Mathematical Modeling on Impulsive Pest Control Strategy: A Review

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Abstract: Pest management is a major cause of concern these days because pests adversely affect plants, crops, and natural vegetation. They are responsible to inflict damage to human beings, animals, and crop yield either directly or indirectly. Thus, the researchers at the global level are engaged to solve this problem of pests through mathematical modeling by implementing several techniques and tactics such as chemical control method, biological control method, integrated pest management, and others. Impulsive differential equations is an effective mathematical tool to study the dynamics of pest control models as natural enemies, pesticides and infected pests are to be released periodically in the targeted field to suppress the pest population.

Index Terms **- Impulsive pest control, integrated pest management, infected pests, natural enemies.**

I. INTRODUCTION

Preservation of non-renewable resources and protection of environment for coming generations while satisfying human requirements for fodder is the main aim of sustainable agriculture. Its biggest component is pest management. In order to prevent major economic and production loss, it is the need of hour to control pest population.

Pesticides play an important role to contain the effect of pests on crop yield. Aktar et al. (1980) mentioned in their paper that India first time started to produce pesticides at a plant established in Calcutta [1]. They described that the immediate effects of pesticides are high yield and better quality food over healthy crop. With the overall increase in production, the revenue of the farmers also increases which ultimately ensure them to meet their expenses. In contrast to the benefits of pesticides, these have deleterious impacts on human health as well as environment. As pesticides ingressed in the food chain, so the number of deaths caused by chronic diseases arising from pesticide poisoning has increased gradually. Aquatic bodies also endure the threat due to water contamination by the excessive use of pesticides. Thus, it is to mention here that to save our environment and human beings, the use of these pesticides must be limited. Kalmakof and Longworth (1999) explained the use of microbial agents to regularize insect pests. The authors categorized the insect pests into two types, that is, Lepidoptera such as butteries and moths and Coleoptera such as beetles [2]. They specified that several pathogens can be used to generate infectious diseases among pest population. These are protozoa, bacteria, fungi and nematodes. Theses insect pathogens reside on the host pest and hamper their growth by intervening in their biological process, which ultimately leads to the death of host pest.

Integrated pest management is technique to annihilate the growth of pest population by effectively combining use of pesticides with biological or natural pest control. Cherry et al. (1971) carried out a study on the potential of certain pathogens for integrated pest management (IPM) of stem borers in West Africa [3]. They found that most of the small scale farmers in Africa could not afford to buy pesticides due to very high cost. Therefore, IPM is its best alternative where unrestrained use of pesticides can be gradually reduced by efficiently combining with biological control. They concluded that the use of insect pathogen Beauveria, which is specific fungi, is very effective for integrated pest management strategy to stop the damage of maize plants from pests. Burges and Hussey (1971) discussed two ways to insert these insect pathogens in the target pest population. These can either be added in the marginal amount to the pest population to create an epidemic or can be used as bio-pesticides when the targeted pests reach at an economically significant level [4].

Freedman (1976) explained that the other way to control pests biologically is through some specific natural enemies which act as predators for the targeted pests [5]. To exemplify, Caterpillars and Aphids are among the common pests of Tomato and Cabbage, respectively. It is found that their natural enemies, Parasitic Wasp and Hover Fly Larva are being used by farmers to control these pests. In this paper, the authors proposed basic prey-predator model for pest control. Prey acts as pest and predator plays the role of natural enemy. Further, studies suggested that if the natural enemies are not available in enough numbers, they can be bred in suitable environment and instantaneously released in the field from outside. This process is called augmentation of natural enemies. Lenteren (1982) discussed the concept of augmentation of natural enemies for biological control in two ways [7]. He specified that approximately 125 species are identified as natural enemies of specific pests. First is inundate release where the natural enemies of the targeted pests are reared in large numbers and released periodically in the field for immediate pest control. This method is generally applied to the crops where only one particular type of pest species are prevalent. Second is seasonal inoculative release which includes periodical release of these natural pest control agents. Apart from providing the immediate control, this method helped to regularize the pest population throughout the season. He concluded that the scope of bio-pest control is very wide because market demand of vegetables grown with minimized or no use of pesticides is continuously rising. Thus, the dynamics of pest control models can be effectively studied with the help of impulsive prey-predator interactions.

