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Weather-Informed Recommendations for Pest and Disease Management in the Cashew Production Zone of Côte d'Ivoire

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Abstract: Poorly informed pest and disease management strategies can have detrimental effects on the environment, crop quality, crop yield, farmers' income, and the overall sustainability of agriculture. For this reason, integrated pest and disease management (IPDM) draws on knowledge from various research fields to effectively manage risks of bio-aggressor outbreaks. However, many agricultural sectors of Sub-Saharan African countries lack such necessary knowledge, including the epidemiology of bio-aggressors in relation to the increased climate variability. The objective of this work is to provide weather-based guidance for the development of sustainable pest and disease control strategies in cashew cultivation areas of Côte d'Ivoire, the second most important cash crop of the country. Leveraging the bioclimatic knowledge in the literature about fungi and insects, we explored four-year hourly data (2017–2020) of 34 sites of the cashew production zone. The outputs showed potentially conducive weather events for fungi and insects throughout the entire cashew production areas, with the forest–savanna transition zone being the most critical. These outputs were used to elicit recommendations for pest and disease management in consultation with a multidisciplinary stakeholder task force. They recommended that effort for disease prevention in the forest–savanna transition zone, the new cashew production zone, should be an incrementation of the one already recommended in the north savanna. Weather-based disease monitoring, entomopathogenic-fungi-based pest control, and the promotion of early-maturing cashew genotypes are also recommended, especially in the forest–savanna transition zone.

Keywords: pests and diseases; IPDM; weather; recommendations; cashew

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1. Introduction

The cashew industry holds significant promise as a cash crop and could help reduce poverty in several climate-sensitive areas [1,2], particularly in Sub-Saharan Africa where cashew nuts production has gained traction in the last few decades [3]. With the increasing price of cashew nuts on the international market, Sub-Saharan African countries are striving to establish sustainable cashew sectors to improve the livelihoods of rural communities. However, achieving this goal requires a multidisciplinary approach that draws on expertise from various research and development fields. Agrometeorology is one such critical area of expertise that can significantly enhance the sustainability of agriculture [4], including cashew nut production systems. Whether related to favorable or unfavorable weather conditions, agrometeorological knowledge plays a vital role in promoting sustainable agriculture. Indeed, having knowledge of how weather affects diseases is crucial for managing them and can result in lower operational costs with reduced risks of environmental pollution [5,6]. Unfortunately, in Sub-Saharan Africa, including Côte d'Ivoire, the potential benefits of using agrometeorology is poorly exploited [7]. For the cashew sector, this is concerning because cashew is a vital source of income for poor rural communities [8]. However, it is often plagued by weather-related pests and diseases [9], which pose a threat to the sustainability of the entire value chain. The responses to dealing with this situation are still in their early stages, beginning with regular monitoring of cashew orchards and research to identify pest and disease control strategies. Consequently, the cashew sector is actively seeking knowledge to develop integrated pest and disease management strategies, including the utilization of agrometeorological knowledge. However, there is a lack of such knowledge, as research in agrometeorology did not produce papers on this subject. Ivorian agrometeorology research has so far been focused on topics other than pest and disease management, including growing season onset/offset [10,11], sowing dates for annual crops [12,13], and bushfires risks [14]. Consequently, there is a scarcity of practical and accessible agrometeorological guidance for implementing sustainable pest and disease management.

As a contribution to filling this research gap, this study was initiated to provide weather-based guidance for the development of sustainable pest and disease management strategies in the cashew production zone of Côte d'Ivoire. It was based on the fact that temperature and relative humidity can provide decision-makers with critical information on spatiotemporal weather suitability profiles for bio-aggressors [5,15]. A combination of literature knowledge (related to fungi and insects) and weather data (temperature and relative humidity) was used to generate weather suitability profiles for pests and diseases. These profiles were shared with stakeholders from various disciplines in the cashew sector, who used them to develop general recommendations for sustainable pest and disease management.

2. Materials and Methods

2.1. The Cashew Production Zone of Côte d'Ivoire

The cashew production area in Côte d'Ivoire spans two different ecoregions: the Sudanian savanna located in the northern region, and the forest–savanna transition zone in the southern region. The latter ecoregion represents a recently developed cultivation subzone, as the initial cashew plantations were established in the northern landscapes above the 8th parallel during the 1960s. The annual rainfall in these areas typically varies between 1000 mm and 1500 mm (Figure 1). Forest–savanna transition areas are more humid, with two rainy seasons alternating with two dry seasons. The first rainy season of the year lasts from March to July and the second from August to November. The Sudanian savanna areas are drier, with one humid season lasting from May to October and one dry season running from November to April.

