Towards an Early Warning System for cotton pests in Benin using long-term and multilocal observational data

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Abstract

Controlling pest populations in cotton fields is crucial to reduce yield losses due to plant damage. However, knowing the economic, environmental and agronomical issues related to the systematic use of chemical insecticides, it is urgently needed to better assist spraying decisions based on the development of an Early Warning System. In Benin, one of the major cotton producers in West Africa, a comprehensive annual monitoring of the incidence of key pests has been implemented for more than ten years. Here, we propose to use these long-term and multilocal observational data to (1) better understand the relationships between environmental variables, including climate, landscape context, but also crop management, and intra- or inter-annu al pest population dynamics within the cotton-growing area, and to (2) better predict the risk of yield loss due to key pests as to better target interventions. As a perspective, we suggest developing standardized data collection and management throughout the West-African cotton-growing area for areawide pest management.

Keywords: cotton, Early Warning System, IPM, *Helicoverpa armigera*, modelling.

A need for better pest control strategies

Insect pests are a major obstacle to the increase of cotton production in West Africa, leading to 25-35% yield losses annually (Amanet *et al.*, 2019; Brévault *et al.*, 2019). Recently, outbreaks of the invasive jassid species, *Amrasca biguttula*, have highlighted the need for monitoring systems for rapid intervention (Kouadio *et al.*, 2022). Other key pests such as the cotton bollworm, *Helicoverpa armigera,* must be closely monitored because of their potential impact on cotton production.

In West Africa, pest control is primarily based on the use of chemical insecticides (Mutsaers *et al.*, 2022). Pest management programs recommend to farmers to spray cotton plots on a calendar basis (Silvie *et al.*, 2013), regardless of pest incidence. If this strategy has enabled the cotton value chain to maintain yields across years (Mutsaers *et al.*, 2022), some important drawbacks can be noted:

- Target imprecision: Insecticidal sprays are sometime unnecessary because targeted pests are not present.
- Timing imprecision: Because products are sprayed on a 14-day calendar basis, pest outbreaks can occur in between two treatments.
- Economical cost: Multiple applications can become costly for farmers over a full cropping season.
- Environmental health cost: Chemical insecticides are responsible for detrimental impacts on ecosystem health and biodiversity in and around fields (Van Der Sluijs *et al.*, 2015).
- Human health cost: Chemical insecticides represent an important health hazard for farmers using them regularly and in large amounts, particularly when they are poorly trained to use them safely (Gouda *et al.*, 2018; Vikkey *et al.*, 2017).
- Resistance evolution: Surviving individuals can carry resistance alleles increasing their frequency in populations over generations, thus leading to pest control failures (Kranthi *et al.*, 2002; Wu & Guo, 2005).

Considering such limitations, pest management strategies should evolve to contribute to more sustainability of cotton-growing systems. Spraying decisions should be triggered dynamically according to the abundance of pest populations in the field and potential associated damage to the crop and yield loss. Such management requires high skill level of farmers and technical advisors. They should be able to sample and identify a diversity of insect pests to take the decision of spraying and to select as specific and environmentally friendly insecticides as possible. Ideally, pest sampling methods and associated intervention thresholds for each target pest could assist decision to spray at the right time according to pest abundance (Silvie *et al.*, 2013). However, yield loss due to insect pests also depends on agronomic factors such as crop phenological stage (Schellhorn *et al.*, 2015), potential of plant compensation (Brook *et al.*, 1992), potential of biological control (Keasar *et al.*, 2023), and co-occurrence of other pests. Thus, intervention thresholds should vary across the cropping season and across fields to consider these factors. Obviously, deploying such a decision system for a cotton production basin might be complex and costly, because it would need many observations as well as training programs to take accurate and relevant decisions at the plot scale (Silvie *et al.*, 2013).

Towards an Early Warning System

Early Warning Systems (EWS) can help overcome this issue (Davies *et al.*, 1991). An EWS is a system that can predict the risk associated with a specific pest or a cohort of pests at a given spatial and temporal scale. The risk is estimated without the need to evaluate pest abundance in the field. It is often based on models predicting insect abundance, date of first occurrence, or daily probability of overpassing the threshold. Risk estimations can be automated and performed at different spatial (field, city, district, *etc.*) and time (daily, weekly, *etc.*) scales. The model can be either statistical or mechanistic. In any case, the prediction will be made based on easily measurable variables. Climate variables are usually critical in predicting pest risk. If climate previsions are available, EWS can predict a risk. EWS can thus greatly help insecticide spraying decisions against the right pest at the right time and the right place. As such, it has the potential optimize spraying decisions at a large scale.