II. IMPULSIVE PEST CONTROL

The concept of IPM came into limelight in the middle of twentieth century. After that, there is continuous development in this field of IPM. Barclay (1982) studied a stage-structured prey-predator model with release of predator, pesticides and habitat management for pest control strategy [6]. He has taken two life stages of pest (prey) population and identified the various factors to be considered while applying prey-predator systems to regulate pests. The first successful attempt in the field of IPM was made by Tang et al (2000). They constructed two impulsive models of IPM with fixed and unfixed time events, respectively [8]. In the first model, the authors adopted the strategies of biological as well as chemical methods in or- der to reduce pest population in the crop with fixed impulsive effects. They took threshold values of impulsive period for the global stability of prey neutral periodic solution. The authors stressed to use these measures integrally as it not only cut down pest population to tolerable level but is environmentally safe and economically feasible. In the second model, they examined the case of state-dependent impulsive control events just after the preys attain an economic threshold value. In this model, the strategies of releasing natural enemies, regular field monitoring and spraying pesticides are taken into account simultaneously.

Hong et al. (2007) showed how certain insect pathogens are beneficial to obstruct the growth of targeted pests by applying continuous and impulsive release of infected pests [9]. These can be germinated in laboratories under suitable conditions and are not capable to cause damage to crops. To exemplify, the viruses of dengue fever are transmitted by Tiger mosquito and spraying with bacterium Bacillus thuringiensis help to control flocks of these mosquitoes. The authors achieved that by controlling the impulsive release amount of infected pests, pest population could be maintained at acceptably low levels. Georgescu and Morosanu (2007), in their research article, studied an integrated pest management (IPM) model with biological and chemical control methods which are used in an impulsive and periodic manner [10]. They included pesticide spraying and impulsive release of infected pests at two different time moments and applied the Floquet theory of impulsive differential equations to check the stability of the system. Bhattacharya and Bhattacharya (2007) conducted a study to examine the problems in an agro-ecosystem [11]. They examined that sterile insect techniques (SIT) is very viable biological control method in controlling pest population. They also favored in the use of pesticides provided it should be in low volume. The study stressed that if these control measures are adopted in plausible manner, it could be helpful in increasing the production of yield also. The study further indicated towards the vulnerability of the system in which climatic factors, particularly effects of temperature has discussed in an interesting way. Depending on the richness of available survival resources, it is evident to consider the patchy distribution of species in an environment. Thus, Georgescu and Zhang (2009) extended the work done in [10] by dividing the environment into two different patches. They proposed a susceptible-infected (SI) model where movement of susceptible pests is allowed between patches but infected pests are forced to stay to their respective patches. Spraying of pesticides and impulsive release of infected pests is incorporated at two different time events. They discussed the effect of dispersal rate from one patch to other on the stability of pest free equilibrium state and highly recommended the diffusion of susceptible pests from unstable to stable patch for effective pest control strategy. Another interesting SI model for IPM was proposed by Jiao et al. (2009) by considering Holling type II function as incidence rate and identified sufficient conditions to maintain the pest population at tolerable level [13].

Georgescu and Zhang (2010) presented susceptible pest-infected pest-natural enemy (SIN) model with two life stages of natural enemies{that is, immature and mature for IPM [14]. The researchers assumed that immature predator could not haunt on prey and completely depend on mature predator for their survival. They summed up that when density of pest population increases, high voracity of predators would encourage timely eradication of pests. Wang et al. (2011) examined impulsive SI model for efficient pest control with more generalized nonlinear transmission rate from susceptible to infected pests [15]. Gao and Tang (2011) compared two different prey-predator models with instantaneous release of predators to curb the growth of pest population. First is the periodic Lotka-Volterra type prey-predator model where fixed amount of natural enemies are released at fixed impulsive moments and in second case, the release amount is proportional to the predator density. It is found that proportional impulsive release is more adequate for annihilation of pests [16]. Zhao et al. (2011) explored a three-species food chain model with mixed functional response and infection in the prey species for pest management. Infected prey (pests) are impulsively released at fixed time events [17]. An extensive numerical simulation is performed to observe the chaotic behavior of system which depends on the impulsive release amount of infected prey population. Further, Georgescua and Zhang (2011) featured the possibility of availability of more than one species of natural enemies for prey species and developed an impulsive pest control model with `n' number of predator species which haunt on common prey [18].

