Construction of Meteorological Monitoring and Early Warning System for Alfalfa Diseases and Pests

Wei DUAN[1*], **Yan LIANG**[1], **Yangyang SHANG**[2]

1. Hohhot Meteorological Bureau, Hohhot 010010, China; 2. Inner Mongolia Meteorologica Meteorological Bureau, Hohhot 010010, China

Abstract Leveraging the achievements of the smart meteorological system nationwide, a meteorological monitoring and early warning system for alfalfa pests and diseases can be formed through the establishment of four systems, namely, "real-time monitoring system, forecasting and prediction system, monitoring and early warning system, and smart service system". It will enable intelligent, dynamic meteorological monitoring, early warning, and forecasting services for the occurrence and development of alfalfa pests and diseases, providing technical support for scientifically controlling their harm and improving yield and quality.

Key words Alfalfa, Pest; Disease; Monitoring and early warning

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China's livestock industry is one of the key pillar industries in agricultural economy, and its total output value accounts for about one third of the total agricultural output value. Within livestock production, cattle and sheep breeding industry plays an important role, with major production areas primarily located in northern provinces such as Inner Mongolia. The average annual precipitation in these regions is typically around 200 -400 mm, or even below 200 mm, classifying them as semi-arid or arid areas. The natural ecosystem can hardly maintain large-scale and high-intensity cattle and sheep farming with natural forage all the year round. Therefore, scientifically selecting and cultivating forage grasses has become one of the key measures for many northern provinces in China to develop rural areas and revitalize the rural economy.

The forage grasses cultivated in China's northern pastoral areas mainly include Poaceae species such as *Avena sativa* L., *Leymus chinensis*, *Bromus inermis* Leyss., and *Elymus dahuricus*, as well as Leguminosae species like *Medicago sativa* L., *Medicago falcata* L., and *Medicago ruthenica*. Depending on regional climatic conditions, soil environments, and traditional herding practices, mixed cultivation of multiple forage species remains the dominant planting model in these pastoral areas. However, with the acceleration of pastoral industrialization, standardized production has become a consensus. Through years of forage cultivation practices, it has been gradually recognized that certain varieties demonstrate significant advantages in both yield and quality. For instance, *M. sativa* in Ar Horqin Banner of Inner Mongolia Autonomous Region achieves a yield of over 12 000 kg/hm^2, nearly double that of conventional varieties while maintaining superior quality. The demands of industrialized production and the high-yield high-quality traits of many forage varieties have driven herders to adopt large-scale monoculture planting. In other words, forage cultivation is now shifting toward concentrated and standardized monoculture of superior varieties across expansive areas. However, as the contiguous monoculture planting areas expand, the pests and diseases specific to these dominant varieties have also become the dominant species in the forage planting area with the expansion of the living environment of the population, and they are possible to spread and break out in a large area.

According to the theory of evolution, environmental conditions directly constrain the growth and development of organisms, and natural resources determine the ecological community of a region. In natural pastures, the growth of forage grasses and their pests and diseases reach an ecological dynamic balance through natural selection, resulting in relatively stable yield and quality. However, humans can alter the ecological environment. For example, weather modification projects (such as artificial rainfall and snowfall) can be implemented, and humans can also alter the population of specific species within an ecological community (*e.g.*, converting dryland to paddy fields for rice cultivation), disrupting the natural ecological balance[1-2]. Alfalfa (*Medicago* spp.), rich in protein (18% -24%), vitamins (A, K, C), and various minerals, is highly nutritious and hailed as the "King of Forage". It is now being extensively cultivated and promoted in pastoral regions of northern China. Additionally, its pinnately trifoliate compound leaves (with obovate or elliptical leaflets) and elegant flowers, ranging from pale yellow to deep blue or dark purple, give it notable ornamental value. Precisely because of its significant forage and aesthetic value, alfalfa has been widely cultivated across China in recent years for both feed and ecological landscaping. However, as its planting area expands, particularly in northern pastoral regions where it is promoted as a dominant forage species, associated pests and diseases have rapidly spread within these cultivation zones, leading to a series of new ecological and environmental challenges. Large-scale alfalfa cultivation faces numerous pest and disease issues, with varying degrees of harm at different growth stages. However, one common characteristic is the significant year-to-year fluctuation in damage severity, primarily driven by differences in meteorological conditions[3-5]. The

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Wei DUAN (1990 -), female, P. R. China, engineer, devoted to research about weather forecast and meteorological services.

