

Article

Preliminary Assessment of Alfalfa Crop Trap Strategy in Regulating Natural Predators for *Aphis gossypii* Glover Control

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Abstract: *Aphis gossypii* Glover is an important pest in cotton plantations. *Medicago sativa* L. (alfalfa) is a host plant for the aphid *Aphis craccivora* Koch and may prove to be an important reservoir of natural enemies to combat this pest. The objective of this study was to analyze the impact of different mowing frequencies of alfalfa traps on *A. gossypii* and their natural enemies, using both ground survey data and UAV remote sensing data. The alfalfa was mowed twice to facilitate the transfer of this primary natural enemy to the cotton fields. Ground surveys were carried out every five days to gather data, while temporal niche and niche overlap methods were used for further analysis. Findings collected over a period ranging from day 31 to day 91 indicated that compared to their counterparts with no alfalfa traps, the cotton fields containing these pest control measures demonstrated a reduction in the *A. gossypii* population of approximately 16%. A survey conducted 5 days after mowing the alfalfa on days 61 and 71 found that the cotton fields with alfalfa traps experienced a 24.14% and 26.09% reduction in *A. gossypii* numbers. In contrast, the cotton fields without alfalfa traps experienced a 76.92% and 55.08% increase in cotton aphid numbers during the same period. It is noteworthy that the cotton fields with alfalfa traps showed a delayed onset of cotton aphid damage of approximately 5 days compared to the fields without alfalfa traps. This discovery has significant implications for understanding the ecological control mechanism of *A. gossypii* within alfalfa traps. Planting alfalfa traps around fields in Xinjiang could be promoted as a method to prevent and control aphid damage.

Keywords: cotton aphid; biological control; pest control; niche; ecological control



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1. Introduction

Aphis gossypii Glover (cotton aphids) are a significant pest for cotton crops. They attach themselves to the backs of plant leaves and cause damage by sucking the sap from leaves. This damage results in yellow and white spots on the leaves, causing them becoming curled or crumpled [1]. Infestation can have a significant impact on the development of new leaves, delay the growth cycle, and ultimately affect the quality and yield of cotton [2]. Currently, the control strategy for *A. gossypii* primarily involves passive, large-scale pesticide spraying. Furthermore, the excessive use of pesticides can result in the development of resistance in *A. gossypii* [3]. To reduce the toxic side effects of pesticides on the ecological environment and beneficial organisms, it is necessary to explore a method for the green control of cotton aphids.

Biological control technologies, stimulated by the goal of repairing agricultural ecosystems in a safe and ecologically conscious manner, are now acknowledged as viable alternatives to chemically focused strategies [4]. Scholars, both domestically and abroad, have increasingly invested their time and effort in discovering green alternatives for the

alleviation of pest burdens on *Gossypium hirsutum* Linn. (cotton) crops. The suggested strategies often involve blending cotton fields with other crops such as *Brassica campestris* L., *Zea mays* L. (corn), *Sorghum bicolor* (Linn.) Moench, *Suaeda glauca* (Bunge), or *Medicago sativa* L. (alfalfa) as a means of boosting natural predator populations, a strategy referred to as planting traps [5–11]. Alfalfa is a host plant for *Aphis craccivora* Koch (the alfalfa aphid) and may prove to be an important reservoir of natural enemies to combat this pest. *A. craccivora* mainly feeds on legumes and does not attack cotton. In contrast, *A. gossypii* primarily use cotton as their host and do not feed on alfalfa [4,12,13]. Research on the effect of green manure intercropping in cotton fields has shown that crops such as rapeseed and hemp have a trapping effect on natural predators [14]. Other studies, using *Triticum aestivum* L. (wheat), suggest that top natural predators spread throughout cotton fields. However, wheat is not as effective as alfalfa in preventing diseases [15]. Additionally, it has been observed that plantations with maize traps show an increase in the number and diversity of natural predators [16]. Further ecological research is necessary to understand the environmental conditions that play key roles in alfalfa–aphid interactions. The identification of natural predators is crucial to protect and promote their populations for the more targeted ecological control of aphids [12,17]. Researchers have conducted studies on the ecological control mechanisms of alfalfa, and these studies will bolster our understanding of the role alfalfa plays within the ecological control processes of different agroecosystems [18].

Xinjiang is a region in China known for producing high-quality cotton. Currently, the prediction of cotton pests and diseases in Xinjiang relies heavily on manual investigation by technicians and their experience-based judgments [2]. There is an urgent need to incorporate remote sensing and implement green control methods to mitigate the damage caused by cotton aphids on cotton. UAVs have a long history of use in monitoring applications and have been used in tasks such as identifying crop diseases, monitoring pests, and estimating pest damage levels [19–22]. Controlling the number of cotton aphids through the carefully orchestrated implementation of ‘trap crops’ like alfalfa draws on certain biological principles [23]. The existing studies on controlling cotton aphids using alfalfa traps have demonstrated that this strategy can have a positive impact on suppressing cotton insect pests and enhancing cotton yield [3,24]. However, the exact mechanism of the ecological aphid control action of alfalfa traps is not yet fully understood. Further research is required to ascertain whether alfalfa requires mowing as well as the optimal frequency of mowing to maintain pest populations in cotton fields long-term and in a low-hazard state.

This study analyzed the population dynamics of *A. craccivora* and their main natural predators in alfalfa traps, as well as the temporal pattern and temporal ecological niche dynamics of cotton aphids and their main natural predators in cotton fields. In addition, this study investigated the effects of different mowing frequencies on cotton aphid populations and their natural predators in alfalfa traps, based on survey data and UAV multispectral images. The objective of this study was to construct practical instructions for the subtle natural control of cotton aphids plaguing cotton plantations.

2. Materials and Methods

2.1. Data Acquisition and Analysis

Our investigation took place in Shaya County, Xinjiang Uygur Autonomous Region, at the following precise coordinates for the 66-acre area (41.190308° N, 82.860537° E), at approximately 896 m above sea level. We organized this study around specifically allocated alfalfa traps, setting their length and breadth as 100 m and 8 m, respectively. This location accommodated two cotton fields within a protective forest belt on the northwest boundary of an agricultural field ensemble; one included dedicated alfalfa traps while the other excluded these devices. Notably, both fields came under uniform farming practices and regulations (Figure 1).