Tang et al. (2013) embodied the duration of residual effects of pesticides on the growth of pests and natural enemies [19]. They mentioned that repeated application of pesticides could be diminished if these have strong and long residual effects. They also considered the decay rate of pest population with pesticide spraying and established permanence of the system. Yang and Yang (2013) constructed an impulsive pest management model. The authors studied periodically impulsive releasing of predators and harvesting of pests at two different fixed time periods [20]. Jatav and Dhar (2014) in a comprehensive study explored a three level plant-pest-natural en- emy model with stage structure and impulsive perturbation [21]. They investigated impulsive releasing of predators and impulsive harvesting of pests in numerical terms. The authors also examined the simultaneous effects of biological and chemical control measures on annihilation and permanence of pests. The study further highlighted that hybrid pest control strategies, in which two or more methods used, are very productive and cost-effective techniques. It is more rational that immature individuals of any species take some time to get mature, thus, Dhar et al. (2014) assimilated delay time for maturation of immature to mature pests and analyzed a prey-predator model with stage structure in pest population with impulsive release of predator for pest control [22]. They calculated the threshold value of impulsive period for the extinction of pests depending on significant factors such as, maturation delay time of pests and impulsive release amount of predators. Because, complete extermination of pests is not appreciated economically and biologically, thus, they recapitulated that short time period of maturation or release of natural enemies at small scale would encourage the permanence of the system. Li et al. (2015) studied an eco-epidemic model with double impulsive control method [23]. They examined global stability of the susceptible prey extinction periodic solution. In the study, the scholars adopted a strategy in which infected preys and predators are acquitted periodically at diverse points. The study confirmed that integrated pest management is a cost-effective and environment-friendly tactic.

Akman et al. (2015), in their review article on pest management models, generalized a number of impulsive differential equation pest control models given by many renowned scholars [24]. In this paper, they discussed random fluctuations in the birth rate of the species. At the end, the authors suggested some valuable points to select the best suitable models to study a problem. They highly stressed on the use of an accurate and precise modeling parameters and simulated numerical techniques. Mathur (2015) made an inquisitive approach in which two-prey one predator model is proposed. He used organic and synthetic pest control techniques at two different time periods [25]. The author determined the threshold values for the eradication of the pests and permanence of the system. Jiao et al. (2016) explored a predator-prey model by using impulsive diffusion which is linked with two patches [26]. They found that the diffusive rate of the natural enemy contributes a lot in controlling pest population. Chaves et al. (2017) conducted a study on the developments occurred in the field of IPM as it contributed a lot in the formation of plethora of mathematical models using in pest control [27]. They discussed differential equations used in agricultural ecosystems right from classical to modern times. The study is quite useful to understand a number of aspects relating to the parametric values of pest control, its impact on environment and economy etc. Apart from these studies, the perception of delay in gestation time of natural enemies is also acknowledged by some researchers. Because, if an infectious disease exists in pest (prey) population, it is evident that the natural enemies would also get infected after the consumption of diseased pests which effects their breeding.

