A MATRIX MODEL FOR INTEGRATED PEST MANAGEMENT AS A COMBINED FUNCTION OF EXTENSION EDUCATION AND ECONOMIC CONCEPTS: SCIENTIFIC NOTE

Mohunnad Massimi[1], Laszlo Radocz[1], Edep Tito[2], Mariem Boukhili[2], Flaviana Marce[2], Philemon Gyamfi[2], Andrea Cheradil[2]

[1]Kerpely Kálmán Doctoral School of Horticultural Sciences, Institute of Plant Protection, University of Debrecen,
[2]Master Program of Institute of Plant Protection, University of Debrecen

Correspondence: mohunnad.massimi@agr.unideb.hu

Abstract: *The Farmer Field Schools (FFS) help to establish the significance of the Integrated Pest Management (IPM) concept, i.e., the FFS contributed to demonstrating the importance of the IPM idea. In this paradigm, the integrated pest management specialist's decision is based on the application of agricultural extension and economic principles. This requires an analysis and understanding of the ecosystem and plant physiology, followed by monitoring the population dynamics of the pest to determine the pest's economic injury level, and finally, determining the appropriate action to suppress it. The transition point from organically integrated pest control measures to chemical pest control is when pest density exceeds economic injury. In other words, when pest density surpasses economic damage, an organically integrated pest control approach gives way to the chemical pest control method. This study advises conducting research experiments and studies to ascertain the economic impacts of pandemic pests on the targeted crop, such as powdery mildew and aphid pests in the protected tomato plant culture.*

Keywords: *Economics, Extension, Integrated Pests Management*
(JEL code: Q16)

INTRODUCTION

Plant health professionals should implement integrated pest management (IPM) strategies. The implementation of IPM is divided into two sections, it is a two-part approach. The first approach incorporates all the procedures before the pest population intensity level reaches an economically significant threshold (ET). The second section/approach is based on the use of chemical pesticides when the economic injury level (EIL) is exceeded. The integrated pest control expert should create a model incorporating agricultural extension skills and economics. The proposed model considers economic concepts and is the primary motivator for an extension expert in integrated pest control to select an extension technology to prepare farmers for adoption.

(MASSIMI et al. 2021) stated that the integrated pest management philosophy is a new form of an agricultural extension developed by the World Food and Agricultural Organization (FAO) under the name of Farmers' Field Schools (FFS). Farmer field schools and integrated pest management are extension projects that deal with the management of technology transfer, training and development techniques. Transfer of technology refers to the entire process of developing, processing, disseminating, and integrating technology through research, extension, and farming systems while keeping in mind the society's resources, organizational limitations, and abilities to solve problems. On the other hand, training is concerned with imparting skills for specific purposes. It is the process of educating growers to make them fit, qualified, and proficient in performing a specific task. Development refers to the direction of change instilled in employees through the training and education process (KARTHIKEYAN et al. 2007). This scientific note attempted to create a model in agricultural extension for plant protection and integrated pest management experts using a farmer field school framework.

The concept of intensive agricultural horticulture contributes to the significance of this model. The ability to maximize crop yield and profit per unit area in a relatively short time is the defining feature of intensive horticulture. The Rural Planning Project Queensland Farmers' Federation (QFF, 2015) has documented a close definition of the economic investment and protected horticulture segments. However, intensive horticulture in developing countries showed the widespread use of chemical pesticides, chemical fertilizers, exogenous growth regulators, and early mature varieties. Intensive horticulture is protected under optimal environmental conditions. Due to space and time constraints, crop rotations are not possible in intensive horticulture. The same scientific source mentioned above contradicts the current paper's opinion that intensive horticulture does not use chemical pesticides. This may sound true, but not in developing countries, at least.

According to the Entomological Society of America (handbook of soybean insect pests), both economic injury level and economic threshold are defined as follows (HIGLEY and BOETHEL, 1994):

1- Economic injury level: "the smallest number of insects (amount of injury) that will cause yield losses equal to the insect management costs".
2- Economic threshold: "the pest density at which management action should be taken to prevent an increasing pest population from reaching the economic injury level".

