Chapter

Impact of Climate Change on Plant Diseases and IPM Strategies

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Abstract

There has been a remarkable scientific output on the topic of how climate change is likely to affect plant diseases. Climate change influences the occurrence, prevalence, and severity of plant diseases. Projected atmospheric and climate change will thus affect the interaction between crops and pathogens in multiple ways. This will also affect disease management with regard to timing, preference, and efficacy of chemical, physical, and biological measures of control and their utilization within integrated pest management (IPM) strategies. Prediction of future requirements in disease management is of great interest for agro-industries, extension services, and practical farmers. A comprehensive analysis of potential climate change effects on disease control is difficult because current knowledge is limited and fragmented and due to the complexity of future risks for plant disease management, particularly if new crops are introduced in an area. Uncertainty in models of plant disease development under climate change calls for a diversity of management strategies, from more participatory approaches to interdisciplinary science. Involvement of stakeholders and scientists from outside plant pathology shows the importance of trade-offs. All these efforts and integrations will produce effective crop protection strategies using novel technologies as appropriate tools to adapt to altered climatic conditions.

Keywords: climate, change, plant, pathology, agriculture

1. Introduction

Climate change is a major concern for agricultural communities worldwide [1, 2]. The agricultural process consists of three main parts, pathogen, host, and environmental conditions, where the relation between them is the main key for the occurrence of infection from its absence (**Figure 1**), where climate change has great effect on all these factors. Changes in climatic parameters greatly affect crop production and susceptibility to pests as well as insect pest longevity. Climate change affects crop pests and disease susceptibility which in turn affects crop health, and these changes cause deviations in farming practices as to cope with the effects of these changes and to prevent a decline in productivity.

Agriculture is an economic activity which is highly reliant on climate and weather in order to produce the food and fiber necessary to sustain human life. Agriculture is, however, an activity which is extremely vulnerable to climate change.

The effects of climate change on agriculture are characterized by various forms of uncertainty. Firstly, there are uncertainties concerning the rate and magnitude

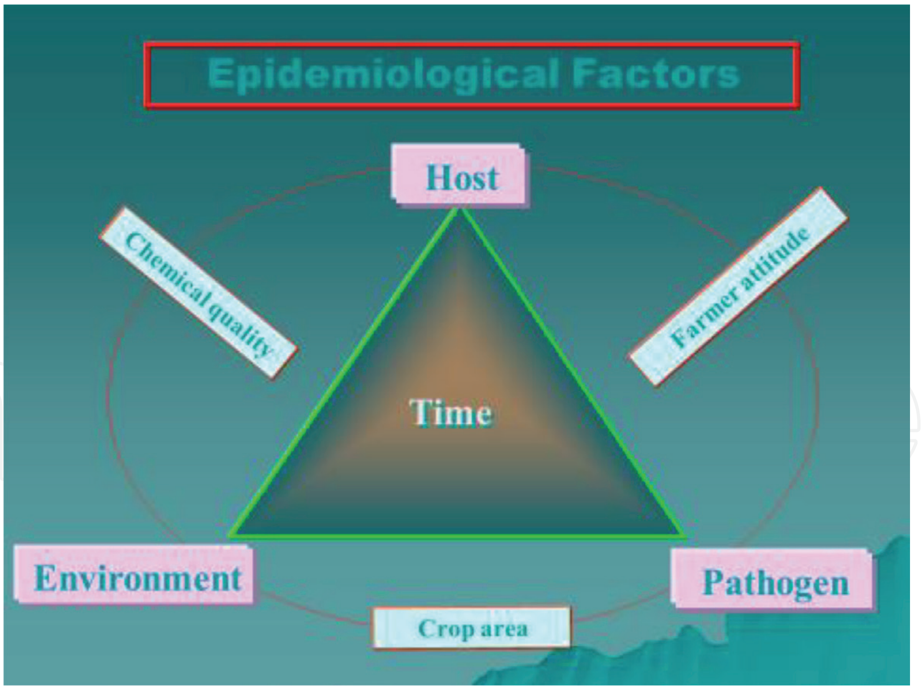

Figure 1.
The relation between the pathogen, host, and environmental conditions which are the main factors required for infections to occur.

of climate change itself. Secondly, there are uncertainties around the response of agriculture-based outputs, for example, with CO_2 fertilization. Thirdly, there are uncertainties as to how society responds or even the aptitude to respond to these expected impacts. Some aspects of climate change research are limited by these uncertainties. Most of these uncertainties cannot be quantified, causing a certain level of ignorance in our understandings of future climate change [3].