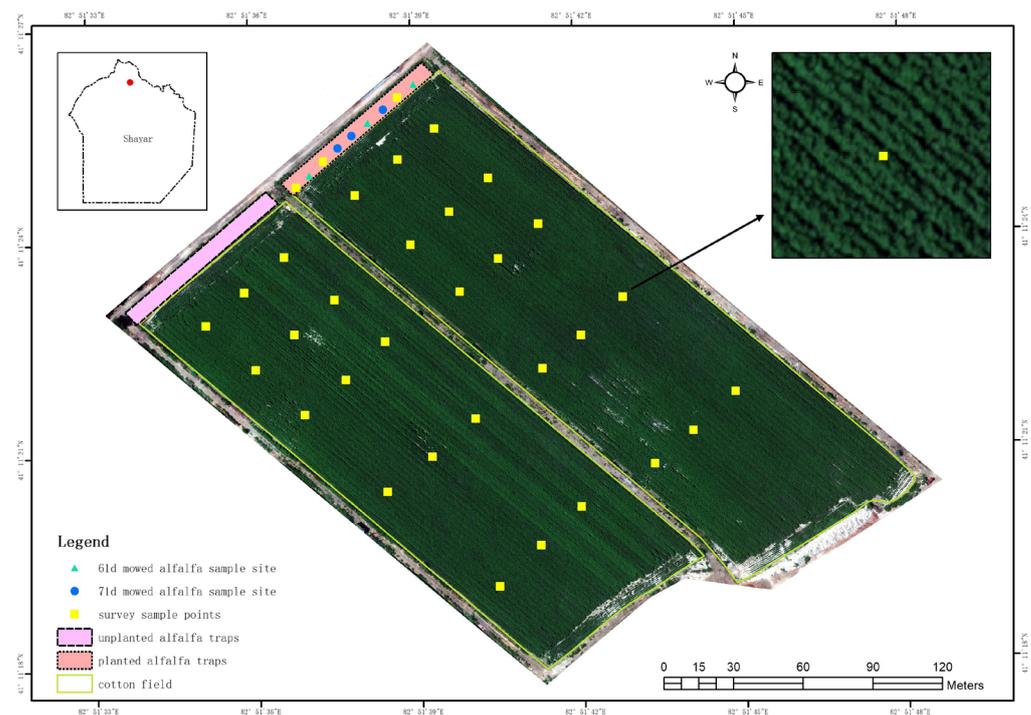


Figure 1. A schematic diagram of the study area. The light red area represents the alfalfa trapping zone planting area, the light pink area represents the unplanted alfalfa traps area, and the light green range represents the cotton planting area. The cyan triangular markers indicate the 61d alfalfa ground survey and alfalfa mowing samples, the blue dots indicate the 71d alfalfa ground survey and alfalfa mowing samples, and the yellow squares indicate the ground survey samples (5 m × 5 m).

The planting started with sowing alfalfa seeds on 5 March 2021, followed by seeding cotton crops on 17 April of the same year. We conducted regular investigations every 5th day, starting 31 days after planting the cotton, covering both the alfalfa and cotton growing regions with precision. The investigations were carried out when the alfalfa growth ranged between 30 cm and 80 scales. During a 91-day period, we recorded objective observations on the growth increments of cotton and alfalfa plantations at 5-day intervals, as well as the number of aphids colonizing the cotton compared to number of their primary natural predators. At distances of 10, 30, 50, 80, and 120 m from the alfalfa traps, three replicate survey sites were selected to quantify bollworms and major predators in the surrounding cotton fields. Fifteen 5 m × 5 m sample plots were established in each cotton field to survey *A. gossypii* and their natural predators. Within each sample plot, five 1 m × 1 m (about 20 cotton plants) areas were randomly selected to conduct a comprehensive survey of the entire cotton plant. The number of *A. gossypii* and their natural predators on one hundred cotton plants was recorded. Major natural predators were identified visually under 4× magnification during the counting process (DNA determination was not performed). Within the alfalfa traps, 9 plots of an area of 5 m × 5 m were randomly selected to meticulously evaluate both the number of *A. craccivora* and their natural predators (for each plot, five survey areas measuring 1 m × 1 m (about 25 plants) were randomly selected for whole-plant surveys of alfalfa.).

Every separate plot incorporated a triplet replicate based on a 'Z'—shaped five-point sampling model [25]. At each point within these parameters, an exhaustive full-plant stationary survey was carried out, which included the 10th plant for each case. In this study, we opted to mow the alfalfa every 10 days. Among all sample areas that we studied, 3 plots were randomly chosen for mowing at the end of day 61; meanwhile, a 3rd set of distinct plots underwent the same procedure but after day 71 (as depicted in Figure 1).

To predict the impact of mowing alfalfa on the aphids in cotton fields, we collected UAV image data simultaneously with the ground surveys. We used PIX4Dmapper software (Pix4D SA, Version: 4.4.12) for the surveys and ArcGIS Pro software (ESRI, Version: 2.8.6) for data alignment and vegetation characterization.

2.2. Research Methodology

The Ecological Niche Breadth Index (ENBI) serves as a metric to quantify the ecological niche breadth, providing insights into the distribution of species based on their resource utilization patterns. The ecological niche breadth denotes the extent or range of ecological niches occupied by species within an ecosystem. In this study, a time series was constructed using 13 survey dates, employing the survey data of the cotton aphid and its principal natural predators in cotton fields, both with and without alfalfa traps, to establish a comprehensive resource series. The ecological niche width was then standardized using Hurlbert's (1978) ENBI [26–28]:

$$B_A = \frac{1 / \sum_{j=1}^n \frac{p_j^2}{N_j} - N_{\min}}{1 - N_{\min}} \quad (1)$$

where B_A is the standard ecological niche breadth index; p_j is the proportion of individuals of species utilizing resource j ; N_j is the number of resources available for resource j ; n is the total number of possible resource states; and N_{\min} is the minimum value in the resource.

The ecological niche overlap index was solved using the Pianka (1973) equation [29–31]:

$$O_{jk} = \frac{\sum_{i=1}^n P_{ij} \cdot P_{ik}}{\sqrt{\sum_{i=1}^n P_{ij}^2 \cdot \sum_{i=1}^n P_{ik}^2}} \quad (2)$$

where O_{jk} is the ecological niche overlap index of species k over species j ; P_{ij} and P_{ik} are the proportion of resource i in the whole resource utilized by species j or k ; and n is the total number of resource states.

We investigated the number of *A. craccivora* and *A. gossypii* as well as those of their natural predators per unit area of alfalfa and cotton during days 31 to 91 after cotton planting. We calculated the population densities of these insects based on their respective host plants and determined the ecological niche widths of *A. craccivora* and *A. gossypii* as well as their natural predators for alfalfa and cotton.

In this study, to gauge how effective these predators are in abating the spread of aphids, indoor experiments specifically examining how *A. gossypii* natural predators can manage the numbers of *A. gossypii* were carried out. This experiment employed Petri dishes as the media for rendering the predation analysis. Three sets of replicated trials were conducted for each natural enemy [32]. *A. gossypii* and their principal natural predators were collected from cotton fields where the experiment was conducted. *A. gossypii* were exposed to various natural predators in the Petri dishes at seven different population density levels: 30, 60, 90, 120, 150, 180 and 210. The number of *A. gossypii* that were preyed upon by the natural predators was observed and recorded after 24 h. Each Petri dish was replicated five times. The average number of *A. gossypii* predated by the natural predators over 24 h was calculated.

To evaluate the impact of mowing alfalfa on aphid control in cotton fields, remote sensing images from the local area were classified using the SVM algorithm of the scikit-learn library, based on the UAV multispectral data and field survey information of cotton and alfalfa. The Rasterio library of Python software (version: 3.12, <https://www.python.org/>) was used to read the images. The classification accuracy was calculated and the prediction results were output [33]. To effectively understand the dynamics of aphid occurrence in cotton fields, an interpolation method with high accuracy and minimal interaction is required due to the insects' nonlinear and random nature. This study employed the

XGBoost–GWO–SVR prediction model to predict *A. gossypii* and was chosen based on previous research [34].

In this study, we utilized the empirical Bayesian kriging (EBK) method for spatial interpolation and simulation of the prediction results [35]. It employs stable data, minimal interactive modelling, and has a smaller standard error of prediction and automatically performs the most difficult steps in constructing an effective kriging model [36]. The cotton aphid distribution map in the cotton field after mowing the alfalfa was generated using the ‘Geostatistical Analyst | Empirical Bayesian Kriging’ function included in the ArcGIS Pro software. The overlap factor was uniformly set to 1.5, the transformations were empirical, and the variability function model was the K-Bessel parameter of trend removal [37]. The image resolution was used as the smallest unit.

3. Results

3.1. Population Dynamics of *A. craccivora* and Major Natural Predators in Alfalfa Traps

The survey showed that the alfalfa traps were occupied by *A. craccivora* and their main natural predators, chiefly *Hippodamia variegata* Goeze, *Propylea japonica* (Thunberg), and lacewings, with the main species being *Chrysoperla carnea* Stephens, *Chrysoperla sinica* (Tjeder), *Chrysopa Formosa* Brauer, and *Chrysopa phyllochroma* Wesmael.

