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A methodological approach to assess the combined reduction of chemical pesticides and chemical fertilizers for low-carbon agriculture

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ABSTRACT

The extensive use of synthetic chemicals for pest control is recognized as a major threat to ecosystem integrity and the realization of low-carbon agriculture. There have been many studies of agrochemical reduction technologies, but little work to date has been done to achieve a combined reduction of chemical pesticides and chemical fertilizers. This fact has led us to the conception of assessment methodologies and the establishment of a relevant ecological model. A significant challenge to the development of assessment methodologies is agro-ecosystem complexity. In this study, we explain the agro-ecosystem as one composed of various social, economic and natural factors that can be defined using a comprehensive positive/negative effect evaluation index system, which is based on fuzzy theory and can be used to assess combinations of technologies for reduced use of chemical pesticides and fertilizers in cauliflower fields. On this basis, a technology using 14% calcium superphosphate 750 kg hm^{-2}, 46% urea 825 kg hm^{-2}, 12% granular boron fertilizer 4.5 kg hm^{-2}, active pesticides 3.09 kg hm^{-2} and hanging sex pheromone lure on the watermelon–cauliflower rotation mode resulted in the largest index evaluation value (0.3795) and was considered the best combined reduction technology in *Chongming* Eco-island, Shanghai of China. The results of our study should be of interest to policy makers and environmental managers who seek to realize low-carbon agriculture and to farmers who seek to optimize application technology in practice.

1. Introduction

Increasing global temperatures have the potential to threaten animals and plant species survival and could lead to human extinction (Easterling et al., 2000; Schmidt and Archer, 2009; Bässler et al., 2010; Körner and Basler, 2010; Helbron et al., 2011). To minimize the impact of global warming, the United Nations Climate Change Conference concluded it necessary to promote low-carbon emissions. To assist in realizing targets established during this conference, China announced that carbon emissions per unit of gross domestic product (GDP) would be reduced 40–50% from 2005 levels by the year 2020 and that the proportion of non-fossil fuels used as a primary energy source would be reduced to 15% of current levels by 2020.

One component of a low carbon economy/agriculture is minimum greenhouse gas emissions from agricultural operations. To achieve this state, future agricultural technologies must be based on low energy consumption, low pollution, and low carbon emissions, the utilization of high carbon sinks, and they should require minimum human, material and financial resources input. These technologies should also be safe and eco-friendly so as to maximize the security of the production process (Compton and Boone, 2000; McCarl and Schneider, 2001; Conant et al., 2010; Davis et al., 2012; Michos et al., 2012).

CO_2, CH_4 and N_2O in agriculture are the main source of greenhouse gas emission (Tate and Striegl, 1993; Willey and Chameides, 2007; Malla, 2008; Russell et al., 2009; Thiere et al., 2011). The development of low-carbon agriculture technologies can play a key role in promoting global low-carbon emission activities. According to the assessment reports released by IPCC, agriculture produced about 14% of the world's total greenhouse gas emissions. Low-carbon agriculture technologies can offset 80% of agricultural greenhouse gas production and appears to be an important step toward solving, food safety and eco-environment problems caused by climate change (Weng et al., 2009).

In the production of field crops, chemicals are applied to control pests and promote crop yields. The large amounts of these materials that are used have led to high-carbon agriculture (Needelman et al., 2007; Rask et al., 2010; Wohlfahrt et al., 2010; Mózner et al., 2012; Pärn et al., 2012). In *Chongming* Eco-island, Shanghai of China, for example, the annual average rates of use of chemical pesticides and fertilizers is 6.20 kg hm^{-2} and 639.25 kg hm^{-2}, respectively. An additional issue in the development of a low-carbon agricultural

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production technology is how to optimize the diversity of available technologies. Here we suggest that the comprehensive effect of different low-carbon technologies acting on agro-system comprises both positive and negative economic, ecological and social factors and that the corresponding index systems can be constructed accordingly.

The agricultural ecosystem consists of economic, ecological and social subsystems (Holling, 2001). For the depiction and assessment of such systems, some of the limitations of conventional classic mathematical methods may be overcome using fuzzy theory (Zadeh, 1965, 1973). This approach has been used to develop chemical pesticide reduction (Jansma et al., 1993; Sathre et al., 1999) and chemical fertilizer reduction strategies (Nazaryuk et al., 2002). In this paper we report the application of fuzzy mathematical methods to the development and evaluation of strategies that combine reduced pesticide and fertilizer usage in cauliflower fields.

2. Methods and materials

2.1. Experiment materials

Agrochemicals and associated materials typically used in cauliflower production, and considered in the analysis presented here, include: phoxim EC, 18% bisultap EC, 0.5% emamecin benzoate EC, 10% chlorfenapyr EC, 14% calcium superphosphate, 46% urea, 12% granular boron fertilizer, 25% foliar fertilizers, "*Xinyi*" cauliflower, tobacco cutworm sex pheromone, beet armyworm sex pheromone, diamondback moth sex pheromone, plastic tube for suspending sex pheromone, irrigation water, pesticide sprayer, etc.

