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An ecological indicator to evaluate the effect of chemical insecticide pollution management on complex ecosystems

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ABSTRACT

The extensive input of chemical insecticides for pest control is considered as a serious risk to the environment, and the ecological disturbance of chemical insecticides has both positive and negative effects on complex agro-ecosystems. This paper proposed an indicator based on ecological two-sidedness theory and Shannon entropy, which is intended for analyzing informational complexity in a decision network of the chemical insecticide pollution management. The results indicated that the order of the value of $R_{CC/CP}$ index (where the $R_{CC/CP}$ index matrix $W_{CC/CP}$ is defined as the index optimization matrix of comprehensive cost divided by the index optimization matrix of comprehensive profit) for three insect pest-controlling strategies in scallion fields was "applying frequency vibration lamps and environment-friendly insecticides 8 times" (0.8714) < "applying trap devices and environment-friendly insecticides 9 times" (0.8858) < "applying common insecticides 15 times" (0.9077). The treatment "applying frequency vibration lamps and environment-friendly insecticides 8 times" was recognized as the optimal strategy for chemical insecticide pollution management in scallion fields in Shanghai, China. The results demonstrate that our proposed ecological indicator might arouse the interest of policy makers and eco-environmentalists who seek to minimize the use of chemicals, and the farmers who hope to optimize pest-controlling strategies in practice.

1. Introduction

Chemical pesticides are often used to control pests and maximize agricultural yields, and the extensive input of chemical pesticides has been one of the major threats to ecosystems (Bacchetta et al., 2014; Macary et al., 2014), leading to environment pollution, pest resistance and biodiversity loss. To protect our planet, some developed countries have already realized a 50% reduction in the use of chemical pesticides (Jansma et al., 1993; Sathre et al., 1999; Smet et al., 2005), and the chemical pesticide reduction techniques have been employed (Syversen, 2005; Rogers and Stringfellow, 2009).

Scallion is the pillar industry of agriculture in China in which the annual cultivation area is 55.0×10^4 hm^2 and the annual yield is 2.0×10^{10} kg. In eastern China, we have found that *Spodoptera exigua*, *Spodoptera litura*, *Liriomyza sativae*, *Thrips alliorum* and aphids are the most serious pests in this system. To control these pests, farmers are accustomed to the use of large amount of insecticides. Our investigation has indicated that the amount of active insecticides in Shanghai of China is more than 1.50 kg hm^{-2} $year^{-1}$, which is far higher than the China's average. In order to avoid insecticide contamination and ensure food safety, insecticide-reducing strategies might be applied to control pests in scallion fields at the source in Shanghai suburbs.

Researchers have suggested that biological control (Andorno and Lopez, 2014), physical control (Grasswitz and Fimbres, 2013),

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agricultural control (Wan et al., 2014a,b,c) and environmentally-friendly chemical control methods are potential approaches to the reduction of chemical pesticides at the source in agro-ecosystems. In practice, we have screened out the main ideal pest-controlling strategies in scallion fields, such as installment of insect-killing lamps, installment of trap devices (sex attractant and color plastic strips), and rotation of different classes of environment-friendly insecticides. However, how to evaluate and determine which technique is the best is a challenging task.

The Shannon entropy (H) is defined by the founder of information theory, Shannon, who introduced the concept of entropy into information theory, suggesting entropy as a measure of the information content or complexity of a measurement series (Shannon, 1948). The Shannon entropy can be utilized to define the degree of uncertainty involved in predicting the output of a probabilistic event (Hillborn, 1994), which has provided a scientific method for understanding the essential state of things (Telesca et al., 2008). Insect pest control can be viewed as a process by which a complex exchange network between regions of the system is generated. Thus, Shannon entropy might be a useful parameter for describing the effects of different pest-controlling strategies in a system in terms of uncertainty about the possible transitions or exchanges between zones. Therefore, this paper used this theory to evaluate the comprehensive effect of insect pest-controlling strategies on agro-ecosystems, so as to provide better methodologies for environmental management in practice.

2. Materials and methods

2.1. Experimental materials

Scallion variety "Tianguangyiben" was provided by Xinfeng Seed Industry Company Limited, based in Qingdao City of Shandong province of China; frequency vibration insecticidal lamps were provided by Jiaduo Company Limited based in Henan province of China, PS-15 II type; manual pesticide sprayers were manufactured by Qiangye Sprayer Factory of Linyi city of Shandong province of China, 3WBS-16 type; trap devices (tobacco cutworm sex pheromone, beet armyworm sex pheromone, diamond back moth sex pheromone, plastic tubes for suspending sex pheromone, yellow and blue plastic strips) were provided by Zhangzhou Enjoy Technology Company Limited of China; insecticides included 10% Imidacloprid WP, 10% chlorfenapyr SC, 20% tebufenozide SC, 48% chlorpyrifos EC, 75% cyromazine WP, 1.45% avermectin and imidacloprid WP, 15% indoxacarb SC, 40% phoxim EC, 2.5% deltamethrin EC, ACNPV SC.