Figure 2 demonstrates how the population of *A. craccivora* began to gradually increase on the 31st day after cotton planting. The first peak occurred on the 36th day, followed by a decline, and then the first peak and trough on the 46th day. The population of *A. craccivora* continued to increase gradually until the second peak appeared on the 61st day, after which it began to decline as the alfalfa was mowed. An observation recorded during the peak phase between 36d and 51d showed an increase in the population of lacewings, which exceeded the numbers for *H. variegata* and *P. japonica*. On day 51, the highest population concentration of lacewings was recorded at 184.2 (± 2.74) per 100 plants inside the alfalfa traps. In contrast, *H. variegata* reached its peak at approximately 91.7 (± 1.82) individuals per set square. Between days 51 and 76, the number of lacewings in the alfalfa traps exceeded *H. variegata* and *P. japonica*. From days 51 to 81, significantly fewer numbers of lacewings were recorded compared to the *P. japonica* population (Figure 2). On the 81st day, there was a notable increase in *P. japonica*, with numbers peaking at 65 (± 1.37) per 100 plants (Figure 2).

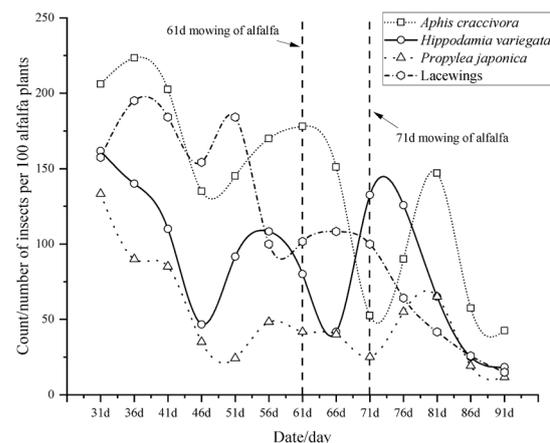


Figure 2. Population dynamics of *A. craccivora* and natural predators in alfalfa traps. Note: Data are the mean \pm SD of three replicates. The different letters in each column represent significant differences among different treatments ($p < 0.05$). The same as below.

Through studying the population dynamics of *A. craccivora* and their principal natural predators within alfalfa traps, we gained a better understanding of their temporal niches and degree of overlap. As illustrated in Table 1, lacewings possess the broadest (0.856) niche, followed by *H. variegata* (0.812), then *A. craccivora* (0.795), with *P. japonica* ending the line-up

at 0.718. The subsequent analysis of “niche overlap” revealed significant interactions, notably between *H. variegata* and *P. japonica* (0.756), *H. variegata* and lacewings (0.847), and finally, *P. japonica* and lacewings (0.827).

Table 1. *A. craccivora* and natural predator niche width and overlap in alfalfa traps.

Description	IA1	IB	IC	ID
IA1	0.795	0.812	0.782	0.856
IB		0.790	0.756	0.847
IC			0.769	0.827
ID				0.811

Note: (1) IA1: *A. craccivora*; IB: *H. variegata*; IC: *P. japonica*; ID: lacewings. (2) The temporal niche breadths are the values on the diagonal, and the temporal niche overlap index is at the upper right of the diagonal.

3.2. Population Dynamics and Temporal Ecological Niche of *A. gossypii* and Primary Natural Predators in Cotton Fields

3.2.1. Population Dynamics

The survey showed that *A. gossypii*, *H. variegata*, *P. japonica*, and lacewings were found in the cotton fields. Figure 3 represents the population changes of *A. gossypii* in cotton fields in both the presence and absence of alfalfa traps. The unmistakable shift began 31 days post-planting when the insects began to infiltrate the fields. As the sprouting stage progressed at pace with staggering crop growth, two divergent peaks were observed in the expansion rate of these insect communities during days 61–66 and 71–76 between the fields with and without alfalfa traps. On the other hand, as day 76 arrived in these fields, an abrupt downswing became evident among *A. gossypii* in both fields. Between days 81 and 91 (a period that marks prolific blossoming of the cotton), as cotton enters the flowering and boll stage, *A. gossypii* showed negligible damage.

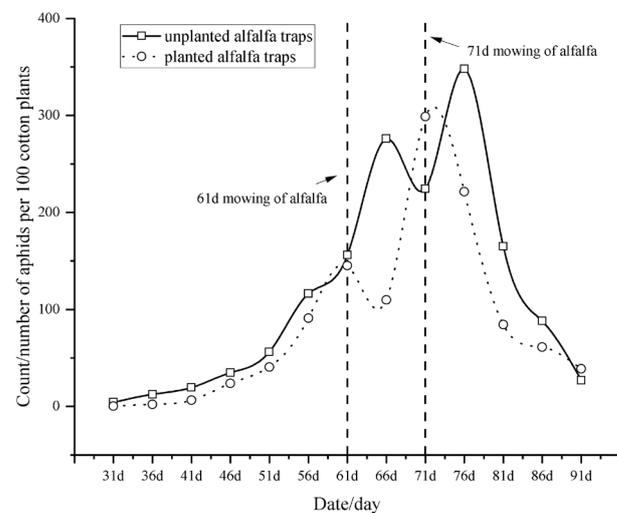


Figure 3. Population dynamics of *A. gossypii* in cotton fields with and without alfalfa traps.

Field visit observations on the 61st day showed that fields with alfalfa safeguards in place had around 14,520 (± 247) aphids per hundred plants sampled, while fields without such defensive mechanisms had a slightly larger population of over 15,600 (± 192). On day 66, after the first mowing, the average density of *A. gossypii* per 100 plant samples decreased to approximately 10,980 (± 149), a 24.14% decrease compared to before mowing.

However, in plots without alfalfa traps, the count of *A. gossypii* continued to increase and at day 66, there were nearly 27,600 (± 464) aphids per 100 plants, which represents a 76.92% increase from the figures obtained on day 61. On day 71, the second alfalfa mowing occurred; subsequently, *A. gossypii* counts per hundred plants were approximately 29,890 (± 471) for trap-cropped spaces and around 22,440 (± 244) for spaces without traps/mowing.

On day 76, approximately 22,143 (± 253) fewer aphids were detected in every hundred plants. The count of *A. gossypii* increased in fields without alfalfa traps, reaching a peak of 34,800 (± 382) aphids per 100 plants on the 76th day. There was a 55.08% increase compared to just before the second mowing on the 71st day. After day 81, there was a decrease in *A. gossypii* counts across both alfalfa and non-alfalfa trap areas.

As illustrated in Table 2, primary predators appeared around five days earlier when alfalfa traps were used than in cotton plantations devoid of alfalfa traps. Several species that prey on *A. gossypii* were observed across the various cotton fields, as displayed in Figure 4. Among these, *H. variegata*, *P. japonica*, and lacewings exhibited a notable dominance. On close observation, it was noticed that before any mowing began, there was a slow build-up in the population of such natural predators residing within the cotton fields. Interestingly, after conducting an alfalfa mow in the vicinity on both days 61 and 71, the quantity of these beneficial foes rose dramatically, reaching a peak volume that was maintained consistently thereafter.

Table 2. Survey of *A. gossypii* and natural predators in cotton fields. (Number of aphids/100 cotton).

Date	IA2	Fields with Planted Alfalfa Traps			Fields without Planted Alfalfa Traps		
		IB	IC	ID	IB	IC	ID
41d	6.43	15.75	7.65	1.88	51.79	32.26	19.23
50d	40.68	20.99	11.43	63.95	80.57	50.18	36.55
66d	109.82	121.00	67.09	95.14	203.72	118.68	113.21
73d	298.90	177.05	104.74	57.43	30.77	15.68	28.79
88d	61.31	23.71	13.86	22.04	69.54	43.30	45.62

Note: IA2: *A. gossypii*; IB: *H. variegata*; IC: *P. japonica*; ID: lacewings.