It is highly possible that climate change will affect food security at the global, regional, and local levels. Climate change can disturb and reduce food availability as well as lower food quality. For example, increases in temperatures, changes in extreme weather events, changes in precipitation patterns, and reductions in water availability could all result in reduced agricultural productivity. Prevalence of extreme weather conditions can also interrupt food delivery and result in increases in food prices due to low supply after extreme events, which are expected to be more frequent in the future. Moreover, increasing temperatures can contribute to spoilage and contamination.

There are four different future scenarios regarding climate change including A1, A2, B1, and B2. The A1 scenario focuses on rapid increases in global economic development, A2 focuses on rapid regional economic development instead of the global one in A1 scenario, B1 focuses on rapid global environmental development regarding agriculture, and B2 focuses on rapid environmental sustainability on regional and local levels.

2. Effect of climate change on plants and plant diseases

A major example for the devastating effects of climate change is floods caused by rising of sea level that can cause the disappearance of low-level lands and major crop losses. Another example is drought, where insufficiencies in water levels in the soil cause plants to lose their biological functions and even become more susceptible to diseases and pests. Climatic conditions contribute to the disease triangle, which involves the presence of a susceptible host, a pathogen, and suitable environmental conditions for infection to occur, and climate change affects environmental conditions whether it be in favor of the host or the pathogen. Examples of these conditions include dew, rain, relative humidity, temperature, aeration (wind), soil moisture, and sunlight intensity.

For any type of crop, the effect exerted by high temperature is highly dependent on the optimal growth and reproduction temperature of the crop. In certain regions, increased temperature may prove beneficial to the types of crops that usually grow there or permit farmers to switch to planting crops that grow in warmer areas. However, that is not always the case; if the higher temperature exceeds a crop's optimum temperature yields will decline, or worse, appearance and infestation of pathogens might occur. Crop yield can be affected by high levels of CO_2. A few laboratory experiments showed that high levels of CO_2 could positively affect growth. However, certain variables such as varying temperatures, water, ozone, and low nutrient levels may oppose these possible increases in yield. For instance, if the temperature is higher than a crop's optimal temperature requirement, if there are insufficiencies in water and nutrients, increase in yield may be low. Increased levels of CO_2 are linked to lower nitrogen and protein content in soybean and alfalfa plants, which results in a great quality reduction. Reduced forage and grain quality can reduce the ability of rangeland and pasture to support livestock which rely on grazing. Although rising CO_2 can stimulate plant growth, it also lowers the nutritional value of the majority of food crops. Rising levels of atmospheric carbon dioxide directly affect the concentrations of protein and essential minerals by reducing their content in a variety of plant species, which include rice, soybeans, and wheat. Therefore, the effect of rising CO_2 on the crops' nutritional value is considered a possible and indirect threat to human health as well. Moreover, due to the increased use and lowered efficiency of pesticides due to development of pest resistance, human health is additionally threatened by pesticide use as well as their residual toxicity in humans. More extreme temperatures and precipitation might decrease growth in certain crops. As previously mentioned, extreme events such as droughts and floods can decrease yield and damage crops. For instance, increased evening temperatures affected corn yield throughout the US Corn Belt. Additionally, premature budding due to a warmer winter instigated losses equivalent to $220 million of cherries in Michigan in 2010 and 2012.

Moreover, drought has developed into a major problem in regions with increased summer temperatures as this causes dryness in soils. Even though higher irrigation may be possible in certain regions, water supplies may be also lowered in other locations, causing a lower availability of water for irrigation when more is needed. Many weeds, pests, and fungi thrive under warmer temperatures, wetter climates, and increased CO_2 levels. Currently, US farmers spend more than $11 billion every year to control weeds, which compete with crops for nutritional resources. The ranges and distribution of weeds and pests are likely to increase with climate change. This could cause new problems for farmers' crops previously unexposed to these species.