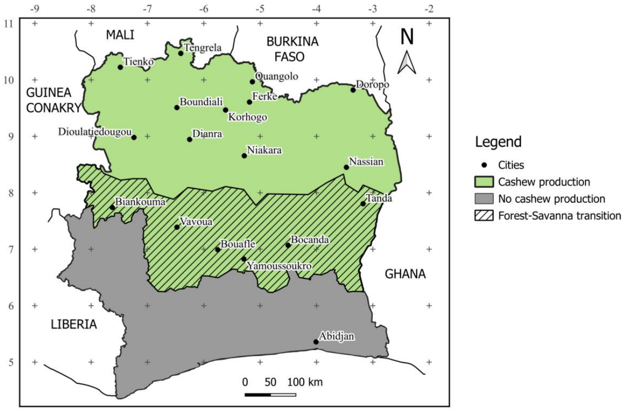

Figure 1. Cashew nuts production zone in Côte d'Ivoire, West Africa.

2.2. Description of the Underpinning Bioclimatic Principles

Pest and fungi abilities to live in the cashew production zone were profiled using two bioclimatic principles: (i) fungi spores can germinate if their agrometeorological requirements regarding leaf wetness duration and temperature are met [5]; (ii) eggs and first-instar larvae of most insects are susceptible to desiccation (drying out) if they are exposed to air with low relative humidity [16,17].

2.2.1. Required Weather Conditions for Fungi Germination

Germination and growth of fungi strongly depend on their surrounding environmental factors [18], more importantly on temperature and leaf wetness duration (LWD) through relative humidity [19,20]. For the life cycle of fungi to start and complete properly, ambient temperature should remain in a certain range of temperature. Though fungi exist which can grow under higher or lower temperatures, most fungi require temperatures falling within the range 5–35 °C [18,21]. In this temperature range, spore germination is strongly subject to LWD, which refers to the duration of continuous time in which free water forms and remains on the foliage of plants [5,22]. Since LWD is not a climatic parameter as such, it is rarely measured comparatively to the other regular climatic variables such as temperature, relative humidity, wind speed and rainfall [5,23]. LWD is most of the time derived from weather data through mathematical models [22,24–26]. Among LWD models, threshold-based ones are simple but require context-specific parameterization [5]. The underlying concept is that when relative humidity (RH) increases and reaches a specific threshold at a given site, free water begins to accumulate on the leaves of plants. When this free water persists on the leaf surface for an extended period (in hours), it creates the suitable conditions for the germination of fungal spores. Generally, the threshold air humidity ranges between 87% and 95%, depending on the geographical areas [5]. In this preliminary investigation, a relative humidity (RH) threshold of 95% was utilized to mitigate the risk of overestimating LWD. Further attention was paid to the minimum LWD required by fungi to start the infection process. The species-specific minimum LWD required by fungi to initiate their infection process varies, ranging from 6 h to longer [5]. If our study was focused on one specific fungal species, it would be mandatory to use the specific minimum LWD of that fungus. However, the study aimed to profile the general disease susceptibility of various locations to fungal infections across different years, rather than focusing on a single fungal species. Therefore, we considered weather conditions at various sites as potentially favorable for disease development if the duration of leaf wetness (defined as the number of consecutive hours when the relative humidity is above 95%) was at least 6 h (LWD $\geq$ 6 h), and the air temperature remained within the range of 5 °C to 35 °C.

2.2.2. Potential Desiccation-Driving Weather Conditions for Insects' Eggs and Larvae

Like any organism, insects including pests can live only within a suitable temperature range characterized by defined lower and upper thresholds. For tropical insects, lower and upper temperature thresholds are broadly 10 °C and 40 °C, respectively [27]. In this temperature range, many other factors including additional climatic drivers can affect insects' proliferation and activities [27]. Among these climatic factors, high vapor deficit (low relative humidity) can irreversibly drive dehydration in insects' eggs and first-instar larvae [17]. It is common for several insects' eggs and larvae (lacking adaptation capabilities) to die after prolonged exposure to low relative humidity [28]. Others may survive such dry air through adaptation mechanisms including physiological and behavioural responses. When such adaptation abilities exist, more often the eggs remain quiescent during a tolerable time, leading to prolonged periods spent before arriving at the pupa stage [19]. Consequently, either way, low humidity regulates the time-course population rates of insects including pests. A threshold of relative humidity less than 20% drives desiccation in several insects' eggs and first-instar larvae [28,29]. Therefore, a threshold criterion of 20% relative humidity was adopted. This enabled the identification of particular locations and time periods in which insects, including pests, were at risk of facing desiccation-inducing weather conditions.

2.3. Weather Data Collection and Exploration

2.3.1. Hourly Weather Data Collection

We selected hourly weather data registered by 62 Automatic Weather Stations (AWS) installed in the cashew production zone. Initially, raw data for each site were in one or more files with formats typical to the Weather Station embedded communication system. Temperature and relative humidity were extracted and aggregated in one file per site. Data quality was graphically checked. When anomalies were pointed out, the data rows containing the anomalies were deleted. At the end, 34 localities were validated having 4 years database (from 2017 to 2020) including 14 localities whose data have no gap. All 34 stations were utilized for the analyses that did not require continuous datasets. However, for the analyses that necessitated uninterrupted hourly datasets, only the 14 stations were used.