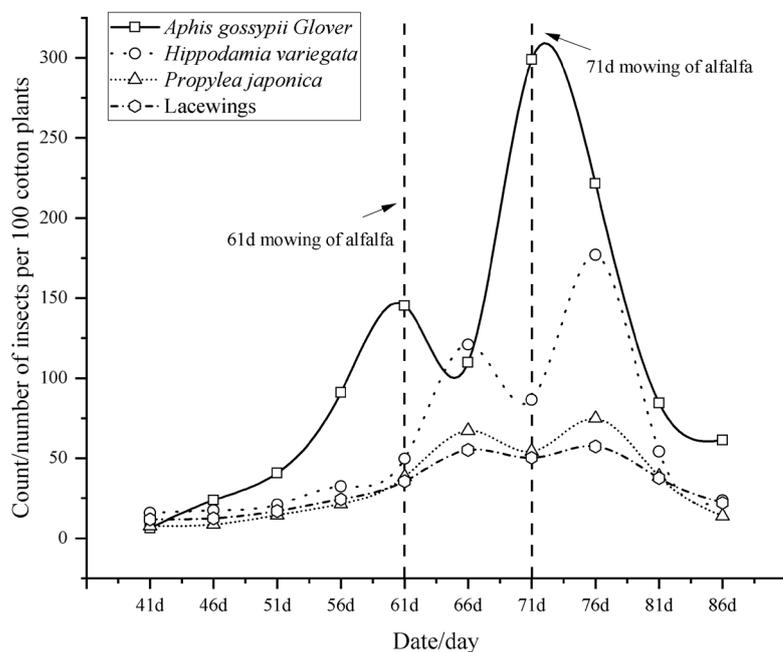


Figure 4. Population dynamics of *A. gossypii* and their natural predators in cotton fields with alfalfa traps.

3.2.2. Temporal Patterns of Community Structure

The results of the 31-day survey indicated that cotton and alfalfa were thriving, and the populations of *A. gossypii* and their primary natural predators were steadily increasing in the cotton fields. The escalating population trend for both *A. gossypii* and their key predators within the cotton fields is directly proportional to their active reproductive cycles.

The population of *A. gossypii* in the cotton fields experienced a sudden increase before the first mowing of alfalfa, as shown in Figure 5. In addition, the main natural predators of *A. gossypii* had already been observed at this stage. The number of *A. gossypii* began to decrease after the first mowing of alfalfa (61d), as their primary natural predators began to steadily increase from that point onwards. The data indicate that the population of *A. gossypii* decreased significantly after the second mowing of alfalfa, specifically after 71 days.

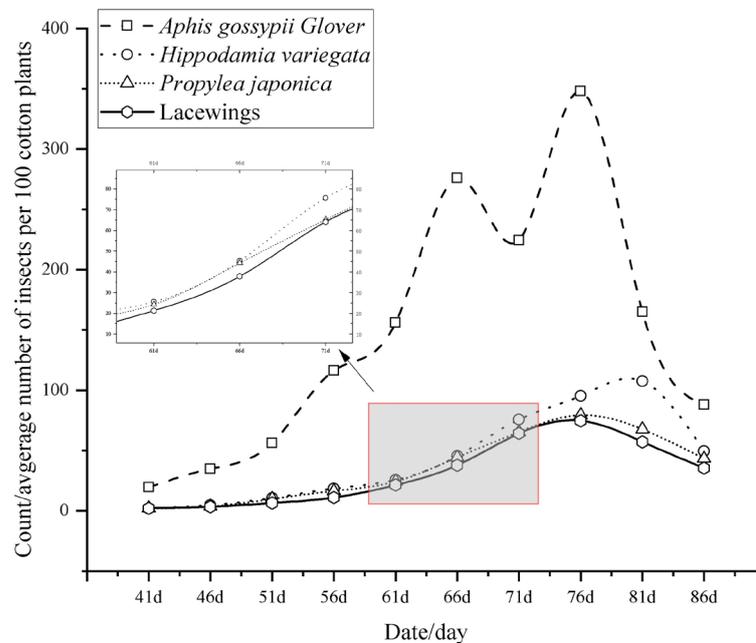


Figure 5. Population dynamics of *A. gossypii* and their natural predators in cotton fields without alfalfa traps.

3.2.3. Temporal Ecological Niche Dynamics

The temporal specifications of niche width for organisms such as *A. gossypii* and their primary predators are displayed in Table 3, including the classifications into *H. variegata* (0.785), *P. japonica* (0.753), and lacewings (0.714), along with *A. gossypii* (0.674). These measurements have broad-ranging implications; the wider niche widths attributed to creatures like *H. variegata*, lacewings, and *P. japonica* convey an evenly spaced distribution throughout time, which implies a strong adaptability and solidity. Moreover, the examination of niche overlap indexes manifests in prominent overlaps such as those among *H. variegata* and *P. japonica* (0.952), *H. variegata* and lacewings (0.919), as well as between *P. japonica* and lacewings (0.913).

Table 3. Niche width and overlap analysis of *A. gossypii* and natural predators in cotton fields.

Description	Fields with Planted Traps				Fields without Planted Traps			
	IA2	IB	IC	ID	IA2	IB	IC	ID
IA2	0.674	0.827	0.801	0.796	0.750	0.942	0.904	0.922
IB		0.785	0.913	0.884		0.764	0.952	0.919
IC			0.753	0.903			0.694	0.913
ID				0.714				0.710

Note: (1) IA2: *A. gossypii*; IB: *H. variegata*; IC: *P. japonica*; ID: lacewings. (2) The temporal niche breadths are the values on the diagonal, and the temporal niche overlap index is at the upper right of the diagonal.

In the fields devoid of alfalfa traps, there was a significant surge in the *A. gossypii* population. Interestingly, this spike did not just peak but stayed elevated for an extended period, leading to a greater niche breadth (0.751). Moreover, differing levels of intersection

existed between the habitats of *A. gossypii* and their primary natural predators. In most cases, we saw substantial habitat intersections; however, limited overlaps occurred against short-winged hoverflies with an index rating of 0.487 as an exception. Significant examples of intersection were manifested between *A. gossypii* and other natural threats like *H. variegata* (0.942), lacewings (0.922), and *P. japonica* (0.904). With regard to cotton fields minus the presence of alfalfa traps, a strong emergence of the key pest deterrents (*H. variegata*, *P. japonica*, and lacewings) was noted.

3.3. Effects of Key Natural Predators on *A. gossypii* Populations

As illustrated in the data observations in Table 4, it can be seen that each day around 201 (±8) *A. gossypii* fall victim to an adult *H. variegata*; thus, these are evidently significantly efficient pest controllers. Similarly, the research data from Table 5 portray each adult *P. japonica* preying on about 189 (±11) aphids every day. Similarly, the consumption rate (Table 6) shows third-instar lacewing larvae consume roughly 147 (±6) *A. gossypii* daily.

Table 4. Predation efficacy of *H. variegata* adults under varied densities of *A. gossypii*.

AGPD	30	60	90	120	150	180	210
EPD1	28.00	54.00	73.00	88.00	91.00	98.00	104.00
EPD2	29.00	48.00	69.00	90.00	93.00	100.00	103.00
EPD3	28.00	52.00	75.00	89.00	94.00	101.00	100.00
ANPs	28.33	51.33	72.33	89.00	92.67	99.67	102.33

Note: AGPD: *A. gossypii* population density; EPD: experimental Petri dishes, triplicates; ANPs: average number of predators. The same below.

Table 5. Predation efficacy of *P. japonica* adults under varied densities of *A. gossypii*.

AGPD	30	60	90	120	150	180	210
EPD1	28.00	53.00	66.00	78.00	84.00	92.00	98.00
EPD2	29.00	48.00	68.00	79.00	85.00	94.00	100.00
EPD3	27.00	52.00	67.00	77.00	86.00	91.00	97.00
ANPs	28.00	51.00	67.00	78.00	85.00	92.33	98.33

Table 6. Predation efficacy of 3rd-instar lacewing larvae under varied densities of *A. gossypii*.