* Corresponding author.

occurrence and development of alfalfa pests and diseases, much like its growth, are closely linked to specific meteorological conditions during different growth stages each year, particularly temperature, precipitation, and other weather factors. Consequently, there is strong demand for specialized meteorological services to monitor and predict pest and disease outbreaks. Therefore, establishing an intelligent meteorological monitoring and forecasting system for alfalfa pests and diseases has significant economic and environmental value.

Identification of Major Alfalfa Pests and Diseases

The high nutritional value of alfalfa naturally provides an ideal growth environment for many organisms that rely on crops as their habita, such as thrips and aphids, and bacteria such as common *Pseudopeziza medicaginis* causing leaf spot, and *Colletotrichum* spp. These pests and pathogens thrive in such conditions, rapidly multiplying and developing. Once their populations exceed a certain threshold, they severely impact alfalfa yield and quality, leading to degraded forage and disrupting livestock production, ultimately causing negative societal effects. Numerous pests and diseases adversely affect the normal growth and development of alfalfa[6-7]. However, their impacts on yield and quality vary significantly. To reduce production costs and improve efficiency, it is crucial to dynamically control pest and disease damage at low levels while maintaining ecological balance. Therefore, scientific pest management in alfalfa involves dynamically regulating the severity of infestations to minimize harm. Accordingly, monitoring and forecasting efforts should focus only on major pests and diseases that significantly impact yield and quality.

In summary, the prevention and control of alfalfa pests and diseases do not aim to eliminate them entirely, but rather to identify key pest and disease species for monitoring and forecasting based on their potential comprehensive impact on alfalfa yield and quality. Therefore, through literature review and practical production data analysis, the major pest and disease species affecting local dominant alfalfa varieties should be statistically determined. Technical support can be provided for scientific pest management by monitoring and issuing early warnings for meteorological conditions critical to their growth and development.

(1) According to literature review, the major diseases affecting alfalfa growth in northern China's main production regions, ranked by severity, are: common leaf spot, alfalfa anthracnose, alfalfa root rot, alfalfa powdery mildew, and alfalfa mosaic virus. Therefore, priority should be given to monitoring, early warning, and forecasting of meteorological conditions conducive to the occurrence and development of two key diseases: "common leaf spot and anthracnose".

(2) Based on comprehensive literature review and field investigations, the major pests affecting alfalfa growth in northern China's main production regions, ranked by severity, are: thrips, aphids, beet armyworms (*Spodoptera exigua*), alfalfa leafminers (*Agromyza frontella*), leafhoppers, scarab beetles (white grubs), and alfalfa weevils (*Hypera postica*). Accordingly, meteorological monitoring and early warning efforts should prioritize four relatively severe pests: "thrips, aphids, beet armyworms, and alfalfa leafminers".

Technical Pathway for Establishing a Monitoring and Forecasting System for Major Alfalfa Pests and Diseases

In the main alfalfa planting regions, the free growth and development of alfalfa pests and diseases adversely affect the crop, leading to a series of physiological, biochemical, and morphological changes in alfalfa. The extent of these changes directly determines the degree of impact on alfalfa yield and quality. The growth and development of all organisms are constrained by natural environmental conditions. For a specific region, the natural geographical environment and climatic background conditions remain relatively stable, exerting minimal influence on the interannual variability of yield and quality. The most significant impact comes from meteorological factors during the current growing season: temperature (daily average, maximum, and minimum temperature), light (sunshine duration, *etc.*), and water (relative humidity, precipitation intensity including amount and frequency of different intensity levels)[8-10]. These factors are the primary determinants of the occurrence and severity of alfalfa pests and diseases during the growing season.

In summary, the monitoring and forecasting of alfalfa pests and diseases are primarily based on the alignment between the meteorological factors (temperature, light, and water) required for the development of major alfalfa pests and diseases and the actual meteorological conditions during the current growing season. This approach enables the establishment of an intelligent meteorological service system for alfalfa pest and disease monitoring and forecasting.

