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Research paper

Bayesian network for decision-support on pest management of tomato fruit borer, *H. armigera*

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Abstract

Fruit borer (*H. armigera*) is the key pest of tomato, a prominent vegetable crop grown in northern plains of India. Timely availability of decision-support to the farmers on 'whether and what management option is required' is imperative for effective pest management. For decades, the pest economic threshold level (ETL) has been the basis to select an appropriate pest management option. This process requires quantitative information about pest activity, which needs to be scientifically observed in the farmers' fields. However, a large section of the farming community is not able to scientifically obtain this kind of information. Moreover, in current pest management, decision-making depends upon a large range of agro-ecological information, besides pest activity. In this study, a Bayesian network-based method/model was devised for the selection of an appropriate management option for the effective management of fruit borer in tomato crop, based on tentative agro-ecological information, beside pest activity, that farmers provided. Thus, the resulting method can be used in decision support systems of agriculture with applies information and communication technology to automate and speed up the process of providing pest management decision-support to the farmers.

Keywords: *Decision-Support; ETL; Fruit Borer (H. Armigera); Tomato; Pest Management.*

1. Introduction

Tomato (*Lycopersicon esculentum* L.) is one of the most important vegetable crops, which is grown in the northern plains of India [1]. Short duration and high yielding crops are important for an economic point of view. The production and productivity of tomato are severely hampered by various insect-pests infesting at different stages during the crop growth. The key insect-pests of tomato include thrips (*Thrips tabaci, Frankliniella sp*.), an aphid (*Myzus persicae, Aphis gossypii*), white fly (*Bemisia tabaci*), tobacco caterpillar (*Spodoptera litura*), leaf through minor (*Liriomyza trifolii*), and fruit borer (*Helicoverpa armigera*) [13]. Out of these insect-pests, fruit borer is the major constraint in higher production and productivity of tomato in the region. In spite of regular spraying of insecticides, fruit borer causes considerable crop loss up to 32% [14].

Decision-making is the core of effective pest management [11]. Whenever a farmer notices any pest activity in his or her field, he/she has to decide 'whether and what pest management action is required based', on the level of pest activity. The farmers' major concern regarding pest management is timely availability of decision-support on 'whether and what pest management action is required'. In the absence of knowledge and expertise, farmers are over dependent on pesticide dealers for pest management decision-support in the country, which results in excessive, injudicious, and irrational use of chemicals in the pest control. This not only degrades the environment, but also affects human health due to the retention of pesticide residues in vegetables [17]. Presently, agricultural decision support systems (DSSs) which use information and communication technology (ICT) and which are available in the country provide pest management decision-support to the farmers on the basis of the pest economic threshold level (ETL), by collecting scientifically-observed quantitative information about pest activity from farmers' fields [15]. Nevertheless, a large section of the farming community is neither qualified nor trained to obtain this kind of information. Hence, in the study, a Bayesian network (BN) based method/model has been developed to overcome this problem of decision-support to the farmers. The method could be used in ICT-based agricultural DSSs for the selection of an appropriate pest management option, on the basis of tentative information about agro-ecological factors affecting the pest activity. The BN approach has been effectively used in ecological decision-making, but only few experiences of its usage have been conducted in pest management [9].

