villages were based on their historical production and productivity status in Kalehe territory. Data was collected from farmers' fields where various bean varieties (local, improved or mixed) have been cultivated sole or in mixture. Randomly selected fields were inspected for data collection. In each field, two diagonals were designed and from each diagonal, using fictive randomized block design, five plants were randomly specified and marked, one at each of the two corners and the three plants in the center of the diagonal center. Plants parts of each plant were inspected for bacterial blight symptom and aphid presences. The number of aphids was counted on all parts of the plant. Only data for the average number of aphids per field is presented.

A hierarchical sampling strategy was adopted as recommended (Munyuli et al. 2017). The sampling started from the marked plant at each corner of the diagonal of the block created within the farmers' fields, and continued on the way to the center, and continued till reaching the last plant fond a the other corner of the diagonal. The following sampling week, there was change in the direction of data collection. If in the previous week, data was collected from the left side of the diagonal, the following week, data was collected starting from the right side of the diagonal. While in the field, observations were conducted till covering the tow diagonal selected plants

Most bean fields are established on various sloppy gradient (highlands, mid lands, valley or wetlands). In each selected village, bean fields were randomly identified and inspected weekly. Bean fields were inspected from seed emerging to maturity growth stages of pods. Growers, to whom fields were inspected, were interviewed to collect additional history, ecological information about the field and its landscape environment. In addition to interviewing farmers, researchers also made visual inspection of the farm landscape for other plant health issues for robustness of the field's data.

Data collection for aphid population density and CBB incidence (%) and interview of growers

The population density of aphids and incidence of CBBC in linkage with agronomic practices of the grower and other pests and diseases including major weed species were inspected. The disease incidence was recorded once a very week post planting of the crop.. Beginning from one week post-emergence on planted bean, assessment for the CBB disease prevalence and incidence and occurrence & population density of aphids were conducted in the selected survey villages. A total of about 120 fields were inspected per study. However, only average data is reported per study field and week of survey for both disease incidence and pest population density.

Visual identification of the diseases and other pests was carried out in all visited fields. Field identification book of pests and diseases of bean were used to guide the field identification and disease assessment. In each field, bean plants within the quadrats were counted and recorded as either diseased/infected or healthy/not-infected with the bacterial blight , or as damaged (attacked, infested) with aphids.

During the survey, altitude, agronomic practices (cropping season, weed management, the presence or absence of other pests and disease, crop growth stage, and plant density (number of plants per m^2) were recorded for each sampled field and at each sampling date.

For aphid population density dynamics assessment, after the emergence of seedlings, weekly field inspections were conducted in each selected field to document the disease incidence and abundance or population density of aphids. Each inspection session involved the random selection of 5 plants from each of the two X diagonal of the field. The evaluation entailed a thorough counting of both winged and wingless aphids present throughout the entire plant, thereby facilitating a nuanced and holistic representation of the prevailing infestation levels. This surveillance of aphid populations commenced from the initial germination phase and persisted throughout the entirety of the growth cycle until the harvest phase, ensuring a thorough assessment of the trends in aphid populations across all bean growth stages .

Disease incidence was determined as the proportion of diseased plants per quadrat (according to visual symptoms). Disease incidence was recorded from 5 randomly selected bean plants (with local, improved or mixed genotypes) by observing symptoms of the target disease. Disease incidence was assessed as follows (Degu et al.2023):

Disease incidence (%)= [Number of plants diseased/Total number of plant observed] X 100

The surveys and interviews were conducted following main and feeder roads on pre-planned routes in the main bean producing villages. Growers were asked information on the cropping system used, varieties grown, cultivation practices (crop rotations, previous crop on the land, planting date, history of disaster events and services received such as training, extension services or external drivers such as market-consumer preference for some varieties or household demand for bean leaves for domestic consumption.

Agronomical practices such as crop rotation, crop cultivar, sources of seed, the cropping pattern, altitude, planting date, weeding conditions and weed density, plant growth and number of plant stands were assessed to determine their relationship with the knowledge of farmers about causes of fluctuation in the pest population density and disease incidence.

To reduce bias in the data, all bean fields where the owner used pesticides to control pests and diseases were not retained in the study. Also, field beans that were considered as multiplication sites and demonstrations sites for NGO promoting dissemination of improved (bioforitified) varieties were also not retained in this study. Only field that were declared not sprayed by the farmers were inspected

Laboratory examination for proper identification of the aphid pest stage and the disease causal agent

Whenever, it was possible, diseased plant parts were collected for laboratory diagnosis and confirmation of the pathogen. The sampled leaves from each some plants were carefully placed in separate paper bags, labeled, kept in plastic bags, and transported to the laboratory for further investigation and confirmation of the disease. Similarly, different staged of aphid specimens were collected and carried out at the laboratory for examination of the stage mostly affecting the plant at the time of survey. Similarly, specimen of aphids were collected for confirmation at the laboratory of the stage (young, adult, mummies) attacking the crop at that particular growth stage.

In the field and in the laboratory, the population density of aphids were counted visually, and in some cases, a stereomicroscope was used for the identification of different stages of the insect and for searching for associated natural enemies (parasitoids) if present .

Mummies were dissected to count underlying eggs and determine the status of the adult (mummies, parasitized or pregnant). Well identified specimen were kept in 70% alcohol for longer preservation. Other specimens were sent to collaborative research laboratory for molecular taxonomic confirmation of the species or for integration in the barcoding studies

2.3. Meteorological (Weather) data

The monthly meteorological parameters, such as maximum/minimum temperature mean rainfall were obtained from INERA Mulungu and Lwiro Natural Sciences Research Center (CRSN-Lwiro) weather stations that are positioned approximately 50-100 km from surveyed field villages. Meteorological parameters collected included monthly total rainfall (mm) and maximum/minimum temperature recorded in degrees Celsius. Ecologically, weather data in the 50-100Km radius can be applied to the study area as climatologist always indicate some changes in the amount in climatic factors beyond these boundaries (Munyuli et al 2022). Weather stations found within 50-100Km radius from the field can provide climatic data that play a significant role in explaining ecological phenomena of vegetations within that radius., beyond such radius, there may significant difference in amount of climatic factors..

2.4. Data and statistical Analysis

The collected data were organized by the use of Microsoft Excel Office Windows 2019. Simple descriptive statistics (count, percentage, tables, and figures) were used to assess different variables. The associations of the response variable(pest/disease) with drivers (climatic factors) were analysed using a regression model, using the MINITAB English version-18.

The regression model allows evaluation of the importance of independent variables that have an effect on the response variable. Hence, regression analyses were applied to investigate the potential level of influence (linkage=relationship) of the climatic factors (rainfall, maximum temperature, minimum temperature) on the incidence of bacterial blight and on the dynamics of the population density of aphids. Regression analysis were conducted to investigates linkage between climatic factors and pest/disease fluctuations over time and space.

The correlation coefficients between aphid density and predictive climatic factors were followed by the determination of coefficient of determination for appreciation of the variance of influence. The resulting coefficients reveal the magnitude and direction of the relationship between meteorological variables and aphid populations over these timeframes (five years).

Factors that increase aphid populations are indicated by positive coefficients, while those that decrease it are suggested by negative coefficients. Subsequently, the obtained correlation coefficients underwent rigorous significance testing at a five percent level it ascertains the reliability of the observed relationships.

In addition, during data analysis, generalized linear models (GLM) were conducted to determine factors (drivers) likely influencing of the level of farmers' knowledge of the causes of fluctuation in the aphid population density and bacterial blight incidence with independent driving variables (Table-1).The generalized linear model (GLM) regression equation was developed in STATA (ver14.) This statistical method allowed for the quantification of the individual contributions made by each driver to the variations observed in the aphid population and bacterial blight incidence.

3. RESULTS

3.1. Weather patterns during the growing seasons

Temperature trends

The five years under scrutiny exhibited distinctive temperature dynamics during the respective growing seasons and monthly total rainfall. Temperatures oscillated from the windy coolest to the hottest conditions. Warm and rainy conditions prevailed in September-October of every year June. June-July experienced the most variable weather, and August brought a blend of cooler and hotter days. July displayed the epitome of variability, with temperatures below the average temperature, and August culminated in the zenith of warmth, featuring maximum temperatures between 26 and 31◦C. The increase in maximum temperature was likely being associated with the risk of aphid population density and with increased number of generations of the pest across the life cycle of beans. Overall, each year exhibited its unique rainfall and temperature characteristics, emphasizing the importance of analysing the nuanced climatic variations within the context of the growing seasons.

Rainfall Patterns

Precipitation patterns displayed diverse trends. There were distinct variations in rainfall patterns (amount) across the five consecutive years of observations. Precipitation dynamics were likely influencing aphid population density fluctuations. June-July received minimal precipitation because of prevailing drier conditions during these months. Mostly July registered the lowest precipitation levels. Concluding the dry season, August witnessed sometimes the most substantial monthly rainfall at 10-70 mm. October-November emerged as the wettest months on the long rainy season A, while March-Aprile were the months with high amount of rainfall in the short rainy season. May-June-July remained notably dry months with some time less than 10 mm of precipitation. June-July featured a climatic blend of elevated temperatures with very low amount of rainfall.

Across years, August exhibited diverse precipitation levels, oscillating between 10 and 40mm. This comparative analysis underscores the nuanced variations in rainfall across the five years, providing valuable insights into the evolving climatic conditions during each g cropping season and year. Quantitatively comparing the years, 2021 emerged as the year with the highest overall precipitation, characterized by extremes in both excess and scarcity. In contrast, 2022 exhibited notable disparities between wet and dry months. Remarkably, 2023 and 2024 demonstrated a balanced distribution of precipitation events, portraying a harmonious blend of dry and wet periods. These intricate variations underscore the necessity of considering not only total monthly precipitation but also the temporal distribution of rainfall regimes.

3.2. Correlation Between Weather Factors and disease incidence (%)

Concerning the oscillation in the incidence (%) of the common bacterial blight , the survey was conducted in major bean producing village areas, with altitudes ranging from 1400m to 2800m. the different fields were characterized by a variability in field slope, weed management, fertility level, plant population density, crop rotations, agronomic practices. The disease/pest was cauterized by high oscillations in the amount (decreasing some seasons/growth stage, increasing in the following seasons/growth stage). Different levels of the disease incidence (%) were recorded in the different survey villages, cropping seasons, environments, altitudes and years. In some years, the incidence of the disease was high, even when moderate levels of rainfall and higher temperatures could be recorded.

The mean disease incidence was significantly (P<0.05) affected by the variability in climatic factors. The mean disease incidence differed significantly (P<0.05) among years and cropping seasons. The study also revealed the interplay between altitude, cropping seasons and climatic factors, even when each factor alone had or not an impact on the disease's development and on the dynamic of the population density of aphids. These points again reinforce the need to undertake successive cropping season studies of bean diseases and pests across different altitudinal ranges, years, environment and management practices.

Overall, the study revealed which weather conditions were made conducive for development and increment incidence of bacterial blight/aphid pest population density. It is likely that rainfall amount and high temperatures were favourable for the disease development and the build-up of the aphid population density (production of multiple generations during the cropping cycle of beans).

Based on these observations made over about 5 years, it is likely that variability in climatic factors will also impact on the population density of aphids(its severe damages, infestation levels), prevalence, severity and incidence of the diseases with the resultant yield loss even when farmers grown resistant varieties. Thus, the need for researchers to think of developing bean genotypes with traits of resistance/tolerance to multiple climatic-biotic stressors (climatic, biotic). Such climate smart varieties are needed to adapt to on going climate change.

Overall, the results of the study revealed that there were significant differences in the population density among the different sampling sites and dates (years) of sampling months. Most highest peaks were recorded in long rainy seasons and the lowest during dry seasons.

3.2.1. Relationships between rainfall and the bacterial blight disease incidence (%)

During year 2019, bacterial blight incidence (%) was positively related to mean monthly rainfall (R^2=47.9%, P<0.001). During year 2020, bacterial blight incidence (%) was positively related to mean monthly rainfall (R^2=12.2%, P=0.047). During year 2021, bacterial blight incidence (%) was negatively related to mean monthly rainfall (R^2=41.18%, P<0.0001). During year 2022, bacterial blight incidence (%) was negatively related to mean monthly rainfall (R^2=18.5618%, P=0.009). During year 2023, bacterial blight incidence (%) was negatively related to mean monthly rainfall (R^2=14.56%, P=0.032). During year 2024, bacterial blight incidence (%) was negatively related to mean monthly rainfall (R^2=35.6%, P=0.002) (Figure-1a).

3.2.2. Relationships between maximum temperature and the bacterial blight incidence (%)

In year 2019, bacterial blight incidence (%) was negatively related to mean maximum temperature (R^2=10.35%, P=0.026). In year 2020, bacterial blight incidence (%) was negatively related to mean maximum temperature (R^2 =48.04%, P<0.0001). During year 2021, bacterial blight incidence (%) was positively related to mean maximum temperature (R^2=17.81%, P=0.011)During year 2022, bacterial blight incidence (%) was negatively related to mean maximum temperature (R^2=13.91%, P=0.034). During year 2023, bacterial blight incidence (%) was negatively related to mean maximum temperature (R^2=21.45%, P=0.004). During year 2024, bacterial blight incidence (%) was negatively related to mean maximum temperature (R^2=10.5%, P=0.004), (Figure-2a)

3.2.3. Relationships between minimum temperature and bacterial blight incidence (%)

During year 2019, bacterial blight incidence (%) was negatively related to mean minimum temperature (R^2=21.5%, P=0.004). During year 2020, bacterial blight incidence (%) was not related to mean minimum temperature (R^2=4.6%, P=0.346) .During year 2021, bacterial blight incidence (%) was not related to mean minimum temperature (R^2=7.72%, P=0.157). During year 2022, bacterial blight incidence (%) was not related to mean minimum temperature (R^2=1.4%, P=0.728). During year 2023, bacterial blight incidence (%) was positively related to mean minimum temperature (R^2=50.3%, $P<0.0001$). During year 2024, bacterial blight incidence (%) was not related to mean minimum temperature (R^2=7.37%, P=0.324) (Figure-3a).

3.3. Correlation Between Weather Factors and aphid Population Density

Concerning the effect of main weather factors on the aphid populations , population fluctuation of aphids followed a nearly similar pattern over the months of the year. There was noticeable aphid population fluctuation with a general trend of decline with a decreasing trend in precipitation. Perceptible aphid persisted with a similar pattern throughout the years at all study villages. In some months of the year, the population density of aphids was almost knocked down below undetectable levels.

In the same activity, there was a some negative/positive relationships between monthly rainfall and aphid population density., this implies that a moderate to high rainfall intensity tends to have a positive/negative impact in the aphid population density. The result revealed that there were a significant and moderate positive relationship between maximum temperature and the monthly counts of the aphid population in some years. This implies that the presence of mean maximum temperature in the environment tends to cause a positive effect on the pest population, while an increase in minimum temperature tends to cause a negative effect on the pest population growth for most years of survey . Negative relationships implied that a steady decrease in temperature tends to cause a negative effect on aphid population density. .

To assess the influence of individual abiotic factors on aphid population density dynamics in bean fields, regressions were computed between aphid population density and weather parameters. The regressions were calculated between two variables in order to find out indications on how one continuous variable affected the other, either positively or negatively. The amount of variance of the influence of climatic factor on aphid populations was revealed with the displayed the coefficient of determination (R^2). Aphid population density showed non-significant to significant relation with climatic factors (maximum/minimum temperature and rainfall). Notably, compared to 2019, several weather parameters exhibited increased significance with aphid population or disease incidence from 2020 to 2024 . The interplay between weather parameters and aphid population density in bean fields across years and cropping seasons is presented in Figures 1 to 3.

The results revealed that there were fluctuations in the population density of aphids (nymphs, adult male females young) at all study village-sites, which followed more or less similar patterns of distribution across the months of the study years. There was a marked increase in population density with a general trend of increased precipitation, and there was a decreased in the aphid population density with a trend of decreased precipitation. Similar patterns were observed for temperature. The population peaks were recorded during high rainfall. The maximum numbers of aphid populations were also recorded during hot temperatures.

Aphid infestations showed temporal nuances in response to evolving field environmental conditions. There was dynamic trend of aphid populations, providing a comprehensive visual representation of the fluctuations over the observed period. In some case, aphid infestation dynamics were positively/negatively synchronized with rainfall intensity. Some field exhibited high aphid population density (above 100 individuals/5plants) at low altitude. In some other cases, there was almost absence of aphids for two to three consecutive weeks in a growing season.

Even though it was unusual, the lack of aphids provided important information about possible change environmental and agroecological conditions that could lead to aphid death. In such fields, several natural enemies (the predator ladybeetles) were abundant when aphids were almost absent. The recurrent emergence of aphids during the following cropping season was concomitantly observed when the predators were not abundant. This observations implies that it is good to observe both the pest and its natural enemies under variability in climatic conditions in the future research.

3.3.1. Relationships between rainfall and the aphid population density

In fact, during year 2019, aphid population density (average adult nbr/5 plants) was positively related to mean monthly rainfall (R^2=31.9%, P<0.001). During year 2020, aphid population density (average adult nbr/5 plants) was positively related to mean monthly rainfall (R^2=22.7%, P=0.003). During year 2021, aphid population density (average adult nbr/5 plants) was positively related to mean monthly rainfall (R^2=15.4%, P=0.021). During year 2022, aphid population density (average adult nbr/5 plants) was positively related to mean monthly rainfall (R^2=17.8%, P=0.012). During year 2023, aphid population density (average adult nbr/5 plants) was positively related to mean monthly rainfall (R^2=12.7%, P=0.047). During year 2024, aphid population density (average adult nbr/5 plants) was not related to mean monthly rainfall (R^2=8.11%, P=0.285) (Figure-1b)

3.3.2. Relationships between maximum temperature and aphid population density

During year 2019, Aphid population density dynamics (average adult nbr/5 plants) was positively related to mean maximum temperature (R^2=51.1%, P=0.026). During year 2020, Aphid population density dynamics (average adult nbr/5 plants) was not related to mean maximum temperature (R^2=2.71%, P=0.556). During year 2021, the dynamics of aphid population density (average adult nbr/5 plants) was positively related to mean maximum temperature (R^2=17.4%, P=0.012). During year 2022, the dynamics of aphid population density (average adult nbr/5 plants) was positively related to mean maximum temperature (R^2=31.4%, P<0.001). During year 2023, the dynamics of aphid population density (average adult nbr/5 plants) was not related to mean maximum temperature (R^2=8.6%, P=0.132). During year 2024, the dynamics of aphid population density (average adult nbr/5 plants) was negatively related to mean maximum temperature (R^2=12.2%, P=0.015) (Figure-2b)

3.3.2. Relationships between minimum temperature and aphid population density

During year 2019, aphid population density (average adult nbr/5 plants) was positively related to mean minimum temperature (R^2=15.3%, P=0.024). During year 2020, aphid population density (average adult nbr/5 plants) was positively related to mean minimum temperature (R^2=23.1%, P=0.003). During year 2021, aphid population density (average adult nbr/5 plants) was not related to mean minimum temperature (R^2=5.1%, P=0.304). During year 2022, aphid population density (average adult nbr/5 plants) was positively related to mean minimum temperature (R^2=34.9%, P<0.001). During year 2023, aphid population density (average adult nbr/5 plants) was not related to mean minimum temperature (R^2=6.6%, P=0.217). During year 2024, aphid population density (average adult nbr/5 plants) was not related to mean minimum temperature (R^2=7.5%, P=0.323), (Figure-3b).

Overall, the estimates of the relationships between incidence (%) of diseases and pest attacks (damages) and the yield (tones/ha) during surveys (Figure-4)

3.4. Drivers of the knowledge of growers of the causes of fluctuations in the aphid population density and oscillations in CBB incidence (%) across time and space.

The determinants of the level of knowledge of farmers about key socio-biophysical drivers causing oscillations in aphid population density and bacterial blight incidence over years and cropping seasons were also investigated during the interview with growers.

Employing general linear model (GLM), the contributions of other drivers were elucidated, revealing nuanced impacts of different driver family, according to the level of knowledge of causes of variations in disease/pest fluctuations.

Within this amalgamation or web of climatic factors, the GLM regression underscored the preeminent impact of some biotic and abiotic factors in influencing aphid population. Some drivers seemed playing a pivotal role in explain better the fluctuation in the aphid population density.. These drivers mirrored analogous patterns in bean fields, where climatic factors (maximum temperature minimum temperature and rainfall) yield significant influences on the population density of aphids and bacterial blight that were monitored for five consecutive years.

The regression model indicated that some independent variables significantly affected both the disease incidence and pest population density . Some independent variables, such cropping season (P<0.05), altitude (P<0.05), seed source (P<0.05), variety type (P<0.05), planting date (P<0.05), weed management (P<0.05), bean growth stage (P<0.005), crop rotation (P<0.05). Infection of other diseases and pests were significantly (P<0.05) associated with aphid populations and bacterial blight incidence (%) across fields, altitudes and years (un shown data) .

While some socio-economic and market had non significant (P>0.06) association with the incidence of the disease, they appeared being significantly associated with aphid population density. This indicates an opposite impact on different kind of pests and diseases. It is likely that some drivers may lead to increase/decrease in some pests and having no effect in other pests/diseases. Obviously , the growth stage was the most important variable in its association with disease incidence/pest population density.

The relevance of cropping season and altitude variables to pest and disease was also evidenced in this study. The chance of pest/disease occurrence/prevalence in a given village may be positively/negatively affected by the environmental variables. Socio-economic, nutritional and market variables had a high risk of being associated pest populations than with disease incidence.

3.4.1. Determinants of the knowledge of farmers of drivers of cause of oscillation in the bacterial blight incidence (%) over years, growth stages and environment

Variables that were selected and used in the generalized linear model are presented in Table-1. The level of knowledge of farmers of the cause of oscillation in the bacterial blight incidence(%) across years, environment and fields, was likely being influenced by: the perception of variability in climatic factors(Z=-4.07, P<0.0001), the fact that the farmers had previously receive or not training on climate information services(z=2.54, P=0.011) or on identification and management of crop pests and diseases (z=2.55, P=0.011), the visual observations of indicators of disaster events in the field (z=2.42, P=0.015) or in its surroundings (Z=1.98, P=0.047), the altitude of the field (z=4.89, P<0.001), the year of survey (z=2.36, P=0.018) , The environmental quality of the village where the field is established (z=2.15, P=0.031), the type of management practice of biotic agents (weeds, pests, diseases) adopted by a farmer, the vegetation type in the neighborhood of field crop (z=2.61, P=0.009), the soil type on which the field was established (z=2.72, P=0.006), the cropping season (z=2.25, P=0.024), the type of seeds used by the farmer (z=2.19, P=0.028), the type of crop that was previously established on the field (z=3.55, P<0.0001), the growth stage of bean (z=3.42, P=0.001), the cropping system (Z=3.97, P<0.001) (Table-2).

3.4.2. Determinants of the knowledge of farmers of drivers of cause of variability in aphid population density

The level of knowledge of farmers of the cause of fluctuation in the population density of aphids across years, environment and fields, was likely being influenced by: the perception of current variability in climatic factors(z=-2.28, P=0.028), previous training on climatic events management and mitigation(z=3.21, P=0.001), previous training on pests identification (z=4.22, P<0.001), au fact that the field is exposed to disaster events (z=2.01, P=0.044), event of disaster event in the neighborhood (z=-2.84,P=0.005), the year of entomological survey (z=-3.29, P=0.001), the type of biotic agents management practices that adopted by the farmers (z=-3.14, P=0.002), the type of vegetation found in the surroundings or vicinity of the ben field (z=-2.49, P=0.013), the soil fertility status where the ben is grown (z=2.76, P=0.006), the cropping season (z=-2.23, P=0.026), the cropping season (z=-2.23, P=0.026), the type of seed variety used by the farmer (z=2.82, P=0.005), the field history or previous crop grown (z=-9.08, P<0.001), The planting density (z=-2.66, P<0.001), the planting date (z=2.06, P=0.039), the cropping system (z=3.94, <0.0001), interacting occurrence of other pests and diseases (Z=3.94, P<0.001), the demand of high quality seeds at local market (Z=-2.22, P=0.026), Farmers preference variety traits (z=-3.06, P<0.0001), the gustative quality of young leaves eaten at the household (z=9.47, P<0.0001) (Table-3).