EILs are typically expressed as a pest density and are derived from yield-loss relationships discovered in field research studies. The EIL has been described as the break-even point and the level of pest a plant can tolerate. The main goal is to manage the pest population before it reaches the EIL. This is where the ET enters the picture. The ET is a practical rule that is used to determine when management action should be taken. The ET is sometimes referred to as the action threshold. The limiting imaginary line between the two levels is the boundary between intensive gardening based on chemical treatments and other protection measures such as prediction, preventive practices, and technical, physical, and biological control tools.

To illustrate the economic concepts, consider the powdery mildew disease on cucumbers. Powdery mildew caused by Sphaerotheca fusca was studied on cucumbers to determine the economic injury level and yield response. The economic threshold was determined by grading the disease severity of powdery mildew based on the relationship between disease severity and yield response. Cucumber yields were reduced overall as disease severity increased. As a result, the presence of powdery mildew harms cucumber yield. $Y= -57.237x+6143.1$ was found in the regression equation between disease severity and yield loss. Based on yield and economic relations, this equation suggests that the disease severity of the economic threshold is 17.6 %, which is a 3% reduction point of yield. These findings suggest that fungicide should be applied when 1 or 2 cucumber leaves are infected with powdery mildew in the growing season (KIM et al. 2006).

Soybean aphids serve as another instance of economic issues being illustrated. (RAGSDALE et al. 2007) found that the average economic threshold (ET) was 273 ±38 aphids per plant of soybean. This ET provides a 7-day lead time before aphid populations are expected to exceed the EIL of 674± 95 aphids per plant. Soybean aphid, Aphis glycines Matsumura (Hemiptera: Aphididae), reached damaging levels in most northern U.S. states and Canadian provinces in 2003 and 2005 in soybean, Glycine max (L.) Merrill, and has become one of the most important pests of soybean throughout the North Central region.

The goal of this scientific note is to create a model that integrated pest management experts can use. By combining the concepts of agricultural extension and pest population economic levels. This model can be applied to a variety of pests that infect crops. Particularly in intensive horticulture. An integrated control program for powdery mildew and aphids on tomatoes will be proposed.

METHODOLOGY

This scientific note is based on the steps outlined below:

1- The scientific concepts of agricultural extension and agricultural economics were converted to smart diagrams and graphs (Figures 1-3) using a set of academic references (MASSIMI et al. 2021) and (HIGLEY and BOETHEL, 1994) and Microsoft Excel Spreadsheet Software (Microsoft 365).
2- A bio-ecological description of tomato plants in protected cultivations is being presented (different stages of development, as well as ideal temperatures and relative humidity) (Table 1).
3- Powdery mildew (*Leveillula taurica*, and *Oidium neolycopersici*) and aphids (*Aphis gossypii*, and *Myzus percisae*) were chosen for this study. Under favorable environmental conditions for tomato plant growth, the likelihood of the emergence of these pests is extremely high.
4- These two pests have been targeted with integrated pest management (IPM) suggested protocols. All possible controls (forecasting, preventive, technical, physical, biological, and chemical) are considered, assuming imaginary economic levels.
5- This scientific note is not based on research or experimental evidence that establishes economic thresholds for specific pests. But this study is significant for academics because it focuses on how to integrate extension and agricultural economics concepts within IPM frameworks.

RESULTS AND DISCUSSION

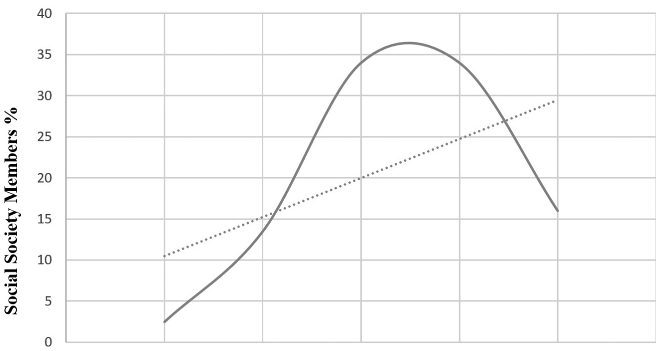
Integrated pest management, integrated plant protection, or integrated crop production is a program and a set of steps that can be used to combat any pest, beginning with technical methods, and progressing to physical, biological, and finally chemical methods. Chemical control is the last remedy after all other methods have failed to control the pest. Mulch, for example, is used as a technical control, deep ploughing is used as physical control, and natural enemies are used in biological control. Through an integrated analysis of the agroecological and biological systems, an integrated pest management program for any pest can be prepared.