2. Material and methods

A variety of agro-ecological factors affect pest activity within the field, but domain experts and earlier studies have reported the presence of natural enemies and unfavorable weather conditions (e.g., temperature, relative humidity, etc.) as the most important. The conditions of the crop, along with the level of pest activity, determine whether and what pest management option needs to be applied [4]. Therefore, Meteorological Standard Week (MSW) wise data records of tomato fruit borer pest activity, weather features and the population of natural enemies (spiders only) for 2012-13 and 2013-14 were obtained from the government institution working within the field of plant protection. These data records were collected form ten farms belonging to major tomato growing villages of Patiala district. Geographically, Patiala is located at 76.3°E longitude and 30.3°N latitude in the state of Punjab, India. Weekly observations of pest activity and natural enemies were recorded from two fixed farmer fields (each near to one acre) selected from each village during the cropping season (October to March) of tomato. In each farm, five spots were selected randomly, four in the corners at least 5 feet inside of the field borders and one in the center of the field. Five random plants from each spot were chosen for recording observations. Fruit over activity was recorded in terms of percentage of bored fruits. Studies have reported a variety of natural enemies attacking *H. armigera* at different stages of its life cycle, but spiders are one of the most important predatory natural enemies of fruit borer, *H. armigera* [12], which were found throughout the region. Population of spiders was recorded on a whole plant basis. However, in the region data, records revealed very scarce presence of spiders that could have had the negligible effect on the pest activity. This may be due to the indiscriminate use of chemical pesticides by the farmers. The maximum temperature was found as the most significant factor affecting the pest activity. This result was ascertained through the correlation analysis. The maximum temperature demonstrated a positive and strong role (r= 0.5082 and 0.5393) during the years in enhancing the *H. armigera* fruit infestation. Relative humidity (RH) did not show any significant correlation with pest activity. Using these data records as well as the expert elicitation, the BN-based model for decision-making about the selection of an appropriate insect-pest management option was constructed.

2.1. Bayesian network

BNs emerged from research into artificial intelligence, where they were originally developed as a formal means to analyze decision strategies under uncertain conditions [18]. BNs are probabilistic graphical models and consist of 'nodes, that represent a set of random variables, and 'links, that represent their conditional interdependencies (cause-effect relationship) via a directed acyclic graph (DAG) [3], [10]. [10]. The values of the nodes are defined in terms of different and mutually exclusive 'states' [8]. A BN can include different types of nodes: 'nature' nodes, 'decision' nodes, and 'utility' nodes. Nature nodes are variables that can be controlled by the decision-maker's actions, and represent the empirical or calculated parameters and the probabilities that various states will occur. Input nodes (i.e., nodes without parents) can either be structured as constants or categorical states with associated marginal probability distributions. A decision node represents control variables or events that can directly be implemented by the decision maker. These nodes typically represent the suite of available management actions. Decision nodes should always be accompanied by utility nodes. These utility nodes represent the value of the decisions or outcomes. A utility node can be linked directly to the decision node [7]. Decision nodes do not have probabilities associated with them. BNs that represent and solve decision problems under uncertainty are also known as Bayesian decision networks [16]. As BNs are causal, they can also be used to calculate the effectiveness of interventions, such as alternative management decisions or policies.

A BN is a pair (G; P) [5], [6], [10] where

- G = (V; E) is a DAG whose set of nodes V = {X1, X2…Xn} represents the system variables and set of arcs E represents direct dependencies among the variables;
- P is a set of conditional probability distributions containing a conditional probability distribution P (Xi/pa (Xi)) for each variable X given the set of parents pa (Xi) in the graph.

The joint probability distribution over V can be recovered from this set P of conditional probability distributions applying the chain rule as:

$$P(X1, X2 \dots Xn) = \prod_{i}^{n} P\,(Xi/pa\,(Xi)) \quad (1)$$

The process of obtaining the probabilities of a BN can be done either manually, from experts' knowledge on the domain, or automatically, from databases [4].

3. Results

On the basis of the relationship between the key factors influencing *H. armigera* pest activity and its management options, a BN structure was established (Figure 1) wherein pest activity, weather (i.e. Maximum temperature, presence of spiders, and crop condition were identified as nature nodes, and pest management option was identified as decision node.

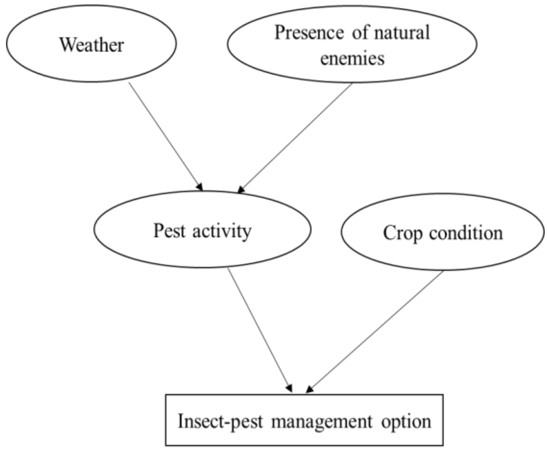

Fig. 1: BN Structure for Pest Management.