4. DISCUSSION

4.1. Effect of variability in climatic factors on oscillations in the bacterial blight incidence (%)

The results of the study confirmed that aphid was present in all sampled study fields throughout the study period with several fluctuating population densities. The population density of aphid recorded in 2019 was relatively similar to the population density recorded in 2020. High population densities were recorded in fields located in lowlands possibly due to the effect of temperature.

The results of this study indicate that when low temperature prevails in bean fields, it had a positive impact on the population density of aphids. That is, as the temperature moderately increased, the density of the aphid population also increased. In this same case, there was a marked increase in aphid population density from during long rainy seasons with a general trend of slight to medium increased precipitation in highland field villages.

A period of population growth was mostly observed during long rainy seasons (September to January). The highest population densities occurred during the warmer and rainy season of almost each year. The highest populations were detected from October and the lowest were detected during the September and January months in the long rainy seasons. This means that, ecologically, aphid populations may be guided by scarcity/abundance of food rather than rain and temperature alone (Tsukaguchi et al.2003). Some times prolonged heavy precipitation (heavy precipitation) wash-down aphids from bean plants (personal surveillance) during the short rainy season (Tsukaguchi et al.2003).

The common bacterial blight was found to be widespread in the major growing villages during the survey periods (2019-2024), indicating that it is one of the major limiting factor of bean productivity. It is likely that the prevalence, incidence of the disease will continue being affected by variability in climatic factors. The population density of aphids will continue being influenced by climatic factors in interaction with cropping practices, crop rotation, environmental conditions and crop growth stage across years and cropping seasons. Bacterial blight epidemics with be affected by various biophysical factors conducing to the development of the disease in interaction with climatic factors.

These findings helped understand how disease epidemiology will affected by various factors including climatic factors. Hence, new appropriate sustainable management strategies should be initiated. Managing pests and diseases under current climate factors in interacting with several socioeconomic and biophysical drivers, require new thinking of researchers to be able to respond positively to future challenges .

According to the current research, altitude, weed density, cultivar, variety, cropping season, planting date, and year of assessment will continue having linked substantial impact on the epidemics of diseases and pest outbreak across the different agro-ecological areas of Kalehe territory. The CBB disease is one of the most devastating biotic factor , which may result in significant loss of yield and degradation of seed quality for the market and household consumption.

However, common bacterial blight epidemic development could be minimized by using climate smart adapted varieties or varieties that are tolerant to variations in climatic factors in interaction with variations in occurrence of pests and diseases incidence management strategies have to be developed and implemented. In some months of the years there was a conducive environment for the disease development due to high rainfall and temperature. Thus, designing sustainable management methods requires an understanding of disease epidemiology, which is influenced by a variety of factors.

Thus, the study revealed that the disease is wide-spread across the different agro-ecological study villages affecting the quality and quantity of seeds which leads to hindering bean production under current climate changes. Several other studies confirms and reported that disease and pest studied are deemed some of the be most devastating biotic factor causing significant loss of yield and degradation of seed quality, especially when variability in climatic factors are observed.

It can be concluded that the disease growth& development is dependent on the type of bean varieties, temperature and rainfall oscillations vis-à-vis all environmental conditions are constant or not. The relationship between temperature levels and crop yields was used to assess the effects of changes in average weather on crop yields. On going climate change is likely to increase impacts of pests and diseases on yield loss at above 30% There might be risk of common bacterial blight epidemic development during temperature increase due to climate change at low, middle and high altitudes.

Different production practices including crop rotation, cropping system, cropping seasons, along with agro-ecology conditions and variability in climatic factors, may continue influencing the level of crop damage by aphids or increase the % infestation of bean plants by other pests. Obviously, it has been reported that in densely populated farm fields, the disease incidence can be higher due to plant-to-plant spread of the foliar diseases as a result of the wind or rain splashes . This situation can causes up to 100% yield losses.

The occurrence, spread, and severity of disease in nature are primarily controlled by different environmental factors. Favourable environmental conditions have large effects on the initiation and spread of the disease infections. Furthermore, the growth and development of common bacterial blight is likely occurring rapidly at above 20°C maximum temperature or at above 8°C minimum temperature. Long cool and moist weather spells are considered to be the most conducive for the disease development m rather than rain splashes. Subsequent wetness, strong winds and rain splashes accelerate the dispersal of disease agents from infected plant parts to healthy populations .Rain splashes disperse young aphid individual to surrounding plant populations. Hence, the disease becomes epidemic in cool and humid environments while warmer conditions may favour the build-up of aphid population.

In several other crop plants, weather factors also have been reported to play major roles in the development of various diseases, and therefore the prediction equations have been derived to estimate the disease severity in these crops by considering the weather factors . Among various weather factors studied, the number of rainy days and cumulative rainfall coupled with advanced crop age have been inferred as most important factors for development of rust disease (Popoola et al.2014).

Low to moderate pest outbreak and disease epidemics mainly, most prominent during the flowering and podding growth stages can also cause high yield loss beyond influences of locations, altitude, farmers' management practices and environmental conditions. With regarding to crop rotation, higher pest population density of aphids can be observed in fields not rotated with non-host crops. Overall sowing of disease free seed, planting resistant genotypes, rotation of crops in such a manner that non host crop follow the host crops, elimination of crop residues, and deep sowing of crop , are among practices that can be effective to minimize disease incidence and pest population pressure despite variability in climatic factors.

This study showed that the economic impact of the disease in all cropping seasons depends on the variety, weather conditions, and influence of farmers' management and production practices. Therefore, strategies are to be made to develop climate-resilient varieties (newer varieties tolerant to multiple-abiotic stresses) based upon screening of large number of gemplasm (Basu et al.2016). Furthermore, climate smart varieties will be able to help in the control of disease and pest population under current climate change.

Agro-ecological and environmental characteristics of farm landscape, agronomic and management approaches, a variety of meteorological conditions, and variations in sowing dates in various fields may contribute to disparity in disease incidence across studied locations. Interactions among drivers may have highly significant effect on pest infestation rates than each driver alone.

Temperature is the most important environmental factor that affects insect distribution, and it is highly correlated with elevation (Azrag et al. 2018). Variation in temperature affects insect population dynamics through insect physiology and behaviour (Azrag et al. 2018). Indirect effects also are expected due to the impact of temperature on host plants and natural enemies (Azrag et al. 2018). The pest infestation can be positively correlated with temperature and negatively correlated with altitude (Constantino et al.2021).

Differences in weather conditions between cropping seasons, altitude and altitudes are likely to exacerbate pest population pressure than favoring disease development into several generations . In a study conducted in Kenya, it was found in most arabica-producing areas of East Africa (Kenya), climate change is predicted to likely to increase from five to ten, the annual number of generations of a coffee pest (*Hypothenemus hampei*) (Jaramillo et al.2011).

Also, analysis of variance (ANOVA) was used in India to partition the variation in the predicted number of generations and generation time of a pest *Spodoptera litura* Fab. on peanut during crop seasons. It was found Geographical location may explain 34% of the total variation in number of generations, followed by time period (26%), model (1.74%) and scenario (0.74%). The remaining 14% of the variation was explained by interactions. Increased number of generations and reduction of generation time across the six peanut growing locations of India suggest that the incidence of *S. litura* may increase due to projected increase in temperatures in future climate change periods (Rao et al.2015).

4.2. Effects of climatic factors on aphid population density fluctuations

The integrated analysis of weather patterns and aphid population dynamics provides a comprehensive understanding of the temporal influences on aphid infestations and bacterial blight incidence. The synchronicity observed between rainfall-temperature variations and aphid population build-up initiation, aligns with existing literature on the correlation between warmer temperatures and increased aphid activity during growth stage of different cultivars. This synchronized action suggested a potential influence of temperature cues on aphid incidence and population build up (Sharmin et al.2021). Temperature is known to play an important role in the incidence and severity of insect pests (Asitoakor et al.2022., Sharmin et al.2021).

It can be inferred that the considerable variations in precipitation, characterized by May-June being the driest as compared to other months , are presumed to have influenced the population density of aphids (Wu et al.2020).This aligns with the findings of the previous studies carried elsewhere between the variation in cropping season precipitation and aphid populations on cowpea (Wu et al.2020).

Combined impacts of environmental conditions and plant ages can explain changes in *A. craccivora* population density (Ghada et al. 2021). The results revealed that the effects of weather conditions and plant ages on population density and infestation incidence percentages by *A. craccivora* are highly significant during cropping seasons although these parameters may varies from season to season (Ghada et al. 2021).

Also, temperature and precipitation have been showed to have significant direct and indirect effects on the population dynamics of the coffee leafminer in Mexico (Nestel et al.1994). It was also found that even moderate fluctuations in climatic conditions were likely playing an important role in the dynamics of the insect pest populations(Nestel et al.1994).

Combined effect of climatic factors (maximum temperature, minimum temperature, solar radiation, rainfall amounts,….) may be responsible for the population changes in nymphs, adult females, mummies and the total population of this insect species (Shipa et al.2021).. Minimum temperature may affect young and nymphal populations while adults and mammies may be sensitive to maximum temperature. Also decreased rainfall amounts in field environment tended to cause a population reduction in aphids(Sharma & Khokhar 2018).

Hence, the fluctuations in aphid populations may be influenced simultaneously with both variability in rainfall and temperature, But lower amount of rainfall and minimum temperatures may be favorable or the most the most appropriate for its initiations and development in bean fields in all sites (Sharmin et al.2021). The combination effect of climatic factors and plant age on aphid population density explained variance which was 75 and 74% in the early and recommended planting dates respectively(Kamel & Megahed 2021) . These results indicate that the recommended planting date and moderately plant nutrition can help plants to avoid insect pests infestation(Kamel & Megahed 2021).

Some aphid population peaks were recorded when rainfall intensity was from minimal to medium precipitation. In addition, the monthly counts of the total aphid population throughout the study period of investigation showed significant differences in the aphid density at different sampling dates of the month in each year. Seasonal fluctuation of different developmental stages of aphids recorded several peak periods for both total numbers of the live population, as well as for immature stages and adult stages (Mandal et al.2018). Hence, climatic factors play an important role in generation development of the pest, although several unexplained (unknown) factors were assumed to be responsible of the remaining variation in the relationships (Pathipati et al.2020).

These factors were not unconsidered /undetermined in advance to be included in the design of the study. Other factors those were not included in this study(that may be important to include in further studies) include sunlight intensity, relative humidity, wind speed., that may cause mortality of aphids of all stages (Pathipati et al.2020). These require further investigations. Based on growers' perception, only some factors were revealed to significantly influence the knowledge of farmers of the cause of variability in the population density of aphids.

Dry conditions are anticipated to elevate aphid populations, building on the insights from the previous study (Munyuli et al. 2007) that linked the observed aphid response to diminished plant vigor and heightened chemical defense in plants experiencing drought stress. Plant phenology plays a crucial role in influencing the extent of aphid species infestation. For instance, it determines the growth stages which are susceptible to aphid invasions and the crops that will most likely be severely affected (Hammad et al.2015).

Peak of aphid populations are some times in correlations with local temperature and precipitation conditions , because the pest is sensitive to the climatic intricacies during years of field surveys. The interaction of drivers may present a unique epidemiological landscape to each village. In some villages, aphid may be absent and present in other villages. This is crucial for elucidating potential environmental factors contributing to aphid death or disappearance. It is suggested that extreme weather events and the presence of natural parasitoids and predators can play a role in aphid population dynamics (Sharma & Khokhar 2018).

Anomalously precipitation-abundant conditions, characterized by extremes in both excess and scarcity, can created an environment inhospitable to aphids. Intense rainfall may cause insects to be displaced from the plants, resulting in a decrease in their population in the field. Also intricated interplay conditions of drivers can lead to similar outputs (Mandal et al.2018).

The occurrence of high population density in some months and numerical surge on other months of the year may underscores the dynamic nature of aphid infestations (Abbasi et al. 2019). When favorable environmental conditions prevail for the pest, significant damages can be observed in the field leading to potential high yield loss (Sharma & Khokhar 2018, Schlenker & Roberts 2009).

Both the pest and the disease studied are favorable evolving environmental conditions of Kalehe territory Such situation may be attributed to a combination of factors, including favorable weather conditions and potential carryover effects from the previous season, as well as bean plant growth stages. The density of aphids can rise with increasing maximum temperature during intense rainfall. Warmer temperatures can accelerate insect development rates and increase the number of generations per year. It is likely thar variability (increase in temperature and rainfall amount) will continue playing key roles in the current climate change situations (Abbasi et al. 2019).

Increased average temperatures can lead to disturbances in predator–prey relationships in a given farm-landscape . Temperature changes affect the phenologies of insects, which, in turn, can cause spatio-temporal mismatch between insect pests and predators or plants(Shipa et al.2021). This kind of knowledge can be used for new forecast models in environmental field conditions and can be recommended for validation in countries with similar to those found in Kalehe territory.

Warmer temperatures positively accelerate development by amplifying aphid reproduction rates or by altering population dynamics, even if the total effect of weather parameters on aphid population may vary among legume crop types (Pathipati et al.2020, Sharmin et al.2021). Climatic factors collectively account for a substantial portion of the variance in pest of legume crops. Temperature regulate and shape pest populations because aphid species are sensitive to temperature fluctuations (Bavisa et al.2018).

Precipitations are known to impact aphid dynamics more than temperatures. Increased rainfall can reduce aphid populations by influencing their reproductive success, feeding ability and movement patterns. However, the variability in the results obtained in this study calls for nuanced interpretations resonance of the broader literature on aphid responses to variability in climatic factors (Bavisa et al.2018).

Aphids and climate have been the subject of many studies (Brabec et al.2014). This study confirms observations obtained elsewhere of the role of climatic factors in shaping the pest aggressivity and harmful impacts on aphids on bean plant (Brabec et al.2014). The populations of aphis may increase under high temperatures and the performance of aphids under heat stress can decrease (Brabec et al.2014).

The location, aphid activity, landscape habitat vegetation and number of natural enemies (which are crucial for keeping low the population density of aphids) , are all impacted by climate change and variability (Kishor et al.2023) . The relationship between weather parameters and aphid populations in bean crops offers actionable insights for practitioners/managers in integrated agricultural pest management (Hammad et al.2015).

During crop production and productivity, insect pests, weeds and nematodes are important limiting factors that affect crop growth and yield output. Modern insect pest management techniques involve the use of agrochemicals. The heavy dependence on insecticides and pesticides has dire consequences on the environment, farmers' health, increase production cost, bioaccumulation and biomagnification, pesticide resistance, residue in food products, and decreased effectiveness of pesticides in addition to the vulnerability of marginalized farmers to climate change (Tikadar & Kamble 2023) . The climate change impacts on pests may include a shift in the species distribution (Tikadar & Kamble 2023). Thus, there is an urgent need for sustainable adaptation strategies for insect pest management which will overcome the above-mentioned limitations(Tikadar & Kamble 2023) .

Climate change also will have severe impacts on insects, especially honeybees, which pollinate crop plants and thus affect crop production highly (Debelo 2020). Combined effects of these will increase the extent of crop losses, and thus, will have a major bearing on crop production and food security (Debelo 2020). Prediction of changes in geographical distribution and population dynamics of insect pests will be useful for adapting pest management strategies to mitigate the adverse effects of climate change on crop production.

This paper summarized the different ways in which climate change impacts on insect pests and will increase the extent of crop losses. Governments should respond to climate change both by reducing the rate and magnitude of change by reducing greenhouse gas emissions (mitigation), and by adapting to its impacts (Debelo 2020). Many impacts can be avoided, reduced or delayed by mitigation, but adaptation will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions(Debelo 2020). Therefore, there is a need to take a concerted look at the likely effects of climate change on crop protection and devise appropriate measures to mitigate the effects of climate change on food security (Debelo 2020).

Rising temperature, modified precipitation patterns, disturbed gaseous composition of atmosphere etc. are causing the change in population, mobility, behavior of insect pest(Shrestha 2019). Along with direct impacts in crop productivity, climate change is threatening global food production via pest related losses of food crops (Shrestha 2019).

Climate change has increased pest population and their damage potential by expanding distribution, enhancing survivability and allowing to develop the adaptability of insect pest (Shrestha 2019). Each additional degree of temperature rise could cause yield losses from insect pests to increase by a further 10-25% (Shrestha 2019).

Utilizing weather-monitoring systems alongside pest surveillance may allow for timely interventions, leveraging knowledge of temperature and rainfall trends to implement targeted control measures. This is important to all stakeholders interested in promoting plant heath management on-going climate change. These results presents an opportunity for further investigation into potential environmental factors that contribute significantly to the dynamics in the pest and disease prevalences and incidence in field conditions. By integrating this findings into on-the-ground practices, farmers can better anticipate and respond to aphid outbreaks and other related pests.

Future research endeavors should focus on elucidating the specific environmental factors influencing aphid exclusion and unraveling the complex interplay between weather patterns, crop characteristics, and natural ecological dynamics within cropping systems

5. CONCLUSIONS

The objective of this study survey was to find out if climate change will continue affecting pests and diseases of bean crop in Kalehe territory. Thus, the current studies have focused on correlation between aphid population density and basic climatic factors. The study results showed that fluctuation in the population density throughout the study period in all study villages. The investigation showed that there were significant ($P<0.05$) differences in aphid population density in all the study areas on different weekly sampling dates of the study months and years.

With a general trend of slight to moderately increased in precipitation amounts, aphid population seemed to increase, while with heavy amounts in precipitation were seen to decrease aphid populations, most likely due to washing down the pest by prolonged heavy precipitation. The study also confirmed that the population peaks were recorded during long rainy seasons across all study sites.

The population dynamics of aphids during the five years(2019-2024) of surveys indicated synchronized infestations with climatic factors, emphasizing the dynamic nature of pest infestation responses to environmental conditions. Rainfall and maximum temperature seemed promoting aphid growth in some cropping seasons and years.

The specific correlation analyses reveal that total rainfall and maximum temperature play significant role in influencing aphid population dynamics, with varying impacts observed across different years and timeframes and field. They are likely continue influencing the occurrence and aggressivity of pests in the future with ongoing climate changes.

In the current study, significant driving factors that influence the disease epidemic, had a high likelihood of association with high population density of aphids. The results of this study indicated relatively high temperatures and high amount of rainfall are likely to continue influencing the dynamics of pest populations in the future in interaction with other drivers(date of planting, variety, management practices, environmental factors, market and socioeconomic factors such as extension services.

The results obtained from this study indicated the importance of future research on the development of genotypes with multiple resistance /tolerance to abiotic and biotic stresses. Such climate smart varieties will adapt in different agroecological conditions of Kalehe territory, and avoiding significant yield loss that undermine food and nutritional security of growers.

There is always significant relationship between habitat suitability and insect pest population density (Kim et al.2024). The Understanding and knowledge of the distribution and density of pests is essential in its control(Kim et al.2024).

Generalized linear model (GLM) indicated that CBB incidence had high probability of association ($P<0.05$) with other drivers such cropping system, farmers' management system, landscape environment, soil fertility level, .. This finding indicate that future research should consider interacting factors and their resultant impact on pests/diseases and bean yield under current climate change. In Ethiopia, it was found that some important abiotic factors, such as, soil types, fertilizer applied, and fungicides sprayed, cropping system, previous crop, management practices, rotation habit, environment can be associated with chocolate pot disease epidemics (incidence and intensity) in Faba bean fields(Eshetu et al.2018).Therefore, it is important to consider all these drivers reduce chocolate spot and rust impact under current on-going climate changes.

Climate change will continue having serious consequences on diversity, distribution, abundance and phenology of pants, pests and pathogens (Asaf 2020). Pest damages may continue a varying in different agro-climatic areas mainly due to differential impacts of abiotic factors such as temperature, humidity and rainfall. The extent of yield loss due to diseases and pests will impact both crop production and food security (Asaf 2020).

Temperature has been revealed to have positive impact, whereas relative humidity and rainfall negatively affected the population of insect pests (Patra et al.2024). Under projected climate change with higher temperatures, pest populations are assumed to increase. Considering the insect diversity management strategies will be an adaptation strategy to conserve biodiversity while ensuring environment-friendly pest management (Patra et al.2024). It is important to consider multitrophic species interactions for predicting the effect of climate change on the abundances of herbivores (Robinson et al.2017).

Considering serious consequences of climate change on diversity and abundance of insect-pests and the extent of crop losses, food security for 21st century is the major challenge for human kind in years to come. In tropical countries that are more challenged with impacts of looming climate change on devising crop protection and mitigation strategies for future pest management programme (Asaf 2020).

The best economic strategy for farmers to follow is to use integrated pest management practices to closely monitor pest and disease occurrence. In this context, there may be a need to have a concerted look at the likely effects of climate change on crop health and devise appropriate measures to mitigate the effects of climate change on food security.

Prediction of changes in geographical distribution and population dynamics of pests will be useful to adopt the pest management strategies to mitigate the adverse effects of climate change on crop production. Climate changes may also upsurge outbreaks of pests more frequently due to differential impacts of abiotic factors such as altered temperature, humidity and rainfall (Asaf 2020)

The pest management components such as plant defense traits, host plant resistance, expression of Bt toxins in transgenic crops, natural enemies, biopesticides and synthetic pesticides will be rendered less effective as a result of climate warming (Asaf 2020). Increased scrutiny of how climate change will affect pest management in the postharvest supply chain will deliver improved outcomes for the entire agricultural system(Gerken & Morrison 2022).

A variety of integrated pest management (IPM) strategies may help increase the resiliency and adaptation of management to climate change. Tactics susceptible to warming temperature changes in climate showing decreased efficacy include semiochemical-based, behaviorally-based tactics, a subset of insecticides (e.g., pyrethrins and pyrethroids), and those that rely on low temperature (e.g., grain aeration, grain chilling). Tactics at food facilities showing resilience to warming temperature changes in climate include packaging, other groups of insecticides, and likely sanitation (Gerken & Morrison 2022).

Risk management is an integral component of coping with the effects of natural hazards and the use of meteorological data is among the risk management strategies available to producers to help assess the probability of events that foster the transmission or prevalence of pests and diseases (Farrow et al.2011). The analysis and monitoring of extreme weather events, and where possible their prediction, can help researchers, extension agents, farmers and pastoralists invest in the most appropriate risk management strategies and prepare for the effects of changes in climates (Farrow et al.2011).

Data on population dynamics are necessary for the development and validation of population models, including various biotic and abiotic factors that affect seasonality (Mahot et al.2024) . The present study represents a further step in understanding how variability in climatic factors change could impact population dynamics of the pest and its associated infestations and damage in bean plantation (Mahot et al.2024) .

The effect of environmental constraints on host and pathogen has positive, negative or neutral effects on crop disease incidence (Pokhrel 2021). With climate change, there will be an overall increased geographical spread of suitable habitats for crop pests (and as follows, crop diseases) that thrive in warmer environments. By the 2030s, crop pests and diseases will increasingly spread across, with a higher likelihood of occurrence. Crop pests and diseases that thrive in cooler environments will experience decreasing habitat suitability in the 2030s, but will transition to a slower decrease in the 2050s (Nguru & Mwongera 2023).

The components of integrated pest management that should be applied to reduce the damage the pest crops. Climatological conditions prevailing in the crop growing season decide the fluctuation and abundance of the pests, abiotic factors as well abiotic factors must be taken into account by the decision-maker in consideration when planning an IPM control strategy for the control of the pest(Bakry & Abdel-Baky, 2023).

It is recommended that preventive mitigation and adaptation measures, including biosecurity, are key to reducing the projected increases in pest risk in agriculture, horticulture, and forestry. Therefore, the sustainable management of pests is urgently needed (Gullino et al.2022) . It requires holistic solutions, including effective phytosanitary regulations, globally coordinated diagnostic and surveillance systems, pest risk modeling and analysis, and preparedness for pro-active management (Gullino et al.2022) .

Environmental factors determine the suitability of natural habitats for crop pests and often facilitate their proliferation and that of the crop diseases they carry. Crop pests and diseases damage food crops, significantly reducing yields for these commodities and threatening food security in developing, predominantly agricultural economies (Nguru & Mwongera 2023).

Given its impact on environmental factors, climate change is an important determinant of crop pest and disease distribution (Nguru & Mwongera 2023). Exploring the potential impact of climate change on select environmental factors linked to crop pest and associated diseases' proliferation, is emergent.