2.3.2. Temperatures Comparison to the Requirements of Fungi and Pests

To begin the process of data exploration, we acknowledged the significance of temperature as a potential primary factor influencing the survival and proliferation of diseases and pests. Thus, we conducted a comparison between the suitable temperature range for the majority of fungi to the hourly temperatures observed within the cashew production zone. This comparison was performed for insects as well. Practically, we generated boxplots that visualized the distribution of temperatures and juxtaposed them with the temperature thresholds (upper and lower) for fungi and insects. All the 34 validated datasets (34 different sites) were utilized in this operation.

2.3.3. Identification and Visualization of Potentially Disease-Conducive Periods

Identification of potential disease-conducive hours was done using gapless datasets and time series analysis in Python. It consisted in filtering hourly weather data on the period from 1 January 2017-00 h 00 min to 31 December 2020-23 h 59 min according to the conditions described previously. The approach is illustrated by Figure 2 and included the following actions:

i. select hours characterized by temperatures (T) between 5 °C and 35 °C (named as $T_{5–35}$ h),
ii. select hours with relative humidity (RH) superior to 95% (named as H_{95} h) from the above $T_{5–35}$ h,
iii. count H_{95} that are consecutive—named as con-H_{95},
iv. count the monthly numbers of times con-H_{95} is superior or equal to 6 h; these numbers are the 6 h leaf wetness duration frequencies (LWD6),
v. aggregate and visualize the LWD6 frequencies.

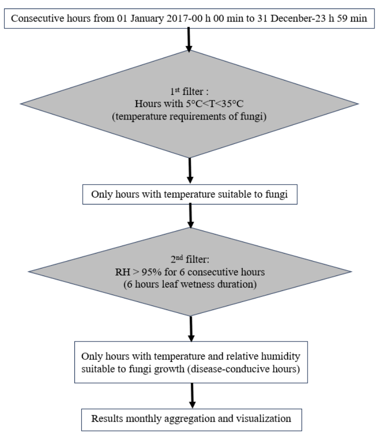

Figure 2. Identification of potential disease-conducive periods.

2.3.4. Identification and Visualization of Potential Desiccation-Conducive Periods for Insects' Eggs and Larvae

Potential desiccation-conducive periods were analyzed for insects' eggs and larvae in the following three steps illustrated by Figure 3:

i. selection of hours that registered relative humidity (RH) inferior to 20% (named H_{20} h),
ii. counting of the frequencies of hours H_{20} at both monthly and yearly scales,
iii. aggregation and visualization of the frequencies of H_{20} h.

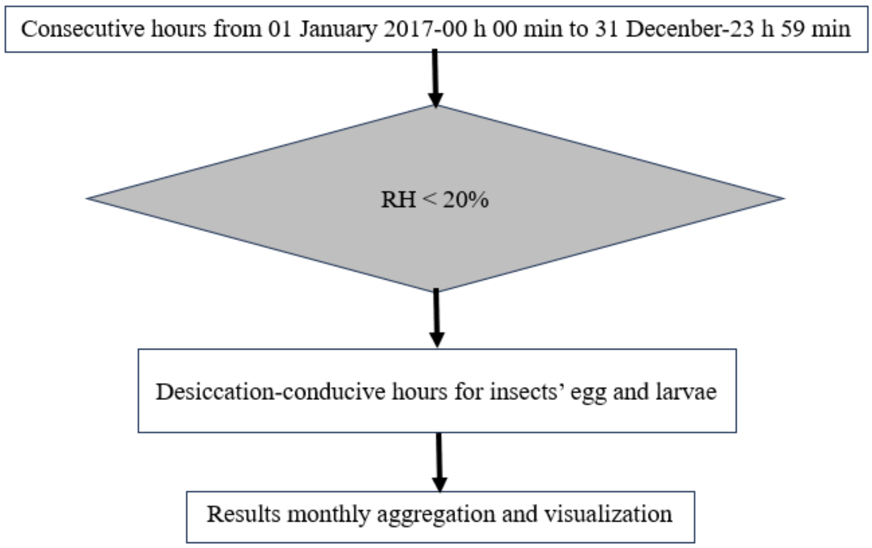

Figure 3. Identification of potential desiccation-conducive hours.

2.4. Stakeholder Consultations

The results of the weather data exploration were shared with a taskforce comprising various key stakeholders through individual interviews. These interviewees included cashew farmers with at least a secondary education level, cashew plant breeders, cashew pest researchers, cashew disease management researchers, climate finance professionals, and research-development management specialists. We first ensured that the interviewees understood well the data-driven information submitted to them. This was considered a vital starting point, as this would determine stakeholders' abilities to provide informed recommendations. Consequently, one-on-one interviews were conducted to ensure a better comprehension of both the methods used and the primary findings of the weather data exploration. Subsequently, the interviewees were asked to propose recommendations based on what they understood with the objective of improving the sustainability of pest and disease management in cashew orchards.