2.2. Experiment design and method

Experiments were conducted using a series of individual 5 hm^2 plots in cauliflower fields in Modern Agriculture Park of *Chongming* Island (121.76°E, 31.52°N) from 2009 to 2010. Three treatments were included in the experimental design:

Treatment 1 comprised 14% calcium superphosphate at750 kg hm^{-2} for base fertilizer, 46% urea at 112.5 kg hm^{-2} for seedling fertilizer, 46% urea at 187.5 kg hm^{-2} for stem-developing fertilizer, 46% urea at 225 kg hm^{-2} for rosette fertilizer, and 46% urea at 300 kg hm^{-2} for heading fertilizer.

Treatment 2 comprised 14% calcium superphosphate at 750 kg hm^{-2} for base fertilizer, 46% urea at 112.5 kg hm^{-2} and 12% granular boron fertilizer at 4.5 kg hm^{-2} with soil fertilization for seedling fertilizer, 46% urea at 187.5 kg hm^{-2} for stem-developing fertilizer, 46% urea at 225 kg hm^{-2} for rosette fertilizer, and 46% urea at 300 kg hm^{-2} for heading fertilizer.

Treatment 3 comprised 14% calcium superphosphate at 750 kg hm^{-2} for base fertilizer, 46% urea at 112.5 kg hm^{-2} and 12% granular boron fertilizer at 4.5 kg hm^{-2} with soil fertilization for seedling fertilizer, 46% urea at 187.5 kg hm^{-2} for stem-developing fertilizer, 46% urea at 225 kg hm^{-2} and 25% foliar boron fertilizers at 0.45 kg hm^{-2} (by diluting 1500 times) for rosette fertilizer, 46% urea, and 300 kg hm^{-2} and 25% foliar boron fertilizers at 0.45 kg hm^{-2} (by diluting 1500 times) for heading fertilizer.

All three treatments included sex pheromone lures that were used throughout the entire watermelon–cauliflower rotation mode. The control comprised 14% calcium superphosphate at 750 kg hm^{-2} and 46% urea at 150 kg hm^{-2} for base fertilizer, 46% urea at 75 kg hm^{-2} for seedling fertilizer, 46% urea at 225 kg hm^{-2} for stem-developing fertilizer, 46% urea at 225 kg hm^{-2} for rosette fertilizer, and 46% urea at 300 kg hm^{-2} for heading fertilizer, throughout the time of continuous cauliflower cultivation and without the use of sex pheromone. Here all pesticides and fertilizers are separately and individually used. Each treatment and the control were repeated three times.

The total growth period of cauliflowers was about 240 d, growing seedling on July 12th, dividing experiment plots and using base fertilizers on July 20th, transplanting with density of 30,765 plants/ha on August 15th. 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 every treatment plot, was hung 0.8 m above ground level, and was replaced once per month. The number of pests in each trap was recorded at 10 d intervals.

The cauliflowers were planted, fertilized and watered according to normal vegetable growing standard. Weeds were managed by manually pulling. The treatments and control fields were offered the same chemical pesticides which were appropriately used according to the population dynamics of pests. All plants were given similar management styles of water and fertilizers during the whole period of vegetable growth. Pests were systematically scouted and sampled with about 10 d intervals in all vegetable fields. "Z" style sampling with 5 dots was conducted during the whole growth stage and in each dot 50 plants were investigated. All arthropods were carefully counted.

Throughout this study, we maintained a specific farming resource inputs database for each of the various treatment regions that consisted of quantitative planting and growing management factors, cost accounting factors, and the value and sales status of crops and products. All data presented in this paper were analyzed using Microsoft Excel and SPSS16.0 software.

2.3. Determination of evaluation indices

The agro-system is composed of interacting social, economic and natural subsystems. The effects of these interactions were taken into consideration when seeking to determine the optimum low-carbon standard-agro-system. The measurement indices we used reflect consideration of the following questions: whether the social subsystem is stable, whether the economic subsystem is beneficial, and whether the natural subsystem is rational. Each of these effects was assessed according to extant material conditions, research levels, social demand and public response. Questions considered in the analysis include: whether the economic subsystem can be developed to be profitable and low-carbon; whether it has a desirable economic benefit for humans; whether the natural subsystem is realistic and sustainable, whether the resulting human environment is comfortable and acceptable.

Because the most desirable low-carbon agro-system will be based on indices from all three subsystems, constructing an index system requires adherence to the following principles (Zhang et al., 2006; Jiang and Wan, 2009; Wan et al., 2009): (1) Integrity: all indices for technologies should equally reflect social, economic and natural aspects. (2) Objectivity: indices should reflect low-carbon reduction strategies under conventional conditions. (3) Independence: avoid correlation and overlap among indices. (4) Measurability: adopt qualified indices; avoid subjective deviation caused by score judgment of qualitative indices, and quantify the qualitative indices. (5) Availability: sufficiently consider the different degree of collecting data and quantifying indices. (6) Stability: indices should be introductory and have long-term application; short-term problems should not be considered. Finally, the index system must be amenable to change over time and with different circumstances. An example of an Index system is shown in Table 1.

Positive economic effect indices were classified as either direct or indirect. Direct effects included: cauliflower income, cauliflower commodity increase value per unit investment, return rate of labor production, and production value created by the labor force.