The constantly increasing environmental temperatures, coupled with accompanying variations in weather conditions, have some direct debilitating effects on coffee production and quality (Ogundeji et al.2019). Pests and pathogens, being able to tolerate a wide range of temperature, have the capabilities to proliferate and negatively influence the crop's yield, quality and production cost (Ogundeji et al.2019).

It is important that well planned monitoring programs are established in order to alert and help farmers to cope with future climatic change and avoid massive yield loss and food insecurity of rural communities. The study gave alight on strategies to propose to managers of farmers on how to adapt and cope up with on going climate changes. The mitigation of negative impacts of climate change on yield require new thinkings. The results highlight the need for future-facing, long-term climate adaptation and mitigation measures that create less suitable microclimates for crop pests and diseases(Nguru & Mwongera 2023).

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Tables and Figures

Fig-01a: The Map of DRCongo with its 26 Provinces including south-Kivu (Sud-Kivu in French) Province

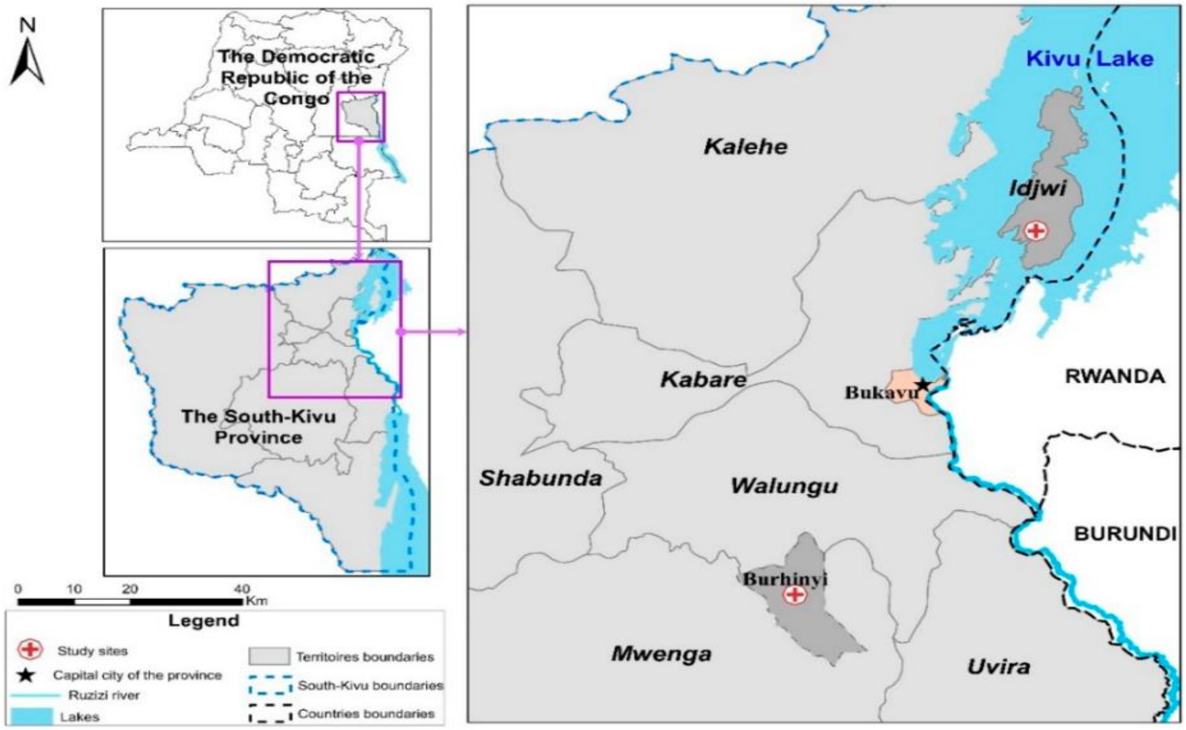


Fig-01b: The Map of the South-Kivu Province showing its territories including Kalehe territory

Fig-01c: The Map of Kalehe territory showing names of some of the surveyed villages (sites) where bean is grown (Luzira, Bushushu, Nyabibwe) at different alrirudes following the R4 national road Bukavu-Goma on the shore of Lake Kivu, eastern DRCongo

Table-1 : List of driving variables suspected and selected to test the likelihood of predictors of knowledge of farmers about bean diseases (severity, incidence, progress) and pests (occurrence, incidence of pest outbreak, % infestation, severity of damage and attacks) in the fields and environments where weekly observations were made from 2019 to 2024

Dependents variables	(i)Farmers' knowledge of the cause of bacterial blight incidence (%) fluctuation across fields (Yes=1, Not=0)
	(ii) Farmers' aware of the causes of the fluctuation dynamics of the population density of aphids (Yes=1, Not=0)
Independent variables	
Environmental factors	
	Indicators of field exposed to disaster risks and events (visible=1, not)
	Exposure/sensitivity to soil erosion-landslide-flood (yes=1, Not=0)
	Event of diseases in the neighborhood field (Present=1, Absent=0)
	Altitude (m)
	Year of survey (numbers)
	Village environment quality (high=1, poor=2)
	Type of neighboring field crops (crops=1, wild plants=2)
	Soil type (ferrisols=1, ultisols=2, clay=3, loam=4)
	Soil fertility status of the field (good=1, moderate=2, Poor=3)
	Slope of the field environment (steeper=1, flat=2, slight=3, Moderate=4)
	Cropping season (A=1, B=2, C=3)
	Agroforestery system of the landscape (simple=1, complex=2)
	Type of wild plants in the field margins (herbs=1, shrubs=2, mixtures=3)
Field characteristics	Weed management practices (twice=1, once=2, none=3)
	Type of seeds (improved=1, landrace=2, both=3)
	Field history & Previous crop on the field (cereals=1, legumes=2, vegetables=3, Root-tubers=4)
	% area under bean cultivation in the landscape environment
	Growth stage (leaf forming=1, flowering=2, podding=3)
	Plant population density (High=3, Moderate=3, Low=3)
	Planting date (on time=1, earlier=1, later=3)
	Cropping system (Sole=1 , Intercrop=2)
	Occurrence of other severe diseases & pests (Yes=1, Not=2)
	Early maturity, high yielding, resistant to pests/diseases, market attractive, easy to cook and store varieties (Yes=1, Not=0)
Post-harvest,market traits	Local market demand of seeds (High=1, Moderate=2, Low=3)
	Cooking quality of the variety (Poor=1, Medium=2, High=2)
	Gustative quality of the leaves (Good=1, Poor=2)
Institutions attributes	Extension visits (receive=1 or not=0)
	Previous training on climate information & services (receive=1, not=0)
	Previous training pest-disease identification (received=1, not=0)
Farmers profile	Farming Experience (years)
	Awareness of threats to yield loss (Yes=1, Not=0)
	Weeds, pests &diseases management practices adopted and implemented by a farmer (Yes=1, Not=0)
	Perception of variability in local climatic factors & micro-weather (has varied =1 or not=0)

Table-2 : Generalized Linear Model (GLM) assessing the probable influence of independent variables (drivers) on the dependent variable across various altitudinal environments where the surveys were conducted every week post planting, during farmers' interviews, South-Kivu, DRCongo

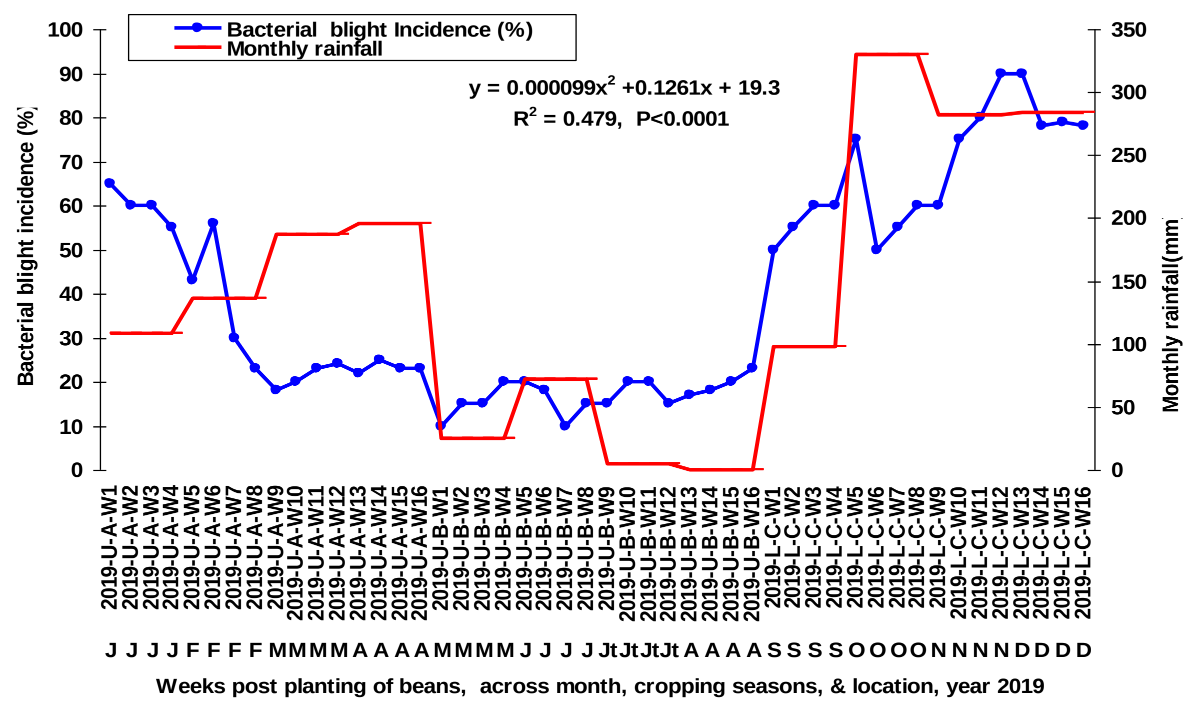
GLM Type: Poisson Distribution Model

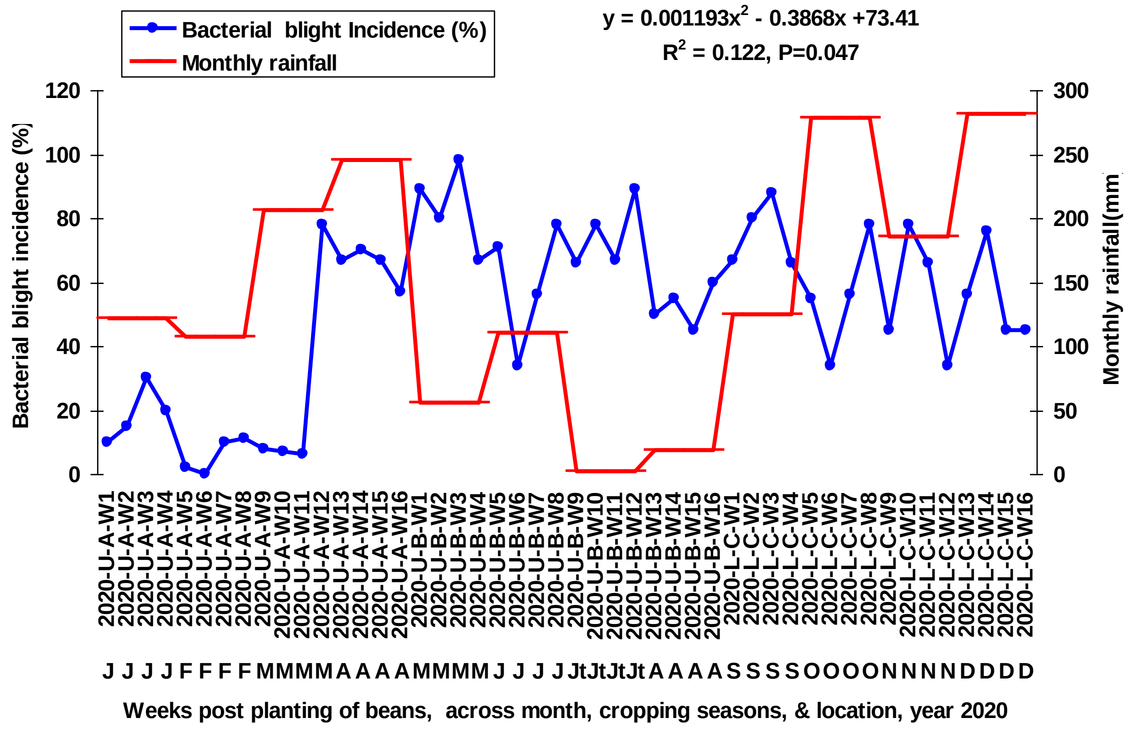
Dependent variable: **Level of farmers knowledge of the cause of bacterial blight incidence (%) oscillations across fields**	**Coef.**	**Std. Err.**	**z**	**P>|z**	**[95% Conf. Interval]**	
Independent variables						
Perception variability climatic factors	-.2352897	.0578266	-4.07	**0.000**	-.3486277	-.1219517
Previous training on climate	.0213824	.008404	2.54	**0.011**	.0049109	.0378539
Previous training pest-disease	.0218277	.0085639	2.55	**0.011**	.0050428	.0386126
Indicators of field exposed to disaster	.1471365	.0607808	2.42	**0.015**	.0280083	.2662646
Exposure/sensitivity to soil erosion	-.0172827	.0323906	-0.53	0.594	-.0807672	.0462018
Event of diseases in the neighborhood	.080186	.0404502	1.98	**0.047**	.0009051	.1594669
Altitude	.2774551	.0567165	4.89	**0.000**	.1662927	.3886175
Year of survey	-.0240851	.010221	-2.36	**0.018**	-.0441179	-.0040524
Village environment quality	.0345789	.0160762	2.15	**0.031**	.0030702	.0660876
Weeds-pests &diseases management	.1021979	.0465863	2.19	**0.028**	.0108904	.1935055
Type of neighboring field crops	.2558343	.0979909	2.61	**0.009**	.0637756	.4478929
Soil type	.0295043	.010834	2.72	**0.006**	.0082701	.0507384
Soil fertility status of the field	-.0048279	.015691	-0.31	0.758	-.0355817	.0259259
Slope of the field environment	-.03685	.0245086	-1.50	0.133	-.084886	.011186
Cropping season	.0763319	.0339275	2.25	**0.024**	.0098352	.1428286
Weed management practices	.0110272	.0329239	0.33	0.738	-.0535025	.075557
Type of wild plants in margins	-.0061952	.0178535	-0.35	0.729	-.0411874	.0287969
Agroforestery system of the landscape	-.0007962	.016979	-0.05	0.963	-.0340744	.0324819
Type of seeds	.1021979	.0465863	2.19	**0.028**	.0108904	.1935055
Field history, previous crop on the field	.1007197	.0283643	3.55	**0.000**	.0451267	.1563127
Awareness of threats to yield loss	.0037687	.0109081	0.35	0.730	-.0176108	.0251482
% area under bean cultivation	.0219155	.036513	0.601	0.548	-.0496486	.0934795
Growth stage	.0343686	.0100625	3.42	**0.001**	.0146464	.0540907
Extension visits	.1198945	.0890385	1.35	0.178	-.0546178	.2944069
Farming experience	-.0426104	.1020249	-0.42	0.676	-.2425756	.1573548
Plant population density	.0025395	.0150894	0.17	0.866	-.0270352	.0321142
Planting date	.0011451	.0032246	0.36	0.722	-.0051749	.0074651
Cropping system	.1156908	.0291254	3.97	**0.000**	.0586062	.1727755
Occurrence of other diseases & pests	-.000755	.0048902	-0.15	0.877	-.0103397	.0088297
Local market demand of seeds	-.0432574	.044388	-0.97	0.330	-.1302562	.0437415
Cooking quality of the variety	.0095443	.0297084	0.32	0.748	-.0486832	.0677717
Early maturity, high yielding varieties	.011136	.0108185	1.03	0.303	-.0100679	.0323399
Gustative quality of the leaves	.0186406	.0317006	0.59	0.557	-.0434914	.0807726
_cons	-.7701619	.468328	-1.64	0.100	-1.688068	.1477441

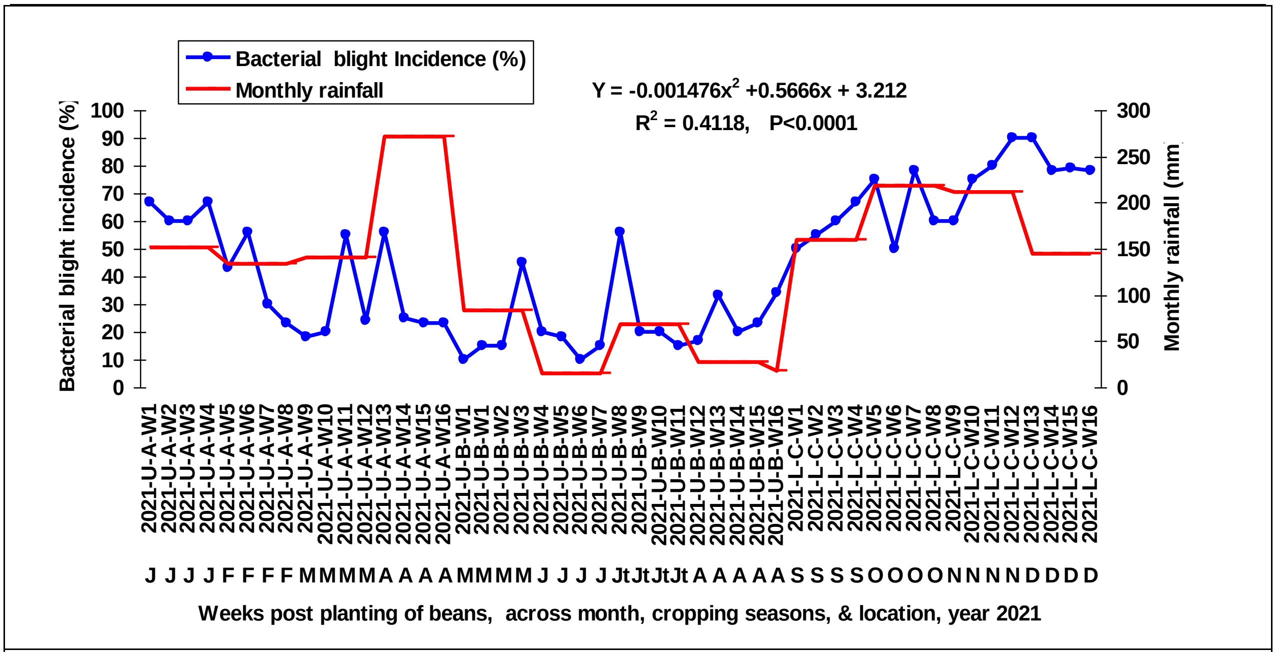
Other statistics : Log likelihood = 169.961894.,
AIC (Akaike's information criterion) = -.539746 ., BIC (Schwarz's Bayesian Criterion) = -1197.841

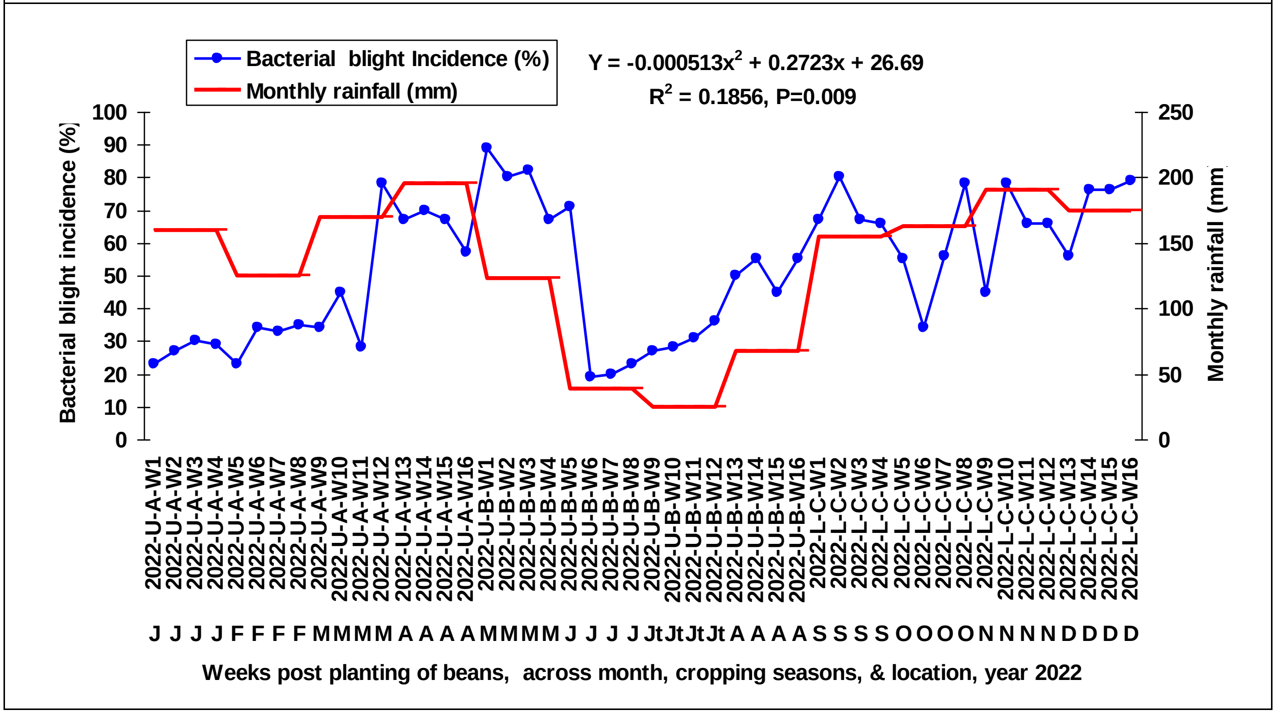
Table-3 : Generalized Linear Model (GLM) assessing the probable influence of independent variables (drivers) on the dependent variable across various altitudinal environments where the surveys were conducted every week post planting, during farmers' interviews, South-Kivu, DRCongo

GLM Type: Gaussian Log Model						
Dependent variable: **Level of farmers' awareness of the cause of the aphid population density fluctuation across fields and years**	**Coef.**	**Std. Err.**	**z**	**P>|z**	**[95% Conf. Interval]**	
Independent variables						
Perception variability climatic factors	-.1086811	.0476879	-2.28	**0.023**	-.2021476	-.0152147
Previous training on climate	.044181	.0137565	3.21	**0.001**	.0172188	.0711431
Previous training pest-disease	.0851927	.0202059	4.22	**0.000**	.0455899	.1247955
Altitude	-.0158052	.0298016	-0.53	0.596	-.0742153	.0426048
Exposure/sensitivity to soil erosion	.0303862	.0150869	2.01	**0.044**	.0008165	.059956
Event of diseases in the neighborhood	-.0276644	.0097507	-2.84	**0.005**	-.0467753	-.0085534
Indicators of field exposed to disaster	.0113184	.0086779	1.30	0.192	-.00569	.0283269
Year of survey	-.2101988	.0638762	-3.29	**0.001**	-.3353939	-.0850037
Village environment quality	-.0640427	.0589013	-1.09	0.277	-.179487	.0514017
Weeds-pests &diseases management	-.2307565	.0735532	-3.14	**0.002**	-.3749181	-.0865948
Type of neighboring field crops	-.0238821	.0095761	-2.49	**0.013**	-.042651	-.0051132
Soil type	-.0148269	.0091218	-1.63	0.104	-.0327053	.0030514
Soil fertility status of the field	.1441112	.0523029	2.76	**0.006**	.0415993	.2466231
Slope of the field environment	-.0037333	.0069523	-0.54	0.591	-.0173595	.0098928
Cropping season	-.1562905	.070189	-2.23	**0.026**	-.2938585	-.0187225
Weed management practices	-.11151	.0933221	-1.19	0.232	-.2944179	.0713979
Type of wild plants in margins	.0851852	.070619	1.21	0.228	-.0532254	.2235959
Agroforestery system of the landscape	.0449916	.0708438	0.64	0.525	-.0938596	.1838429
Type of seeds	.1211651	.0429698	2.82	**0.005**	.0369459	.2053842
Field history, previous crop on the field	-.3795121	.041791	-9.08	**0.000**	-.461421	-.2976032
Awareness of threats to yield loss	-.1246953	.0949222	-1.31	0.189	-.3107393	.0613488
% area under bean cultivation	.0654056	.0523817	1.25	0.212	-.0372606	.1680717
Growth stage	.0298264	.0402072	0.74	0.458	-.0489782	.1086311
Extension visits	.0056719	.0096627	0.59	0.557	-.0132666	.0246103
Farming experience	.0250156	.0230298	1.09	0.277	-.0201219	.0701531
Plant population density	.0767727	.0288598	-2.66	**0.008**	-.1333368	-.0202087
Planting date	.0653074	.0317107	2.06	**0.039**	.0031554	.1274593
Cropping system	.049703	.0126153	3.94	**0.000**	.0249774	.0744286
Occurrence of other diseases & pests	-.0223759	.0102147	-2.19	**0.028**	-.0423964	-.0023554
Local market demand of seeds	-.0128531	.0057779	-2.22	**0.026**	-.0241775	-.0015287
Cooking quality of the variety	-.0077075	.0057344	-1.34	0.179	-.0189467	.0035316
Early maturity, high yielding varieties	-.2021012	.0661012	-3.06	**0.002**	-.3316571	-.0725453
Gustative quality of the leaves	.1640415	.0310389	5.29	**0.000**	.1032063	.2248766
_cons	2.985452	.315414	9.47	**0.000**	2.367252	3.603652
Other statistics : Log likelihood = 258.2663802, **AIC (Akaike's information criterion) = -1.658131, BIC (Shwarz's Bayesian information criterion) = -1096.917**						