To enhance the "precise, refined and personalized" comprehensive agricultural meteorological service capabilities, China's meteorological system, with strong financial support from the national government, has strengthened specialized meteorological service programs for agriculture, rural areas, and farmers. In recent years, significant progress has been made in meteorological services for conventional field crop production as well as specialty cultivation and aquaculture industries. Some service products have adopted a "chain-based" service model (identification of service needs, product development, release of products for service delivery, evaluation of service effectiveness, and identification of new improved service needs), partially meeting the demands of industrialized agricultural production[11-14]. Therefore, meteorological departments engaged in alfalfa pest and disease monitoring and forecasting should fully leverage recent achievements in smart meteorological construction[15-16]. With the optimal use of the existing monitoring and forecasting capabilities within the meteorological system's agricultural service framework, they can significantly reduce operational costs for intelligent monitoring and forecasting of six major alfalfa pests and diseases: alfalfa common leaf spot, alfalfa anthracnose, alfalfa thrips, alfalfa aphids, alfalfa beet armyworms, and alfalfa leafminers. Guided by the concept of smart meteorological development, an intelligent monitoring and forecasting system for major alfalfa pests and diseases shall be established. This system will achieve automated real-scene monitoring and real-time data collection for six key pests and diseases throughout alfalfa's growth cycle, while intelligently generating forecasts, warnings, and service products. We will comprehensively enhance specialized meteorological services and provide meteorological safeguards for alfalfa production enterprises by implementing smart monitoring and forecasting services for major alfalfa pests and diseases. Accordingly, the technical roadmap for constructing the alfalfa pest and disease monitoring and forecasting system is established as shown in Fig. 1.

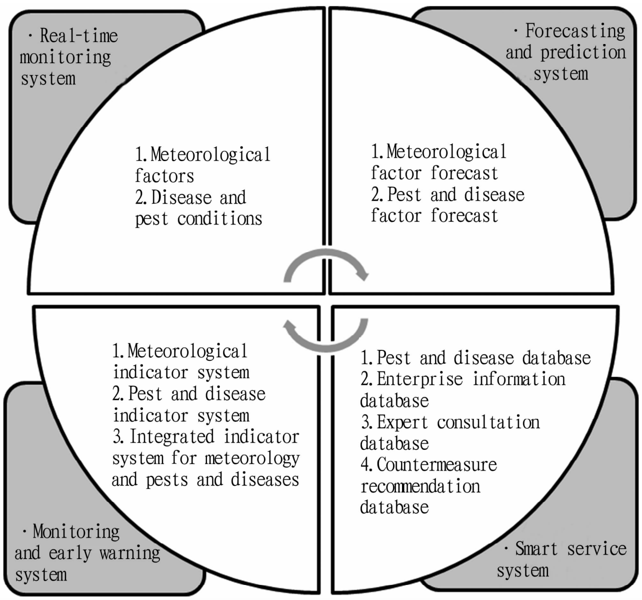

Fig. 1 Technical roadmap for the construction of monitoring and forecasting system for major alfalfa pests and diseases

Construction Content of Pest and Disease Monitoring and Forecasting System

Specific construction content of monitoring system

The system will fully utilize China Meteorological Administration's existing comprehensive observation network featuring "space-based, air-based and ground-based integration with relatively complete categories and basically rational layout". According to the operational requirements of "alfalfa pest and disease monitoring and forecasting" service system, it will specify the essential meteorological data required for daily operation and maintenance of this service. The system will automatically collect historical and real-time hourly observations of four meteorological elements (temperature, sunshine, relative humidity, and precipitation) from automatic weather stations near alfalfa planting areas. It will also obtain two parameters from meteorological remote sensing satellites: greenness index values of alfalfa planting areas and their actual field images collected through meteorological monitoring. Additionally, it will incorporate manually surveyed field data on current pest and disease occurrences. These three types of data will be intelligently input into the database system following the standardized format of the "Pest and Disease Specialized Database", and the database will be automatically intelligently maintained to ensure data safety and convenient use.