The arcs indicated the general direction of cause-effect relationship. Based on the analysis of data records, expert consultations, and the numerical definitions that Table 1 provides, all the nodes or variables of the model were discretized.

Table 1: Description of the Nodes´ States in the Bayesian Network

Node name	Definition	State
Weather	Standard weekly maximum temperature.	Warm: >= 18 0C. Cold: < 18 0C.
Presence of natural enemies	Plant wise weekly population of spiders.	Moderate: >= 2.0/plant. Low: < 2.0/plant.
Pest activity	Percent fruit damaged by *H. armigera*.	High: >=4% damaged fruits/plant. Medium: >=2% and <4% damaged fruits/plant. Low: <2% damaged fruits/plant.
Crop condition	Crop health in the field.	Good & Poor (randomized).

The BN model for *H. armigera* was built using the Netica software (Figure 2). The relationships in the BN are conditionally probabilistic rather than deterministic, except for the utility node.

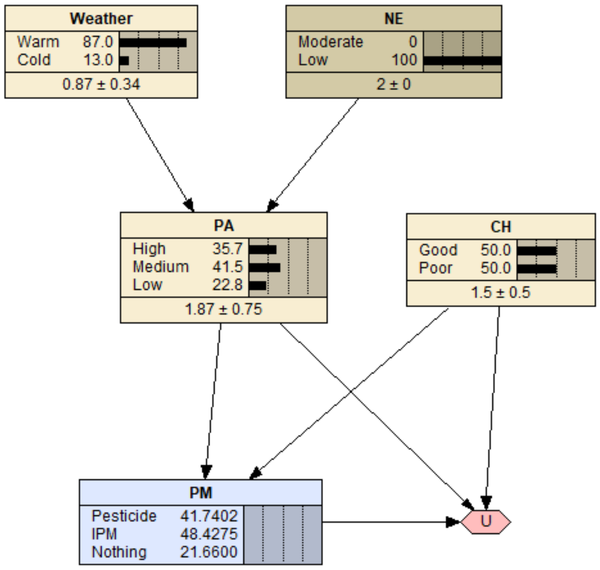

Fig. 2: Bayesian Network for Selection of *H. armigera* pest Management Option.

3.1. Evaluation of model

The evaluation of the model helps to ensure the accuracy and feasibility of the outcome. The model should be evaluated according to the purpose and objective of the exercise. The accuracy of the model should be tested against empirical data, but in many cases, these data are not available, at least not voluminously. If data on the system are limited or unavailable, qualitative forms of model evaluation, such as a peer review, are valuable [2].

The performance accuracy of the model was measured with *H. armigera* pest activity and weather data records of the selected region available for year 2015-16. Maximum temperature was found as the variable having the most influence on the pest activity that is an important variable of the model in the selection of a pest management option. The behavior of pest activity was tested by applying input values of temperature whereas the value of the presence of natural enemies remained scarce. The software generated probabilities for level of pest activity, which were compared with its true values; the outcomes were found reasonable and logical. The model produced 60% of accuracy. Thus, the pest activity level probabilities which were generated by the model and the crop condition randomized probabilities were propagated through the model to select an appropriate management option. The BN was also qualitatively evaluated in a meeting involving domain experts, where the model and its results were presented and discussed. The reviewers were satisfied with the results produced by the model as it was intended.

4. Conclusion

In brief, the BN results were very near to satisfactory. The BN is supposed to be a part of an ongoing iterative model development process, which will be advanced as more knowledge and data relevant to tomato fruit borer activity are available. The BN which was presented would be considered an initial level of the model which would be further updated. As a result, the final model, which will be developed and validated, can be can be used in ICT-based agricultural systems to provide real time pest management decisions-support to farmers.

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