Benin is one of the countries with highest cotton production in Africa (Food and Agriculture Organization of the United Nations, 2023). To better monitor spatiotemporal pest population dynamics, the National Institute for Research on Cotton (IRC) has led a comprehensive program to sample pest populations at the country scale from 14 experimental stations distributed over the territory (Figure 1). In each station, the abundance of key pest species has been measured weekly since 2010 with a standardized protocol. A database has been compiled from all the data collected on experiments at stations and on farmer fields. It has been primarily developed to monitor the pest pressure throughout the growing season over the cotton-growing area and to realize yearly assessments of the performance of the recommended spraying program. A supplementary design has been set up since 2018 on 100-300 farmer fields sampled within the cotton production basin.

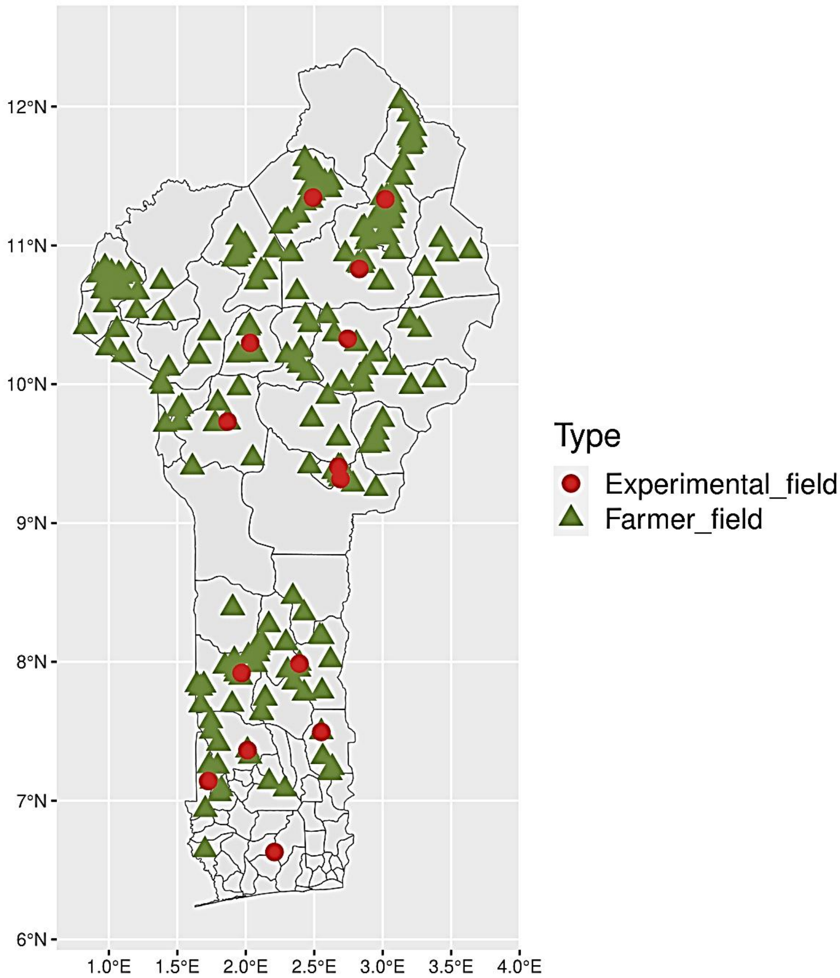

Figure 1. Distribution of fields sampled by the Institute of Research on Cotton (IRC) in Benin in 2023. Red dots represent sampling in experimental stations. Green triangles represent farmer fields.

A project has been launched in 2022 to capitalize this multi-year and multi-site dataset to better identify the determinants of pest outbreaks from a seasonal to decennial temporal scale, but also to predict pest risk using statistical modelling. This project targets two main outputs:

1. Automated representation of real time pest abundance on maps based on weekly field observations on experimental stations and farmer fields. Monthly maps are given in figure 2 for the sake of illustration.
2. Early prediction of pest risk based on a statistical model relying on environmental variables (*e.g.* meteorological variables, landscape context) and crop management (*e.g.* sowing date). This system will be able to produce risk predictions up to one week in advance.