Climate change parameters can have effects on both the host and the pathogen, for example, certain degrees of temperature promote pathogen growth, and certain temperatures can cause the host to have higher resistance to pathogenic infections. An example highlighting these events involves wheat and oats, which become more susceptible to rust diseases with increased temperature, while some forage species become more resistant [2]. Moreover, changes in temperature as limited as CO_2 changes could cause certain pests to undergo from 1 to 5 additional lifecycles per season, which increases the ability of the pests to overcome plant resistance.

Certain mycotoxins such as fusarium mycotoxins (produced by *Fusarium* spp.) have increased concentrations at harvest due to high humidity and temperature. Humid conditions also increase proliferation of weeds, and weed biomass increases with increasing temperatures.

Certain parameters can have different effects depending on plant physiology, for example, increased CO_2 levels can cause a decrease in plant decomposition rates, which results in higher fungal inoculum levels, and these concentrations may induce the production of more fungal spores. On the other hand, high CO_2 concentrations may cause physiological changes to plants, causing them to acquire higher resistance to certain pathogens.

Other extreme conditions may include low water levels and soil erosion which causes a decline in soil fertility and hence plant health.

Fungicide activity is also a major determinant factor; climate change may highly affect fungicide efficiency. Highly frequent rainfalls greatly impact the efficiency of contact fungicides, as rain has the ability to sweep and eliminate contact fungicides from the hosts' surface, rendering them ineffective. However, plants with high metabolic rates have increased intake of fungicides and aren't highly affected by this parameter.

In 2008, the International Food Policy Research Institute estimated that due to climate changes, by 2050, 25 million additional children will have malnutrition due to increased consumption of food products with little efforts done to adapt to and deal with these changes. In addition, the yearly costs to deal with the issue by reducing its impacts by 2050 will be $7 billion. It will generally be difficult to deal with international trade of crops due to appearance of unexpected pathogens more frequently (Food and Agriculture Organization of the United Nations, 2008).

3. Integrated pest management and mitigating pest management

IPM stands for integrated pest management, according to the Food and Agricultural Organizations (FAO) in the United States, IPM is an ecosystem approach involving crop protection which combines different strategies and practices toward growing healthier crops and minimizing the use of pesticides to protect the environment. It is an analytical method used to analyze the agroecosystem and its different elements in order to optimally manage these elements to control and minimize pests while protecting the environment and the economic health.

That is, the available methods of control (biological, cultural, chemical, and physical) should be considered and rationally applied by the farmers. However, IPM is more than just a tool and collection of control choices. It also comprises precaution techniques (which mainly include monitoring, prevention, early diagnosis, and forecasting) which assist in the control of pest populations as where data is collected, and preventive actions is recommended as explained in **Figure 2**. A significant part in IPM techniques is proper decision-making for any interferences. Every decision made must be justifiable both ecologically and economically. Consequently, control programs which involve systematic application of chemicals which may harm the environment are unacceptable in IPM processes. As an alternative, precedence is given to alternative control techniques as well as preventive methods. IPM has been applied in various countries and areas that differ in their natural, social, and economic circumstances in addition to their levels of agricultural expansion. However, advancement in crop yield and safety may be realized in any existing conditions through the implementation of IPM. The practice of IPM is not a strict and simple form of submission to regulations and rules, but it rather involves taking actions with environmentally friendly approaches through principles and approaches that contribute to the reduction of the use of chemicals and increasing food security to achieve agricultural sustainability. In order to make IPM as effective as possible, it should be modified to local conditions.