Bacterial blight Incidence (%)
Monthly rainfall
y = 0.000099x^2 +0.1261x + 19.3
R^2 = 0.479, P<0.0001
Bacterial blight incidence (%)
Monthly rainfall(mm
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
300
350
2019-U-A-W1 … 2019-U-A-W16
2019-U-B-W1 … 2019-U-B-W16
2019-L-C-W1 … 2019-L-C-W16
J J J J F F F F M M M M M A A A A M M M M M J J J J Jt Jt Jt Jt A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2019


Bacterial blight Incidence (%)
Monthly rainfall
y = 0.001193x^2 - 0.3868x +73.41
R^2 = 0.122, P=0.047
Bacterial blight incidence (%)
Monthly rainfall(mm
0
20
40
60
80
100
120
0
50
100
150
200
250
300
2020-U-A-W1 … 2020-U-A-W16
2020-U-B-W1 … 2020-U-B-W16
2020-L-C-W1 … 2020-L-C-W16
J J J J F F F F M M M M M A A A A M M M M M J J J J Jt Jt Jt Jt A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2020


Bacterial blight Incidence (%)
Monthly rainfall
Y = -0.001476x² +0.5666x + 3.212
R² = 0.4118, P<0.0001
Bacterial blight incidence (%)
Monthly rainfall (mm
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
300
2021-U-A-W1 … 2021-U-A-W16
2021-U-B-W1 … 2021-U-B-W16
2021-L-C-W1 … 2021-L-C-W16
J J J J F F F F MMMMMA A A AMMMMM J J J J JtJtJtJt A A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2021


Bacterial blight Incidence (%)
Monthly rainfall (mm)
Y = -0.000513x² + 0.2723x + 26.69
R² = 0.1856, P=0.009
Bacterial blight incidence (%)
Monthly rainfall (mm
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
2022-U-A-W1 … 2022-U-A-W16
2022-U-B-W1 … 2022-U-B-W16
2022-L-C-W1 … 2022-L-C-W16
J J J J F F F F MMMMMA A A AMMMMM J J J J JtJtJtJt A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2022

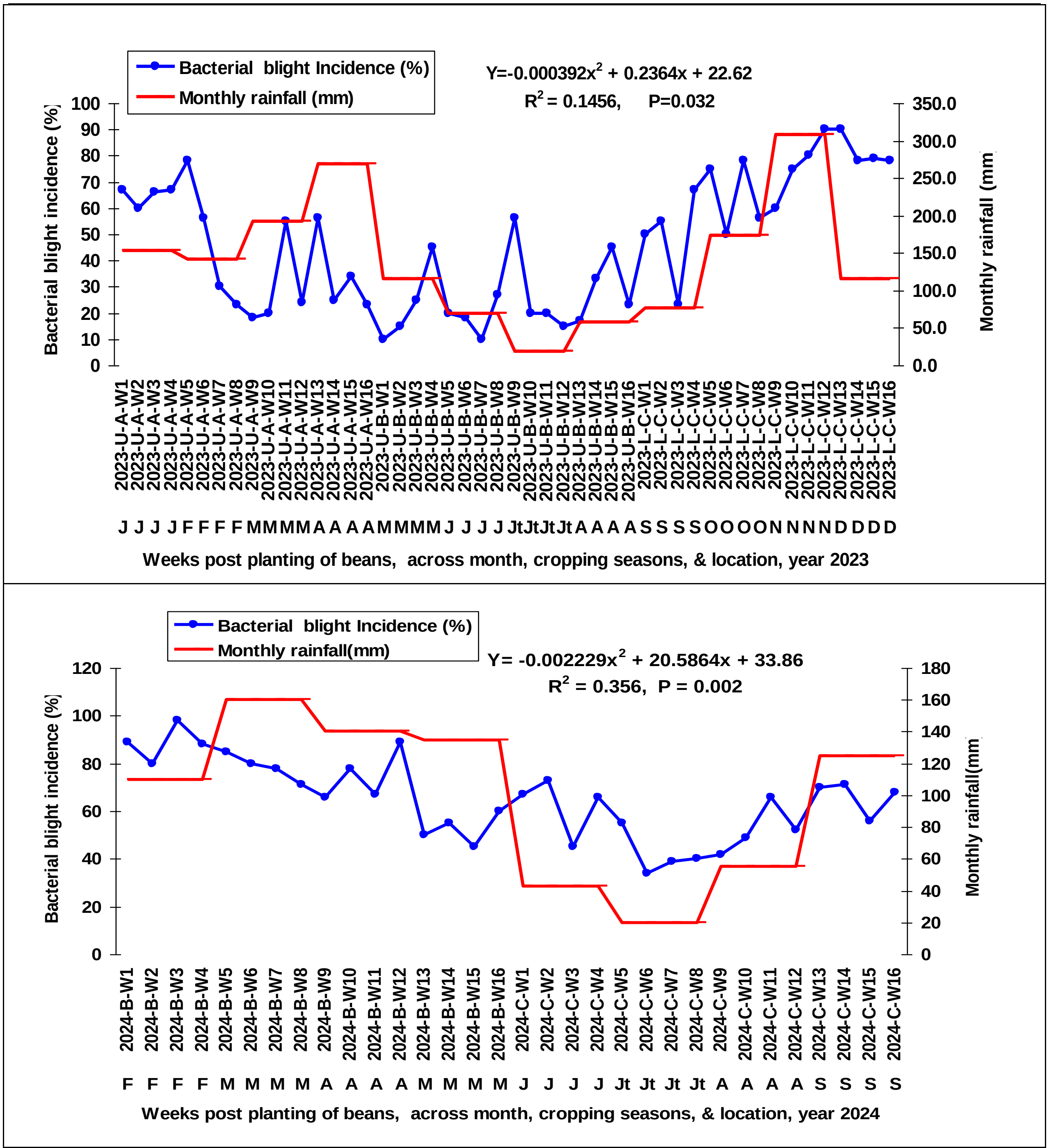


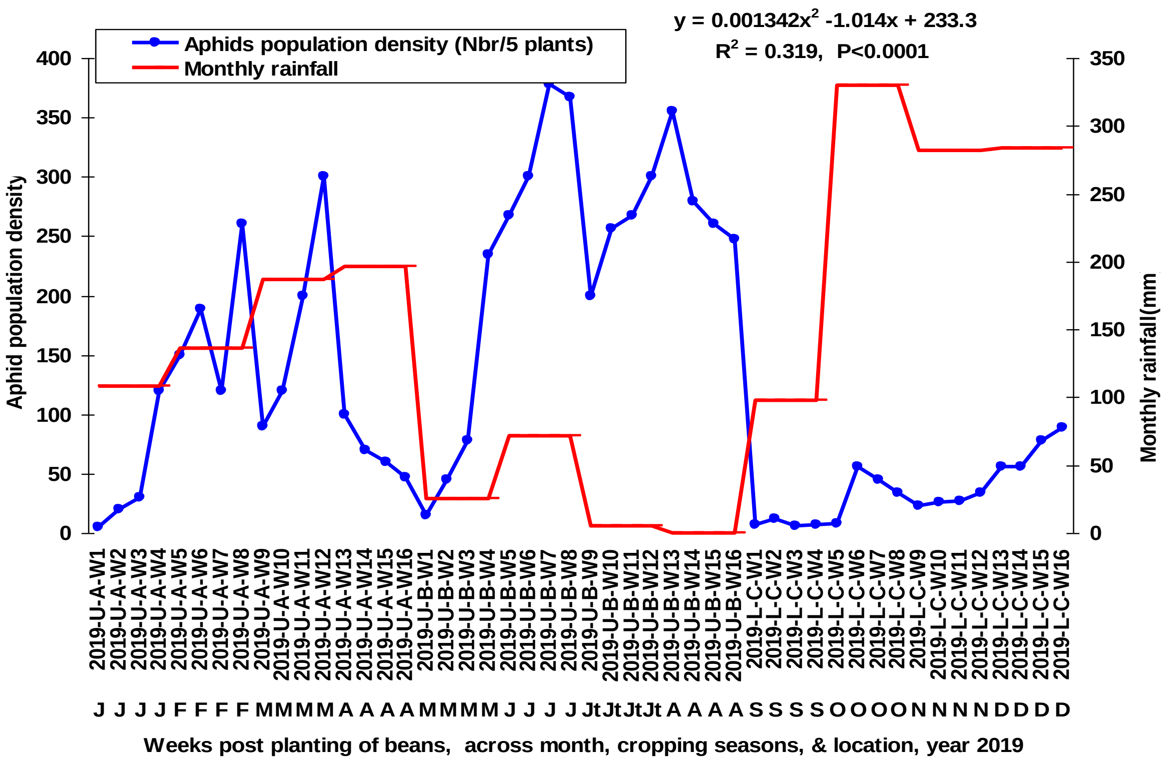
Figure-1a: Trends in the bacterial blight incidence(%) in relationship to rainfall(mm) across years (2019-2024) , cropping seasons and environmental locations of bean fields in rural areas

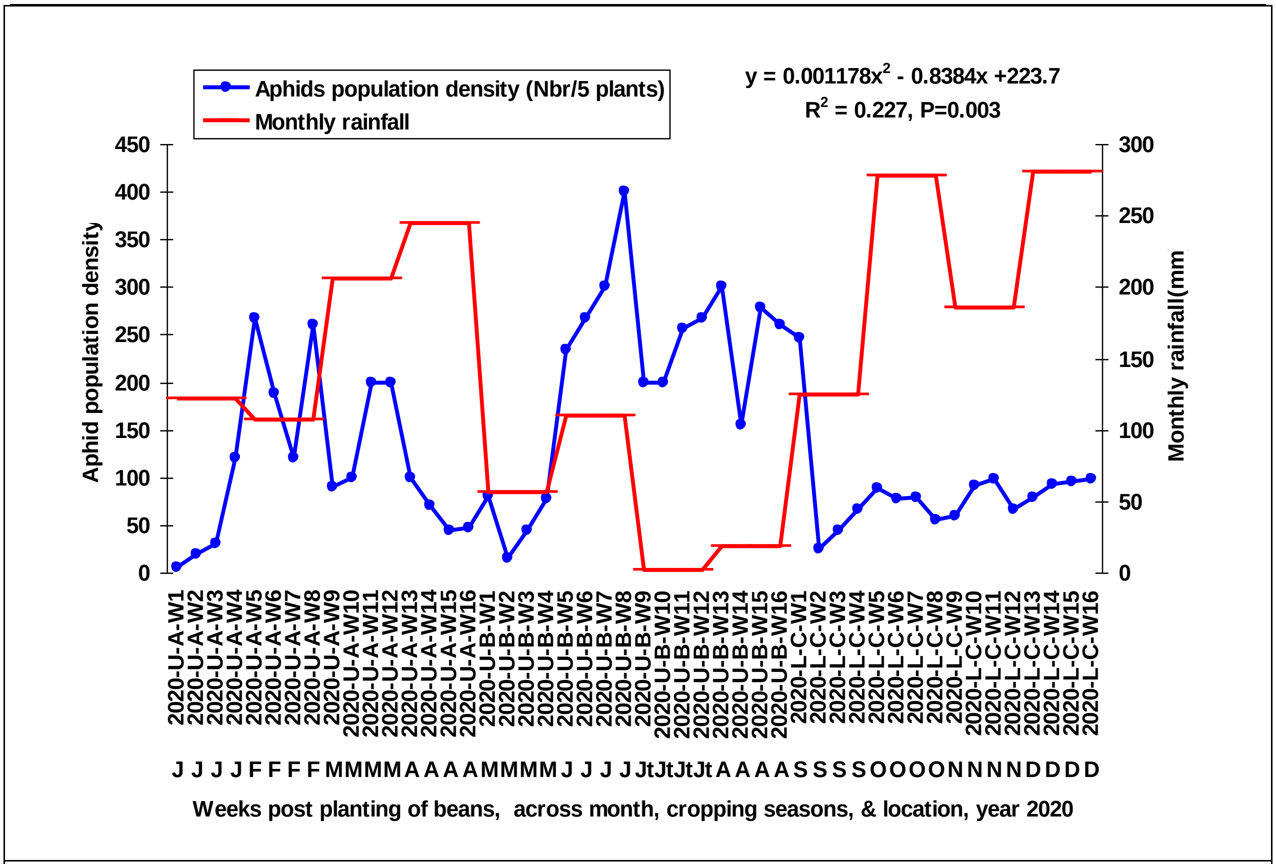
Legends:

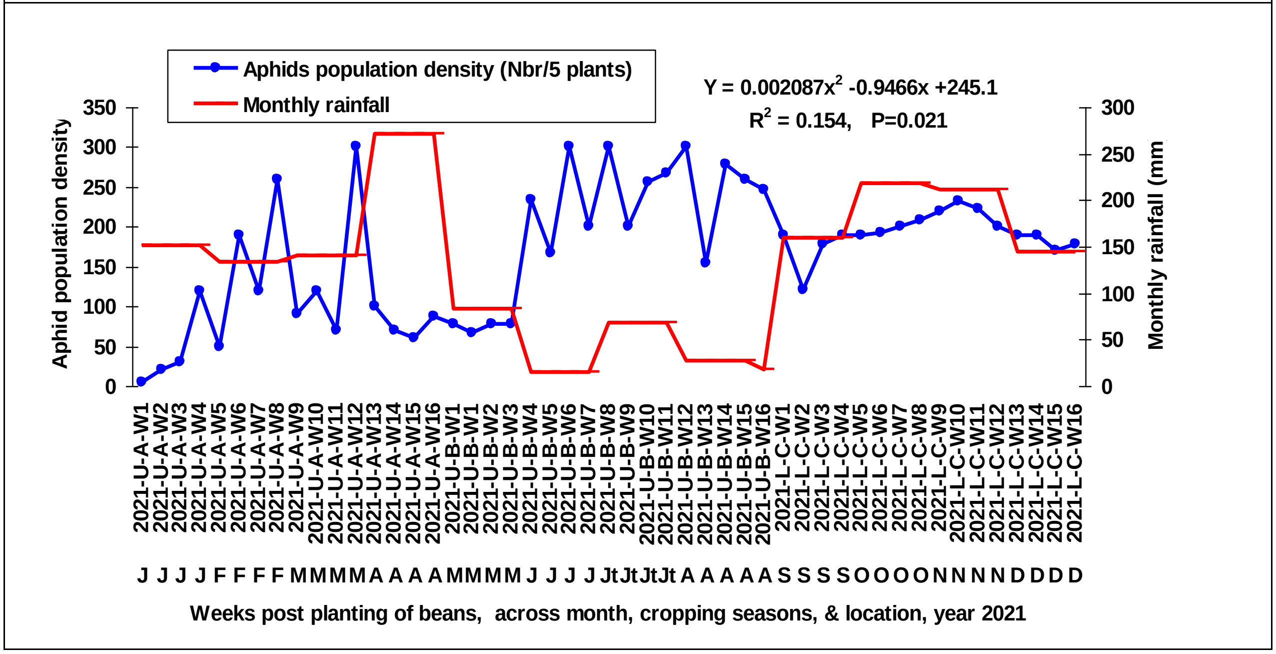
(i): ***Cropping seasons*** : cropping **A**(sept-Dec, early rainy season=long rains), cropping season **B(**Jan-May, late rainy season=short rains), cropping season **C**(June-August, dry season in upland, but wet in marshlands

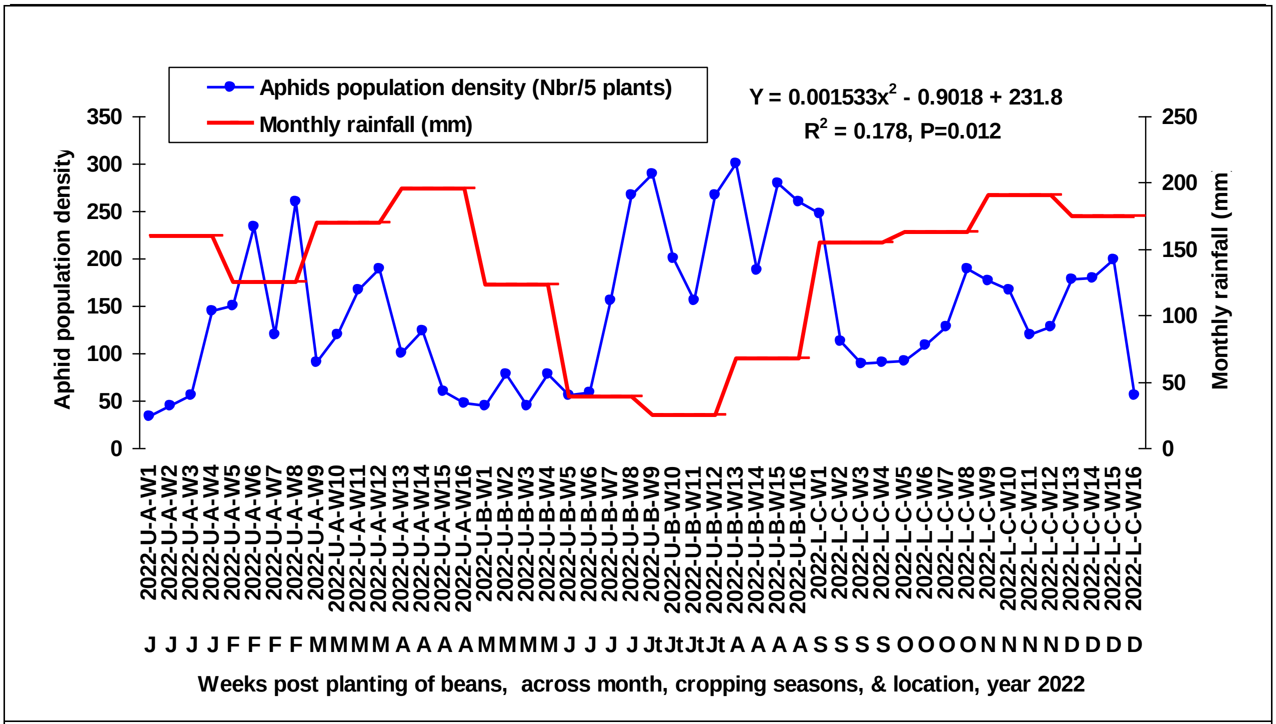
(ii):***Environmental Locations of the bean field***: **U**=Uplands or sloppy lands (1500-2400m altitude), **L**=Lowland, valley or Marshland (1350-1500m), **W**: weeks post planting of beans (Varieties: Landraces grown in mixture) (iv): ***For the quadratic regression equation***, **Y**=Average bacterial blight incidence (%), **X**=Mean monthly rainfall (mm)

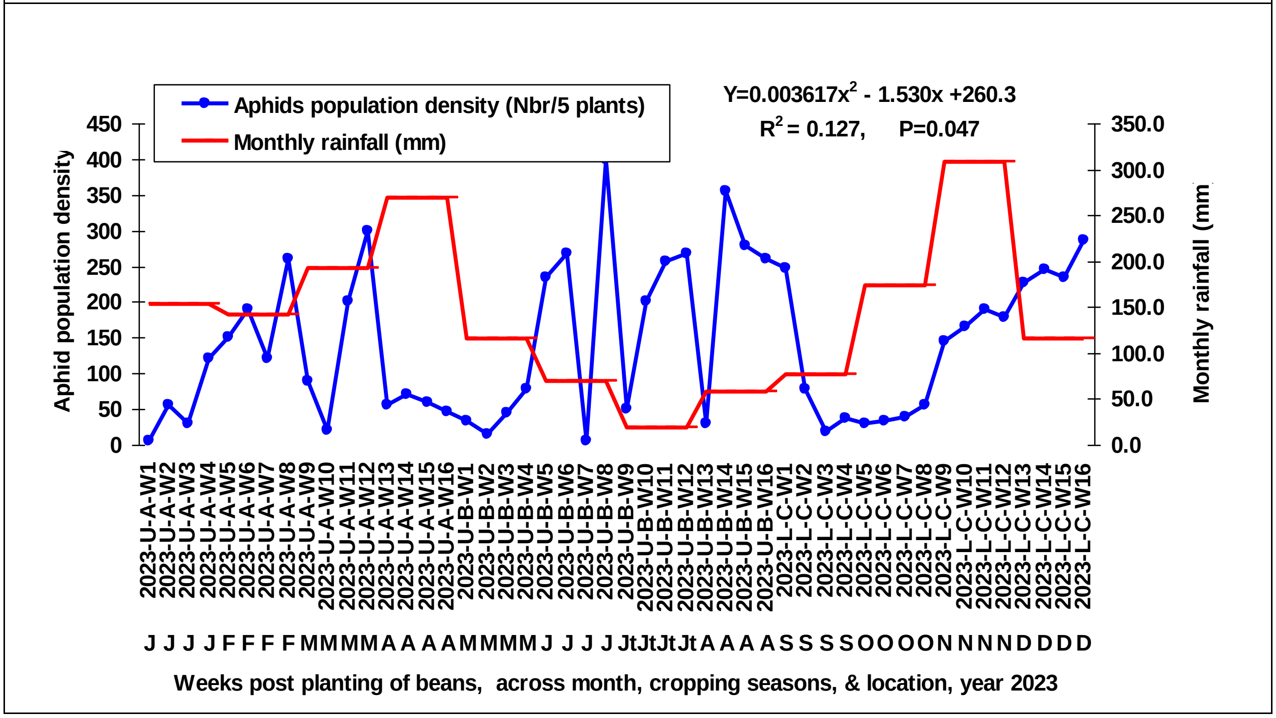
(v): ***Months of the year during weekly data collection*** : **J**-January, **F**=February, **M**=March, **A**=April, **M**=May, J=June, Jt=July, A-August, **S**=September, **O**=October, **N**=November, **D**=December




Aphids population density (Nbr/5 plants)
Monthly rainfall
$y = 0.001178x^2 - 0.8384x + 223.7$
$R^2 = 0.227$, P=0.003
Aphid population density
Monthly rainfall(mm
0
50
100
150
200
250
300
350
400
450
0
50
100
150
200
250
300
2020-U-A-W1
2020-U-A-W2
2020-U-A-W3
2020-U-A-W4
2020-U-A-W5
2020-U-A-W6
2020-U-A-W7
2020-U-A-W8
2020-U-A-W9
2020-U-A-W10
2020-U-A-W11
2020-U-A-W12
2020-U-A-W13
2020-U-A-W14
2020-U-A-W15
2020-U-A-W16
2020-U-B-W1
2020-U-B-W2
2020-U-B-W3
2020-U-B-W4
2020-U-B-W5
2020-U-B-W6
2020-U-B-W7
2020-U-B-W8
2020-U-B-W9
2020-U-B-W10
2020-U-B-W11
2020-U-B-W12
2020-U-B-W13
2020-U-B-W14
2020-U-B-W15
2020-U-B-W16
2020-L-C-W1
2020-L-C-W2
2020-L-C-W3
2020-L-C-W4
2020-L-C-W5
2020-L-C-W6
2020-L-C-W7
2020-L-C-W8
2020-L-C-W9
2020-L-C-W10
2020-L-C-W11
2020-L-C-W12
2020-L-C-W13
2020-L-C-W14
2020-L-C-W15
2020-L-C-W16
J J J J F F F F MMMMMA A A AMMMMM J J J JtJtJtJt A A A A S S S S OOOONNNNDDDD
Weeks post planting of beans, across month, cropping seasons, & location, year 2020


