Ecological Effects of Regional Agricultural Landscape Patterns on Cotton Aphid Population Abundance: Postprint

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Date: 2018-03-08T00:00:00+00:00

Abstract

Changes in farmland landscape patterns significantly influence pest occurrence and damage, with different landscape patterns exerting varying degrees of effects on pest population sizes. Therefore, clarifying the ecological effects of farmland landscape patterns on pests represents an important prerequisite for pest control. Taking the cotton-growing regions of Shandong Province as the study area, 14 typical cotton-producing counties proximal to different land cover types were selected. Landscape factor indices for the sampled counties/districts were obtained through comprehensive analysis of satellite remote sensing imagery and land cover classification data, and cotton aphid population sizes in the corresponding counties/districts were systematically surveyed. At the large spatial scale of the provincial level, correlations between multiple factors—including landscape composition, landscape configuration, and landscape structure—and populations of seedling aphids and summer aphids in cotton fields were analyzed separately. The results demonstrate that cotton aphid population sizes are closely associated with landscape patterns, and the response characteristics of the two aphid occurrence stages—seedling aphids and summer aphids—to landscape factors are not entirely consistent. Seedling aphid population sizes exhibit significant positive correlations with total landscape area, fractal index of cultivated land, contagion index at the county scale, and radius of gyration at the county scale, and significant negative correlations with the Simpson diversity index. Summer aphid population sizes show significant positive correlations with patch richness density and the contagion index of residential, industrial, and transportation areas. In summary, the responses of both seedling aphids and summer aphids to landscape contagion (form) are essentially consistent: the lower the degree of landscape fragmentation, the more severe the occurrence of both summer aphids and seedling aphids. However, their responses to landscape diversity (quality) are inconsistent. Farmland landscapes with high landscape diversity are unfavorable for seedling aphid occurrence and have no significant effect on summer aphids, whereas richness density facilitates summer aphid occurrence but has no significant effect on seedling aphids. These results reveal the complexity of agricultural pest responses to farmland landscape patterns during different occurrence periods.

Full Text

Ecological Effects of Farmland Landscape Patterns on Cotton Aphid Populations in North China

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Abstract

Changes in farmland landscape patterns can significantly affect pest occurrence and damage. Different landscape patterns exert varying effects on pest populations, making it crucial to elucidate the ecological effects of farmland landscape patterns for effective pest control. This study examined the cotton-growing region of Shandong Province in North China, selecting 14 representative counties or districts with diverse land cover types. Using satellite remote sensing imagery and comprehensive land cover classification data, we analyzed landscape composition, configuration, and structure factors and their correlations with cotton seedling aphid and summer aphid populations at the provincial scale. Results demonstrated close associations between landscape patterns and aphid populations, though the response characteristics differed between the two aphid types. Cotton seedling aphid populations showed significant positive correlations with total landscape area, farmland fractal dimension index, county-level contiguity index, and county-level radius of gyration, but were negatively correlated with Simpson' s diversity index. Summer aphid populations exhibited significant positive correlations with patch richness density and the contiguity index of residential-industrial-traffic areas. Overall, both aphid types responded similarly to landscape contiguity, with lower fragmentation associated with higher aphid populations. However, their responses to landscape diversity differed: high landscape diversity suppressed seedling aphids but did not significantly affect summer aphids, while patch richness density promoted summer aphids without significantly influencing seedling aphids. These findings reveal the complex responses of agricultural pests at different developmental stages to farmland landscape patterns.

Keywords: farmland landscape pattern; landscape factor index; cotton seedling aphids; summer aphids; population size

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Introduction

Farmland landscapes are mosaic systems composed of multiple crop habitats and their surrounding environments, forming spatial network structures of fragmented habitats for species at the landscape scale. While farmland landscapes maintain relatively stable patterns, intensified land use in recent years has caused dramatic changes in landscape configuration, inevitably affecting pest occurrence, dispersal, and the biological control functions of natural enemies, thereby influencing pest populations and crop damage. Investigating the ecological effects of landscape pattern changes on pest populations not only reveals how human activities impact biodiversity structure and function and clarifies mechanisms of biodiversity integration and maintenance in farmland landscapes, but also provides foundational information for developing regional pest management strategies.