The tool depicted by Table 1 was used to that effect. In this tool, the column "Submitted key information" plays a central role, as it summarizes results of the data analysis. The "Case highlighted" column displays issues or opportunities previously hidden but brought to light by the key information. Issues and opportunities were expected to be identified by interviewees based on the provided information and her/his knowledge in the cashew production systems; we contributed, however, to the identification of the highlighted cases. The "Recommendation" column receives strategies or actions recommended by the interviewees given the highlighted issues or opportunities. The column "Target" specifies stakeholders targeted by the recommendations.

Table 1. Tool for the stakeholder consultations.

Submitted Key Information	Case Highlighted by the Key Information	Recommendation	Target
Information 1	Issues or opportunities evidenced given key information 1	Recommendation 1	List of stakeholders targeted by recommendation 1
Information 2	Issues or opportunities evidenced given key information 2	Recommendation 2	List of stakeholders targeted by recommendation 2
Information 3	Issues or opportunities evidenced given key information 3	Recommendation 3	List of stakeholders targeted by recommendation 3

3. Results

3.1. Temperature Suitability for Fungi and Pests in the Cashew Zone

Except for one location (Biankouma), hourly temperatures, at some point, surpassed 35 °C during certain periods, while none of the locations experienced temperatures below 5 °C (Figure 4). This observation highlights that elevated temperatures could potentially impede the growth and presence of fungi within the cashew production zone of Côte d'Ivoire.

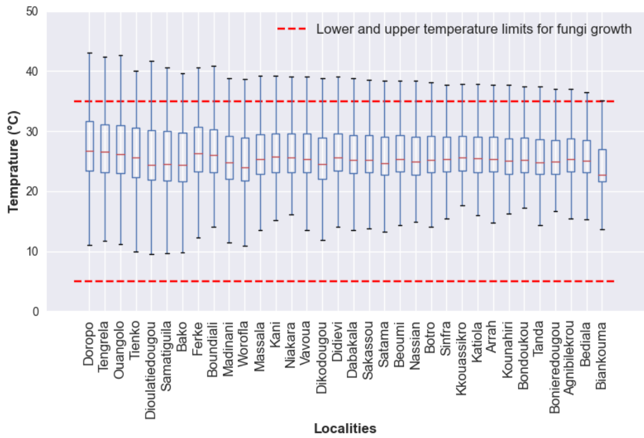

Figure 4. Hourly temperature of the sites versus temperature requirements of fungi.

Between 2017 and 2020, the majority of hourly temperatures were recorded within the range of 10 °C to 40 °C throughout the cashew production zone (Figure 5). However, in the western areas of Dioulatiédougou, Tienko, Samatiguila, and Bako, hourly temperatures sometimes fell below the 10 °C limit. The far-north areas of Boundiali, Ferké, Samatiguila, Dioulatiédougou, Tienko, Ouangolo, Tengrela and Doropo registered temperatures above the 40 °C threshold.

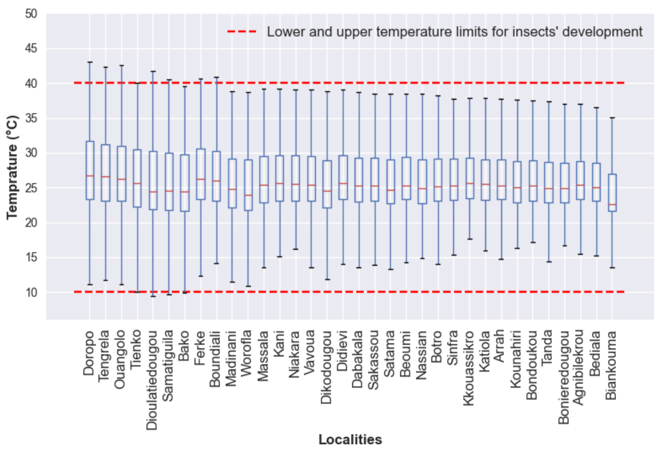

Figure 5. Hourly temperatures of the sites versus temperature requirements of insects.

3.2. Yearly and Monthly Frequencies of Potentially Disease-Conducive Weather Events

Weather conditions potentially conducive to diseases were observed throughout the cashew production zone, but not in the same months nor with the same frequencies (Figure 6). This indicates that plant pathogenic fungi can find their favourable weather conditions in each site of the cashew production zone. However, the frequency of suitable weather conditions varies from one site to another. The sites of the Forest–Savanna Transition (FST) zone, including Bocanda, Vavoua, Biankouma, Bouaflé and Tanda, displayed higher annual frequencies of 6 h leaf wetness duration (LWD6). In other words, their weather conditions are more potentially disease-conducive (Figure 6) than those of the savanna zone.