Aphids population density (Nbr/5 plants)
Monthly rainfall
$Y = 0.002087x^2 - 0.9466x + 245.1$
$R^2 = 0.154$, P=0.021
Aphid population density
Monthly rainfall (mm
0
50
100
150
200
250
300
350
0
50
100
150
200
250
300
2021-U-A-W1
2021-U-A-W2
2021-U-A-W3
2021-U-A-W4
2021-U-A-W5
2021-U-A-W6
2021-U-A-W7
2021-U-A-W8
2021-U-A-W9
2021-U-A-W10
2021-U-A-W11
2021-U-A-W12
2021-U-A-W13
2021-U-A-W14
2021-U-A-W15
2021-U-A-W16
2021-U-B-W1
2021-U-B-W2
2021-U-B-W3
2021-U-B-W4
2021-U-B-W5
2021-U-B-W6
2021-U-B-W7
2021-U-B-W8
2021-U-B-W9
2021-U-B-W10
2021-U-B-W11
2021-U-B-W12
2021-U-B-W13
2021-U-B-W14
2021-U-B-W15
2021-U-B-W16
2021-L-C-W1
2021-L-C-W2
2021-L-C-W3
2021-L-C-W4
2021-L-C-W5
2021-L-C-W6
2021-L-C-W7
2021-L-C-W8
2021-L-C-W9
2021-L-C-W10
2021-L-C-W11
2021-L-C-W12
2021-L-C-W13
2021-L-C-W14
2021-L-C-W15
2021-L-C-W16
J J J J F F F F MMMMA A A AMMMM J J J JtJtJtJt A A A A A S S S SOOOONNNNDDDD
Weeks post planting of beans, across month, cropping seasons, & location, year 2021


Aphids population density (Nbr/5 plants)
Monthly rainfall (mm)
Y = 0.001533x^2 - 0.9018 + 231.8
R^2 = 0.178, P=0.012
Aphid population density
0 50 100 150 200 250 300 350
Monthly rainfall (mm)
0 50 100 150 200 250
2022-U-A-W1 … 2022-U-A-W16, 2022-U-B-W1 … 2022-U-B-W16, 2022-L-C-W1 … 2022-L-C-W16
J J J J F F F F M M M M A A A A M M M M J J J J Jt Jt Jt Jt A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2022


Aphids population density (Nbr/5 plants)
Monthly rainfall (mm)
Y=0.003617x^2 - 1.530x +260.3
R^2 = 0.127, P=0.047
Aphid population density
0 50 100 150 200 250 300 350 400 450
Monthly rainfall (mm
0.0 50.0 100.0 150.0 200.0 250.0 300.0 350.0
2023-U-A-W1 … 2023-U-A-W16, 2023-U-B-W1 … 2023-U-B-W16, 2023-L-C-W1 … 2023-L-C-W16
J J J J F F F F M M M M A A A A M M M M J J J J Jt Jt Jt Jt A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2023

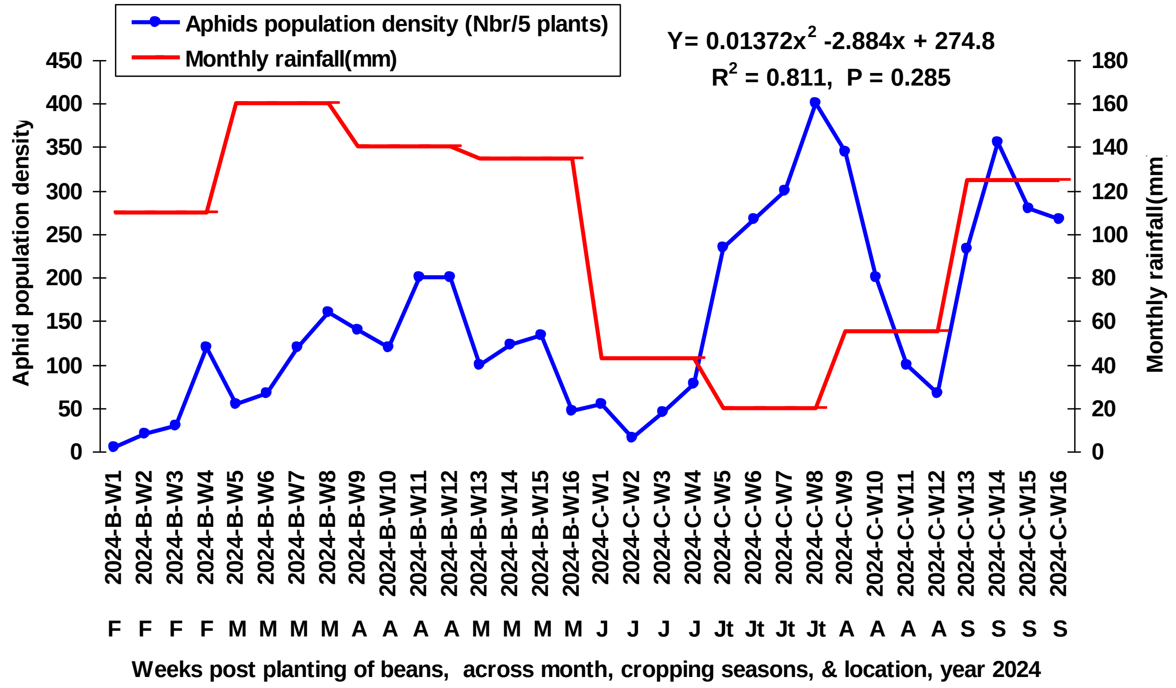


Figure-1b: Trends in the population density of aphids (*Aphis craccivora* L.) in relationship to rainfall(mm) across years(2019-2024) , cropping seasons and environmental locations of bean fields in rural areas

Legends:

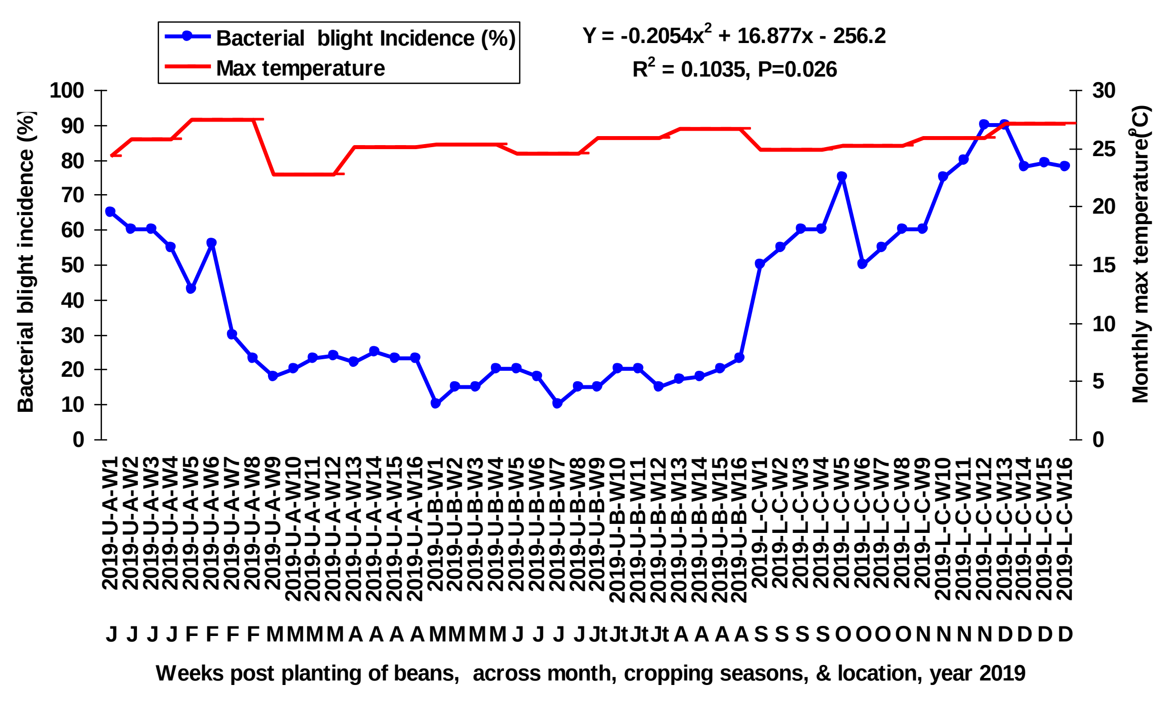
(i): ***Cropping seasons*** : cropping **A**(sept-Dec, early rainy season=long rains), cropping season **B(**Jan-May, late rainy season=short rains), cropping season **C**(June-August, dry season in upland, but wet in marshlands

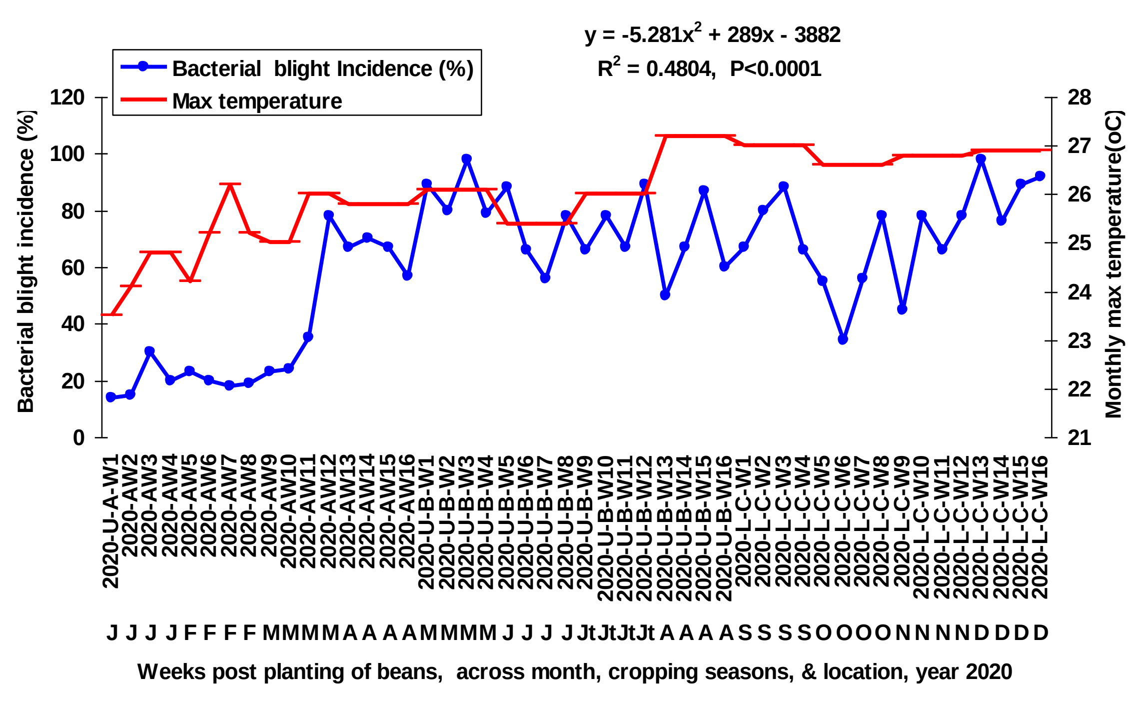
(ii):***Environmental Locations of the bean field***: **U**=Uplands or sloppy lands (1500-2400m altitude), **L**=Lowland, valley or Marshland (1350-1500m), **W**: weeks post planting of beans (Varieties: Landraces grown in mixture)

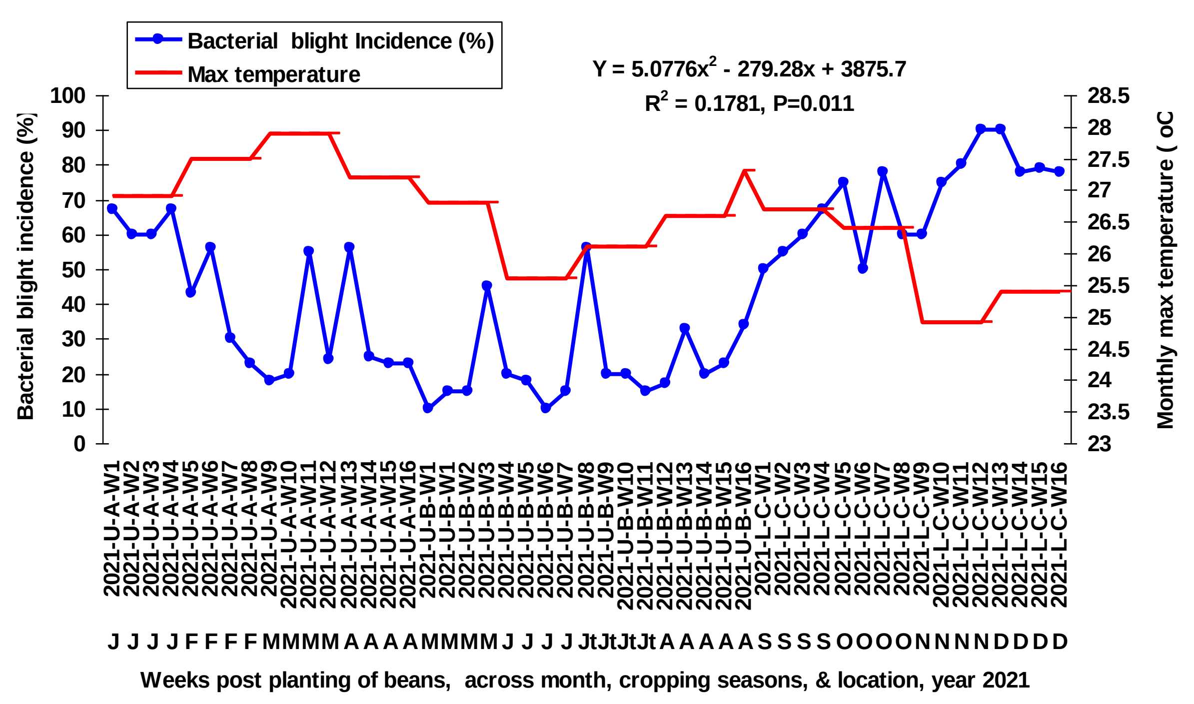
(iv): ***For the quadratic regression equation***, **Y**=Average population density of aphids , **X**=Mean monthly rainfall (mm)

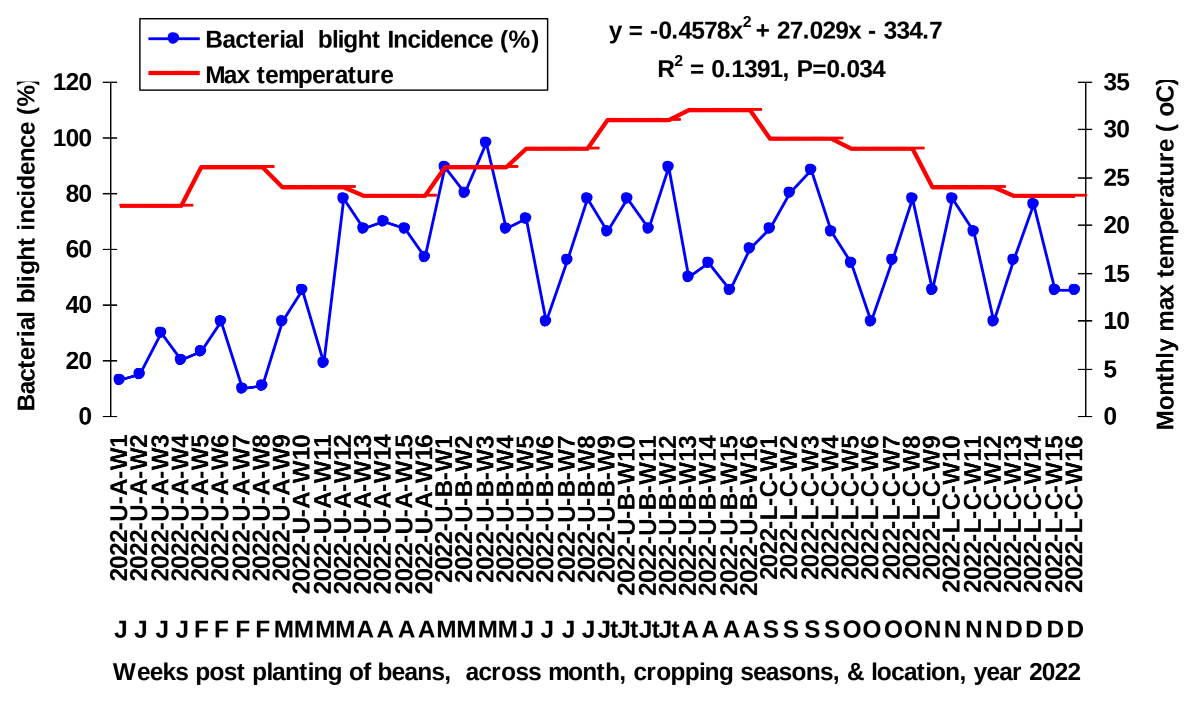
(v): ***Months of the year during weekly data collection*** : **J**-January, **F**=February, **M**=March, **A**=April, **M**=May, J=June, Jt=July, A-August, **S**=September, **O**=October, **N**=November, **D**=December

H


Bacterial blight Incidence (%)
Max temperature
Y = -0.2054x2 + 16.877x - 256.2
R2 = 0.1035, P=0.026
Bacterial blight incidence (%)
100
90
80
70
60
50
40
30
20
10
0
Monthly max temperature(0C)
30
25
20
15
10
5
0
2019-U-A-W1
2019-U-A-W2
2019-U-A-W3
2019-U-A-W4
2019-U-A-W5
2019-U-A-W6
2019-U-A-W7
2019-U-A-W8
2019-U-A-W9
2019-U-A-W10
2019-U-A-W11
2019-U-A-W12
2019-U-A-W13
2019-U-A-W14
2019-U-A-W15
2019-U-A-W16
2019-U-B-W1
2019-U-B-W2
2019-U-B-W3
2019-U-B-W4
2019-U-B-W5
2019-U-B-W6
2019-U-B-W7
2019-U-B-W8
2019-U-B-W9
2019-U-B-W10
2019-U-B-W11
2019-U-B-W12
2019-U-B-W13
2019-U-B-W14
2019-U-B-W15
2019-U-B-W16
2019-L-C-W1
2019-L-C-W2
2019-L-C-W3
2019-L-C-W4
2019-L-C-W5
2019-L-C-W6
2019-L-C-W7
2019-L-C-W8
2019-L-C-W9
2019-L-C-W10
2019-L-C-W11
2019-L-C-W12
2019-L-C-W13
2019-L-C-W14
2019-L-C-W15
2019-L-C-W16
J J J J F F F F MMMMMA A A A MMMMMJ J J J JtJtJtJt A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2019


y = -5.281x2 + 289x - 3882
R2 = 0.4804, P<0.0001
Bacterial blight Incidence (%)
Max temperature
Bacterial blight incidence (%)
120
100
80
60
40
20
0
Monthly max temperature(oC)
28
27
26
25
24
23
22
21
2020-U-A-W1
2020-AW2
2020-AW3
2020-AW4
2020-AW5
2020-AW6
2020-AW7
2020-AW8
2020-AW9
2020-AW10
2020-AW11
2020-AW12
2020-AW13
2020-AW14
2020-AW15
2020-AW16
2020-U-B-W1
2020-U-B-W2
2020-U-B-W3
2020-U-B-W4
2020-U-B-W5
2020-U-B-W6
2020-U-B-W7
2020-U-B-W8
2020-U-B-W9
2020-U-B-W10
2020-U-B-W11
2020-U-B-W12
2020-U-B-W13
2020-U-B-W14
2020-U-B-W15
2020-U-B-W16
2020-L-C-W1
2020-L-C-W2
2020-L-C-W3
2020-L-C-W4
2020-L-C-W5
2020-L-C-W6
2020-L-C-W7
2020-L-C-W8
2020-L-C-W9
2020-L-C-W10
2020-L-C-W11
2020-L-C-W12
2020-L-C-W13
2020-L-C-W14
2020-L-C-W15
2020-L-C-W16
J J J J F F F F MMMMMA A A A MMMMMJ J J J JtJtJtJt A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2020


Bacterial blight Incidence (%)
Max temperature
Y = 5.0776x² - 279.28x + 3875.7
R² = 0.1781, P=0.011
Bacterial blight incidence (%)
0
10
20
30
40
50
60
70
80
90
100
Monthly max temperature (oC
23
23.5
24
24.5
25
25.5
26
26.5
27
27.5
28
28.5
2021-U-A-W1
2021-U-A-W2
2021-U-A-W3
2021-U-A-W4
2021-U-A-W5
2021-U-A-W6
2021-U-A-W7
2021-U-A-W8
2021-U-A-W9
2021-U-A-W10
2021-U-A-W11
2021-U-A-W12
2021-U-A-W13
2021-U-A-W14
2021-U-A-W15
2021-U-A-W16
2021-U-B-W1
2021-U-B-W2
2021-U-B-W3
2021-U-B-W4
2021-U-B-W5
2021-U-B-W6
2021-U-B-W7
2021-U-B-W8
2021-U-B-W9
2021-U-B-W10
2021-U-B-W11
2021-U-B-W12
2021-U-B-W13
2021-U-B-W14
2021-U-B-W15
2021-U-B-W16
2021-L-C-W1
2021-L-C-W2
2021-L-C-W3
2021-L-C-W4
2021-L-C-W5
2021-L-C-W6
2021-L-C-W7
2021-L-C-W8
2021-L-C-W9
2021-L-C-W10
2021-L-C-W11
2021-L-C-W12
2021-L-C-W13
2021-L-C-W14
2021-L-C-W15
2021-L-C-W16
J J J J F F F F MMMMM A A A AMMMMM J J J J JtJtJtJt A A A A A S S S S OOOONNNNDDDD
Weeks post planting of beans, across month, cropping seasons, & location, year 2021


Bacterial blight Incidence (%)
Max temperature
y = -0.4578x² + 27.029x - 334.7
R² = 0.1391, P=0.034
Bacterial blight incidence (%)
0
20
40
60
80
100
120
Monthly max temperature (oC)
0
5
10
15
20
25
30
35
2022-U-A-W1
2022-U-A-W2
2022-U-A-W3
2022-U-A-W4
2022-U-A-W5
2022-U-A-W6
2022-U-A-W7
2022-U-A-W8
2022-U-A-W9
2022-U-A-W10
2022-U-A-W11
2022-U-A-W12
2022-U-A-W13
2022-U-A-W14
2022-U-A-W15
2022-U-A-W16
2022-U-B-W1
2022-U-B-W2
2022-U-B-W3
2022-U-B-W4
2022-U-B-W5
2022-U-B-W6
2022-U-B-W7
2022-U-B-W8
2022-U-B-W9
2022-U-B-W10
2022-U-B-W11
2022-U-B-W12
2022-U-B-W13
2022-U-B-W14
2022-U-B-W15
2022-U-B-W16
2022-L-C-W1
2022-L-C-W2
2022-L-C-W3
2022-L-C-W4
2022-L-C-W5
2022-L-C-W6
2022-L-C-W7
2022-L-C-W8
2022-L-C-W9
2022-L-C-W10
2022-L-C-W11
2022-L-C-W12
2022-L-C-W13
2022-L-C-W14
2022-L-C-W15
2022-L-C-W16
J J J J F F F F MMMMAA A AMMMMM J J J JtJtJtJtA A A A S S S SOOOONNNNDDDD
Weeks post planting of beans, across month, cropping seasons, & location, year 2022