Kumar et al. (2017) proposed and analyzed a food chain model consisting plant, pest and natural enemies with disease in pest population for pest control [28]. They assimilated the gestation delay time for natural enemies and studied the stability of different equilibrium states. Jose and Usha (2018) studied the nature of plant-pest virus, bio pesticides and predators food chain model. The major focus of the study was to examine plant pest extinction and pest eradication periodic solution [29]. They applied Floquet theory of impulsive differential equations. The study concluded that the use of organic pesticides is very effective as it is not just to minimize the effect of pest but also to increase the period of impulsive release of infected pests and natural enemies. Akman et al. (2017) in their study made an attempt to propose an integrated pest management (IPM) model with prey refuge effect which describes the capability of pests to camouage themselves from the attack of pesticides and predators [30]. The authors constructed a stage structured impulsive differential equation model which assumes that in order to control pest population, it is essential to use pesticides and discharge predators in the field at specified time period. The authors claimed that the present study has the potential to extend in medical immunotherapy which helps in reducing the risk of cancer and other harmful cells in human body. Chavez et al. (2018) examined the similarities and differences of two ecological models which are based on chemical and biological control, implemented in periodic and impulsive manner [31]. They applied Path-Following technique which provides numerical explanation to system parameters in pest control. It is essential to know that the authors focused on the effect of the impulse period on the ecosystems with the help of a branching point (BP). Kumari et al. (2018) studied integrated pest management approach which significantly suppresses pest population and prevents pest resistance to yield [32]. They opined that these control measures are proved to be more effective in reducing pest population if they applied in combination. This approach also led to positive economic and environment outcomes.

The main aim of studying these models is to have in-depth knowledge of use of impulsive differential equations in integrated pest control. Models can help us in optimization of resources to target control measures in the direction of suppressing the pest population.

III. Conclusion

The war between pests and humans is going on from several decades and time to time, different pest control techniques are acquired by mankind. Working on the same path, here we have thoroughly analyzed that how impulsive pest control strategy is implemented for the purpose of integrated pest management. It is found that instead of using pesticides alone, combination of chemical control along with natural enemies is more efficient in pest control. Different researchers are working to help the world to control pest population using mathematical modeling. Factors associated with pest control like insect behavior, temperature, geographical conditions and contact rate, availability of control measures like periodic release of natural enemies, infected pests or pesticides are included in the models and analyzed by using stability theory. This analysis help in making more effective pest control strategies.

References

[1] .Aktar, M. W., Sengupta, D. and Chowdhury, A. (2009). Impact of pesticides use in agriculture: their benefits and hazards. Interdisciplinary Toxicology, 2: 1-12.

[2] Kalmako, J. and Longworth, J. F. (1980). Microbia Control of Insect Pests, New Zealand Department of Scientific and Industrial Research, Wellington.

[3] Cherry, A. J., Lomer, C. J., Djegui, D. and Schulthess, F. (1999). Pathogen incidence and their potential as microbial control agents in IPM of maize stem borrers in West Africa, Biocontrol, 44: 301-327.

[4] Burges, H. D. and Hussey, N. W. (1971). Microbial control of Insects and Mites, Academic Press, New York.

[5] Freedman, H. J. (1976) Graphical stability, enrichment and pest control by a natural enemy. Mathematical Biosciences, 31 207-225.

[6] Barclay, H. J. (1982). Models for pest control using predator release, habitat management and pesticide release in combination, Journal of Applied Ecology, 19: 337-348.

[7] Van Lenteren, J. C. (2000). Success in biological control of arthropods by augmentation of natural enemies, in Biological Control: Measures of Success, (eds. G. Gurr and S.Wratten), Kluwer Academic Publishers, 77-103.

[8] Tang, S., Xiao, Y., Chenand, L., Cheke, R. A. (2000). Integrated pest management models and their dynamical behavior, Bulletin of Mathematical Biology, 67: 115-135.

[9] Hong, Z., Jianjun, J. and Lansun, C. (2007). Pest management through continuous and impulsive control strategies. Biosystems, 90: 350-361.

[10] Georgescu, P. and Morosanu, G. (2007). Pest regulation by means of impulsive controls. Applied Mathematics and Computation, 190: 790-803.

[11] Bhattacharyya, S. andBhattacharya, D. K. (2007). An improved integrated pest management model under 2-control parameters (sterile male and pesticide). Mathematical Biosciences, 209: 256-281.

[12] Georgescu, P. and Zhang, H. (2009). The Impulsive control of a two-patch integrated pest management model. Acta Universitatis Apulensis, 297-320.