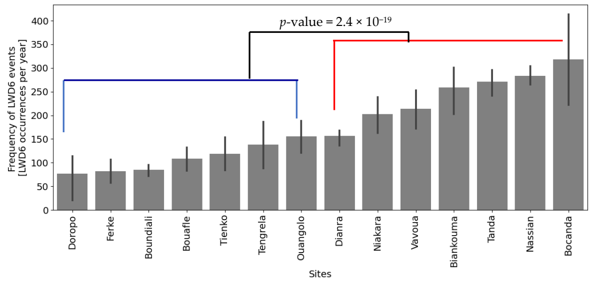

Figure 6. Yearly frequencies of disease-conducive weather events over the period 2017–2020 (p-value indicating the level of significance difference between the two specified groups of sites.).

LWD6 events occurred between March and December in the FST zone, and between May and October in the northern zone (Figure 7). This indicates that the periods conducive to diseases were longer (10 months) in the FST areas compared to the northern areas (6 months). These northern sites consistently experienced maximum frequencies of LWD6 in September, whereas in the FST areas, the maximum frequencies were observed in June, July, August, and September, with variations from year to year. This indicates that the high-risk periods for plant disease differed largely from year to year in the FST areas.

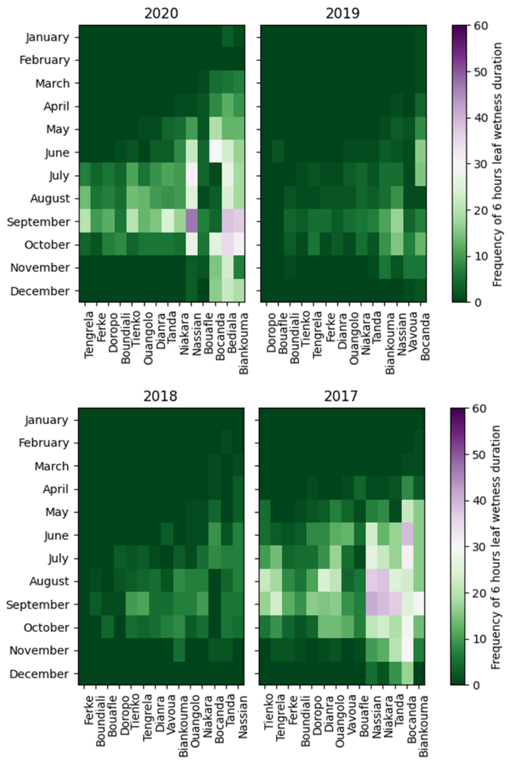

Figure 7. Monthly frequencies of disease-conducive events from 2017 to 2020.

3.3. Potential Desiccation-Conducive Weather Events for Insects' Eggs and Larvae

The occurrence of desiccation-inducing weather events (RH < 20%) that potentially affect insect eggs and larvae was more frequent in the northern region of Côte d'Ivoire's cashew production zone, as depicted in Figure 8. The weather conditions in the northern sites seemed to pose greater constraints on the survival of insect eggs and larvae. In other word, this suggests that the weather in the FST sites, in comparison to the northern sites, was more conducive to the proliferation of insects.

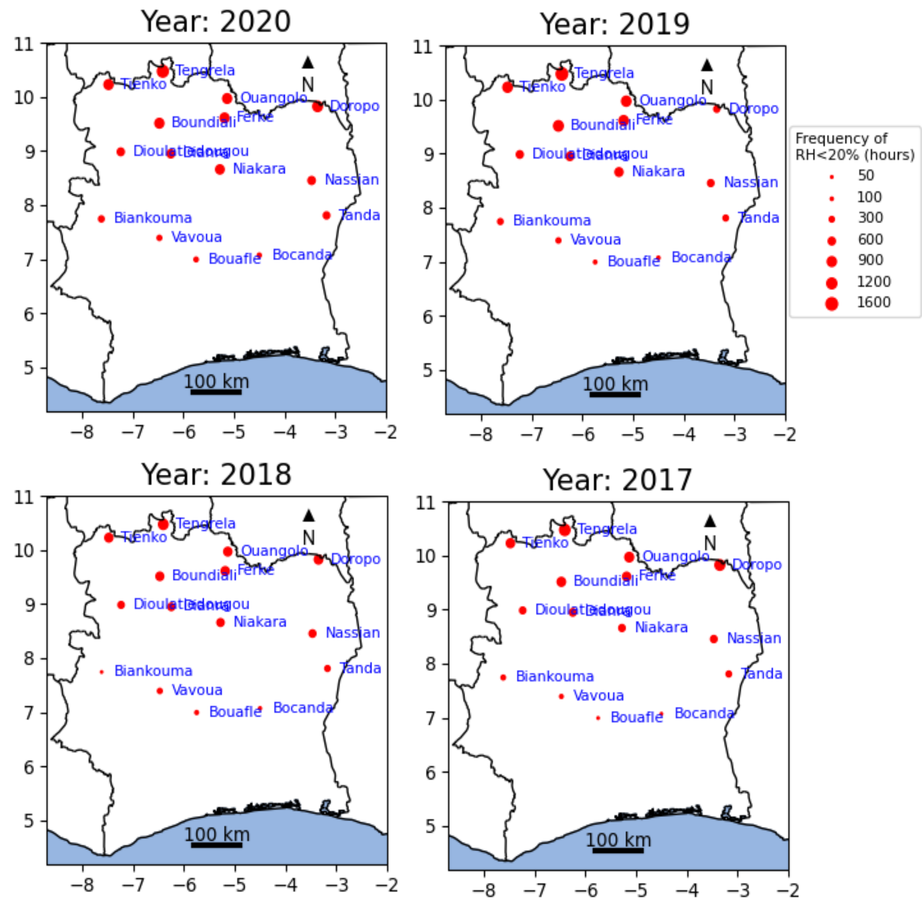

Figure 8. Frequencies of potential desiccation-conducive weather events for insects' eggs and larvae (RH: air relative humidity).