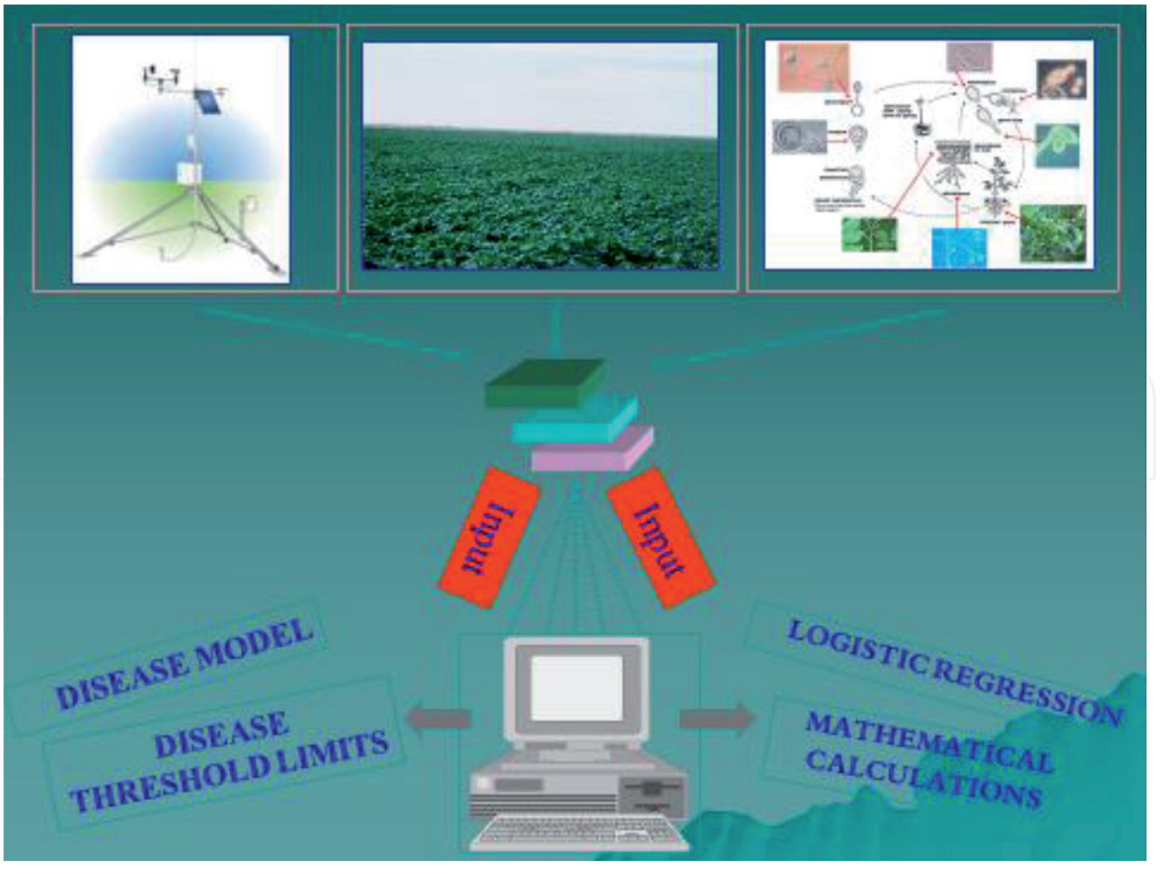

Figure 2.
The correlation between forecasting data input, pathogen studies, and environmental conditions as input and disease modeling to develop preventive measures.

The process does not involve a single pest management step, but a collection of pest management steps where decisions, evaluations, and control steps have to be made in order to successfully apply the chosen strategy. In IPM practice, farmers who understand the potential of pests when it comes to crop infestation follow a four-step approach. These steps include:

3.1 Setting action thresholds

Prior to taking any control decision or action, IPM first sets a threshold, which is a point at which the set of involved variable levels specifies that proper control actions must be made in order to control pest populations. Detection of a pest does not mean a certain control action is required. However, the detection of pests or variables at certain thresholds/levels is the determining factor. Therefore, the level at which pests could develop into threats is extremely important while taking pest management decisions.

3.2 Monitoring and identification of pests

A lot of insects, weeds, and other living organisms are not considered pests which require control. Most organisms are not harmful; on the contrary, some of them are useful. IPM programs are to accurately detect and screen for pests, so that proper management decisions can be made in combination with the action deciding thresholds. This process removes the probability that pesticides will be applied when there is no need for their use or that the incorrect type of pesticide will be applied.

3.3 Prevention

In order to achieve proper pest control, IPM programs are designed to manage the crop, lawn, or indoor space to prevent the appearance and development of pests. In the case of agricultural crops, this could mean using proper planting methods, for example, rotating between crops, planting resistant plant varieties, and the use of pest-free rootstock. These control techniques can be very useful and efficient in terms of cost and present lower risk to human health and the environment.

