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Effects of land use and insecticides on natural enemies of aphids in cotton: First evidence from smallholder agriculture in the North China Plain

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ABSTRACT

Studies conducted in the USA and Europe have shown that diverse landscapes in general support greater natural enemy abundance. No quantitative evidence on the relationship between land use diversity and natural enemies has been reported from developing countries, where fields and farms are much smaller than in modernized agriculture in the west, and where insecticide use is often high and indiscriminate. This paper examines the effects of land use and farmers' insecticide application on natural enemies of aphids in cotton production, based on a unique dataset that links household and cotton field surveys to a detailed assessment of land uses in the landscapes surrounding the cotton fields in the North China Plain (NCP), a major grain and cotton production region in China. Our results show that, in the NCP where farms are small and landscape is dominated by a few crops, Shannon or Simpson land use diversity index is not a good indicator for explaining the relationship between land use and densities of aphid natural enemies. Instead, the types and proportions of cropland habitat mattered. Landscapes with more maize and grassland have higher ladybeetle populations in cotton fields. Farmers' pest management practices such as the amount and timing of insecticide use significantly affect ladybeetle densities. These results imply that there is a need to recognize the potential positive role of cropland use in pest management and call for more judicious insecticide use strategies by smallholder farmers in the North China Plain.

1. Introduction

Biological control of pests by natural enemies represents an important ecosystem service for agriculture (Naylor and Ehrlich, 1997; Losey and Vaughan, 2006). Biological control can mitigate crop yield loss and pest control costs in agricultural ecosystems (Costamagna et al., 2007; Landis et al., 2008). Increased landscape complexity is typically correlated with higher natural enemy populations and, in many cases, enhanced pest control in agricultural landscapes (Landis et al., 2000; Tscharntke et al., 2005; Bianchi et al., 2006; Gardiner et al., 2009).

Empirical evidence in support of this relationship has been collected mainly for cropping systems in North America and Europe (Marino and Landis, 1996; Thies et al., 2003; Schmidt and Tscharntke, 2005; Gardiner et al., 2009). Virtually no information is available from small-scale farming dominated systems in developing countries, where field sizes are often small, and fields with different land uses may be mixed at fine spatial scales. While people in developing countries have similar needs for safe food and environmentally sound pest control by natural enemies as people in developed countries, pest control ecosystem services have been often ignored in pest management decision making by farmers in developing countries (Wyckhuys et al., 2012). Small-scale farms highly depend on the use of broad-spectrum insecticides to control pests (Huang et al., 2002), which can damage the populations of natural enemies, reducing the cost-effectiveness of insecticide investment if unaccounted for in treatment decisions (Zhang and Swinton, 2009).

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Insecticides are intensively used in Chinese agriculture, and insecticide use in cotton is among the highest on a per area basis, despite the extensive adoption of Bt-cotton since the late 1990s (Huang et al., 2010). Besides the well-documented human health and environmental risks (Pimentel et al., 1992; Naylor and Ehrlich, 1997), the economic costs of insecticide use have been increasing since around 2005 (Huang et al., 2010), hindering the growth of farm income. Therefore, research on managing landscape and improving farmers' insecticide application practices for enhanced pest control ecosystem services, which have the potential to protect crop yield while reducing insecticide use in cotton, is meaningful and urgently needed.

The overall goal of this study is to fill the knowledge gap about the effects of land use and farmers' insecticide application on natural enemies in a developing country context characterized by small farm sizes and high use of insecticides such as China. Specifically, this paper examines the following three research questions: (1) what are the effects of land use on natural enemies of aphids in cotton production? (2) what are the effects of farmers' insecticide use on natural enemies? and (3) how to appropriately apply land use data to measure landscape impacts on natural enemies? To address these questions, we collected a unique set of data that included insect samplings in farmers' fields, household survey questionnaires on pest management practices, and detailed land use data obtained through high resolution satellite imagery and extensive ground trothing in the North China Plain (NCP).

We selected the North China Plain (NCP) because it is a major cotton production region in China. The region accounts for 27% of the agricultural land area of China but produces 40% of cotton (NSBC, 2012). Other major crops in the NCP include wheat, maize, and vegetables. Small areas of fruit trees and trees for wood production (mostly *Populus* sp.) are present in the NCP. Agricultural landscapes of the NCP consist of a mosaic of small cultivated plots crisscrossed by irrigation canals and ditches, with small patches of grassland and woodland interspersed between crop fields as the main non-crop elements. In addition, water bodies have some bordering wetland vegetation. Broad spectrum insecticides, particular pyrethroid and organophosphate insecticides, are used intensively, sometimes two times per week over extended periods of time (Lu et al., 2012; Huang et al., 2002).