[13] Jiao, J. Chen, L. and Cai, S. (2009). Impulsive control strategy of a pest management SI model with non- linear incidence rate. Applied Mathematical Modelling, 33: 555-563.

[14] Georgescu, P. and Zhang, H. (2010). An impulsively controlled predator-pest model with disease in the pest. Nonlinear Analysis: Real World Applications, 11: 270-287.

[15] Wang, X. Guo, Z. and Song, X. (2011). Dynamical behavior of a pest management model with impulsive effect and non-linear incidence rate. Numerical Analysis: Hybrid Systems, 30: 381-398.

[16] Gao, W. and Tang, S. (2011). The effects of impulsive releasing methods of natural enemies on pest control and dynamical complexity. Numerical Analysis: Hybrid Systems, 5: 540-553.

[17] Zhao, M., Wang, Y. and Chen, L. (2011). Dynamic analysis of a predator-prey (pest) model with disease in prey and involving an impulsive control strategy. Journal of Applied Mathematics, 2012: 1-18.

[18] Georgescua, P. and Zhang, H. (2011). An impulsively controlled pest management model withn predator species and a common prey. Biosystems, 110: 162-170.

[19] Tang, S. Liang, J., Tan, Y. and Cheke, R. A. (2013). Threshold conditions for integrated pest management models with pesticides that have residual effects. Journal of Mathematical Biology, 66: 1-35.

[20] Yang, J. and Yang, Z. (2013). Stability and permanence of a pest management model with impulsive releasing and harvesting. Abstract and Applied Analysis, 2013: 1-18.

[21] Jatav, K. S. and Dhar, J. (2014). Hybrid approach for pest control with impulsive releasing of natural enemies and chemical pesticides: A plant-pest-natural enemy model. Nonlinear Analysis: Hybrid Systems, 12: 79-92.

[22] Jatav, K. S., Dhar, J. and .Nagar, A. K. (2014). Mathematical study of stage-structured pests control through impulsively released natural enemies with discrete and distributed delays. Applied Mathematics and Computation, 238: 511- 526.

[23] Li, Y., Teng, Z., Wang, K. and Muhammadhaji, A. (2015). Dynamic analysis of general integrated pes management model with double impulsive control. Discrete Dynamics in Nature and Society, 2015: 1-10.

[24] Akman, O., Comar, T. D. and Hrozencik, D. (2015). Onimpulsive integrated pest management models with stochastic effects. Frontiers in Neuroscience, 9.

[25] Mathur, K. S. (2015). A prey-dependent consumption two-prey one predator eco-epidemic model concerning biological and chemical controls at different pulses. Journal of the Franklin Institute, 353: 3897-3919.

[26] Jiao, J., Cai, S., Li, L. and Zhang, Y. (2016). Dynamics of a predator-prey model with impulsive biological control and unilaterally impulsive diffusion. Advances in Difference Equations, 1: 1-19.

[27] Chavez, J. P., Jungmann, D. and Siegmund, S. (2017). Modeling and analysis of integrated pest control strategies via impulsive differential equations. International Journal of Differential Equations, 2017: 1-18.

[28] Kumar, V., Dhar, J., Bhatti, H. S. and Singh, H. (2017). Plant-pest-natural enemy dynamics with disease in pest and gestation delay for natural enemy. Journal of Mathematical and Computational Science, 7: 948-965.

[29] Jose, S. A. and Usha, V. (2017). Hybrid approach for pest management model with impulsive control. International Journal of Technical Innovation in Modern Engineering & Science, 4: 1052-1060.

[30] Akman, O., Comara, T. and Henderson, M. (2017). Ananalysis of an impulsive stage structured integrated pest management model with refuge effect. Chaos, Solitons and Fractals, 111: 44-54.

[31] Ch_avez, J. P., Jungmannc, D. and Siegmundb, S. (2018). A comparative study of integrated pest management strategies based on impulsive control. Journal of Biological Dynamics, 12: 218-341.

[32] Kumari, V., Chauhan, S., Bhatia, S. K. and Dhar, J. (2018). Plant-pest-natural enemy mode lwith impulsive biological and chemical control,. Differential Equations and Applications, 10: 413-431.