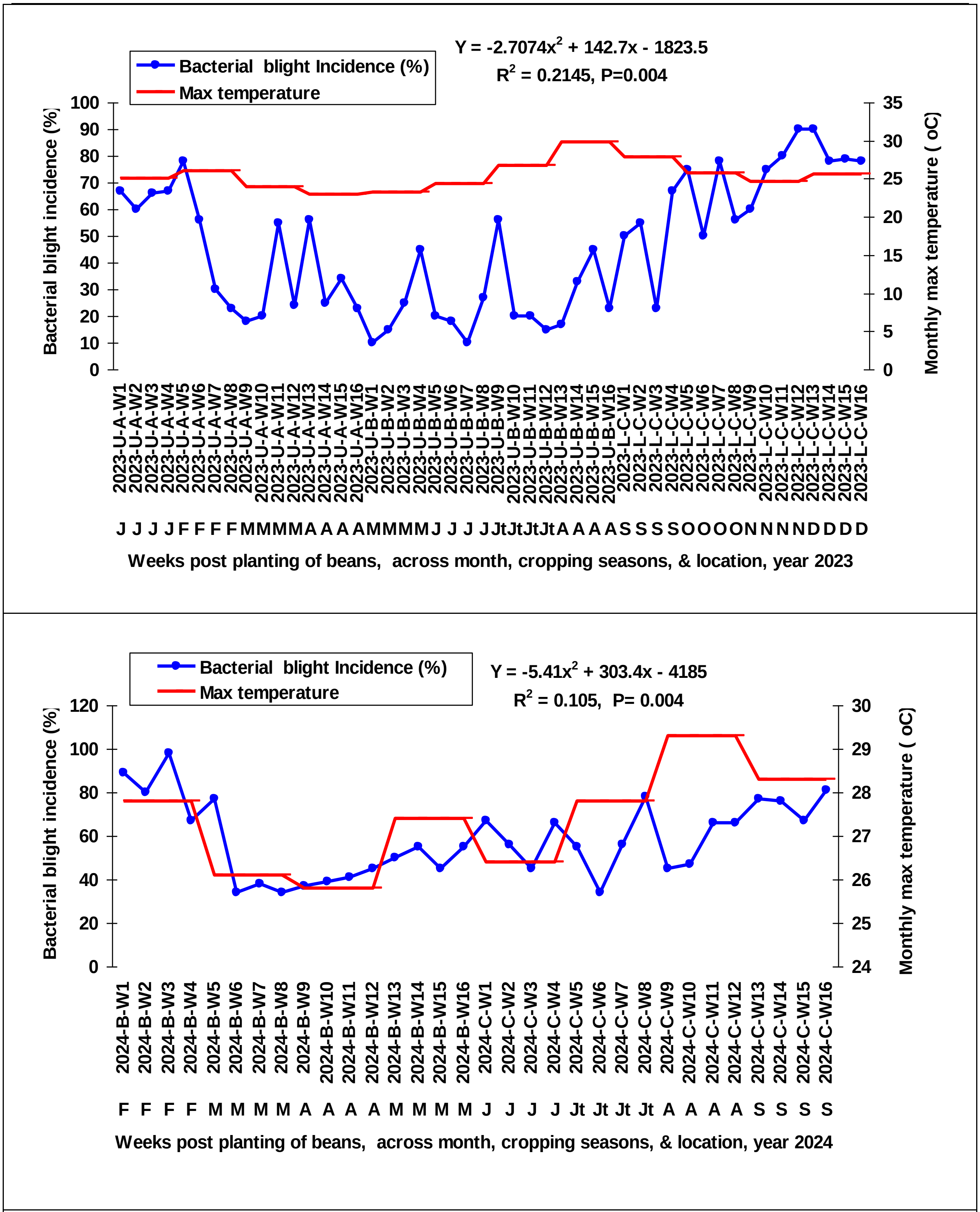


Figure-2a: Trends in the bacterial blight incidence(%) in relationship to Mean Maximum temperature(^{0}C) across years (2019-2024) , cropping seasons and

environmental locations of bean fields in rural areas

Legends:

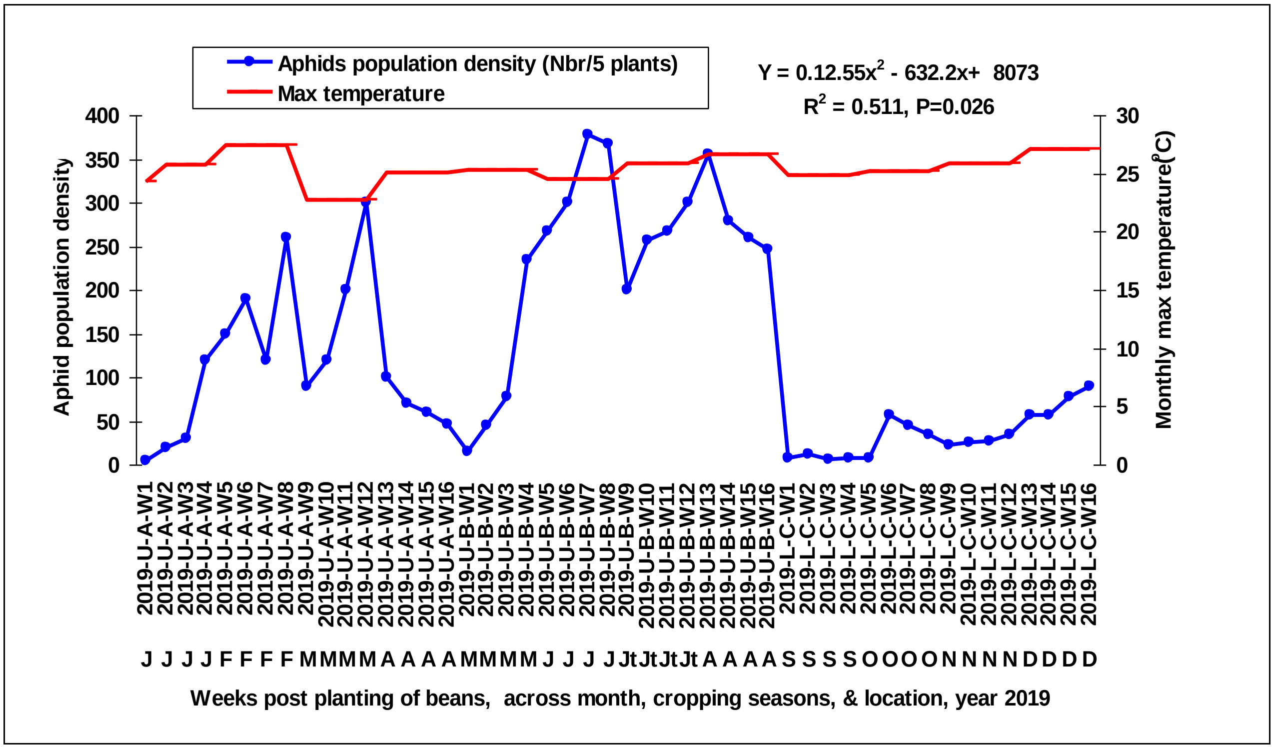
(i): ***Cropping seasons*** : cropping **A**(sept-Dec, long rains), cropping season **B(**Jan-May, short rains), cropping season **C**(June-August, dry season in upland, but wet in marshlands)

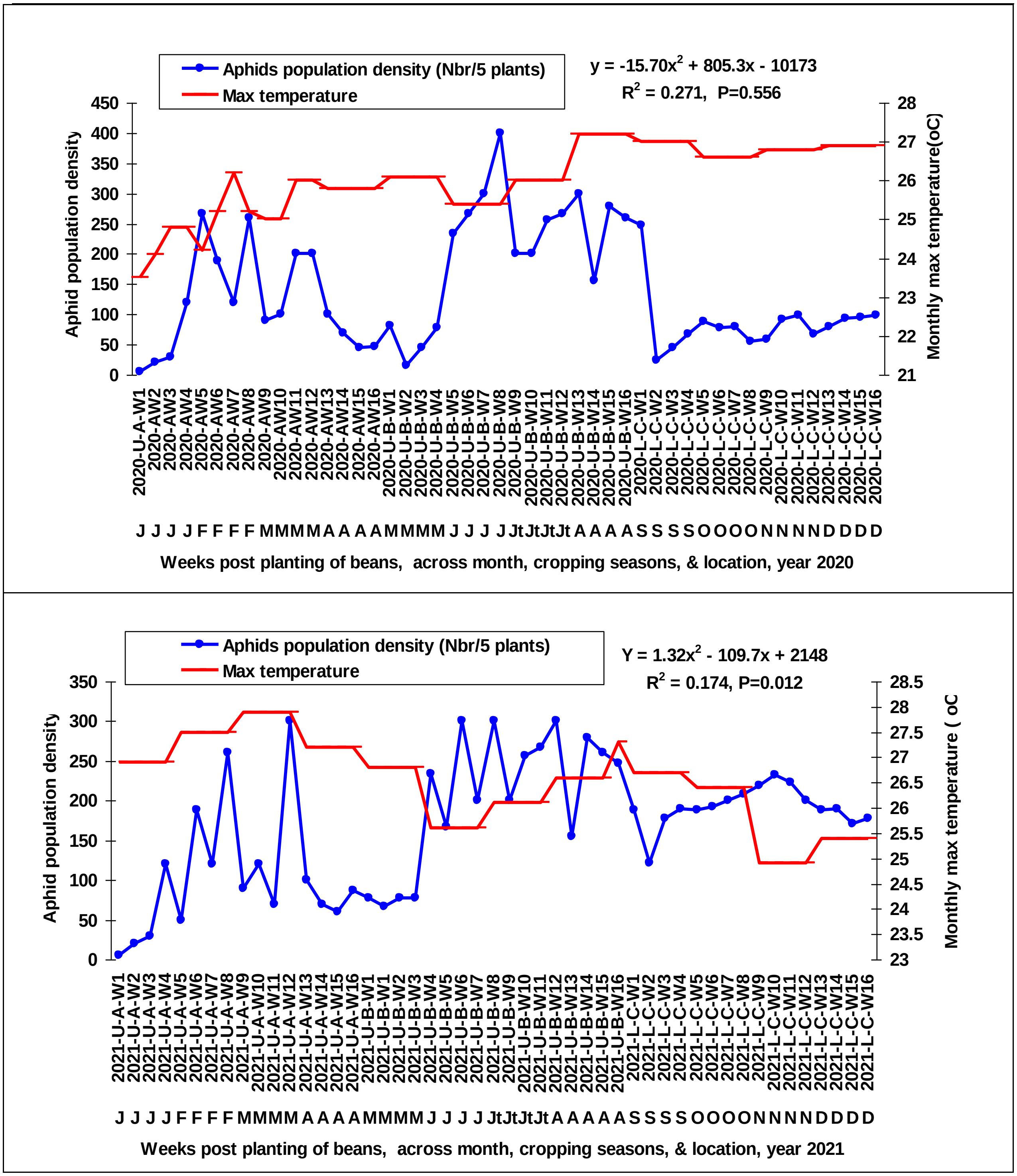
(ii): ***Environmental Locations of the bean field***: **U**=Highland/Uplands to midland or sloppy lands (1500-2400m altitude), **L**=Lowland/wetland, valley or Marshland (1350-1500m), **W**: weeks post planting of beans (varieties: Landraces grown in mixture).

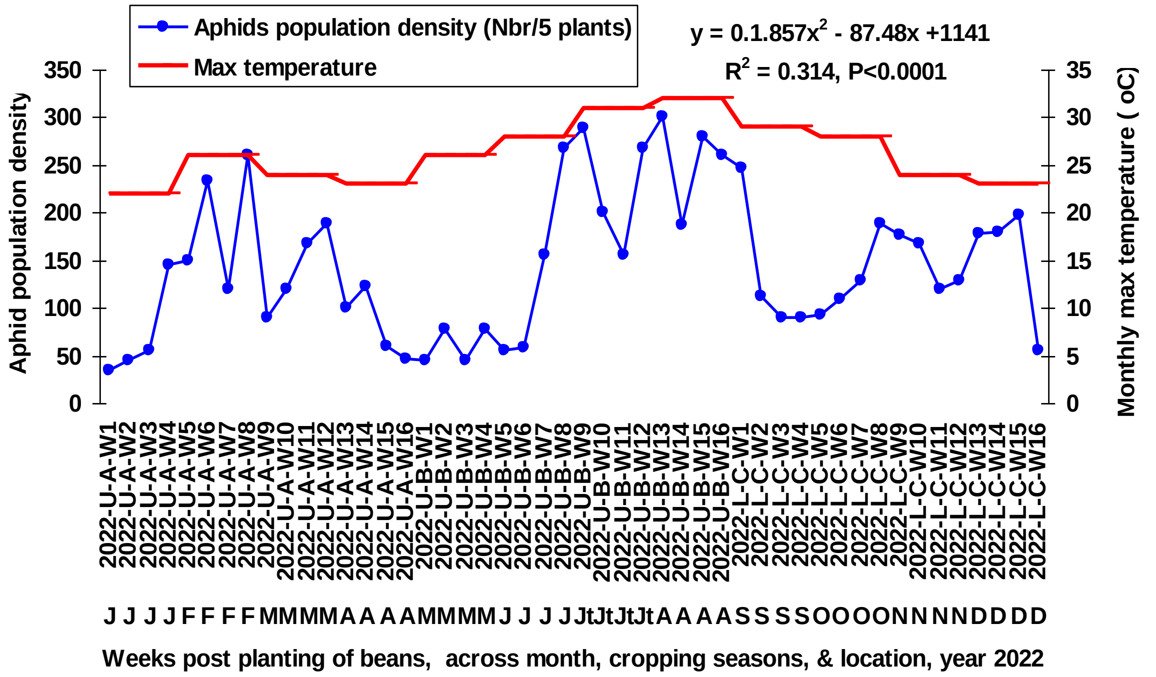
(iv): ***For the quadratic regression equation***, **Y**=Average bacterial blight incidence (%), **X**=Mean monthly Maximum temperature

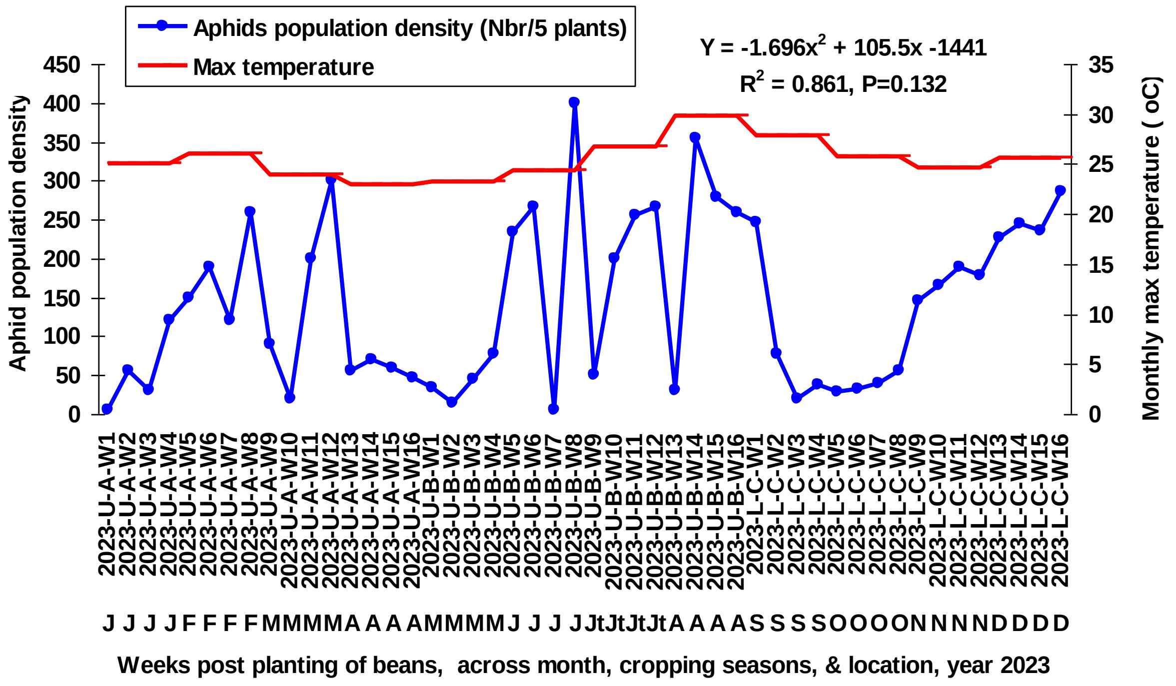
(v): ***Months of the year during weekly data collection*** across foliage, flowering, podding : **J**-January, **F**=February, **M**=March, **A**=April, **M**=May, J=June, Jt=July, A-August, **S**=September, **O**=October, **N**=November, **D**=December

H




Aphids population density (Nbr/5 plants)
Max temperature
y = -15.70x^2 + 805.3x - 10173
R^2 = 0.271, P=0.556
Aphid population density
0
50
100
150
200
250
300
350
400
450
Monthly max temperature(oC)
21
22
23
24
25
26
27
28
2020-U-A-W1 … 2020-AW16, 2020-U-B-W1 … 2020-U-B-W16, 2020-L-C-W1 … 2020-L-C-W16
J J J J F F F F MMMMM A A A A MMMMM J J J J Jt Jt Jt Jt A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2020
Aphids population density (Nbr/5 plants)
Max temperature
Y = 1.32x^2 - 109.7x + 2148
R^2 = 0.174, P=0.012
Aphid population density
0
50
100
150
200
250
300
350
Monthly max temperature (oC
23
23.5
24
24.5
25
25.5
26
26.5
27
27.5
28
28.5
2021-U-A-W1 … 2021-U-A-W16, 2021-U-B-W1 … 2021-U-B-W16, 2021-L-C-W1 … 2021-L-C-W16
J J J J F F F F MMMMM A A A A MMMMM J J J J Jt Jt Jt Jt A A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2021


Aphids population density (Nbr/5 plants)
Max temperature
y = 0.1.857x^2 - 87.48x +1141
R^2 = 0.314, P<0.0001
Aphid population density
0
50
100
150
200
250
300
350
Monthly max temperature (oC)
0
5
10
15
20
25
30
35
2022-U-A-W1 … 2022-U-A-W16
2022-U-B-W1 … 2022-U-B-W16
2022-L-C-W1 … 2022-L-C-W16
J J J J F F F F MMMMMA A A AMMMMMJ J J JJtJtJtJtA A A ASSSSOOOONNNNNDDDDD
Weeks post planting of beans, across month, cropping seasons, & location, year 2022


Aphids population density (Nbr/5 plants)
Max temperature
Y = -1.696x^2 + 105.5x -1441
R^2 = 0.861, P=0.132
Aphid population density
0
50
100
150
200
250
300
350
400
450
Monthly max temperature (oC)
0
5
10
15
20
25
30
35
2023-U-A-W1 … 2023-U-A-W16
2023-U-B-W1 … 2023-U-B-W16
2023-L-C-W1 … 2023-L-C-W16
J J J J F F F F MMMMMA A A AMMMMMJ J J JJtJtJtJtA A A ASSSSOOOONNNNNDDDDD
Weeks post planting of beans, across month, cropping seasons, & location, year 2023

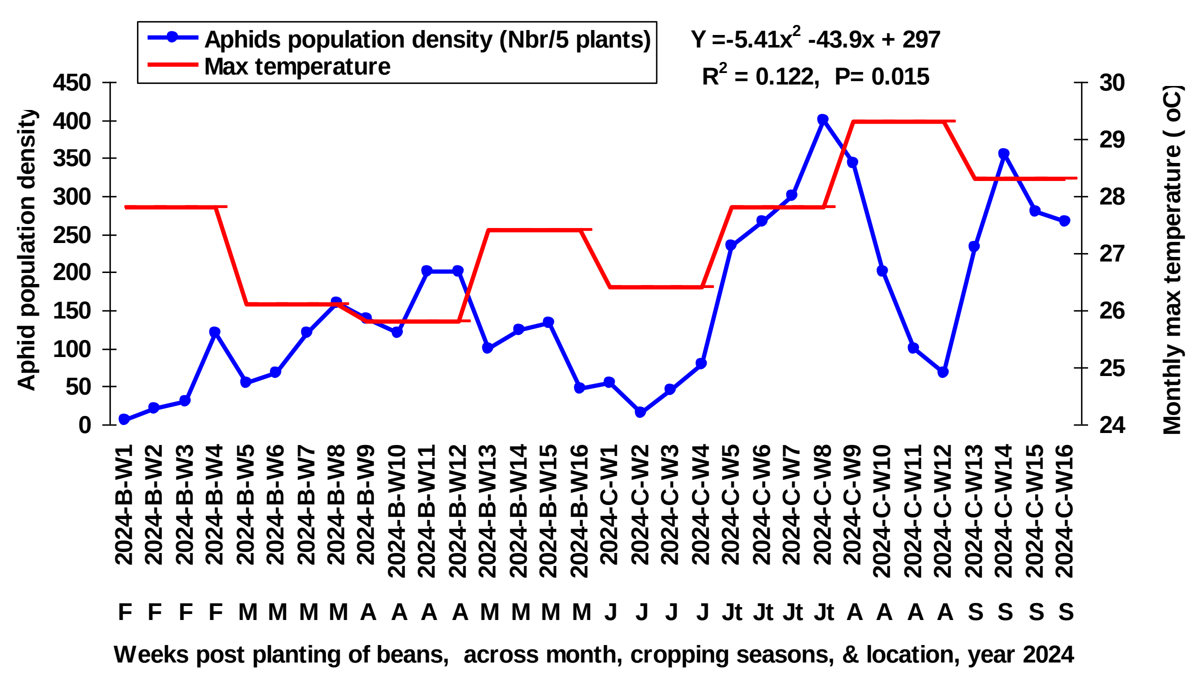


Figure-2b: Trends in the population density of aphids (*Aphis craccivora* L.) in relationship to Mean Maximum temperature (^{0}C)) across years(2019-2024) , cropping seasons and environmental locations of bean fields in rural areas

Legends:

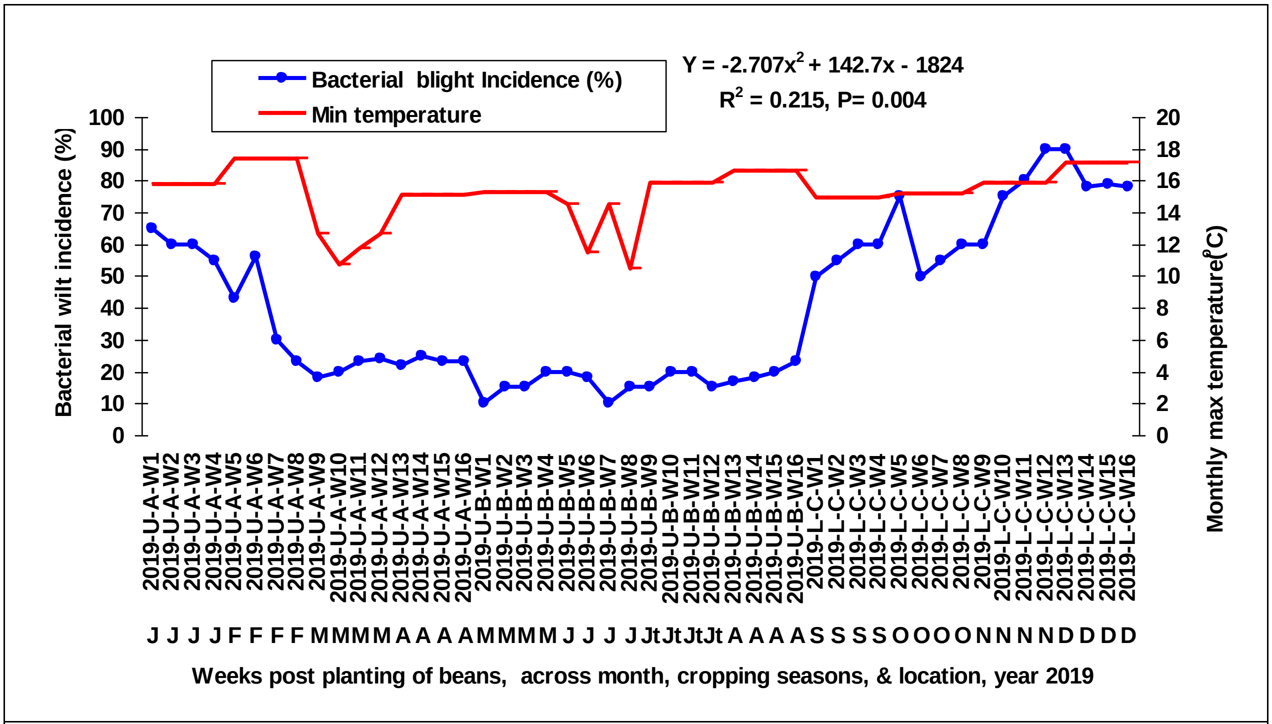
(i): ***Cropping seasons*** : cropping **A**(sept-Dec, long rains), cropping season **B(**Jan-May, short rains), cropping season **C**(June-August, dry season in upland, but wet in marshlands)