3.4 Control

Once the previously mentioned variables specify that control actions are needed and that protective approaches are ineffective, IPM programs then assess the appropriate control actions in terms of efficiency and risk. Efficient and low-risk control methods are considered first, including targeted and ecofriendly chemicals, such as pheromones which disrupt pest reproduction, or mechanical control, including trapping and weeding. If data generated by the previously mentioned steps specify that less risky management methods are ineffective, then further pest control attempts should be considered, for example, directed use of pesticides. The use of nontargeted pesticides is a less recommended alternative.

A lot of agricultural growers identify their pests prior to pesticide application. Less risky pesticides such as pheromones are employed by a lower subset of growers. In the end, a lot of these farmers are using IPM techniques. The objective is to make more growers use the proper IPM practices. Mostly, crops produced using IPM techniques are not recognized in the marketplace as organic crops. Growers who use IPM practices have no national certifications in certain countries. Due to the complexity of the IPM pest management techniques, it is not possible to use a single IPM description for all crops and all regions of a country. Many growers of certain crops including strawberries and potatoes are attempting to define what IPM means in their crops case as well as the region of growth. Moreover, certified IPM crops are unavailable in a lot of regions. With definitions, farmers can start to market their crops as IPM-grown, which would give consumers alternative and better options while purchasing their food.

The previously mentioned processes of IPM have been redefined and modified over time, and the IPM pyramid was created to provide an easier understanding of the approach. The IPM pyramid consists of three main processes which include preventive or indirect crop protection, risk assessment or monitoring, and responsive or direct crop protection. The three processes aim to increase the efficiency of each step involving crop breading and maintenance. Preventive crop protection involves the use of certified seeds, cultivars which have high tolerance to pathogens, and enhancement of natural enemies of plant pathogens such as microbiological competitors. Risk assessment and monitoring is the most crucial process in IPM; it involves the use of an early warning forecast system which provides information related to current climate and how it could affect plant health and by using such information and understanding plant physiology and susceptibility to pathogens; one can determine timeframes where plants are most susceptible to pathogens and take countermeasures to prevent or minimize pathogen severity (e.g., through the use of fungicides). Direct crop protection basically involves the countermeasures taken to deal with unfavorable conditions, which include the use of antagonistic microorganisms or application of fungicides.

A simple example for how an integrated system for pest management can be created as illustrated in **Figure 3**; generally in order to create such a system, the main information needed include weather data, crop, and disease information. Through knowing the weather data, which is most commonly obtained from meteorological