The agricultural extension follows a specific mechanism to implement any control technique based on the various segments of society. The curve in Figure (1) depicts the normal distribution of rural community segments in terms of innovation adoption. Over time, as technology is adopted, the proportion of community members (social system members) is divided into the following types and proportions:

- 2.5 % are innovators.
- 13.5 % are early adopters.
- Early majority is 34%.
- 34% have a late majority.
- 16 % laggards.

Any technology takes time to be adopted and spread because of the surrounding environment and the needs of the rural community. The time indicated in Figure (1) is speculative (varied) and not standard.

Figure 1: The normal distribution curve of social system adoption of chemical pesticide innovation



Extension projects are classified into extension programs and farmer field schools. Field schools for farmers are more focused on plant protection and integrated pest management. Farmer Field Schools (FFS) is an extension project developed basically by the Food and Agricultural Organization (FAO) and its agricultural extension aim to:

1- Grow healthy crops.
2- Maintain natural enemies
3- Promote field monitoring.
4- Develop expert farmers.

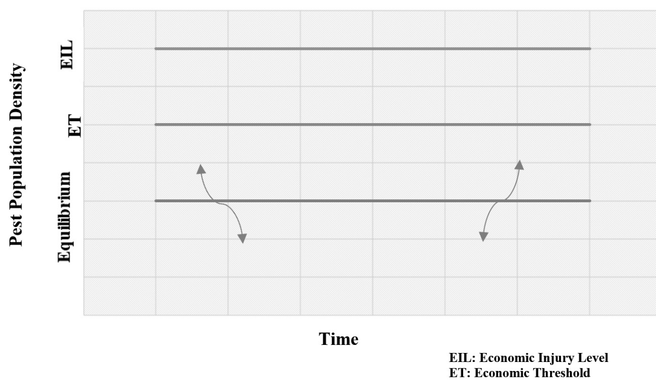
The following are examples of protocols of plant protection methods used in the farmer field schools:

- Preventive methods by plant protection forecasting based on environmental records and agricultural practices such as growing pests-resistant varieties, and foliar nutrition (before infection as a preventive practice).
- Agri-technical techniques such as reduced tillage, using of mulch, foliar nutrition (both as a preventive practice or for treating infections), and irrigation modeling.
- Physical and mechanical means of pest control, such as soil cultivation for weed control.
- Biological control, such as plant-derived bio-herbicides, biological pesticides, natural enemies, and parasitoids.
- A chemical, such as GPS-based chemical spraying and seed dressing chemicals.

Figure (2) explains the economic threshold concept as the number of insects per plant or the amount of damage caused by the pest that justifies the use of control measures economically. Controlling a pest population before it reaches the economic threshold will suppress the population before it reaches the economic injury level. The goal of integrated pest management is to keep pest populations below the level that causes economic injury level. The level of economic injury is reached when the cost of pest control equals the revenue loss caused by a pest. It is calculated by estimating the potential yield loss, crop value, and treatment cost. Figure (2) also indicates natural enemies balance pest population equilibrium (chemical control is not needed at this level). In another sense, the level of balance of natural enemies with the density of the pest necessitates only biological and organic control. It is worth noting that agricultural extension can direct producers to use primary methods of control such as preventive, technical, mechanical, biological, and organic protocols at this level and before reaching other economic levels.

The pest's damage can be avoided at the economic threshold level (ET). Control is vital at this level. An integrated and diverse protocol of integrated pest management approaches can be used, keeping in mind that the chemical solution is the last option in the incident that the previous methods of control fail (Figure 2).