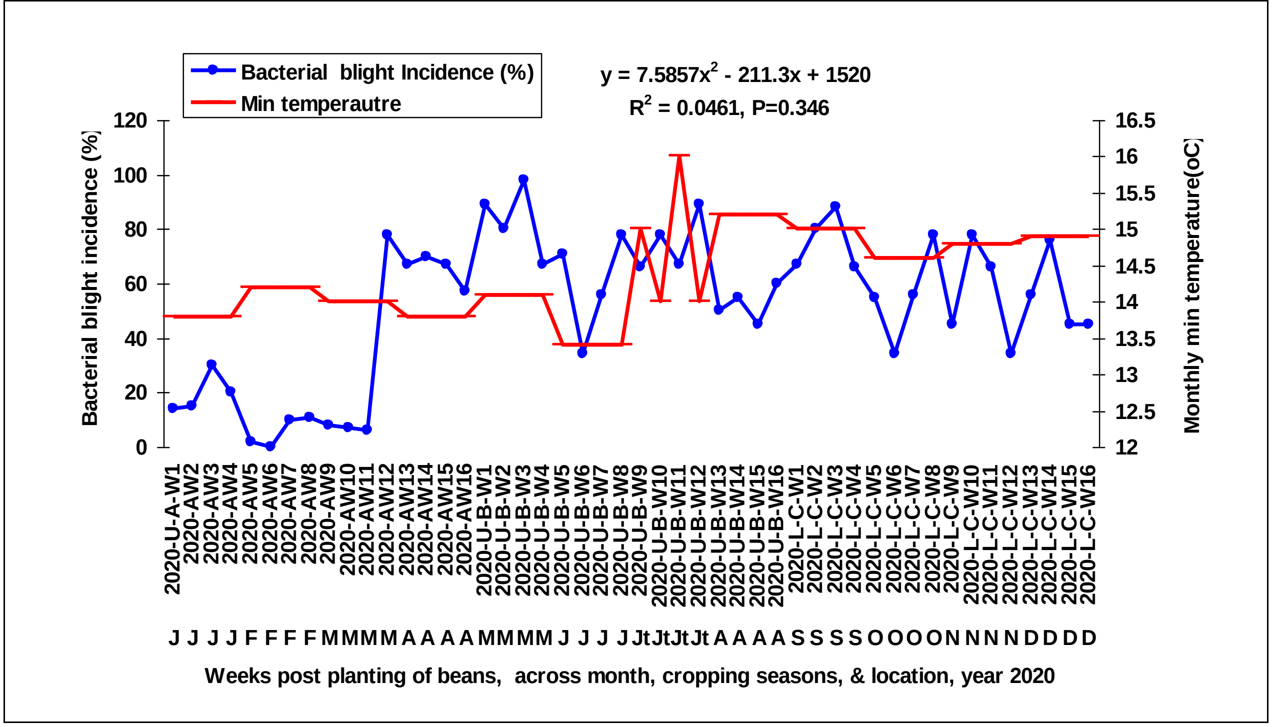
(ii): ***Environmental Locations of the bean field***: **U**=Uplands or sloppy lands (1500-2400m altitude), **L**=Lowland, valley or Marshland (1350-1500m), **W**: weeks post planting of beans (varieties: Landraces grown in mixture)

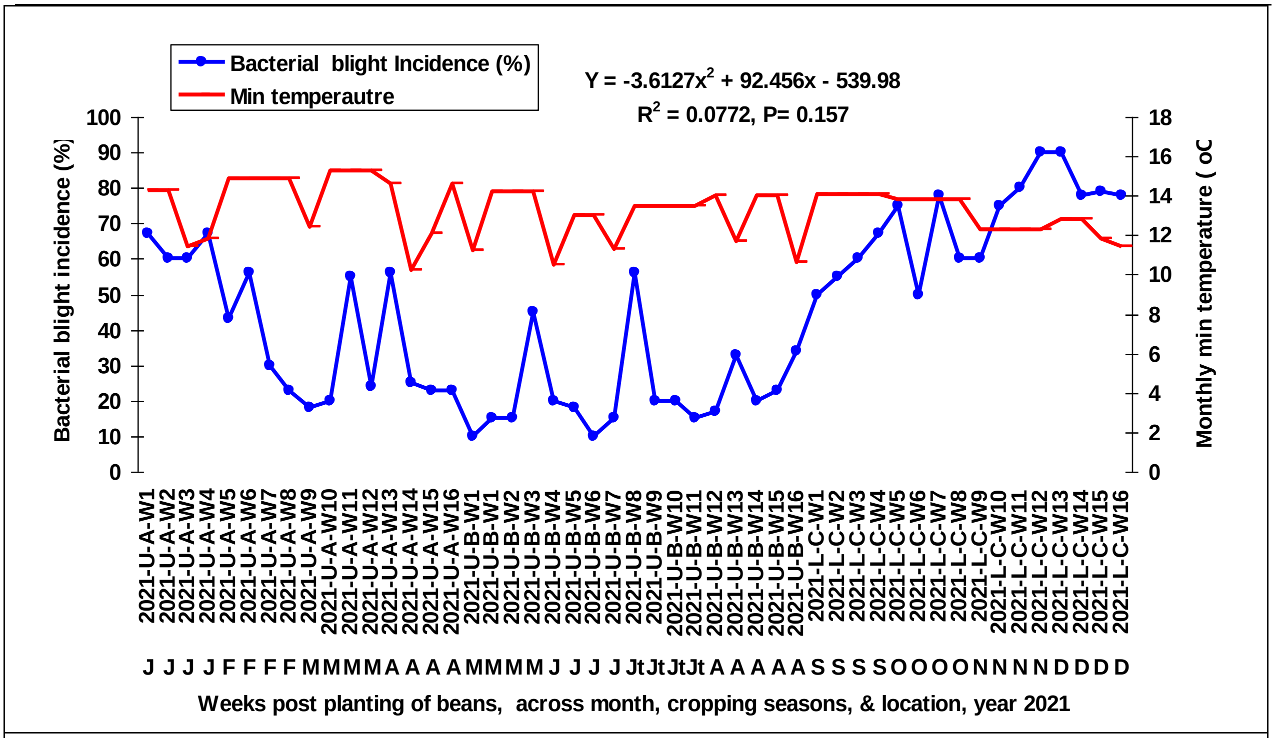
(iv): ***For the quadratic regression equation***, **Y**=Average population density of aphids, **X**=Mean monthly Maximum temperature

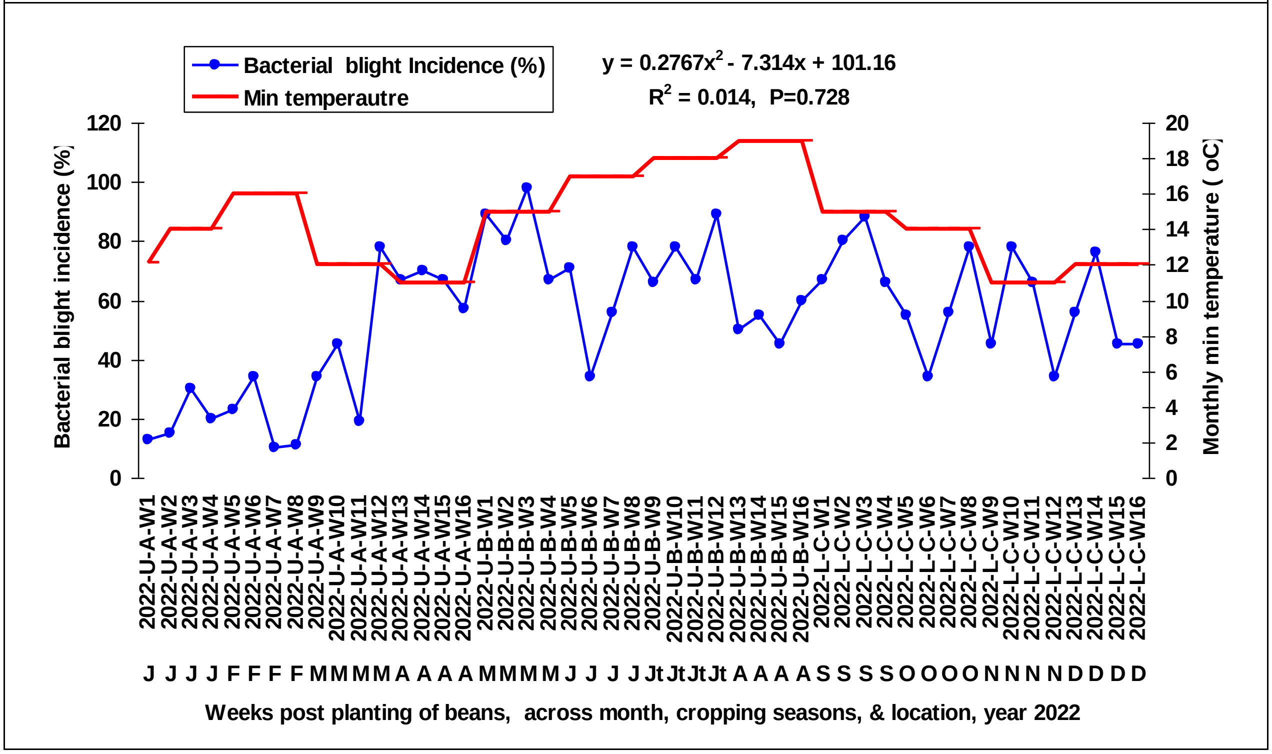
(v): ***Months of the year during weekly data collection*** : **J**-January, **F**=February, **M**=March, **A**=April, **M**=May, J=June, Jt=July, A-August, **S**=September, **O**=October, **N**=November, **D**=December

H


Bacterial blight Incidence (%)
Min temperature
Y = -2.707x^2 + 142.7x - 1824
R^2 = 0.215, P= 0.004
Bacterial wilt incidence (%)
100
90
80
70
60
50
40
30
20
10
0
Monthly max temperature(^{0}C)
20
18
16
14
12
10
8
6
4
2
0
2019-U-A-W1
2019-U-A-W2
2019-U-A-W3
2019-U-A-W4
2019-U-A-W5
2019-U-A-W6
2019-U-A-W7
2019-U-A-W8
2019-U-A-W9
2019-U-A-W10
2019-U-A-W11
2019-U-A-W12
2019-U-A-W13
2019-U-A-W14
2019-U-A-W15
2019-U-A-W16
2019-U-B-W1
2019-U-B-W2
2019-U-B-W3
2019-U-B-W4
2019-U-B-W5
2019-U-B-W6
2019-U-B-W7
2019-U-B-W8
2019-U-B-W9
2019-U-B-W10
2019-U-B-W11
2019-U-B-W12
2019-U-B-W13
2019-U-B-W14
2019-U-B-W15
2019-U-B-W16
2019-L-C-W1
2019-L-C-W2
2019-L-C-W3
2019-L-C-W4
2019-L-C-W5
2019-L-C-W6
2019-L-C-W7
2019-L-C-W8
2019-L-C-W9
2019-L-C-W10
2019-L-C-W11
2019-L-C-W12
2019-L-C-W13
2019-L-C-W14
2019-L-C-W15
2019-L-C-W16
J J J J F F F F M M M M M A A A A M M M M M J J J J Jt Jt Jt Jt A A A A A S S S S O O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2019


Bacterial blight Incidence (%)
Min temperautre
y = 7.5857x^2 - 211.3x + 1520
R^2 = 0.0461, P=0.346
Bacterial blight incidence (%)
120
100
80
60
40
20
0
Monthly min temperature(oC)
16.5
16
15.5
15
14.5
14
13.5
13
12.5
12
2020-U-A-W1
2020-AW2
2020-AW3
2020-AW4
2020-AW5
2020-AW6
2020-AW7
2020-AW8
2020-AW9
2020-AW10
2020-AW11
2020-AW12
2020-AW13
2020-AW14
2020-AW15
2020-AW16
2020-U-B-W1
2020-U-B-W2
2020-U-B-W3
2020-U-B-W4
2020-U-B-W5
2020-U-B-W6
2020-U-B-W7
2020-U-B-W8
2020-U-B-W9
2020-U-B-W10
2020-U-B-W11
2020-U-B-W12
2020-U-B-W13
2020-U-B-W14
2020-U-B-W15
2020-U-B-W16
2020-L-C-W1
2020-L-C-W2
2020-L-C-W3
2020-L-C-W4
2020-L-C-W5
2020-L-C-W6
2020-L-C-W7
2020-L-C-W8
2020-L-C-W9
2020-L-C-W10
2020-L-C-W11
2020-L-C-W12
2020-L-C-W13
2020-L-C-W14
2020-L-C-W15
2020-L-C-W16
J J J J F F F F M M M M M A A A A M M M M M J J J J Jt Jt Jt Jt A A A A A S S S S O O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2020


Bacterial blight Incidence (%)
Min temperautre
Y = -3.6127x2 + 92.456x - 539.98
R2 = 0.0772, P= 0.157
Bacterial blight incidence (%)
0 10 20 30 40 50 60 70 80 90 100
Monthly min temperature (oC
0 2 4 6 8 10 12 14 16 18
2021-U-A-W1 2021-U-A-W2 2021-U-A-W3 2021-U-A-W4 2021-U-A-W5 2021-U-A-W6 2021-U-A-W7 2021-U-A-W8 2021-U-A-W9 2021-U-A-W10 2021-U-A-W11 2021-U-A-W12 2021-U-A-W13 2021-U-A-W14 2021-U-A-W15 2021-U-A-W16
2021-U-B-W1 2021-U-B-W2 2021-U-B-W3 2021-U-B-W4 2021-U-B-W5 2021-U-B-W6 2021-U-B-W7 2021-U-B-W8 2021-U-B-W9 2021-U-B-W10 2021-U-B-W11 2021-U-B-W12 2021-U-B-W13 2021-U-B-W14 2021-U-B-W15 2021-U-B-W16
2021-L-C-W1 2021-L-C-W2 2021-L-C-W3 2021-L-C-W4 2021-L-C-W5 2021-L-C-W6 2021-L-C-W7 2021-L-C-W8 2021-L-C-W9 2021-L-C-W10 2021-L-C-W11 2021-L-C-W12 2021-L-C-W13 2021-L-C-W14 2021-L-C-W15 2021-L-C-W16
J J J J F F F F M M M M M A A A A M M M M M J J J Jt Jt Jt Jt A A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2021


Bacterial blight Incidence (%)
Min temperautre
y = 0.2767x2 - 7.314x + 101.16
R2 = 0.014, P=0.728
Bacterial blight incidence (%)
0 20 40 60 80 100 120
Monthly min temperature (oC)
0 2 4 6 8 10 12 14 16 18 20
2022-U-A-W1 2022-U-A-W2 2022-U-A-W3 2022-U-A-W4 2022-U-A-W5 2022-U-A-W6 2022-U-A-W7 2022-U-A-W8 2022-U-A-W9 2022-U-A-W10 2022-U-A-W11 2022-U-A-W12 2022-U-A-W13 2022-U-A-W14 2022-U-A-W15 2022-U-A-W16
2022-U-B-W1 2022-U-B-W2 2022-U-B-W3 2022-U-B-W4 2022-U-B-W5 2022-U-B-W6 2022-U-B-W7 2022-U-B-W8 2022-U-B-W9 2022-U-B-W10 2022-U-B-W11 2022-U-B-W12 2022-U-B-W13 2022-U-B-W14 2022-U-B-W15 2022-U-B-W16
2022-L-C-W1 2022-L-C-W2 2022-L-C-W3 2022-L-C-W4 2022-L-C-W5 2022-L-C-W6 2022-L-C-W7 2022-L-C-W8 2022-L-C-W9 2022-L-C-W10 2022-L-C-W11 2022-L-C-W12 2022-L-C-W13 2022-L-C-W14 2022-L-C-W15 2022-L-C-W16
J J J J F F F F M M M M M A A A A M M M M M J J J Jt Jt Jt Jt A A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2022

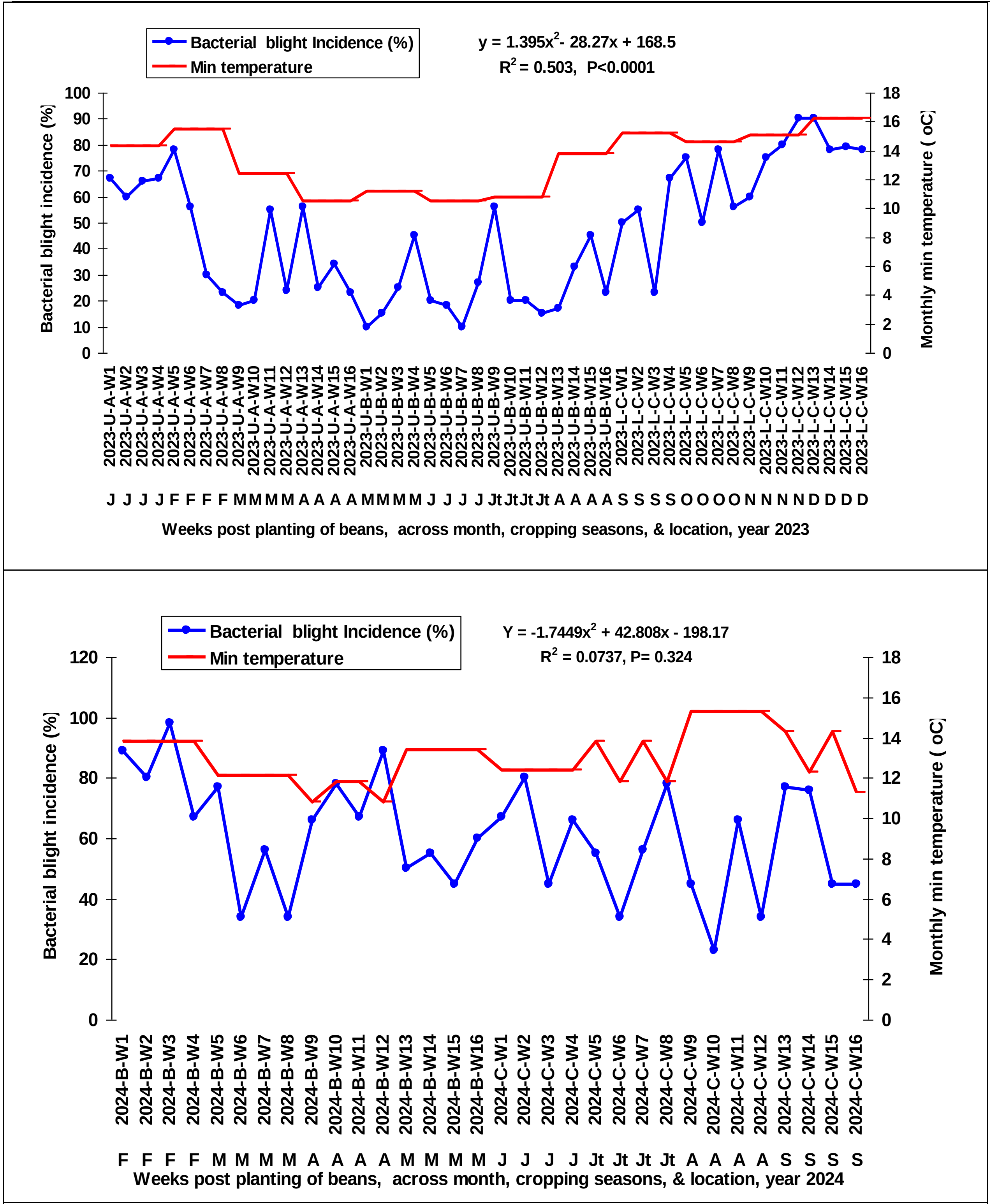
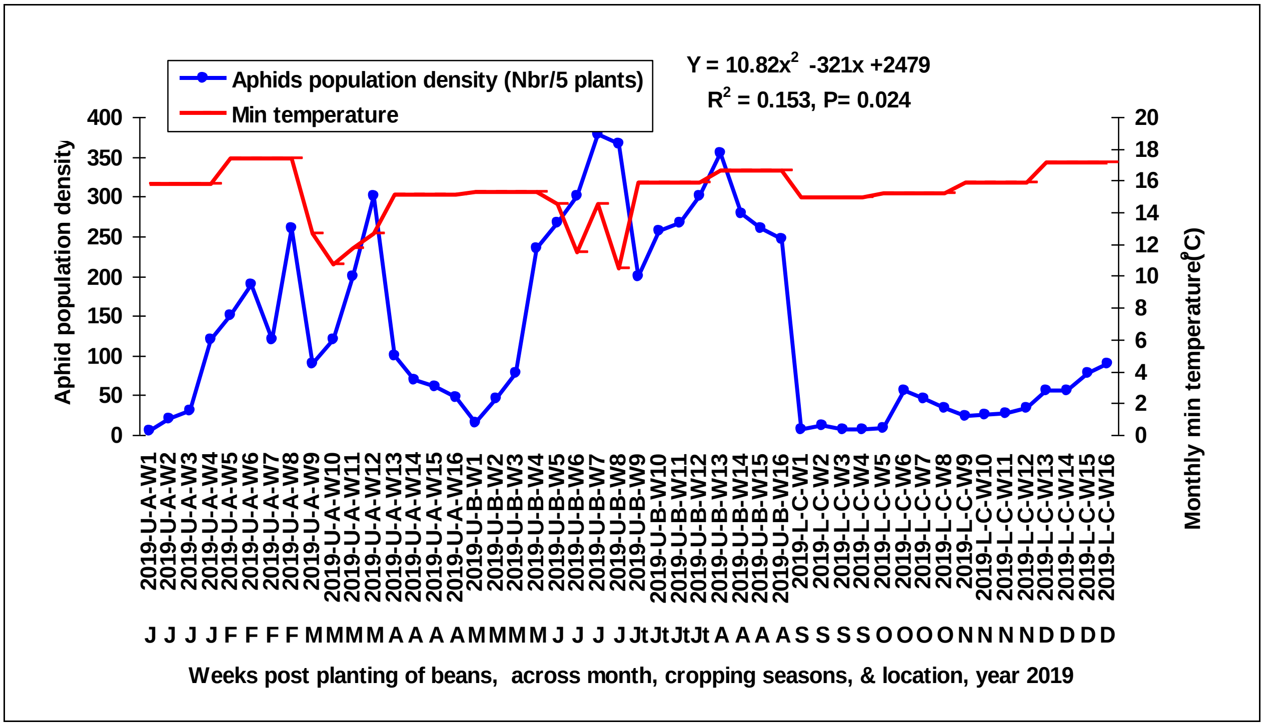
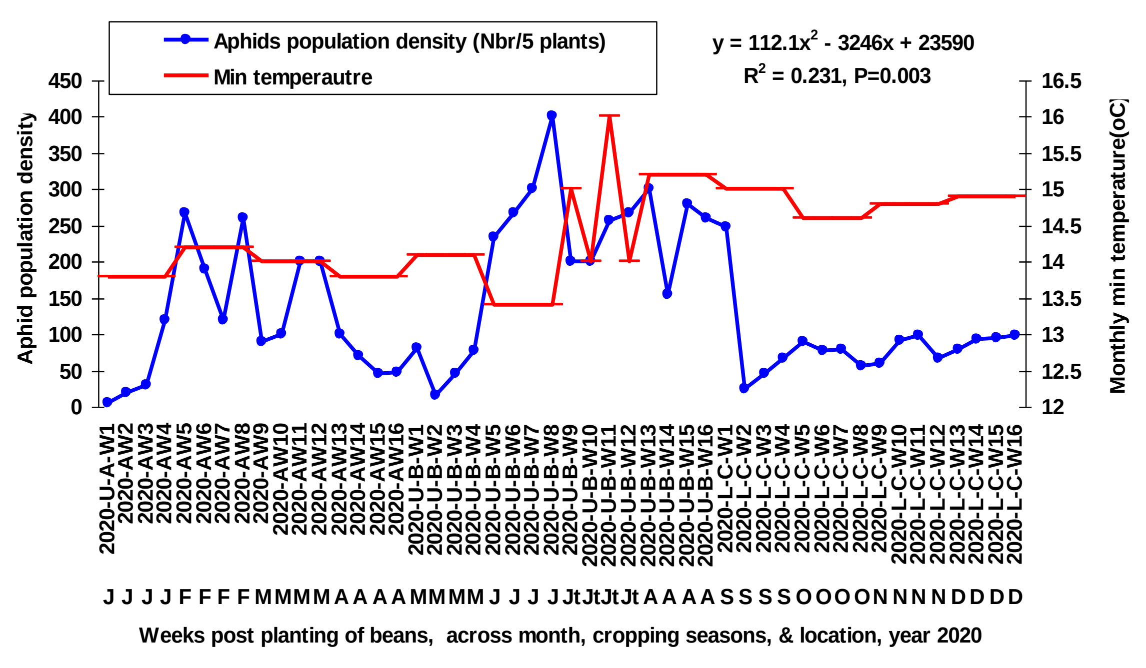