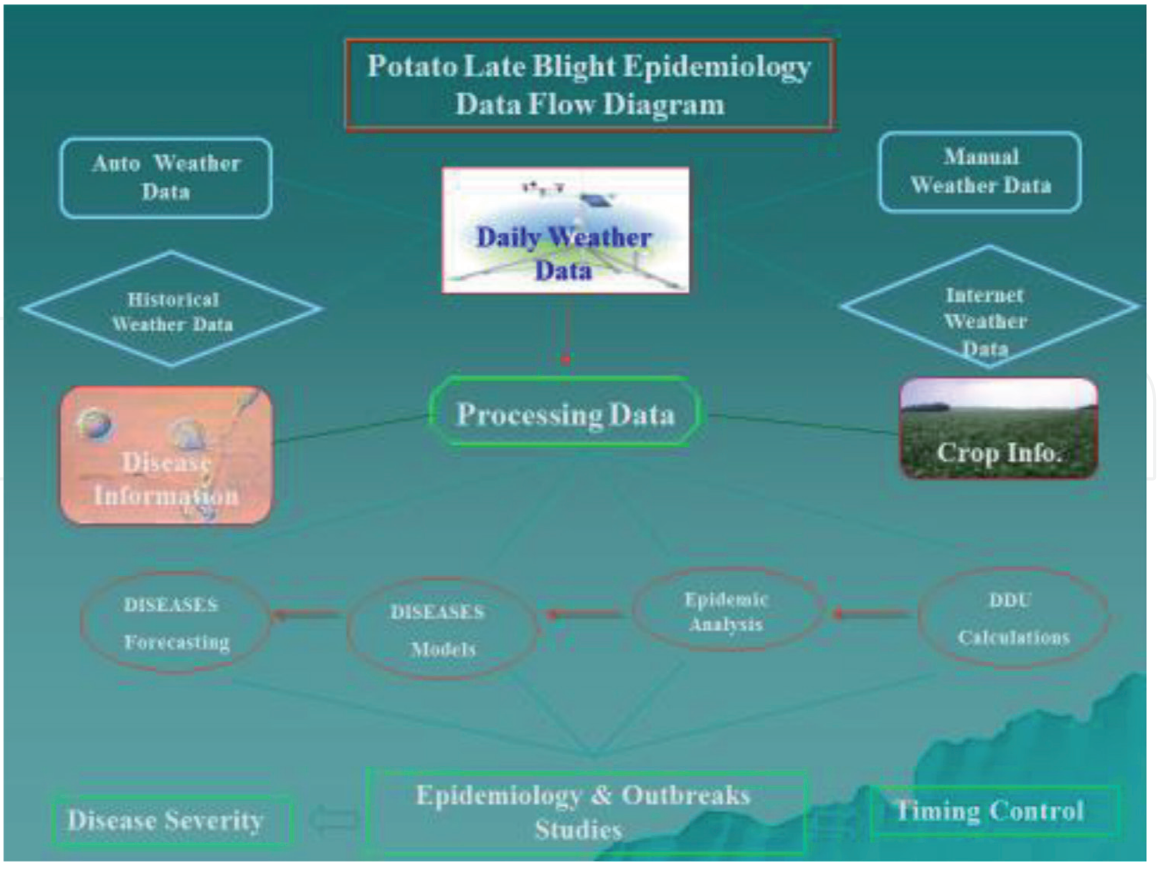

Figure 3.
Example of pathogen epidemiology system in potato late blight and its integrated components.

stations to obtain micro environment weather data and not that of the macro environment, macro environment data can still be used using certain equations to relate to the micro environment. This would allow the prediction and knowledge of current and upcoming weather conditions, in hand with obtaining information about the crop as in which pests affect the grown crops, optimal growth conditions, and lifetime as well as obtaining specific disease information for diseases which have the capability of affecting said crops. One can create a forecasting tool which helps prevent the spread of certain diseases.

After obtaining information about the disease, in order to create a disease model, its efficiency is determined through several tests. The general scopes of these tests would be the difference between disease spread and crop loss before and after the implementation of the model. Did delaying the use of pesticides until the threshold point for disease spread determined by the model actually cause a positive difference or was the threshold inaccurate? Was there a noticeable increase in crop yield after implementation? Was there any human error in pesticide management and spraying timelines? Several questions can be answered, and through these answers, the efficiency of the model can be determined.

There are several advantages for the use of IPM in mitigating agricultural problems which include:

Slower development of resistance to pesticides: Pesticide resistance can be incurred by the repeated use of pesticides; this would occur if a farmer is using traditional farming methods as pests would develop resistance to the pesticide due to repeated exposure to the pesticides through development of resistance by natural selection; then the resistant genes would be transferred to the offsprings, incurring permanent resistance to a given pesticide. However, this would not occur with reduced and efficient application of pesticides which is a main strategy adopted by IPM systems.

Maintaining a balanced ecosystem: Increased use of pesticides might affect non-target and beneficial organisms; if these organisms are wiped out, the ecosystem will suffer and in turn results in species loss. IPM eradicates pests while minimizing the damage dealt to nontarget species.

Better cost vs. value: Since pesticides incur the highest cost for a farmer during a growing season. Reducing the use of pesticides proves more cost-efficient on the long run than the price for equipment used to determine thresholds, weather conditions, and application of IPM strategies. This is due to limited and efficient pesticide application.

The disadvantages of using IPM strategies include:

More involvement in the technicalities of the method

All individuals involved have to be educated about the available methods and importance of IPM.

Time and energy consuming

IPM strategies are critical strategies; failure to proceed with certain decisions during the IPM process can prove fatal to the entire process due to the need of different control methods for different pests and the need to monitor the application process.