AGPD	30	60	90	120	150	180	210
EPD1	22.00	43.00	55.00	66.00	75.00	80.00	83.00
EPD2	24.00	41.00	58.00	63.00	73.00	79.00	82.00
EPD3	23.00	40.00	56.00	67.00	76.00	82.00	85.00
ANPs	23.00	41.33	56.33	65.33	74.67	80.33	83.33

These findings align with the evidence confirming that *H. variegata* adults, *P. japonica* adults, and third-instar lacewing larvae positively contribute toward maintaining control over the rampant crop infestation caused exclusively by rapid proliferation among *A. gossypii*. In this spectrum, the extent of *H. variegata* adults' contribution is significantly enhanced when compared with other predators, followed by *P. japonica*. In comparison, predation output produced from the third-instar larvae population appeared somewhat ineffective.

3.4. Ecological Regulatory Effects of Alfalfa Traps on *A. gossypii*

3.4.1. Population Dynamics of *A. gossypii* in Cotton Fields with Mowed Alfalfa Traps

This study found that the main natural predators of *A. gossypii* appeared approximately 5 days earlier in the cotton field with alfalfa traps than in the field without them. Furthermore, the population of natural predators increased after the initial mowing of the alfalfa traps, which effectively controlled the initial outbreak of *A. gossypii*.

A. gossypii populations and their main natural predators undergo significant alterations associated with the mowing of alfalfa in cotton fields. The first mowing of the alfalfa on the 61st day increased by three times the populations of the ladybird beetles (*H. variegata*, *P. japonica*) and lacewings as predators in the cotton fields. At that time, cotton fields with alfalfa traps had 2.8 times more primary natural predators than those lacking the traps. After a 10-day control period, while the population of aphids decreased by 71.9% in the areas with mown alfalfa traps, there was an increase in aphids by 33.7% in places without alfalfa traps. After conducting a second mowing on the 71st day, the numbers of ladybirds and lacewings in the cotton fields with alfalfa traps increased by 1.5 times, and the total number of natural predators was 2.4 times that of the fields without alfalfa traps. At this time, *A. gossypii* population in fields with alfalfa traps experienced a 71.7% decrease; meanwhile, the aphid population in fields without alfalfa traps increased.

3.4.2. Ecological Suppression of *A. gossypii* by Alfalfa Trap Prediction

Figure 6 shows two adjacent cotton fields separated by a 3 m field ridge, one with alfalfa traps and the other without. The field ridge includes *Phragmites australis* (Cav.) Trin. ex Steud., *Tamarix ramosissima* Ledeb., and other types. Alfalfa is only planted in predetermined areas [30]. In addition, the ground is bare, and *P. australis* and *T. ramosissima* are everywhere. Aphids and their natural predators were not observed on either *P. australis* or *T. ramosissima*. Table 7 shows that the SVM classification method has an overall classification accuracy of 95.67% for cotton within the tested cotton field.

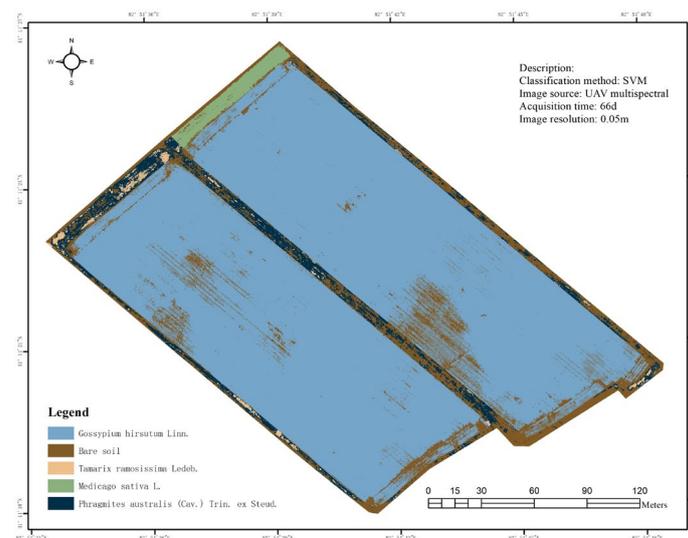


Figure 6. Cotton field feature classification using UAV multispectral data (SVM methods).

Table 7. SVM object classification results and accuracy evaluation.

Type	Classification Results/m ²	OA [33]	Kappa Coefficient
Cotton	36,971.45	95.67%	0.93
Bare Soil	2593.33	96.31%	0.92

Figure 7 illustrates that at 61 days, the *A. gossypii* abundance was notable in cotton fields without alfalfa traps, with some areas recording over 200 *A. gossypii* per 100 cotton samples. In contrast, the cotton fields equipped with alfalfa traps had significantly fewer *A. gossypii*, with numbers not exceeding 68 per 100 cotton samples after the first mowing. As depicted in Figure 8, at 71 days, *A. gossypii* abundance was notable in cotton fields without alfalfa traps, with some areas recording over 256 pests per 100 cotton samples. On the contrary, cotton fields equipped with alfalfa traps had significantly fewer *A. gossypii*, with

numbers not exceeding 75 per 100 cotton samples after the second mowing. This significant discovery derived from these studies provides confirmation of the importance of investing in the optimal timing of both the planting and mowing of alfalfa traps associated with cotton farming. Figures 7 and 8 demonstrate that following the mowing of the alfalfa, the number of *A. gossypii* in the vicinity of the alfalfa traps is significantly higher than in other areas.

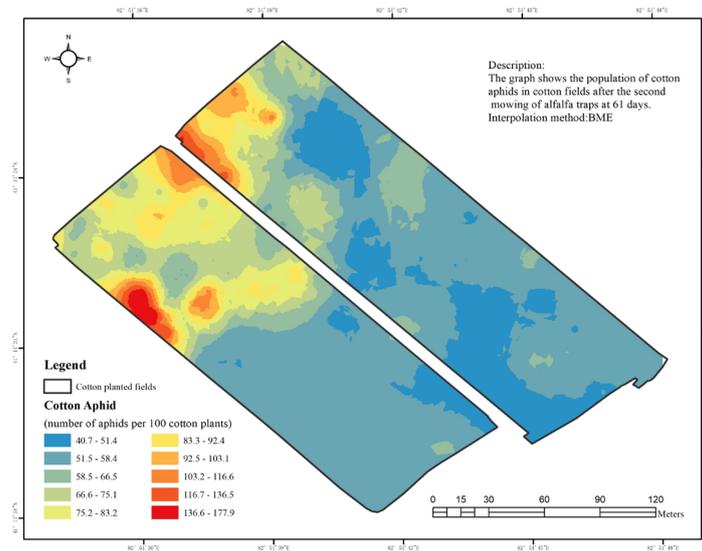


Figure 7. Spatial distribution characteristics of *A. gossypii* after 61 d alfalfa mowing.

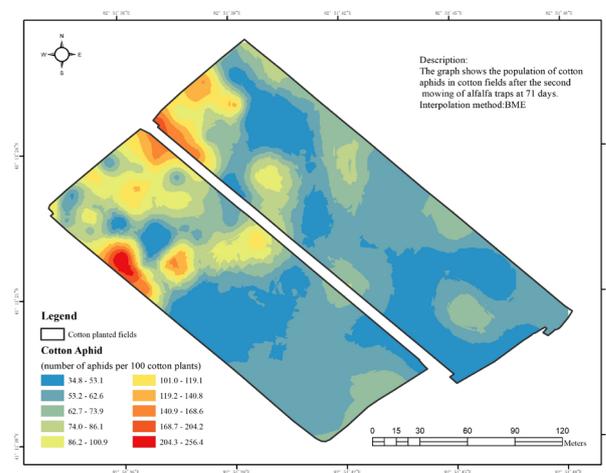


Figure 8. Spatial distribution characteristics of *A. gossypii* after 71 d of alfalfa mowing.