Landscape pattern characteristics can be represented by three main aspects: landscape composition (type and proportion of different patches), landscape configuration (size and area ratio of patch types), and landscape structure (shape and arrangement of different patch types), which collectively reflect temporal and spatial scales of landscape pattern changes. Previous research has primarily focused on how non-crop habitat composition at the field scale affects crop pests. Non-crop habitats maintain insect biodiversity, with various woody and grassland habitats providing alternative food for parasitoids and predators. However, non-crop habitats can also provide safe overwintering sites for some pests, facilitating their survival. Studies on pest responses to landscape patterns at larger spatial scales remain relatively scarce. Systematic investigation of multiple landscape factors at broad scales can better clarify the driving mechanisms of landscape factors on farmland pest populations.

Different pest species respond differently to farmland landscape patterns. For example, grassland and forest habitats maximize population growth rates of wheat aphids, while plastic greenhouses inhibit their growth; both forests and greenhouses promote parasitoid wasp populations. Research has shown that wheat aphid populations exceed those in simple landscapes in complex agricultural landscapes, while another wheat aphid species shows the opposite pattern. Even similar species within the same crop ecosystem may respond differently to landscape patterns. For instance, the abundance of one mite species shows significant positive correlation with forest patch structure, while another mite species correlates closely with water body patch structure—differences reflecting their distinct biological characteristics. However, whether different developmental stages of pests within the same agricultural ecosystem respond differently to landscape patterns remains unreported.

Cotton is a globally important economic crop. China is the world's largest cotton producer and importer. The cotton aphid (*Aphis gossypii* Glover) is a major cotton pest widely distributed across cotton-growing regions, causing severe damage in the Yellow River cotton region. Based on occurrence timing, cotton aphids are classified as seedling aphids (occurring during the cotton seedling stage) and summer aphids (occurring during the adult plant stage). Seedling aphids feed on the underside of leaves and tender shoots, causing leaf curling, stunted growth, and disrupted metabolism; their honeydew secretions also affect photosynthesis. Summer aphids densely colonize entire plants, feeding on leaf undersides and tender stems, causing leaf yellowing, blackening, bud and boll shedding, and even defoliation, leading to severe yield losses.

Shandong Province, located in the Yellow River basin, has historically been a major cotton-producing region in China. Industrial restructuring, farming system changes, and urbanization have transformed farmland landscape patterns, creating diverse regional landscape characteristics. This study used Shandong' s cotton-growing region as the research area, analyzing satellite remote sensing imagery and land cover classification data to examine relationships between landscape factors (composition type, proportion, and structural configuration) and populations of cotton seedling aphids and summer aphids. The objectives were to clarify the ecological effects of farmland landscape patterns on both aphid types, 解析 differences in their responses, and provide theoretical and technical support for regional cotton aphid management.

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1. Study Area

Shandong Province has a temperate monsoon climate with average annual temperatures of 12-16°C and precipitation of 600-1200 mm, providing excellent conditions for cotton growth. The study selected 14 cotton-growing counties or districts in Shandong, including Zhanhua and Bincheng districts, ensuring representation of different land cover types near cotton fields.

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2. Methods

2.1 Remote Sensing Imagery and Land Cover Classification The remote sensing data source was Landsat TM/ETM medium-resolution satellite imagery (10-30 m) from 2008-2010. Image preprocessing was conducted using ENVI 5.0 remote sensing image processing software. A spectral interpretation database was established by combining field survey data. Land cover types in the study area were classified into forest, water bodies, farmland, and residential-industrial-transportation areas. Since grassland and wetland are scarce in Shandong and orchards near cotton fields are limited, these categories were not included in the classification.