2. Materials and methods

2.1. Study area

Within the NCP, we conducted surveys in 20 villages spread across three counties (Anci, Bazhou and Wuqing) of Hebei province (Fig. 1). This region is about 100 km South-East of the perimeter of the outskirts of Beijing. Ten villages were selected from Wuqing, six from Anci, and four from Bazhou, representing a gradient in land use pattern (see below). Village centers were separated by at least 3 km.

2.2. Selection of households

A random sampling approach was used to select households to avoid selection bias in econometric analysis. In each of the 20 villages, we obtained a list of all cotton farmers from the office of village committee, based on which we randomly selected 16 households. Nine households were removed from the total sample of 320 because of missing data. Thus, the sample used in the analysis included 311 households, 311 cotton fields associated with the households, and landscape data for 20 villages (see below for details).

2.3. Household survey

Detailed data on household characteristics, insecticide use decision making and actual insecticide use were collected for each household via face-to-face interview during the 2011 growing season[1]. Four rounds of interviews were carried out in: (1) late June, (2) late July, (3) late August and (4) mid-November, 2011. For each household, we selected the largest cotton field as our target field (or plot) to monitor cotton pests and their natural enemies. To obtain information on insecticide use decision making, we asked farmers whether they had considered pest numbers in their cotton fields and other factors when deciding on the application of insecticides. In this question "other factors" could include, for instance, the number of pest natural enemies (e.g. ladybeetles), the desire to prevent problems in the future (i.e. spray prophylactically), or following suggestions by other people. Data on dosage and frequency of actual insecticide use in the target fields were also collected in all four rounds. This procedure allowed us to link farmers' insecticide uses in each target cotton field to biological data on pests and natural enemies in the same cotton field obtained by field observation at the same time.

2.4. Field observations on insects

Observations on the densities of cotton pests and natural enemies were made in each of the 311 cotton plots three times in late June, late July and late August in 2011. In each plot each time, five clusters of plants were sampled, using an "X"-shaped sampling path covering the entire plot. Each cluster included 5 plants, resulting in a total sample of 25 plants per plot. The assessment of agronomically important arthropods was made for the whole plant (or all leaves in the plant). Our team of enumerators, which consisted of 15 graduate students majoring in agronomy, entomology, and agricultural economics, were trained by entomologists and IPM specialists on population sampling and assessing pests and natural enemies in cotton. On average, an enumerator spent 1 h, 2.5 h and 3 h in one field (i.e. 25 plants) to count the insect numbers in late June, late July and late August, respectively.

We collected data for five common pests: cotton aphid (*Aphis gossypii* Glover), spider mites (*Tetranychus cinnabarinus* Boisduval), mirid bugs (mainly *Apolygus lucorum* (Meyer-Dür), cotton bollworm (*Helicoverpa armigera* Hübner), and whitefly (*Bemisia tabaci*). We further collected density data for three groups of natural enemies: ladybirds (predominantly *Harmonia axyridis* Pallas, *Propylea japonica* Thunberg, *Coccinella septempunctata* L.), lacewings (predominantly *Chrysopa septempunctata* Wesmael, *Chrysoperla sinica* Tjeder and *Chrysopa formosa* Brauer) and spiders (predominantly *Erigonidium graminicolum* Sundevall, *Pardosa t-insignita* Boes. et Str. and *Misumenopos tricuspidata* Fabricius).

For pest and natural enemy survey, we adopted the entire-plant counts and counted the number of individuals at the developmental stages, when the pests fed on cotton plants and natural enemies preyed upon insect pests.

[1] Different active ingredients may have different impacts on natural enemies (e.g. ladybeetles). Ideally, the amount of insecticides used by farmers should be separated on the basis of active ingredient. In this study, the amount of insecticide use and names of insecticide products are based on farmer survey. We found that many farmers were unable to report the names of the insecticides used. It is known, however, from administrative records at county level that in northern China, where this study was conducted, pyrethroid and organophosphate insecticides represent more than 85% of all pesticide use and have similarly deleterious effects on natural enemies in cotton (Lu et al., 2012).