The *A. gossypii* data from the sample points in the study area were predicted for stability and accuracy using the XGBoost–GWO–SVR prediction model. For validation purposes, 66 days of *A. gossypii* survey data were selected for this study. Figure 9 shows that the predicted data from the XGBoost–GWO–SVR cotton aphid prediction model based on remotely sensed data closely matched the 66-day field survey data.

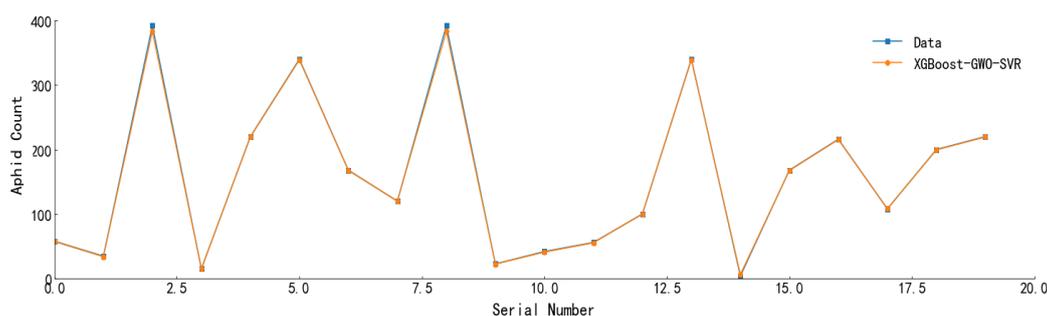


Figure 9. Validation results of *A. gossypii* predicted using XGBoost-GWO-SVR model against ground survey data (66d).

4. Discussion

The aim of this study was to assess the effectiveness of using alfalfa traps for ecologically controlling *A. gossypii* in cotton fields. We mowed the alfalfa to promote the transfer of aphids' natural predators to the cotton fields, which led to a reduction in the population of *A. gossypii*. The analyses revealed differences in the activity periods or 'temporal niche widths' of these organisms. This study analyzed the population dynamics of alfalfa aphids and their natural predators. Natural predator populations inhabiting alfalfa traps display variable density rates depending on the different phases of alfalfa growth, leading to substantial changes in predator counts [11]. In a significant advance in bolstering aphid control through the optimum use of cotton aphids' natural predators, researchers specializing in plant protection have unveiled the results of their examinations into the predatory influence exerted by primary natural predators like *H. variegata*, *P. japonica*, and lacewings. In the scenario where alfalfa traps are utilized in cotton fields, *H. variegata*, *P. japonica*, and lacewings emerge as the key adversaries of the *A. gossypii*. This is attributable to their sizeable numbers and coordinated actions as well as their potent predation abilities. The influence exerted by the cotton bollworm over the cotton fields is, without a doubt, profound. The current study aimed to assess how successful adult *H. variegata*, adult *P. japonica*, and lacewings might be when dealing with these *A. gossypii* [23,32,38–43]. These findings underscore a concerted effort among these pivotal predators to harvest *A. craccivora* populations by occurring simultaneously during specific periods. However, the reasons for the accumulation of so many alfalfa aphids in alfalfa were not quantitatively studied. This requires further research, particularly into the spreading sources, growth, and declining patterns of alfalfa aphids and other natural predators.

This study analyzed the reasons for the rapid increase in *A. gossypii* in cotton fields. The increased *A. gossypii* population can be attributed to cotton growing providing a favorable food source for *A. gossypii*. The mowing of the alfalfa traps reduced the number of alfalfa aphids present. Natural enemies of the alfalfa aphid have migrated to cotton fields and may, therefore, have access to additional food sources [25]. The survey data revealed that cotton fields without alfalfa traps had to wait passively for the migration of the main natural predators of the *A. gossypii*. However, our experimental design did not aim to breed the natural predators that were originally present in the cotton fields. This aspect could be further developed in the next phase of this study.

The continual fluctuation between growth and decline observed in the population of *A. gossypii*, alongside that of their prevalent natural predators, demonstrates the intricate balance they maintain [12,13]. Figure 5 illustrates this dynamic equilibrium process that the population of *A. gossypii* in cotton fields undergoes in the absence of alfalfa trap control. The analysis of the temporal patterns of *A. gossypii* and their primary natural predators indicates that the damage caused by *A. gossypii* in the cotton fields before alfalfa mowing was greater and lasted longer than that in cotton fields with alfalfa traps. *A. gossypii* populations were more abundant in cotton fields without alfalfa traps after alfalfa mowing. This hindered the efficiency of reducing the pest population via their natural predators [18]. Fields with

traps managed to significantly slow down the growth rate of this aphid species. These findings suggest that establishing an overlap in time between the life cycle of the aphid and its predators is crucial for effective control of *A. gossypii* infestations using their natural predators. However, upon examining the overall distribution of the *A. gossypii* population, no significant difference was observed in the number of major natural predators of *A. gossypii* between cotton fields with alfalfa traps and those without.

In the area under investigation, cultivable land is engaged in growing crops such as wheat, cotton, and corn. Winter wheat farms represent a significant source of natural predators for *A. gossypii*. While there have been favorable outcomes from cultivating cotton, an overlap occurs between the harvest time of wheat and when cotton planting starts [15]. Over time, this timing clash has spurred a decrease in wheat production spaces yearly, which concurrently has diminished the number of these predator adversaries that combat *A. gossypii* [44]. In addition, global climate change issues have led to temperature elevations triggering pest and disease appearances earlier during the period when the planting and nurturing of cotton takes place [25]. The decline in populations of natural predators that regulate cotton pests, along with timing mismatches, has led to a weaker control over *A. gossypii*. Consequently, the intensity of *A. gossypii* infestations has been rising annually [45]. Using alfalfa planting in protective forestry surrounding cotton fields can achieve two objectives: it fills the void left by the diminishing number of wheat fields (the original habitat where natural predators thrived), and acts as an invaluable feed crop. The timely trimming of alfalfa helps alleviate potential damage from *A. gossypii* in the primary field and presents an eco-friendly solution to pest management. Compared to other crop traps, alfalfa can provide a breeding ground for the natural predators of cotton pests, such as *A. gossypii*. Studies in the literature have affirmed that alfalfa mowing aids natural predators in transitioning as it assists in relocating them from their indigenous habitats to cotton fields. This approach maintains elevated levels of the natural remedy against pests over time; subsequently, it leads to a substantial decrease in crop parasite populations. Previous studies have emphasized the importance of judiciously managing the frequency of mowing based on the specific requirements of field production and management [30,46]. This study did not thoroughly investigate the optimal ratio of alfalfa and cotton planting or the optimal aphid control effect of alfalfa planting patterns around cotton fields. These aspects require further research.

In the experimental design shown in Figure 6, the results of the remote sensing feature classification indicate that in the area where alfalfa traps were not planted, the field weeds contained *P. australis* and *T. ramosissima*. The survey data revealed that the number of *H. variegata* and lacewings on the natural weeds on both sides of the cotton field was 0 throughout the survey period. Additionally, at the height of the cotton aphid population, there were less than 50 *P. japonica* per 100 cotton plants on the natural weeds on both sides of the field [25]. In 2023, Peng et al. conducted a biological control trial of cotton aphids using trap plants (*Brassica napus* L., *T. aestivum*, *Lupinus micranthus* Guss., *Mentha haplocalyx* Briq., *Fagopyrum esculentum* Moench, and natural weeds) in a plot adjacent to the experimental area. The results showed that *B. napus* and *T. aestivum* were the most effective crops for trapping natural enemies, while natural weeds were not effective in trapping the natural enemies of *A. gossypii* [25]. However, further investigation is needed to understand the mechanism of the effect of trapping plants on the transfer and spread of natural enemies to cotton fields. In parallel, Jiang et al. constructed an XGBoost–GWO–SVR prediction model for cotton aphid populations in 2023, utilizing artificial intelligence methodologies [34]. Future research will aim to construct cotton growth models, as well as *A. gossypii* and natural enemy growth and dispersal models, using a wider range of data. This study also found a positive correlation between *A. gossypii* population and temperature, with populations collapsing after prolonged periods of high temperatures [8]. Therefore, to improve *A. gossypii* prediction models, it is necessary to include meteorological factors, such as temperature and precipitation, in addition to the collection and application of imaging data. It is important to understand the mechanism of these effects, so the model should

comprehensively analyze the synergistic effects of these indicators on the population of *A. gossypii* and their natural predators.