4. Decision support system (DSS)

In order to produce an efficient model, understanding the decision support system is essential. The decision support system is an informatics tool which uses mathematical models such as equations and statistics to help the decision-maker take action. The three main phases of a decision-making system include intelligence, design, and choice; two other subsequent phases include implementation of the decision and monitoring of its effect and outcomes. The decision-making process in IPM is highly complex and dynamic; it requires a high level of organization and constant update of operators; it requires the presence of databases and means to collect data and information as well as tools to handle data. The decision-making process generally provides the capability to identify when difficulties may occur and how to deal with these difficulties depending on data provided.

The main properties of a successful DSS include ease of use, presentation format, system restrictiveness, decisional guidance, feedback, and interaction support:

4.1 Ease of use

A DSS system is only beneficial if users perceive a DSS to be easy to use and that using it enhances their performance and productivity. The system should be easy to operate and interact with and requires minimal cognitive efforts; to sum up it should reduce mental effort and time consumed to analyze data and increase comfort of the user.

4.2 Presentation format

The way information is presented through the program/system may influence the user's judgment/decision; therefore, the way information is presented through the decision support system should be focused on showing key data in an accurate and favorable format.

4.3 System restrictiveness and decisional guidance

These refer to how much a DSS limits the options of the user and to which extent it guides the user toward a certain decision. A good DSS provides a reasonable amount of options within the scope of the topic/field at hand, as well as ample guidance to perform the optimal decision and achieve the most beneficial outcome.

4.4 Feedback

The way the system provides messages and the wording of certain commands is important because they promote positive user experience and enhance the decision-making process.

4.5 Interaction support

Interaction support means that users are permitted a particular level of interaction with a DSS. The DSS design is the determining factor on the presence as well as the level of interactivity between the user and the system. Users may have control over the system when a certain level of interaction support is present. The received control over the use of a system may have a motivational effect on its use.

The system involves an integration of certain components and interacting factors with a common objective. In the case of pathogen monitoring, a pathogen monitoring system would basically receive input based on environmental factors and properties, and the output is expressed in the form of maps, information, and graphs. The system would then, based on information provided by threshold charts for pathogen favorable growth conditions, give out options that would determine the best possible course of actions in order to prevent disease outbreaks and crop loss.

With this, an integrated model is illustrated. Although the systems are accurate, the main drawbacks include maintenance needs of meteorological stations, the requirement of different systems with different parameters depending on the type of plant, and disease as well as their growth conditions and application of these processes in farms which could be a difficult task due to old farming traditions.

4.6 Forecasting and early warning system

Forecasting of pests and diseases appearance in plants is an additional application that demands a consistent and dependable stock of weather data. There are huge losses in yields due to pests and diseases prevalence which could have been controlled in several situations if the appropriate forecasting techniques were available. Consequently, the forecasting and early warning system, within the Plant Pathology Research Institute of the Agricultural Research Center, was established in the same timeframe of system and climate change applications in agriculture.

Prediction of pest, disease prevalence, and progression based on weather data is extremely crucial when planning and implementing control measures.

The idea of forecasting and early warning system has been introduced in 1926; with the appearance of computers and information technology, softwares were developed in order to produce convenient warning systems. Currently, early warning systems are being used to deal with pathogens of certain crops such as faba beans. The main concept involves the use of a mobile telemetry automated weather station system to monitor environmental conditions and softwares to interpret the input; based on the information provided, a decision can be made regarding the protection and maintenance of plant health.

An early warning system is shown in **Figure 4** which is used to predict and prevent the development of chocolate spot in faba beans that has been developed by Dr. Sahar Zayan, Head of the Early Warning Unit, Plant Pathology Research Institute [4].

A set of computer programs have been successfully produced by the unit's work team, and some of them were applied on crop databases in different governorates. These programs have proven to be successful early warning systems, as they predicted the appearance of diseases before infection and before they reached the epidemic level as well as the reduction of the amount of fungicides used for disease resistance.

The first computer simulation model for prediction of late blight in potato was being produced in Egypt by Prof. Dr. Mohsen Abd El Razek Afifi and Dr. Sahar Zayan in the forecasting and early warning unit in the plant pathology research institute, Agricultural Research Center. The model was applied in the fields, and it produced results which assisted in the protection of the potato crops from infection and the reduction of pesticide application periods which was equivalent to 75% in certain regions.