2.2 Landscape Pattern Analysis Landscape pattern analysis software FRAGSTATS 4.2 was used to calculate 14 landscape indices for each study county/district: total landscape area (TA), patch richness density (PRD), Simpson' s diversity index (SIDI), Shannon' s diversity index (SHDI), largest patch index (LPI), landscape shape index (LSI), perimeter-area ratio (PARA), fractal dimension index (FRACT), contiguity index (CONTIG), and radius of gyration (GYRATE). The total landscape area was calculated as: TA = A × 1/10000, where A is the original area. The radius of gyration (GYRATE) was calculated as: GYRATE = Σhijr, where hijr represents the distance from grid cell ijr within a patch to the patch center (measured as grid center to grid center distance), and z is the number of grid cells in patch ij. Calculation methods for other indices followed Lu et al. [15].

2.3 Cotton Aphid Population Survey Aphid populations were surveyed according to the National Standard of the People' s Republic of China "Rules for Investigation and Forecast of Cotton Aphids" (GB/T 15799—1995). Seedling aphid surveys were conducted from mid-to-late May during the peak damage period, while summer aphid surveys were conducted around June 25 when populations peaked. In each county/district, cotton fields adjacent to different land cover types were selected. Before seedling establishment, 100 plants were examined at 5 points; after establishment, 20 plants were examined at 5 points. The number of aphids per 100 plants was counted, examining the upper, middle, and lower leaves (first expanded leaf, first fruit branch leaf, and main stem leaf). Data from 2008-2010 were collected for 14 counties/districts.

2.4 Data Analysis SPSS 16.0 was used to analyze frequency distributions of seedling and summer aphid populations and fit normal distribution curves. Statistical software R 3.3.1 was used to calculate correlation coefficients (r) between aphid populations and landscape indices, with significance tested at P = 0.05.

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3. Results

3.1 Data Characteristics and Distribution of Cotton Aphid Populations Cotton aphid populations showed distinct regional distribution patterns across Shandong' s cotton-growing areas. Seedling aphid populations ranged from 187.06 to 1416.67 individuals per 100 plants, with a mean of 1611.42 across the 14 counties. Summer aphid populations ranged from 328.10 to 1105.83 individuals per 100 plants, with a mean of 6968.33. There was no significant correlation between seedling aphid and summer aphid populations across counties (r = 0.4511, P = 0.1092). The ranking of counties by aphid abundance differed substantially between the two aphid types. For example, Shanghe County had the highest seedling aphid population (265.33/100 plants) but a moderate summer aphid population (907.00/100 plants), while Pingdu had the lowest seedling aphids (173.33/100 plants) but high summer aphids (1105.83/100 plants). Zouping showed the highest summer aphid population.

[Figure 1: see original paper] The characteristics of cotton seedling aphid and summer aphid populations in Shandong Province

[Figure 2: see original paper] Population density of cotton seedling aphids and summer aphids in 14 counties of Shandong Province

3.2 Effects of Landscape Composition on Cotton Aphid Populations
The relationships between aphid populations and landscape composition factors differed between aphid types. Seedling aphid populations showed significant positive correlation with total landscape area (TA) (r = 0.9582, $P < 0.0010$) and significant negative correlation with Simpson' s diversity index (SIDI) (r = -0.6094, P = 0.0461). Summer aphid populations showed significant positive correlation with patch richness density (PRD) (r = 0.6911, P = 0.0062). No other landscape composition factors showed significant correlations with either aphid type.

Correlation analysis between landscape composition and cotton aphids

3.3 Effects of Landscape Configuration on Cotton Aphid Populations
Landscape configuration indices showed inconsistent relationships with the two aphid types. The most influential configuration factor for seedling aphids was Simpson' s diversity index (SIDI), which showed significant negative correlation (r = -0.6094, P = 0.0461). Summer aphids showed no significant correlations with configuration factors.

Correlation analysis between landscape configuration and cotton aphids

3.4 Effects of Landscape Structure on Cotton Aphid Populations
Landscape structure indices also showed differential relationships. Seedling aphid populations were significantly positively correlated with farmland fractal dimension index (FRACT) (r = 0.6103, P = 0.0323), county-level contiguity index (CONTIG) (r = 0.5677, P = 0.0317), and county-level radius of gyration (GYRATE) (r = 0.6327, P = 0.0152). Summer aphid populations were significantly positively correlated with the contiguity index of residential-industrial-traffic areas (r = 0.5435, P = 0.0446).