The manuscript's studies on the role of the ecological regulation of *A. gossypii* in alfalfa traps are still dominated by small plots. Future applied studies should expand to larger regions. This study also proposed a method for reconstructing ground hyperspectral reflectance data from sampling points in cotton fields to generate data for the entire area, providing a new basis for the fine classification of cotton field features. This method can be used to effectively predict *A. gossypii* infestations in the study area [34]. The collected and processed dataset was used to research *A. gossypii* identification, prediction, and control. Some deficiencies were identified during the preliminary study of this technology, and further follow-up studies are needed. Additionally, further research is needed to determine the scientifically appropriate number and frequency of alfalfa mowing to maintain low pest levels in cotton fields.

5. Conclusions

This study delves into the ecological control provided through the use of *A. gossypii*' natural foes and its impact in areas with alfalfa trap placements for controlling aphid populations. We explored the key population changes concerning alfalfa aphids as well as their primary predators inside these traps, and likewise the dynamics related to cotton aphids and their main natural predators in the cotton fields. Moreover, this exploration aimed to gain intricate insights into the communities of cotton aphids along with their naturally occurring predators inhabiting cotton fields. A glimpse of the population fluctuations over time delivers results for examination while observing how ecological influences balance themselves out in managing alfalfa-induced pest management. Additionally, undertaking remote sensing assessments can offer a new perspective on scrutinizing such controls over troublesome swarms of these crop pests. The more noteworthy deductions from our analysis can be encapsulated as follows:

- (1) This experimental study of the temporal ecological niche of the *A. craccivora* population, as well as its main natural predators within the alfalfa traps, has shown that the key natural predators such as lacewings, *H. variegata*, and *P. japonica* are highly effective in controlling aphids in alfalfa.
- (2) Two mowings of alfalfa were found to decrease the number of *A. gossypii* in cotton fields with alfalfa traps by 24.14% and 26.09%, respectively. In contrast, the number of *A. gossypii* increased by 33.71% and 76.92% without the presence of alfalfa. Additionally, the damage time for cotton aphids in cotton fields with alfalfa traps was about five days shorter than in those without such traps. The number of cotton aphids in cotton fields without alfalfa was 1.16 times higher than that in cotton fields with alfalfa.
- (3) The average number of *A. gossypii* per hundred plants, determined through remote sensing after two mowings, was less than 68 and 75, respectively. This suggests that the presence of alfalfa traps may effectively inhibit the occurrence and spread of *A. gossypii*.

To conclude, this study shows that planting alfalfa traps in cotton fields can be an effective tool to control *A. gossypii* populations. Promoting alfalfa planting in cotton fields in Xinjiang can help prevent and control aphid damage.

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References

1. Yu, S.M.; Zhang, H.Z.; Liu, Y.M.; Xu, F. Ecological Control and Chemical Control Measures of Cotton Aphids. *Mod. Agric. Sci. Technol.* **2017**, *12*, 126+131.
2. Song, R.M.; He, Q.Z.; Liu, X.L. Characteristics of the Occurrence of Major Pests and Diseases in Cotton Cultivation in Xinjiang and Control Technology. *Agric. Eng. Technol.* **2020**, *40*, 44–45. [[CrossRef](#)]
3. Ren, C.; Liu, Y.; Wang, W.; Ma, X. Current Status and Countermeasures of Pesticide Use in Cotton Fields in Xinjiang. *Xinjiang Agric. Reclam. Technol.* **2020**, *43*, 20–21.
4. Chen, M.; Zhou, Z.X.; Luo, J.C. Niche and Temporal Pattern of Arthropod Community in Cotton-Alfalfa Intercrop Fields. *Acta Prataculture Sin.* **2008**, *17*, 132–140.
5. Chen, M.; Luo, J.C.; Zhou, Z.X. Advances in Arthropod Community Ecology in Cotton Fields. *Plant Prot.* **2010**, *36*, 25–30.
6. Howarth, F.G. Environmental Impacts of Classical Biological Control. *Annu. Rev. Entomol.* **1991**, *36*, 485–509. [[CrossRef](#)]
7. Tian, C.Y. Ecological Prevention and Control of Aphides for Forest Belt's Shade-Land Planting Alfalfa Belt. *Environ. Prot. Xinjiang* **2004**, *26*, 132–134.
8. Cui, J.J.; Wen, S.G. The Ecological Effects of Intercropping Pattern on Main Cotton Pests and Their Enemies. *Acta Agric. Univ. Henanensis* **1997**, *31*, 45–49.
9. Liang, H.B.; Zhang, R.Z.; Zhang, G.X.; Wei, Z.M.; Wen, Y.L.; Wang, G.P. Population Dynamics of *Diuraphis noaxia* Mordv. and Impacts of Natural Enemies. *Acta Phytophylacica Sin.* **1997**, *24*, 193–198.
10. Wang, C.Y.; Xia, J.Y. Community Structure and Diversity of Arthropod in Different Cotton Fields in North Xinjiang. *Cotton Sci.* **2004**, *16*, 112–116.
11. Wei, S.H.; Liu, X.Q.; Wang, Y.; Liu, C.; Zhang, R. Effects of Intercropping of Alfalfa and Functional Plants on Population of Thrips and Their Natural Enemies *Orius similis*. *Chin. J. Biol. Control* **2024**, *40*, 99–107.
12. Chen, M.; Li, G.Q.; Luo, J.C. The Structure and Dynamics of Natural Enemy Community and Controlling Effect against *Aphis gossypii* in Cotton-Alfalfa Intercrop Fields. *Acta Phytophylacica Sin.* **2007**, *34*, 631–636.
13. Li, H.Q.; Wang, D.M.; Liu, J. Effects of Walnut—Cotton Intercropping on Arthropod Community Structure and the Population of Natural Enemies in Cotton Fields. *Xinjiang Agric. Sci.* **2022**, *59*, 934–941.
14. Zhao, M.; Mi, Q. Effects of Intercropping Green Manure in Cotton Fields on the Growth and Decline of Major Pests and Natural Enemies of Cotton during the Seedling Stage. *China Cotton* **2002**, *29*, 10–11.
15. Lin, R.H.; Feng, L.H.; Zhang, R.Z.; Tian, C.Y. Community Structure of Predatory Arthropods in Agricultural Landscape of Southern Xinjiang. *Chin. J. Biol. Control* **2003**, *19*, 1–5. [[CrossRef](#)]
16. Wang, L.; Tian, C.Y.; Ma, Y.; Hu, M. Effect of Trap Corn on the Population Dynamics of Native Predators in Cotton Field. *Agric. Res. Arid Areas* **2004**, *22*, 86–89.
17. Bimonte, S.; Billaud, O.; Fontaine, B.; Martin, T.; Flouvat, F.; Hassan, A.; Rouillier, N.; Sautot, L. Collect and Analysis of Agro-Biodiversity Data in a Participative Context: A Business Intelligence Framework. *Ecol. Inform.* **2021**, *61*, 101231. [[CrossRef](#)]
18. Cui, X.N.; Xi, B.X.; Zhang, B.H.; Sun, Y.X.; Hu, G.X.; Liu, Y.J.; Hao, Y.N. Predatory Functional Response and Predation Preference of Ladybeetle *Harmonia axyridis* to *Acyrtosiphon pisum* and *Odontothrips loti* on Alfalfa. *Chin. J. Biol. Control* **2023**, *39*, 38–45.
19. Backoulou, G.F.; Elliott, N.C.; Giles, K.; Phoofolo, M.; Catana, V.; Mirik, M.; Michels, J. Spatially Discriminating Russian Wheat Aphid Induced Plant Stress from Other Wheat Stressing Factors. *Comput. Electron. Agric.* **2011**, *78*, 123–129. [[CrossRef](#)]
20. Zhang, B.; Huang, W.; Li, J.; Zhao, C.; Fan, S.; Wu, J.; Liu, C. Principles, Developments and Applications of Computer Vision for External Quality Inspection of Fruits and Vegetables: A Review. *Food Res. Int.* **2014**, *62*, 326–343. [[CrossRef](#)]
21. Ferentinos, K.P. Deep Learning Models for Plant Disease Detection and Diagnosis. *Comput. Electron. Agric.* **2018**, *145*, 311–318. [[CrossRef](#)]