Specific construction content of the forecasting system

With the widespread application of AI technology in the field of numerical weather prediction, improved next-generation numerical weather prediction models have become more intelligent and user-friendly, enabling more accurate and timely provision of specific numerical weather prediction products tailored to alfalfa pest and disease monitoring and early warning needs[18]. Accordingly, existing numerical weather prediction model outputs are fully utilized by directly extracting long-, medium-, and short-term numerical weather forecasts for temperature, humidity, and precipitation. The system will employ numerical weather prediction models with multi-dimensional parameterization schemes to develop specialized forecasting models for sunshine duration and vegetation greenness values, automatically generating synchronized numerical prediction products for these parameters alongside conventional weather forecasts. A dedicated expert team will develop meteorological prediction models specifically for alfalfa pest/disease development stages and damage severity levels. Specific mathematical calculation models can be established taking the growth and development of pests and diseases and the degree of damage as the prediction object and corresponding meteorological elements as factors.

Specific construction content of the monitoring and early warning system

The severity of pest damage is generally determined based on a relatively objective evaluation index system tailored to the specific pest species and the target of harm. For example, the population dynamics of *Lygocoris lucorum* are used as an indicator to assess the extent of damage to cotton growth and development caused by this pest[20]. Accordingly, to facilitate the establishment of a monitoring, forecasting and early warning model for the severity of alfalfa pests and diseases, as well as to enable comparisons of damage levels among different alfalfa pests and diseases, the severity of six pests and diseases, namely, alfalfa common leaf spot, alfalfa anthracnose, alfalfa thrips, alfalfa aphids, alfalfa beet armyworms, and alfalfa leafminers, is uniformly classified into five levels based on symptoms and severity: mild, moderately mild, moderate, moderately severe, and severe (Table 1)[6-8]. Based on historical severity levels of six alfalfa pests and diseases, alfalfa common leaf spot, alfalfa anthracnose, alfalfa thrips, alfalfa aphids, alfalfa beet armyworms, and alfalfa leafminers, and concurrent meteorological factors, an expert system approach can be used to establish two meteorological index models for alfalfa pest development and damage severity. These models (specifically constructed using local historical data on pest growth, occurrence severity, and corresponding meteorological factors) can calculate daily meteorological indices. Then, monitoring and early warnings can be issued based on the index severity levels.

Table 1 Classification table of alfalfa disease and pest occurrence degree

Level	Degree	Status description	Main control measures
1	Mild	Sporadic pest and disease occurrence with little alfalfa damage	Strengthening monitoring
2	Moderately mild	Moderate pest and disease occurrence with scattered alfalfa damage	Adopting physical and biological control
3	Moderate	Noticeable pest and disease occurrence with considerable alfalfa damage	Adopting physical, biological, and chemical control
4	Moderately severe	Severe pest and disease occurrence with extensive alfalfa damage	Adopting physical, biological, and chemical control
5	Severe	Critical pest and disease occurrence with most alfalfa damaged	Adopting physical (including cutting and eradication), biological, and chemical control

Specific construction content of the intelligent service system

The core of the intelligent service system lies in fully leveraging the achievements of smart meteorological technology. It will incorporate the growth periods and meteorological index systems for two alfalfa diseases (common leaf spot and anthracnose) and four pests (thrips, aphids, beet armyworms, and leafminers). Dynamic forecasting and evaluation models will be established and embedded into the existing smart meteorological service system for automated operation, enabling intelligent services. To achieve automated and dynamic production of alfalfa pest and disease monitoring and forecasting products, we should intelligently distribute them to required clients, accurately collect customer feedback, and intelligently optimize service products and solutions for precise service delivery. Alfalfa pest and disease monitoring and forecasting is essentially specialized agricultural weather forecasting. Each alfalfa pest and disease monitoring and forecasting report must include, but not be limited to: weather and climate forecasts and predictions, assessment of weather and climate impacts, and agricultural production management measures[24-25]. Accordingly, the main content of the alfalfa intelligent service system construction will focus on six types of service products for two diseases, "brown spot and anthracnose", and four pests, "thrips, aphids, beet armyworms, and alfalfa leafminers", and it will include weather and climate forecasting, impact assessment, and agricultural production management measures. Targeted services will be provided to production enterprises (primarily through automated push notifications and expert consultations). The specific occurrence stages, suitable meteorological conditions, and control measures for alfalfa "brown spot, anthracnose, thrips, aphids, beet armyworms, and alfalfa leafminers" are detailed in Table 2 and Table 3.