Following the above spatial pattern, monthly frequencies of desiccation-conducive weather events were visualized comparing northern savanna sites with the FST zone (Figure 9).

In FST sites, the occurrence of weather events conducive to insect larvae desiccation significantly decreased from February to April but spiked again in December or January of the subsequent year. Conversely, in northern savanna sites, the frequency of desiccation-inducing weather events became negligible by April or May, and gradually increased in October or November. This indicates that periods favourable for desiccation last more in the northern regions compared to the FST areas. January and February always portrayed the highest frequencies of desiccation-conducive weather events. Tengrela, Doropo, Ferkessedougou, Boundiali and Niakara registered the most desiccation-conducive events. These areas were less pest-conducive, in contrast to FST localities of Tanda, Bocanda, Bouaflé, Biankouma and Vavoua (Figure 9). Also, it is obvious that all the four studied years registered desiccation-conducive periods in the cashew zone, but the period from April to November were generally not constraining to insects.

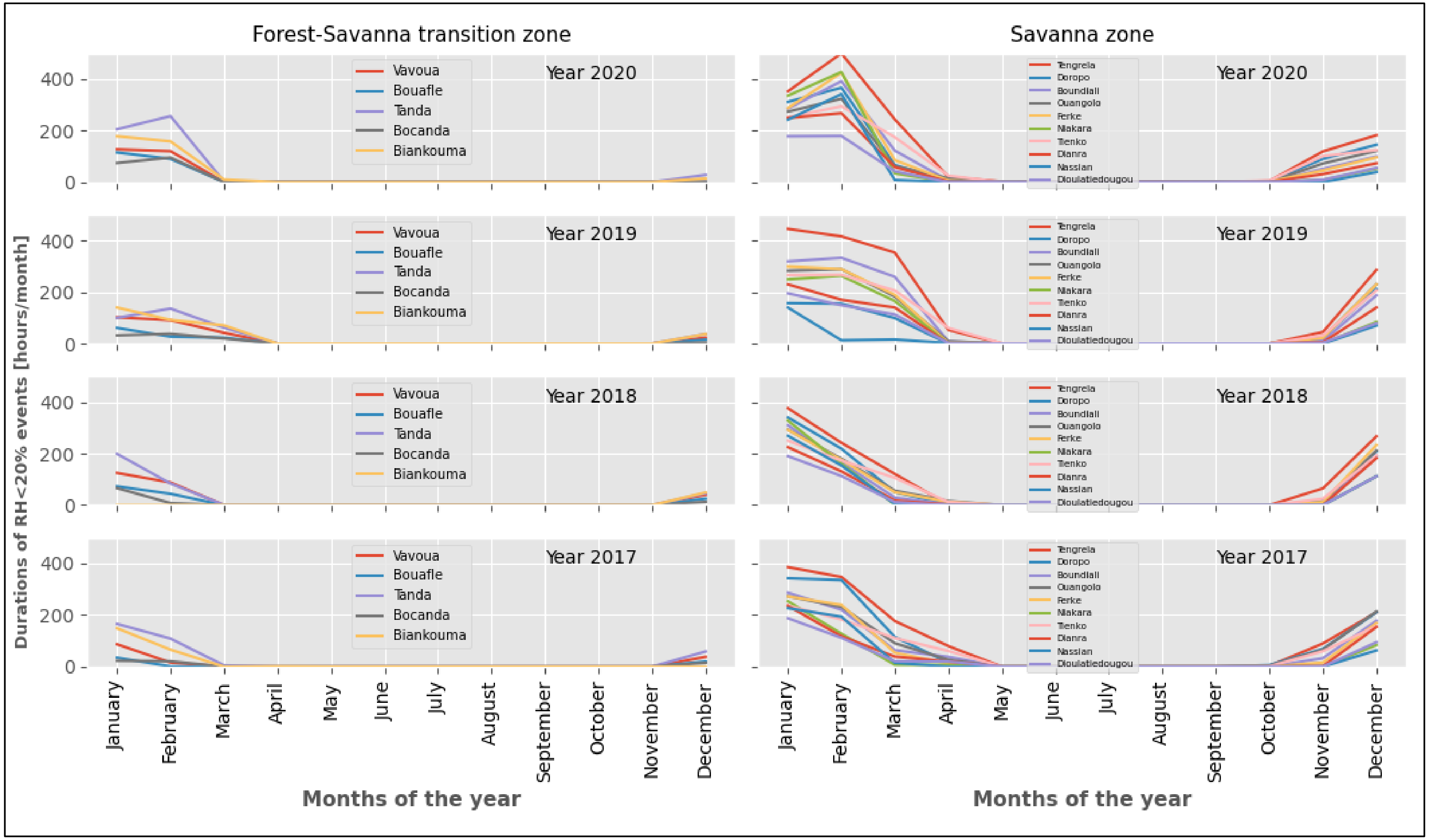

Figure 9. Monthly frequency of unfavourable weather events for insects' eggs and larvae.