After the construction of the first Egyptian computer model, the creator named it EGY-BLIGHTCAST, and its efficiency was verified in all the computer laboratories (Workstations) as well as the field conditions by the potato producing private sector companies [5]; the model was applied in 1998 and 1999, and it preserved the crop from the risks of epidemic infection; pesticide savings reached 50% in a season and 75% in another, and the productivity increased by a ton and 300 kilograms per acre which was denoted in official reports by the applying company. Afterward the model was developed in 2002 and 2003; it was used in different regions (hotspots of late blight on potato crops) in the main governorates for potato production in Egypt throughout 2004–2008; the methodologies for prediction of late blight were linked and modified based on short-term observation.

Throughout several growing seasons of potato and the analysis of the relation between 24-hour meteorological data which were collected in real-time from the forecasting station (AdconTelemetry A733) and its effect on the possibility of daily infection by diseases triggered by late blight, it is possible for the EGY-BLIGHTCAST (DDIP) model to accurately predict the outbreak of the late blight disease and to drastically reduce the cost of necessary fungicide to control the outbreak when compared to routine spraying programs (schedule based programs)

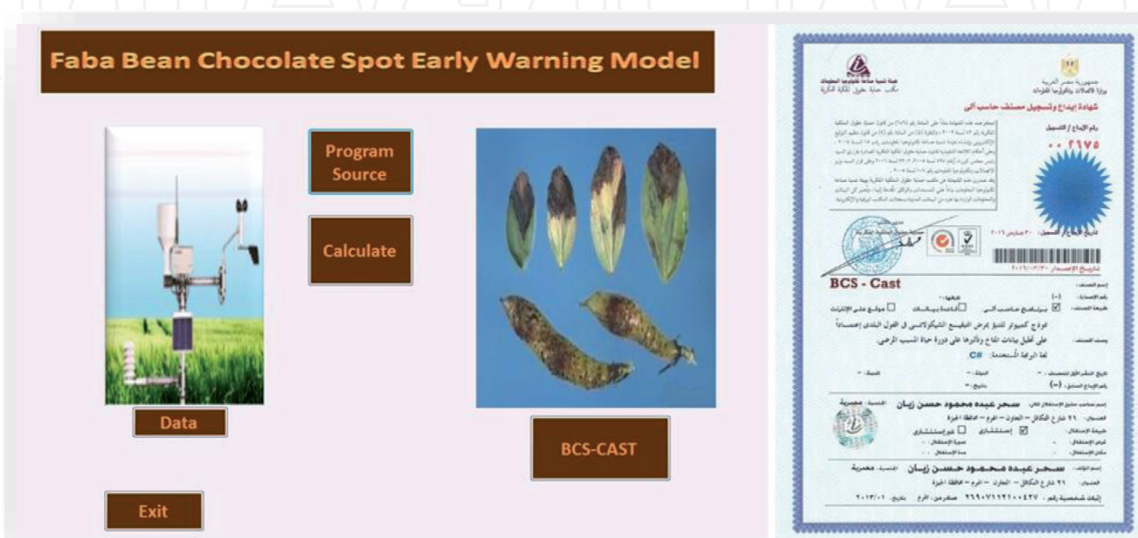

Figure 4.
A certified early warning system for faba bean chocolate spot [4].

in light of the field conditions. The main roles for the analysis of the model validation system were discussed through a study which was published in the year 2009. Moreover, several computer simulation models were produced on the same basis for a number of important diseases on strategic crops in Egypt, including downy and powdery mildew in grapes—downy mildew in onions and early blight in tomatoes. All of these forecasting models were applied in test fields, and their efficiency in disease prediction was proven as well as the actual savings in application of pesticides used in disease control.

In the year 2015, the system and model production techniques were developed by Dr. Sahar Zayan, and a study was published for a computer model for brown spot on beans which received an Intellectual Property Rights (IPR) license from official authorities in Egypt [6].

With the appearance of climate change phenomena, farmers and decision-makers will need more decision support systems especially plant disease forecasting systems.

Thanks

I would like to thank my team who helped me in developing this work.

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