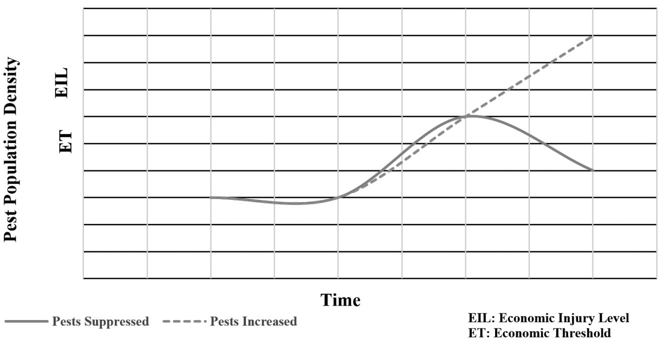
Figure 2: Various pest levels on the crop during the agricultural season



If the integrated control schedule failed to eradicate/suppress the pest development and the pest density reached the maximum (economic injury level), the damage can be considered done at that time, and it is also late to take action to control the pest (Figure 2).

If integrated control methods fail to prevent the pest from expanding, the pest population's density will deviate from the normal distribution and continue to grow until it exceeds the economic injury level (EIL) (Figure 3). The level of economic injury is reached when the cost of pest control equals the revenue loss caused by a pest (i.e., financial return savings by control). It is determined by assessing the potential yield loss, crop value, and treatment cost. The cost usually represents the cost of chemical treatments whereas other integrated control methods are regarded as relatively inexpensive. Before pest levels reach the critical economic level (EIL), non-chemical integrated control methods are economically profitable in terms of crop yield production and profits. Pesticide chemotherapy is not financially viable at this stage. Given that the benefit from the use of chemical pesticides is very small due to the risk factors of pesticides on humans' health, animals, natural enemies, and natural resources. In this case, the agricultural extension advisor must use integrated pest management and should only use chemical control as a last resort (after other means of control fail in the elimination of pests).

Figure 2: Various pest levels on the crop during the agricultural season



In contrast, if the pest's density exceeds the level of economic injury, the cost of chemical control becomes less than the benefits (in other words, the damage due to the pest is economically higher than the cost of chemical control). The use of chemical control is required at this stage. If an agricultural extension agent is in a similar situation and employs the integrated pest management method, he or she must make a chemical control decision right away (Figure 3).

Based on the foregoing, an integrated control program for tomatoes will be stated. Particularly in the case of powdery mildew and aphids. Tomato (Lycopersicon esculentum Mill.) is a summer crop that grows, develops, and produces best in warm weather. Temperature, light, and relative humidity are all factors that influence crop success. (ZEIDAN, 2005) detailed the most important climatic factors for tomato germination, growth, and production, such as heat and humidity. According to the reference, this data is shown in Table (1).

Consequently, any expected or unexpected temperature and relative humidity extremes will directly affect growth and production, as well as indirectly by adapting the ideal conditions for the spread of pests such as fungi, insects, and weeds that attack the crop.

To develop hierarchical and sequential plant protection protocols, it is critical to examine the tomato crop's ecological and biological system within integrated pest control strategies. Environmental variables can be used to create prediction models for pest control and management.

Table 1: Tomato temperature and relative humidity requirements in different growth stages

Growing Stage	Minimum temperature (°C)	Optimum temperature (°C)	Maximum temperature (°C)	Relative humidity (%)
Germination	11	16-29	34	
Growth	18	21-24	32	65-85
Fruit set at night	10	14-17	22	
Fruit set at day	18	23-26	32	
Chilling injury		6		
Frost (Freezing)		-2 - -1		

Source: Zeidan, O. (2005). Tomato production under protected conditions.

Plant protection techniques are currently heavily reliant on integrated pest management, which entails monitoring plant health in terms of nutrition, irrigation, and autoimmunity, as well as developing a plant with a genetic composition that interacts positively with environmental conditions, enhancing growth and production while avoiding physiological, environmental, and biological stress factors.

Disease and pest management consumes a sizable portion of tomato production costs (ZEIDAN, 2005). Pesticides have become less common in recent years for a variety of reasons, including:

1- Cost-cutting in the production process.
2- Toxic residues on fresh fruits and vegetables (crop products) are avoided.
3- Prevention of air pollution of environmental components (air, water, and soil) and environmental damage.

Other reasons such as:

4- Protection of natural enemies and other non-target species
5- Reducing increased pesticide resistance.

Projections for plant protection emphasize the importance of integrated pest control protocols as a current scientific strategy for reducing the use of manufactured chemical pesticides. The application of synthetic chemical pesticides is critical to IPM's final control option. It is strongly recommended that extension agents use an organic IPM program (MULVIHILL, 2021).