3.4. Stakeholders' Recommendations

Based on the above results, stakeholders highlighted the cases (issues or opportunities) and recommendations in Table 2.

Table 2. Cases (issues/opportunities) and recommendations.

Submitted Key Information (KI)	Case (Issue or Opportunity) Highlighted by the Key Information (Case)	Recommendation (R)	Target Actor (TA)
KI-1: High temperature occurrences potentially limited fungi multiplication in the cashew zone.	Case 1: No case identified	R1: -	TA1: -
KI-2: Disease-conducive periods were identified at least once everywhere.	Case 2: Fungal diseases have the potential to thrive in the entire cashew production zone of Côte d'Ivoire due to favourable weather conditions.	R2: Promotion of integrated disease management strategies is recommended across the entire cashew production zone.	TA2: Farmers, research extensionists, plant pathologists, research donors, cashew sector decision makers
KI-3: Disease-conducive periods were intense and longer in FST areas comparatively to the northern areas.	Case 3-1: Disease-conduciveness varies over the areas. Still, the disease-prevention measures so far recommended, including cashew tree density, is the same for the entire cashew production zone. This is not appropriate, as disease risks are not the same everywhere.	R3-1: The disease-prevention strategies initially implemented in the savanna areas should be incremented for matching the higher risks of disease in the FST sites.	TA3-1: Farmers, research extensionists, agronomists, plant pathologists, research donors, cashew sector decision makers
	Case 3-2: In the FST zone, disease-tolerant cashew trees can naturally emerge due to the exposure of trees to multiple pathogens facilitated by the prevailing weather conditions.	R3-2: Cashew plant breeders are encouraged to select disease-tolerant genotypes in FST areas without doing artificial inoculation.	TA3-2: Cashew breeders and plant pathology specialists
	Case 3-3: The more disease-conducive periods are extended, the more reproductive stages (the most sensitive stages) of cashew trees may be exposed to pathogens. Cashew trees that flower and mature during short time windows in the dry season (when disease risk is at its lowest level) can escape the long disease-conducive periods.	R3-3: Cashew trees that can flower and mature in short time windows during the dry season should be selected and promoted in the FST zone	TA3-3: Farmers, research extensionists, agronomists, cashew breeders, plant pathologists, research donors, cashew sector decision makers
KI-4: Higher in-year variability of disease-conducive periods in the FST areas.	Case 4: In situations where disease attack periods exhibit high variability, it is typically advisable to implement a reliable alert system for tactically alerting farmers on disease management timing. Unfortunately, the existing technical guidelines for cashew production in Côte d'Ivoire suggest fixed and generalized calendar periods instead.	R4: Robust weather-based disease alert tools should be set up and promoted as part of Integrated Pest and Disease Management system of cashews in the FST areas.	TA4: Agrometeorologists, plant pathologists, research extensionists, farmers, research donors, cashew sector decision makers
KI-5: Pest might proliferate more easily in the areas than in the savanna zone.	Case 5: Pest attacks on cashew trees are more likely in the FST areas than in the savanna regions	R5: Robust and sustainable pest management strategies should be deployed in the FST areas	TA5: Entomologists, farmers, research extensionists, research donors, cashew sector decision makers
KI-6: Fungi can proliferate easily and simultaneously with insects in FST zones.	Case 6: When weather is simultaneously favourable to fungi and insects like in the FST zones, entomopathogenic fungi species can be used as biological control agents of pests.	R6: Entomopathogenic fungi species should be selected and used for sustainable pest control in the FST zone.	TA6: Entomologists, plant pathologists, research donors, cashew sector decision makers

4. Discussion

4.1. Occurrences of High Temperatures Probably Limiting for Fungi

The comparison of weather station-recorded temperatures and fungal thermal requirements evidenced occurrences of high temperature that are potentially limiting for fungi. However, as high air temperatures are generally mitigated in the tree canopies [30,31], whether this temperature barrier ultimately applies needs to be investigated in further studies.

4.2. Disease Management Strategies in the Cashew Production Zone

Leaf wetness duration results showed there were disease-conducive weather events everywhere in the cashew production zone of Côte d'Ivoire, but unevenly distributed in space and time. This is a sign revealing that disease can occur everywhere in the cashew zone, depending on the year. This result is in line with field observations carried out by [9] who observed disease attacks in almost the entire cashew production zone in at least one of the previous four years. Given this, stakeholders emphasized the need to promote integrated disease management strategies in the entire cashew production zone.