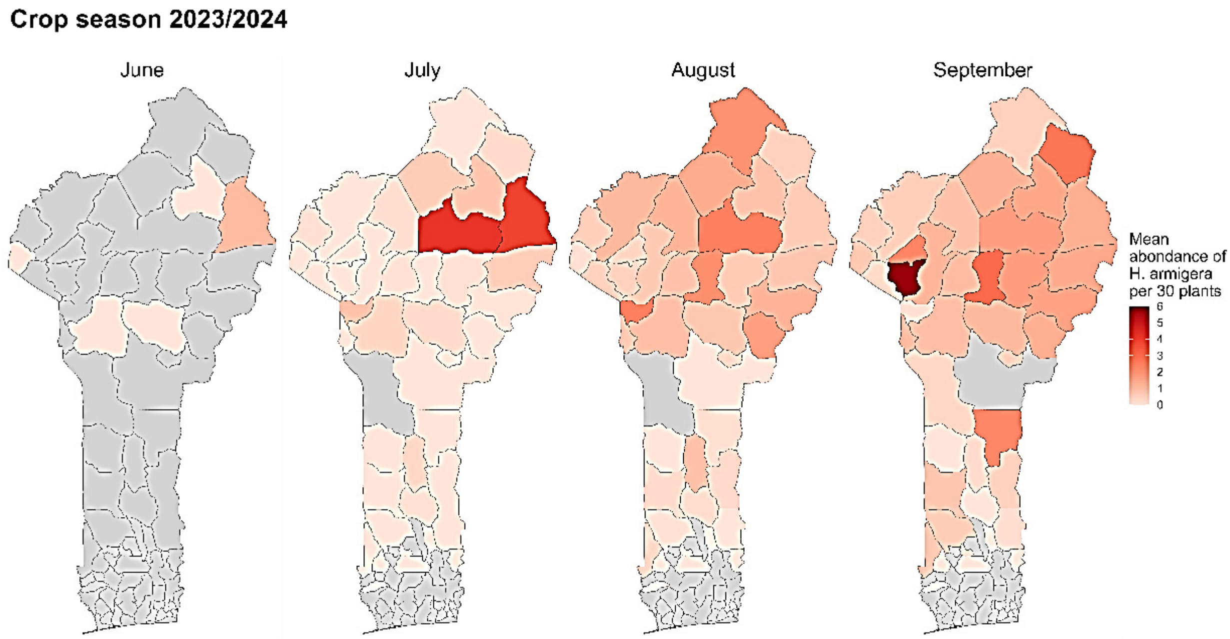

Figure 2. Spatio-temporal evolution of <u>H. armigera</u> density (number of larvae per 30 cotton plants) across months and counties in 2023.

Information will be aggregated at the county level. Among the 13 pests present in the database, *H. armigera* is probably the species of most concern regarding yield loss. As such, the early prediction system will be developed on this pest. On the longer run, the process could be adapted to other pests according to their relative importance in terms of yield loss. An online platform will be then developed to give stakeholders access to such information.

In the case of a large-scale deployment of such early warning system, it is essential to discuss in advance with potential end users to define the nature of the information that will be delivered, and to detail the specifications to be made before its development. Here are some crucial points to focus on:

- <u>Objective</u>. An EWS is developed with an applied objective for crop management.

One could be seeking to decrease the frequency of insecticide spraying or to simply concentrate them in an optimal window of time for increased efficiency. This point is central because it conditions the others.

- Choice of the risk variable. Risk can be defined very differently from pest to pest depending on their biology and type of damage. Some insects present a continuous threat for the crop yield by their occurrence, while others are only detrimental during a specific phenological stage of the crop, or when their abundance reaches a certain threshold. Here, one could choose to represent the risk by a daily probability of occurrence, an index based on the probability of occurrence and the phenological stage of the crop, or the probability for the insect abundance to reach a threshold beyond which the risk of yield loss is greater than the cost of one insecticide spraying. The risk level can also integrate agronomical, biological and strategic considerations in accordance with the objective previously defined.

- Spatial and temporal scales. It is necessary to define the resolution at which the EWS will represent the risk. When the EWS is based on a model relying on external variables, the precision is constrained by the granularity of available data. For instance, meteorological data are often collected through synoptic stations. They are distributed in space and have a certain time resolution. They usually collect daily data. In this case, it is not possible to predict a risk for less than a day, and with a spatial precision less than the number of stations per unit of area. Thus, scales are also responsible for part of the uncertainty associated with the risk estimation. This uncertainty becomes more important when predictive variables strongly fluctuate in space and time.