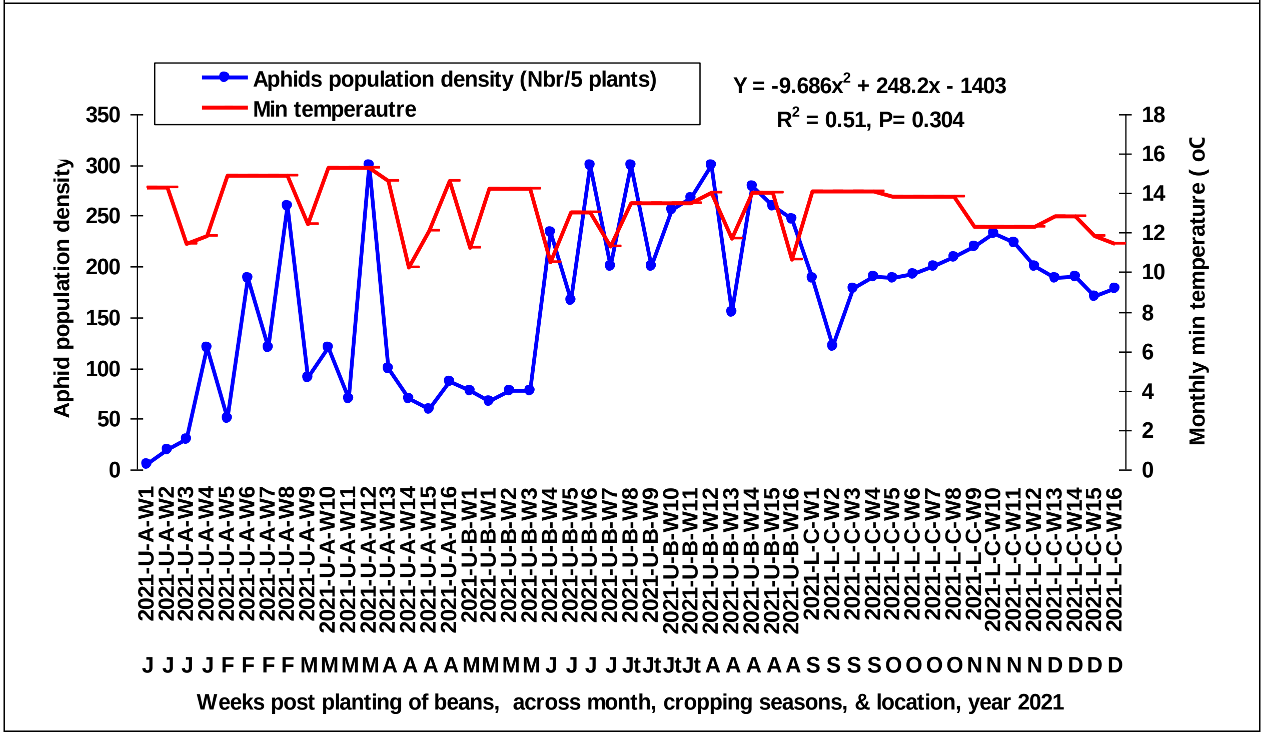
Figure-3a: Trends in the bacterial blight incidence(%) in relationship to Mean Minimum temperature (^{0}C) across years (2019-2024), cropping seasons and environmental locations of bean fields in rural areas

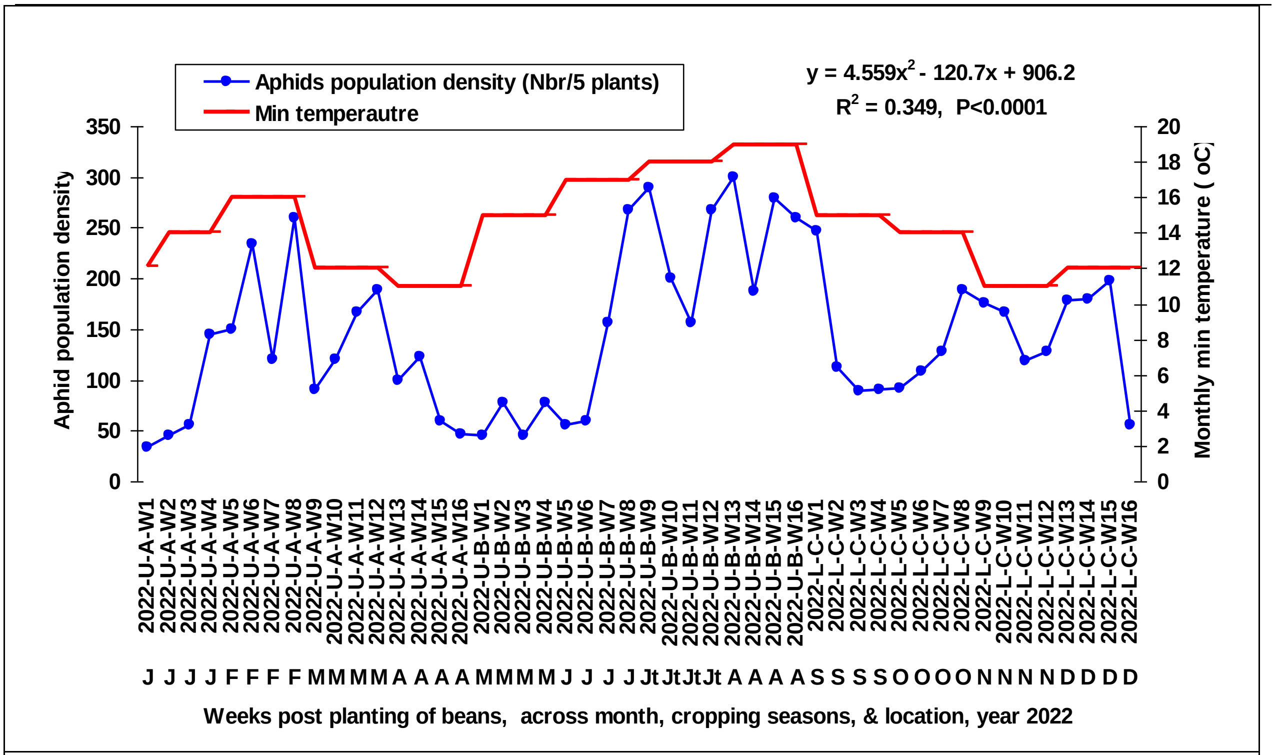
Legends:
(i): ***Cropping seasons*** : cropping **A**(sept-Dec, long rains), cropping season **B(**Jan-May, short rains), cropping season **C**(June-August, dry season in upland, but wet in marshlands
(ii): ***Environmental Locations of the bean field*** : **U**=Uplands or sloppy lands (1500-2400m altitude), **L**=Lowland, valley or Marshland (1350-1500m), **W**: weeks post planting of beans (varieties: Landraces grown in mixture)
(iv): ***For the quadratic regression equation***, **Y**=Average bacterial blight incidence (%), **X**=Mean monthly Minimum temperature(^{0}C)
(v): ***Months of the year during weekly data collection*** : **J**-January, **F**=February, **M**=March, **A**=April, **M**=May, J=June, Jt=July, A-August, **S**=September, **O**=October, **N**=November, **D**=December

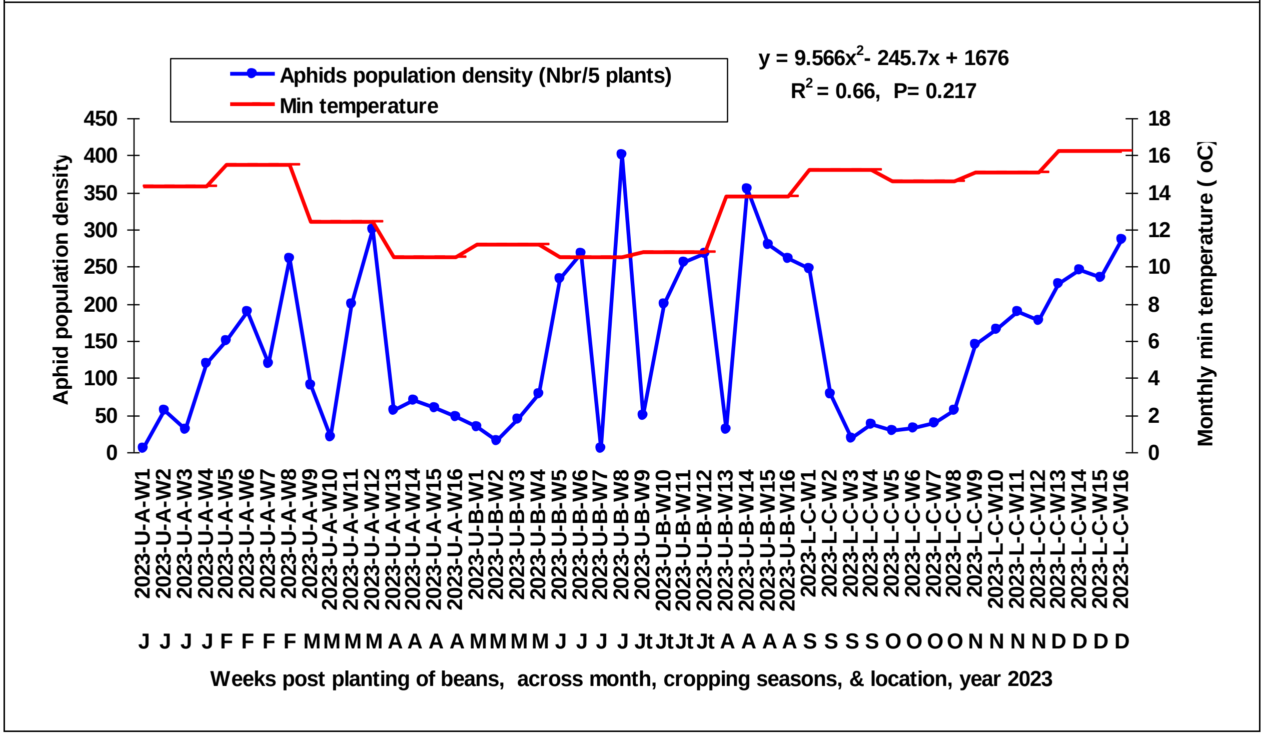
H




Aphids population density (Nbr/5 plants)
Min temperautre
y = 112.1x^2 - 3246x + 23590
R^2 = 0.231, P=0.003
Aphid population density
0
50
100
150
200
250
300
350
400
450
Monthly min temperature(oC)
12
12.5
13
13.5
14
14.5
15
15.5
16
16.5
2020-U-A-W1
2020-AW2
2020-AW3
2020-AW4
2020-AW5
2020-AW6
2020-AW7
2020-AW8
2020-AW9
2020-AW10
2020-AW11
2020-AW12
2020-AW13
2020-AW14
2020-AW15
2020-AW16
2020-U-B-W1
2020-U-B-W2
2020-U-B-W3
2020-U-B-W4
2020-U-B-W5
2020-U-B-W6
2020-U-B-W7
2020-U-B-W8
2020-U-B-W9
2020-U-B-W10
2020-U-B-W11
2020-U-B-W12
2020-U-B-W13
2020-U-B-W14
2020-U-B-W15
2020-U-B-W16
2020-L-C-W1
2020-L-C-W2
2020-L-C-W3
2020-L-C-W4
2020-L-C-W5
2020-L-C-W6
2020-L-C-W7
2020-L-C-W8
2020-L-C-W9
2020-L-C-W10
2020-L-C-W11
2020-L-C-W12
2020-L-C-W13
2020-L-C-W14
2020-L-C-W15
2020-L-C-W16
J J J J F F F F MMMMM A A A A MMMMM J J J J Jt Jt Jt Jt A A A A A S S S S O O O O O N N N N D D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2020


Aphids population density (Nbr/5 plants)
Min temperautre
Y = -9.686x^2 + 248.2x - 1403
R^2 = 0.51, P= 0.304
Aphid population density
0
50
100
150
200
250
300
350
Monthly min temperature (oC
0
2
4
6
8
10
12
14
16
18
2021-U-A-W1
2021-U-A-W2
2021-U-A-W3
2021-U-A-W4
2021-U-A-W5
2021-U-A-W6
2021-U-A-W7
2021-U-A-W8
2021-U-A-W9
2021-U-A-W10
2021-U-A-W11
2021-U-A-W12
2021-U-A-W13
2021-U-A-W14
2021-U-A-W15
2021-U-A-W16
2021-U-B-W1
2021-U-B-W1
2021-U-B-W2
2021-U-B-W3
2021-U-B-W4
2021-U-B-W5
2021-U-B-W6
2021-U-B-W7
2021-U-B-W8
2021-U-B-W9
2021-U-B-W10
2021-U-B-W11
2021-U-B-W12
2021-U-B-W13
2021-U-B-W14
2021-U-B-W15
2021-U-B-W16
2021-L-C-W1
2021-L-C-W2
2021-L-C-W3
2021-L-C-W4
2021-L-C-W5
2021-L-C-W6
2021-L-C-W7
2021-L-C-W8
2021-L-C-W9
2021-L-C-W10
2021-L-C-W11
2021-L-C-W12
2021-L-C-W13
2021-L-C-W14
2021-L-C-W15
2021-L-C-W16
J J J J F F F F F MMMMM A A A A MMMMM J J J J Jt Jt Jt Jt A A A A A S S S S O O O O O N N N N N D D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2021


Aphids population density (Nbr/5 plants)
Min temperautre
$y = 4.559x^2 - 120.7x + 906.2$
$R^2 = 0.349$, $P<0.0001$
Aphid population density
0
50
100
150
200
250
300
350
Monthly min temperature (oC)
0
2
4
6
8
10
12
14
16
18
20
2022-U-A-W1
2022-U-A-W2
2022-U-A-W3
2022-U-A-W4
2022-U-A-W5
2022-U-A-W6
2022-U-A-W7
2022-U-A-W8
2022-U-A-W9
2022-U-A-W10
2022-U-A-W11
2022-U-A-W12
2022-U-A-W13
2022-U-A-W14
2022-U-A-W15
2022-U-A-W16
2022-U-B-W1
2022-U-B-W2
2022-U-B-W3
2022-U-B-W4
2022-U-B-W5
2022-U-B-W6
2022-U-B-W7
2022-U-B-W8
2022-U-B-W9
2022-U-B-W10
2022-U-B-W11
2022-U-B-W12
2022-U-B-W13
2022-U-B-W14
2022-U-B-W15
2022-U-B-W16
2022-L-C-W1
2022-L-C-W2
2022-L-C-W3
2022-L-C-W4
2022-L-C-W5
2022-L-C-W6
2022-L-C-W7
2022-L-C-W8
2022-L-C-W9
2022-L-C-W10
2022-L-C-W11
2022-L-C-W12
2022-L-C-W13
2022-L-C-W14
2022-L-C-W15
2022-L-C-W16
J J J J F F F F M M M M M A A A A M M M M M J J J Jt Jt Jt Jt A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2022


Aphids population density (Nbr/5 plants)
Min temperature
$y = 9.566x^2 - 245.7x + 1676$
$R^2 = 0.66$, P= 0.217
Aphid population density
0
50
100
150
200
250
300
350
400
450
Monthly min temperature (oC)
0
2
4
6
8
10
12
14
16
18
2023-U-A-W1
2023-U-A-W2
2023-U-A-W3
2023-U-A-W4
2023-U-A-W5
2023-U-A-W6
2023-U-A-W7
2023-U-A-W8
2023-U-A-W9
2023-U-A-W10
2023-U-A-W11
2023-U-A-W12
2023-U-A-W13
2023-U-A-W14
2023-U-A-W15
2023-U-A-W16
2023-U-B-W1
2023-U-B-W2
2023-U-B-W3
2023-U-B-W4
2023-U-B-W5
2023-U-B-W6
2023-U-B-W7
2023-U-B-W8
2023-U-B-W9
2023-U-B-W10
2023-U-B-W11
2023-U-B-W12
2023-U-B-W13
2023-U-B-W14
2023-U-B-W15
2023-U-B-W16
2023-L-C-W1
2023-L-C-W2
2023-L-C-W3
2023-L-C-W4
2023-L-C-W5
2023-L-C-W6
2023-L-C-W7
2023-L-C-W8
2023-L-C-W9
2023-L-C-W10
2023-L-C-W11
2023-L-C-W12
2023-L-C-W13
2023-L-C-W14
2023-L-C-W15
2023-L-C-W16
J J J J F F F F M M M M M A A A A M M M M M J J J Jt Jt Jt Jt A A A A S S S S O O O O N N N N D D D D
Weeks post planting of beans, across month, cropping seasons, & location, year 2023

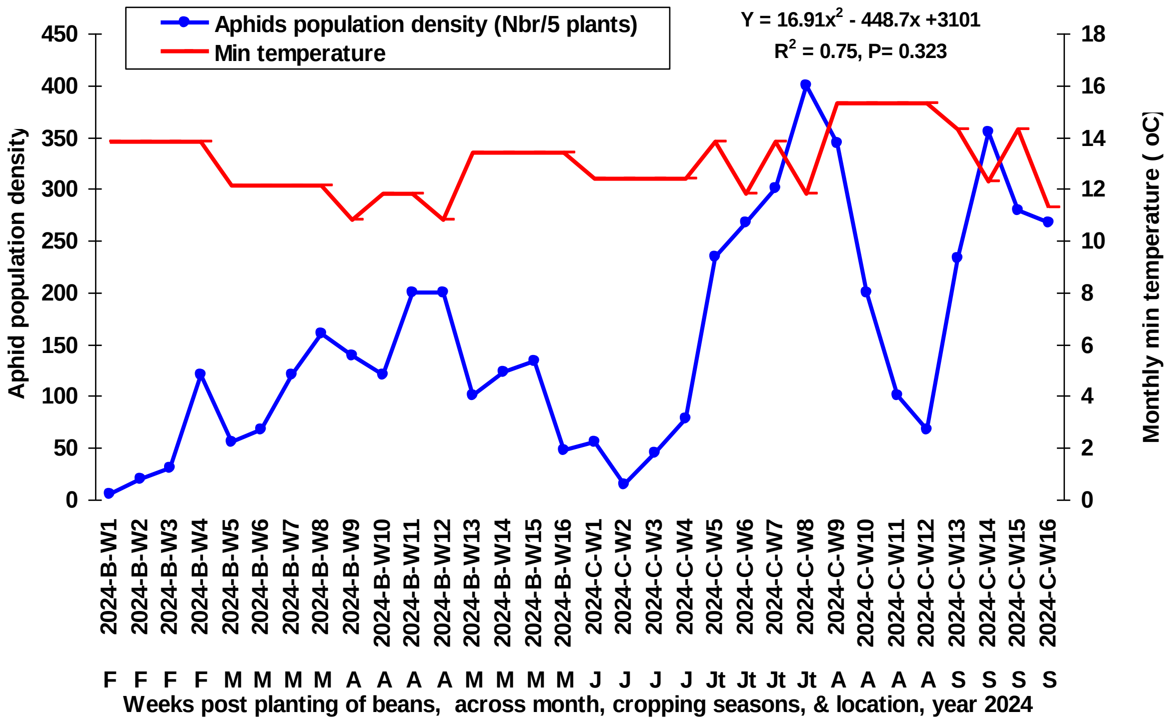


Figure-3b: Trends in the population density of aphids (*Aphis craccivora* L.) in relationship to Mean Minimum temperature (^{0}C) across years (2019-2024), cropping seasons and environmental locations of bean fields in rural areas

Legends:

(i): ***Cropping seasons*** : cropping **A**(sept-Dec, long rains), cropping season **B(**Jan-May, short rains), cropping season **C**(June-August, dry season in upland, but wet in marshlands

(ii): ***Environmental Locations of the bean field*** : **U**=Uplands or sloppy lands (1500-2400m altitude), **L**=Lowland, valley or Marshland (1350-1500m), **W**: weeks post planting of beans (varieties: Landraces grown in mixture)

(iv): ***For the quadratic regression equation***, **Y**= Average population density of aphids , **X**=Mean monthly Minimum temperature(^{0}C)

(v): ***Months of the year during weekly data collection*** : **J**-January, **F**=February, **M**=March, **A**=April, **M**=May, J=June, Jt=July, A-August, **S**=September, **O**=October, **N**=November, **D**=December

k

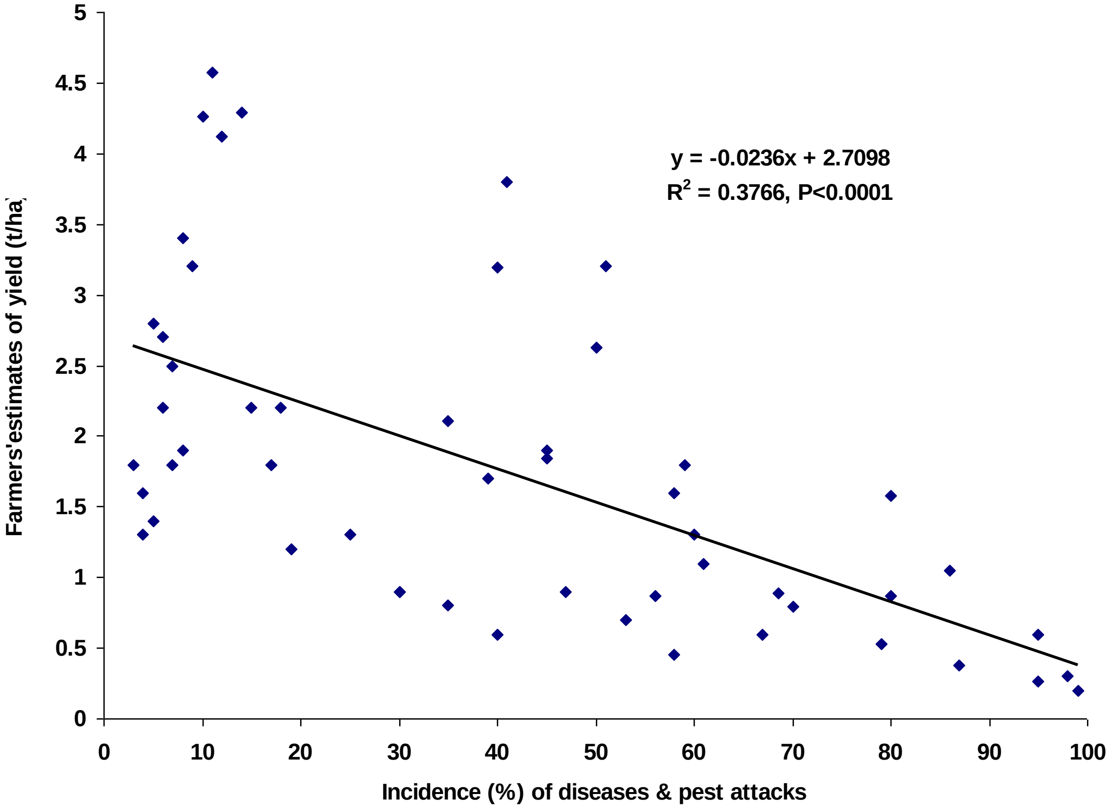


Figure-4: Estimates of the relationships between incidence (%) of diseases and pest attacks (damages) and the yield (tones/ha) during surveys

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