Compared to the northern regions, the forest–savanna transition areas were found to have longer periods conducive to diseases. But the technical guidelines [32] so far in use with farmers and research extensionists do not pay any attention to such difference between the savanna areas and the forest–savanna transition areas. For instance, it recommends cashew tree spacing to help mitigate cashew disease risks, but this recommended cashew tree spacing is the same (10 m $\times$ 10 m) for all sites [33]. Logically, as this tree spacing option was prescribed as a possible way to address the risk of diseases spreading, it should have been differentiated considering the contrasts between the agroecological zones. Instead of that, farmers are taught everywhere to plant cashew trees at a spacing density of 10 m $\times$ 10 m. Recommendations made in this regard are hence crucial for improving IPDM in cashew orchards.

Furthermore, the FST zone exhibited higher variability in disease-conducive periods. Hence, the use of fixed calendar periods for disease management as recommended by the guidelines can lead to inappropriate timings of field operations. This could mislead farmers to spend more money for fungicides, overuse chemicals, and even get low cashew yield because of ineffective disease-control timings like those reported by [6]. A disease forecasting system as a climate smart tool [34] can be developed to robustly optimize field operation timing [5].

4.3. Pest Management Strategies in the Cashew Production Zone

The analysis of the data did not provide direct information on the locations where insects, including pests, can thrive. Instead, it indicated the areas and times when they are potentially exposed to unfavourable weather conditions. As a result, it was understood that the northern regions were more restrictive than the FST areas. This suggests that the growth cycles of pests are less impeded by adverse weather conditions in the FST areas. These areas are thus more favourable to insects, including cashew pests. This result is in line with the findings of [35], who observed that the importance of pest attacks in cashew orchards increased from the Abengourou (southern) to Bouna (northern). Another element about an FST zone is its dual conduciveness for both fungi and insects. According to [36], such an environmental setting is the one needed for successfully applying entomopathogenic fungi for pest control. This is a climatic possibility that cashew entomologists and decision makers can explore for reducing the potential overuse of chemicals in the FST zone. As little is known about cashew pests' pathogenic fungi, specific research could be conducted for making this possibility exploitable in cashew pest management. Such research will undoubtedly require putting entomologists, epidemiologists, plant pathologists and agrometeorologists under the same collaboration roof.

4.4. Consistency of the Analyses

Given that the suggestions outlined in this study can assist in informing decisions within the cashew industry in Côte d'Ivoire, it is important to examine the advantages and limitations of the underlying approach. First, the 95% threshold of relative humidity and the 6 h leaf wetness duration used to define whether sites are disease-conducive were not set by local parameterization. From a disease-forecast perspective, this is an apparent limit. But in this exploratory study, it allowed simple comparisons of the sites of the cashew production zone in terms of their potential conduciveness to diseases and pests. The robustness of such an approach is seen through the alignment between the pest and disease surveys done, respectively, by [33,36]. Given this fact, stakeholders involved in this study felt confident enough to make recommendations. Moreover, for activities like disease forecasting using the leaf wetness model, we suggest model parameterization with both site-specific weather data and species-specific leaf wetness durations thresholds.

5. Conclusions

In this study, an investigation of hourly weather data unveiled spatiotemporal patterns of weather events that could potentially be conducive to fungal growth in the cashew production zone. Additionally, a second analysis was conducted to indirectly identify areas that are more favourable to pests, based on the desiccation predisposition of insects' eggs and larvae under dry conditions. Among other findings, it was seen that suitable weather conditions for fungi and pests are more important in the forest–savanna transitional areas than in the savanna regions. These outputs were used to generate recommendations from stakeholders for the implementation of integrated pest and disease management in Côte d'Ivoire's cashew orchards, resulting in the following recommendations:

i. disease-prevention measures including cashew tree spacing should be tailored, when possible, to the climatic conditions of the main agroecological zones. This means the current recommended planting density (10 m $\times$ 10 m) needs to be updated while considering that the conduciveness to pests and diseases is not the same everywhere;
ii. potential disease-conducive periods being of important variability, weather-based monitoring tools should be set up and promoted as part of an Integrated Pest and Disease Management system for cashews, demonstrating the need for close collaboration between weather specialists, epidemiologists, plant pathologists, research extension agents and farmers;
iii. early-maturing cashew genotypes that flower and mature in short time windows during the dry season should be selected and promoted in the forest–savanna transition zones. This will help avoid flowers and nuts being attacked by fungi;
iv. as the sites of forest–savanna transition areas are highly fungi-conducive, these sites are recommended to plant breeders for disease-tolerance experiments on cashew genotypes;
v. also, the forest–savanna transition zone being very suitable for both fungi and insects, entomopathogenic fungi species can be selected and used there for biological pest control. This will help mitigate the risks of environmental pollution related to pest and disease management.

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