- Targeted audience. An EWS can target different audiences, usually either farmers, field advisors, decision makers or a combination of them. In any case, the audience should be trained to be able to properly interpret and analyse EWP outputs. The understanding of how the risk is represented, how the calculation is made, and the level of uncertainty associated with it is crucial for a rational use of the outputs.

Towards better understanding of pest bioecology

The exploration of this database will also deliver precious information about spatial and inter and intra-annual population dynamics of pests.

Hypothesis 1. The population dynamics of the cotton bollworm, *H. armigera,* is probably driven by the area of cotton in the agricultural landscape, but also of alternative host plants (e.g., maize). We expect to find a significant and positive relationship between resource availability and *H. armigera* abundance (Cunningham & Zalucki, 2014; Riaz *et al.*, 2021).

Hypothesis 2. Knowing that *H. armigera* populations start to build up at the beginning of the rainy season in the cotton-growing area, the sequence of host plants is crucial for population growth or maintenance before cotton offers resources for larval development

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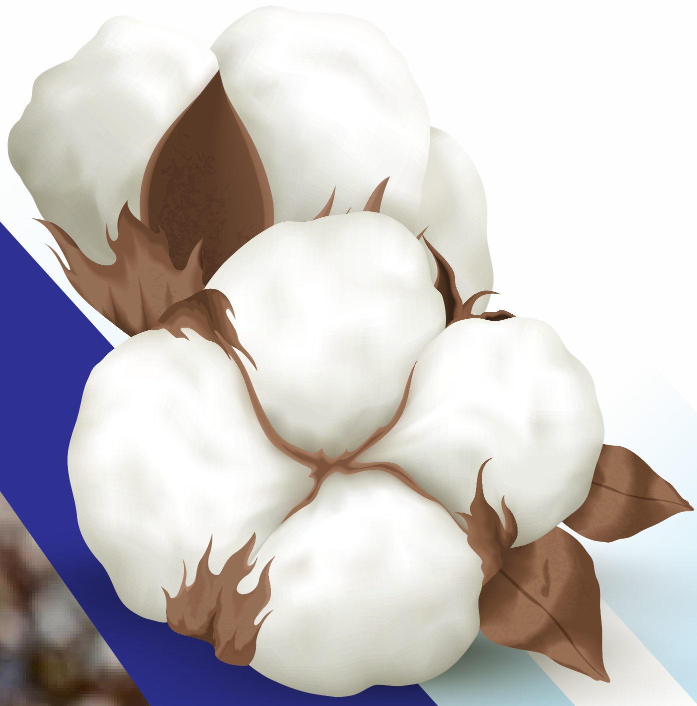

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(Brévault *et al.*, 2012). We expect to observe a lower density of this pest in cotton fields as long as alternative host plants are available in the agricultural landscape.

Hypothesis 3. Pest populations can be impacted by cultural practices such as the nature of insecticide sprays (Fanigliulo & Sacchetti, 2008; Men *et al.*, 2005), frequency and dose of applications, cotton varieties (Riaz *et al.*, 2021) or sowing date. We expect to detect long-term impacts of significant changes in pest management programs or crop management on the population dynamics of some key pests.

The validation of those hypotheses could open avenues for the re-design of pest management strategies. For instance, in relation to hypothesis 1, we know that maize is widely cultivated in Benin and that it is an important alternative host for *H. armigera*. Thus, a systemic control strategy should also involve maize crops as a potential source or trap crop.

Perspectives: a common effort to monitor pest populations

Beyond the development of an EWS, this work highlights the major importance of standardizing data collection over a long period of time, at large scale, for efficient valuation. Above all, the data needs to be cleaned, harmonised and structured in relational databases, so that it can be easily shared and made available to researchers and stakeholders. A second important lesson is that observational data must be completed by environmental variables such as weather, landscape context, and variables related to crop management (e.g., insecticide sprays in the case of crop pests). The quality and quantity of information will be key for analyses and predictions.

The database described here focus on cotton pests in Benin. Enlarging it to other West African countries could open new research avenues to better understand pest population dynamics at a regional scale. Area-wide strategies could also be considered over the entire cotton-growing area in West Africa, which would be particularly interesting in the case of long-distance migrating pest like *H. armigera*. Finally, developing a common monitoring program could also catalyse collaboration and concertation on pest management strategies among countries.

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