Powdery Mildew (Leveillula taurica, and Oidium neolycopersici):

The following environmental factors are critical for forecasting the infection of tomato plants with this fungal pathogen:

1- The high relative humidity is ideal for infection to begin, and infection can occur at humidity levels of 50%, and temperatures ranging from 10 to 32 °C.
2- Disease development, as well as the formation, reproduction, and distribution of spores, benefit from dry circumstances.
3- The ideal temperature for the disease to develop is between 20 and 27 °C. (DOUGLAS, 2003) stated that maximum disease development occurs at temperatures below 30°C.

So, based on signs and predictions of the existence of powdery mildew disease in tomatoes, a model of integrated pest management of this pathogen can be created in the following sequence:

1- Because powdery mildew pathogens can hibernate or overwinter in buds and plant residues during the winter, removing previous crop remnants from the field is critical.
2- Select drought and powdery mildew tolerant cultivars in collaboration with scientific research, professional agricultural extension, and concerned enterprises.
3- Proper greenhouse ventilation is required during the seedling and vegetative stages of plant growth and the implementation of a regular irrigation program to avoid the appearance of drought impact symptoms.
4- The foliar nutrition technique is one of the means of organic integrated pest control, and some non-formal scientific reports are indicating that spraying tomatoes with a solution of sodium bicarbonate (NaHCO3) can eliminate powdery mildew pathogen, as it is recommended to make a homogeneous solution of (10 to 15 gm L-1) and sprayed it once a week on plants.
5- It is highly recommended as a last resort to spray chemically with manufactured fungicides of a special type for the powdery mildew disease if the infection surpasses the economic injury level. Chemical fungicides should be applied differently from season to season to avoid the emergence of resistant strains.

Aphids (Aphis gossypii) and Green Peach Aphids (Myzus percisae):

Tomatoes can be affected by two different species of aphids: Aphis gossypii, and Myzus percisae. Aphids have sucking mouthparts that pierce plant leaves, stems, and roots to drink the sap. As a protection measure against predators, aphids leak waxy material from their cornicles (MULVIHILL, 2021). Honeydew, a sugary liquid excreted by aphids, attracts ants, who consume it and defend the aphids from predators. The season for aphids is all year, and they reproduce a sexually. It eats leaves that curl because of this. Potato virus Y (PVY) and Cucumber Mosaic Virus (CMV) are transmitted by aphids (ZEIDAN, 2005). Clusters of little insects on the undersides of leaves, honeydew, yellow or curled leaves, reduced growth, and malformed buds are all indications of aphid infections (MULVIHILL, 2021).

Integrated control compromises a variety of agricultural strategies (NCARTT and GTZ, 2001):

1- Agricultural (both preventive and technical) methods:
   1.1- Avoid using too much nitrogen fertilizer.
   1.2- Grow healthy seedlings, which are free of the insect.
   1.3- Cover the soil with plastic silver mulch.
2- Mechanical approaches are:
   2.1- Remove weeds from inside and outside the greenhouse.
   2.1- Remove any leaves that have been infected.
   2.2- Complete closure of the greenhouse.
   2.3-Infected seedlings should be removed and disposed of.
   2.4- Crush aphids and blast them off with a jet of water.
3- Biological control:
   3.1- The Aphidius parasitoid is the most well-known of these natural enemies, and it is widely utilized commercially (spray rate is 2 insects per meter square of land). This parasite's female lays her eggs in the aphid's body. They hatch into a larva within days inside the aphid's body, which feeds on the contents of the aphid's body. The procedure takes no more than 13 days.
   3.2- Natural predators are: assassin bugs, big-eyed bugs, damsel bugs, earwigs, ground beetles, hoverflies, lacewings, ladybugs, minute pirate bugs, parasitic wasps, praying mantids, robber flies, soldier beetles, spiders, and syrphid flies (MULVIHILL, 2021).
   3.3- Common native insects such as ladybugs (Coccinella septempunctata) and aphid lion (Chrysopa pallens).
4- Organic aphid control by spraying tomatoes with plant extracts such as neem oil, and pyrethrin (MULVIHILL, 2021).
5- According to some non-published scientific sources, spraying tomatoes with a sodium bicarbonate ($NaHCO_3$) solution can minimize aphids. It is recommended that a homogeneous solution of (10 to 15 mg L-1) be prepared and sprayed on plants once a week. It is a certified organic retreat.
6- Chemical control: spraying chemically with synthetic insecticide of a particular type is strongly suggested as the last option if the infection surpasses the economic injury level. To avoid the emergence of resistant strains, chemical insecticides should be sprayed differently from season to season.