2.2. Experiment design and method

Experiments were conducted using a series of individual 1 hm^2 plots in scallion fields in Modern Agriculture Park of Songjiang District, Shanghai of China (121.13°E, 30.94°N) from April to October in 2006. Three treatments were designed in this experiment. In Treatment 1, frequency vibration lamps with 1.0 m height were installed the 30 day after transplanting of scallion. In Treatment 2, lamps were not applied but trap devices were utilized, i.e., sex pheromone lures and color trap strips were used throughout the entire growth periods of scallions after transplanting. Insecticides with slight toxicity (10% imidacloprid WP, 10% chlorfenapyr SC, 20% tebufenozide SC, 75% cyromazine WP, 1.45% avermectin and imidacloprid WP, 15% indoxacarb SC, 40% phoxim EC, ACNPV SC) were used in Treatments 1 and 2. However, the control (Treatment 3), i.e., farmers' conventional insect pest-controlling method, did not install lamps or trap devices, and used 48% chlorpyrifos EC and 2.5% deltamethrin EC with moderate toxicity besides above slightly hazardous chemical insecticides. Treatments 1 and 2 received slightly toxic insecticides 8 and 9 times, respectively, while Treatment 3 received insecticides 15 times. Each treatment and the control were replicated three times.

The total growth period of scallions was about 180 days, during which seeds were sown on April 1st, seedlings transplanted with density of 25,000 plants ha^{-1} on June 4th, and plant materials harvested in early October. The sex pheromone was placed inside a capillary vessel (0.1-m long and 1.5-mm caliber). One each tobacco cutworm, beet armyworm and diamondback moth sex pheromone trap was installed at 20 m intervals in every direction in each plot of Treatment 2, was hung 1.0 m above ground level, and was replaced once per month. Five yellow plastic strips per 666.7 m^2 and five blue plastic strips per 666.7 m^2 were installed with equidistance in each plot of Treatment 2, and were suspended 0.2 m above plants. Color strips' dimensions were all 0.3-m long, 0.4-m wide, 1.5-mm thick, with sticky jelly well distributed on. Small pests like aphids, whiteflies and leaf miners tend toward yellow objects while thrips tend toward blue ones so that they stick to death on the plastic strips, and the goal of pest control can be achieved.

The scallions were planted, fertilized and watered as the farmers practice. Weeds were managed by pulling. In treatment and control fields, insecticides were appropriately applied according to the population dynamics of insect pests. All plants were given similar managerial measures of water and fertilizers during the whole period of scallion growth. Arthropods were scouted and sampled every 20–30 d in all experiment fields. "Z" style sampling with 5 dots of about 100 plants was sampled at random from seedling stage to harvesting stage (Wan et al., 2009). All arthropods were carefully counted. To ensure the continuity and reliability of the statistics, we routinely recorded the service condition of the agricultural resources in each of the plots, the planting and growing management procedures, cost accounting factors, the sales status of scallions, and so forth. All data presented in this paper were analyzed using Microsoft Excel and SPSS16.0 software.

2.3. Evaluation principles

When measuring the standard for the complex ecosystem, we focused on whether the economic subsystem is beneficial, whether the ecological subsystem is stable, and whether the social subsystem is rational (Wan et al., 2013b). In the light of above three goals, a specific indicator system was identified that maximized the comprehensive profit term (CP) while minimizing the comprehensive cost term (CC). Establishing an indicator system for pest control should adhere to the following principles: (1) all evaluation indicators should reflect economic, ecological and social aspects, economic cost and profit, resource and time consumption, acceptance degree, as well as the impact of candidate strategies on society and nature (Wan et al., 2013b); (2) the short-term and long-term profits, as well as both partial and total cost should be reflected (Jiang and Wan, 2009); (3) quantitative indicators should be adopted as far as possible, and subjective deviation caused by score judgment of qualitative indices should be avoided (Wan et al., 2013a); (4) comprehensive indicators should be adopted as more as possible, and each indicator should keep independent without direct interactive relationship (Young, 1991; Wan et al., 2009); (5) the indicators should complement each other, and the structure produced by the indicators should reflect fully and even completely its various functional characteristics and be constituted completely (Wu, 1998); and (6) indicators should reflect the diversity, stability and structure characteristics of arthropods (Wan et al., 2008).