Correlation analysis between landscape structure and cotton aphids

4. Discussion

This study revealed that cotton aphid populations are closely related to landscape composition, configuration, and structure, with seedling aphids and summer aphids showing different responses to landscape factors. Previous studies demonstrated that different pest species respond differently to landscape patterns, likely due to variations in food resource quantity/quality and environmental conditions like temperature and humidity. Our results indicate that different developmental stages of the same pest species also show distinct responses.

4.1 Effects of Landscape Composition and Configuration Seedling aphid occurrence showed significant correlation with total landscape area, though the mechanism requires further investigation. Simpson' s diversity index (SIDI) reflects farmland landscape diversity—higher diversity indicates more patch types, which may provide aphids with feeding and overwintering resources. However, our results showed significant negative correlation between SIDI and seedling aphids, suggesting that diverse landscapes provide natural enemies with abundant alternative food and habitats, enhancing their population persistence and pest control functions. Natural enemy migration between patches can effectively control seedling aphids, with previous research indicating that predators like lady beetles provide strong natural control of seedling aphids in Shandong (control efficacy >80%).

In contrast, summer aphids showed significant positive correlation with patch richness density (PRD), which represents the ratio of patch type number to total landscape area. Higher PRD values indicate greater landscape diversity, which may benefit summer aphids by providing diverse hosts. Previous studies showed that PRD increases wheat aphid populations, as aphids migrate to non-crop habitats after wheat harvest and recolonize fields in the next season. Natural enemy control of summer aphids in Shandong is relatively weak (<20%), so although diverse landscapes benefit natural enemies, their control effect on summer aphids is limited. Diverse patches may instead provide more host resources for summer aphids, increasing their populations. Research has shown that patch diversity can increase populations of other cotton pests like lygus bugs and bollworms. The divergent responses of seedling versus summer aphids likely reflect differential effects of food resources and natural enemy control at different developmental stages.

4.2 Effects of Landscape Structure Another important landscape factor affecting aphids is landscape structure. The contiguity index (CONTIG) measures the non-randomness or aggregation of different patch types—higher values indicate better connectivity of dominant patch types and lower landscape fragmentation. Our results showed that higher county-level contiguity promoted seedling aphid populations. Previous research indicated that larger, more concentrated fields with fewer other landscape elements are less conducive to maintaining stable natural enemy populations, potentially leading to seedling aphid outbreaks. Species at different trophic levels exhibit varying sensitivity to landscape fragmentation. Seedling aphids may be more sensitive to fragmentation than their natural enemies; when r-strategist aphids outbreak in well-connected patches, natural enemies cannot reproduce rapidly enough to control them (this mechanism requires further verification).

Summer aphid populations showed significant positive correlation with the contiguity index of residential-industrial-traffic areas. Higher values in this index indicate greater human activity range and relatively less fragmentation of the agricultural ecosystem. Linear landscape elements like highways can isolate animal populations on either side, affecting genetic structure and gene flow. Thus, lower fragmentation of agricultural ecosystems benefits summer aphid occurrence.

5. Conclusion

Both seedling and summer aphids are intimately related to landscape patterns, but their responses are not entirely consistent. While both aphid types respond similarly to landscape contiguity (lower fragmentation promotes higher populations), their responses to landscape diversity diverge. High landscape diversity suppresses seedling aphids but does not significantly affect summer aphids, whereas patch richness density promotes summer aphids without significantly influencing seedling aphids. These results demonstrate the complexity of pest responses to farmland landscape patterns at different developmental stages.

In regions with severe cotton aphid problems, management strategies should be tailored to the specific occurrence patterns of seedling versus summer aphids. Potential measures include reducing overwintering sites, decreasing patch contiguity (especially of residential-industrial-traffic areas), and increasing Simpson's diversity index. Combining these landscape-level approaches with biological and chemical control methods could form a comprehensive regional management strategy. The underlying mechanisms causing different responses of the same species at different growth stages to landscape structure warrant further investigation.

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Note: Figure translations are in progress. See original paper for figures.