The previous examples demonstrate the possibility of incorporating extension and agricultural economics concepts into the framework of integrated pest management for any pests that pose a threat to the agricultural crop. Before beginning pest control, extensive research is required to determine the economic levels of pests in charge. Powdery mildew disease symptoms (Figure 4) and Aphis gossypii infections on tomatoes (Figures 5 and 6) (STREY, 2022) are picked from the PLANTIX application, version code 3.6.7, 227-R PRO.

Figure 4: Powdery mildew

Figure 5: Aphids on leaves

Figure 6: Aphids on fruits

RECOMMENDATIONS AND CONCLUSIONS

It is extracted from this study the academic and scientific values in the employment of agricultural extension and agricultural economics concepts to determine the decision that needs to be made by the integrated pest management specialist. This requires the analysis of the ecosystem and the biological status of the plant, then monitoring the density level of the pest to determine the economic limit of the pest, and finally, determining the appropriate action to combat it.

The level of pest density exceeding the critical economic limit (economic injury level) is about the transition point from traditional integrated pest control measures that use low-cost methods (usually organic biological procedures) to chemical pest control. In terms of agricultural extension and rural development, it is considered an agricultural technique regardless of the agricultural procedure adopted by growers.

One of the most important recommendations that this study creates is to conduct research experiments to determine the economic levels of each pandemic pest on the targeted crop.

ACKNOWLEDGMENTS

We would like to express our deepest appreciation to employees and international students in the Institute of Plant Protection at the University of Debrecen. We would like also to express our special thanks of gratitude to our senior teacher Gábor Tarcali who gave us the golden opportunity to do this wonderful project on the topic (of plant protection forecasting).

REFERENCES

Douglas SM. (2003): Powdery mildew of tomato, The Connecticut agricultural experimental station, PP037(11/03R).

Higley LG, Boethel DJ (eds.). (1994): Handbook of soybean insect pests, Vol. 1, Entomological society of America.

Karthikeyan C, Sendikumar R, Jaganathan D. (2007): A textbook of agricultural extension management, Atlantic publishers and distributors, 2007 ISBN: 9788126908745.

Kim JY, Hong SS, Lee JG, Park KY, Kim HG, Kim JW. (2006): Determinants of economic threshold for powdery mildew on cucumber, Research in Plant Disease, Vol.12 Iss 3 pp. 231-234.

Massimi M, Tuly NM, Sanga S. (2021): Fundamentals of agricultural extension and education, AgroScience Today, Vol. 2 Iss 8 pp. 215-220.

Mulvihill S. (2021): The Vegetable garden pest handbook. Identify and solve pest problems on edible plants, Quarto publishing group USA Inc, 2021 ISBN: 9780760370063.

National Center for Agricultural Research and Technology Transfer NCARTT, and German Agency for Technical Cooperation GTZ. (2001): Tomato crop production by integrated pests' management method. (Arabic), Integrated pest management project.

Ragsdale DW, McCornack BP, Venette RC, Potter BD, MacRae IV, Hodgson EW, O'Neal ME, Johnson KD, O'Neal RJ, Difonzo CD, Hunt TE, Glogoza PA, Cullen EM. (2007): Economic threshold for soybean aphid (Hemiptera: Aphididae), Journal of Economic Entomology, Vol 100 Iss 4 pp.1258-1267.

Rural Planning Project Queensland Farmers' Federation QFF. (2015): Planning guideline for intensive horticulture and production nurseries, Queensland farmers' federation, 2015 ISBN: 978099437844.

Strey R. (2022): PLANTIX application, 3.6.7, 227-R PRO. (2022), Progressive environmental & agricultural technologies (PEAT GMBH), Germany.

Zeidan O. (2005): Tomato production under protected conditions, Israeli ministry of agriculture and rural development, extension service.