22. Su, J.; Liu, C.; Coombes, M.; Hu, X.; Wang, C.; Xu, X.; Li, Q.; Guo, L.; Chen, W.-H. Wheat Yellow Rust Monitoring by Learning from Multispectral UAV Aerial Imagery. *Comput. Electron. Agric.* **2018**, *155*, 157–166. [[CrossRef](#)]
23. Li, S.Y.; Zhu, J.B.; Lu, X.Y.; Cui, J.J.; Ma, Y.; Luo, J.Y.; Cheng, F.R. Dynamic Temporal Pattern of Dominant Population of Pests and Natural Enemies in Spring Cotton Field in Southwestern Anhui Province. *Chin. Agric. Sci. Bull.* **2016**, *32*, 68–74.
24. Cui, J.; Chen, H.; Zhao, X.; Luo, J. Research Course of the Cotton IPM and Its Prospect. *Cotton Sci.* **2007**, *19*, 385–390.
25. Peng, J.M.; Patima, W.; Guo, X.H.; Kurbanisaguli, O.; Yang, S.P.; Li, T.F.; Wang, X.C.; Zhu, L.H.; Ma, D.Y. Effects of Trap Crops in Cotton Field on the Population Dynamics of *Aphis gossypii* and Predatory Natural Enemies. *Chin. J. Biol. Control* **2023**, *39*, 1038–1048.
26. Hurlbert, S.H. The Measurement of Niche Overlap and Some Relatives. *Ecology* **1978**, *59*, 67–77. [[CrossRef](#)]
27. Krebs, C.J. *Ecological Methodology*, 2nd ed.; Addison Wesley Longman: Menlo Park, CA, USA, 1998; ISBN 978-0-321-02173-1.
28. Smith, H.A.; McSorley, R. Intercropping and Pest Management: A Review of Major Concepts. *Am. Entomol.* **2000**, *46*, 154–161. [[CrossRef](#)]
29. Thompson, K.; Gaston, K.J.; Band, S.R. Range Size, Dispersal and Niche Breadth in the *Herbaceous flora* of Central England. *J. Ecol.* **1999**, *87*, 150–155. [[CrossRef](#)]
30. Chen, M.; Luo, J.C.; Li, G.Q. Evaluating Alfalfa Cutting as a Potential Measure to Enhance Predator Abundance of *Aphis gossypii* (Homoptera: Aphididae) in Cotton-Alfalfa Intercropping System. *Acta Agric. Sin.* **2011**, *19*, 922–926.
31. Ge, Y.B.; Mao, X.H.; Dang, Z.H. Adult Population Dynamics and Temporal Niche of Insects and Natural Enemies on Sunflower in Gansu Province. *Chin. J. Oil Crop Sci.* **2015**, *37*, 868–875.
32. Dang, W.W.; Liu, B.; Zhe, D.; Lu, Y.H. Dominated Species and the Predation Assessment of Natural Enemies on Thrips in Cotton Fields in Xinjiang. *Sci. Agric. Sin.* **2023**, *56*, 3347–3357.
33. Mountrakis, G.; Im, J.; Ogole, C. Support Vector Machines in Remote Sensing: A Review. *ISPRS J. Photogramm. Remote Sens.* **2011**, *66*, 247–259. [[CrossRef](#)]
34. Jiang, P.; Zhou, X.; Liu, T.; Guo, X.; Ma, D.; Zhang, C.; Li, Y.; Liu, S. Prediction Dynamics in Cotton Aphid Using Unmanned Aerial Vehicle Multispectral Images and Vegetation Indices. *IEEE Access* **2023**, *11*, 5908–5918. [[CrossRef](#)]
35. Zhao, H.; Yang, C.; Guo, W.; Zhang, L.; Zhang, D. Automatic Estimation of Crop Disease Severity Levels Based on Vegetation Index Normalization. *Remote Sens.* **2020**, *12*, 1930. [[CrossRef](#)]
36. Gribov, A.; Krivoruchko, K. Empirical Bayesian Kriging Implementation and Usage. *Sci. Total Environ.* **2020**, *722*, 137290. [[CrossRef](#)]
37. Krivoruchko, K. Empirical Bayesian Kriging Implemented in ArcGIS Geostatistical Analyst. *ArcUser* **2012**, *15*, 6–10.
38. Li, G.Q.; Chen, M.; Luo, J.C.; Zhou, Z.X. Predational Function of *Pardosa astrigera* on *Aphis gossypii*. *J. Gansu Agric. Univ.* **2006**, *41*, 68–70.
39. Ding, R.F.; Zhu, X.H.; Akedan, W.; Amanguli, Niu, Z.P.; Ding, A.; Wang, L.; Aimaiti, A.; Patiguli, W.; Shadaiti, A. Control Effects on *Aphis gossypii* (Glover) by Releasing *Chrysoperla carnea* (Stephens) in Cotton Field. *Plant Prot.* **2015**, *41*, 200–204.
40. Pan, H.; Li, H.B.; Ding, R.F.; Li, H.Q.; Wang, D.M.; AKEDAN, W.; Liu, J. Predation Capacity of *Adonia variegata* to *Aphis atrata*. *Chin. J. Biol. Control* **2020**, *36*, 628–631.
41. Lai, Y.; Liu, X.Y. The Natural Enemy Species of Chrysopidae from China and Their Applications in Biological Control: A Review. *J. Plant Prot.* **2020**, *47*, 1169–1187.
42. Jiang, Y.; Xiu, C.L.; Wang, D.M.; Liu, J.; Pan, H.S.; Liu, X.N. Research Progress on Biological Ecology, Conservation and Utilization of *Hippodamia variegata* (Goeze). *Chin. J. Biol. Control* **2022**, *38*, 50–62.
43. Jiang, Y.; Chen, X.; Song, B.M.; Zhang, Y.; Chen, W.N.; Pan, H.S. Population Dynamics of *Hippodamia variegata* and Its Behavioral Response to Three Leguminous Weeds. *Plant Prot.* **2023**, *49*, 254–261.
44. Chi, B.J.; Dong, H.Z. Prevention and Controlling Effect of Intercropping on Pests and Diseases and Its Risk Control in Cotton Fields. *Cotton Sci.* **2019**, *31*, 341–351.
45. Tang, R.; Sun, X.Y.; Zhuo, F.Y.; Zhu, J.Q.; Guo, R. Investigation and Research on the Dynamic Occurrence of Major Crop Diseases and Pests and the Succession of Control Strategy in China During 2015–2019. *Xinjiang Agric. Sci.* **2021**, *58*, 2208–2219.
46. Zhu, M.M.; Liu, Y.; Zhang, R.; Huang, W.G. Effects of Intercropping and Monoculture of Alfalfa on Population Dynamics and Community Structure of Insects. *Grassl. Turf.* **2013**, *33*, 25–29.

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