Table 2 Occurrence stages and suitable meteorological conditions of "alfalfa brown spot, anthracnose, thrips, aphids, beet armyworms and alfalfa leafminers"

No.	Name of disease or pest	Occurrence period (month. day)	Suitable meteorological conditions
1	Leaf spot	May 21 – Oct. 30	(1) Temperature: The optimal ambient temperature for the germination of ascospores is 14 ℃, and an average temperature of 10 – 16 ℃ per ten-day period is conducive to their outbreak. (2) Humidity: The ideal relative humidity for spore germination is ≥98%. High-humidity environments caused by continuous rain are very likely to cause the prevalence of brown spot disease. A relative humidity <93% is not conducive to spore germination. (3) Generally, the incidence of the disease is mild in arid areas without irrigation conditions. On the contrary, the incidence is severe in fields with good irrigation conditions and other areas prone to moisture.
2	Anthracnose	Jun. 20 – Sept. 20	(1) Temperature: The disease begins to develop at an environmental temperature of 16 ℃, and becomes severe at 20 – 28 ℃. Its optimal development temperature is 24 ℃. (2) Humidity: A relative humidity ≥95% is most conducive to the rapid spread of anthracnose. (3) The disease progresses fastest under combined high temperature and high humidity conditions. All conditions that increase field humidity, including Prolonged rainy weather, sprinkler irrigation, and poor field drainage, are potential triggers for anthracnose outbreaks.
3	Thrips	Mar. 21 – Sept. 20	(1) Temperature: An ambient temperature range of 20 – 28 ℃ is optimal for the growth, development and reproduction of alfalfa thrips. (2) Humidity: Relative humidity levels in the range of 40% – 70% are favorable for their growth, development and reproduction. (3) Hot and rainy conditions are detrimental to their normal growth and reproduction. Rainwater impact and water immersion cause significant damage, while excessive humidity also reduces their survival rate. All nymphs will die when exposed to temperatures ≥31 ℃ combined with 100% humidity.
4	Aphids	Apr. 21 – Sept. 20	(1) Temperature: The optimal temperature range for alfalfa aphid reproduction is 16 – 23 ℃, and the most favorable range is 19 – 22 ℃. Reproduction is inhibited below 19 ℃ and above 25 ℃. (2) Humidity: A relative humidity within the range of 60% – 70% is most conducive to reproduction, while levels >80% or <50% significantly suppress reproduction. (3) Under suitable temperature conditions, aphid population dynamics are primarily influenced by fluctuations in relative humidity and rainfall.

(Continued)

(Table 2)

No.	Name of disease or pest	Occurrence period (month. day)	Suitable meteorological conditions
5	Beet armyworms	Jan. 1 – Sept. 10	(1) Temperature: Egg stage: The optimal hatching temperature for the egg stage is 25 – 35 ℃. The hatching rate drops significantly below 15 ℃ or above 38 ℃, and the larval survival rate is extremely low. Larval stage: The optimal temperature range is 20 – 30 ℃. The survival rate of 5^{th}-instar larvae declines notably above 35 ℃. Pupal stage: The optimal developmental temperature for pupae is 20 – 24 ℃. The pupal survival and emergence rates decrease significantly below 15 ℃ or above 30 ℃. Adult stage: The optimal reproductive temperature is 25 – 30 ℃. Egg production is significantly inhibited below 20 ℃ or above 35 ℃. (2) Humidity: Egg hatching: The optimal relative humidity for the egg hatching of beet armyworms is approximately 80% – 94%. The hatching rate significantly decreases below 62%. Larval survival: Larval survival improves when environmental relative humidity exceeds 80%, but body length growth rate decreases with increasing humidity. Below 60%, the larval survival rate declines rapidly. Adult reproduction: The optimal mating humidity is 80% – 94%. Egg production decreases when humidity falls below 62%. (3) Temperature and precipitation are the primary factors influencing the growth, development, and reproduction of beet armyworms. These two factors interact synergistically, with high temperature and drought conditions generally favoring outbreaks, while low temperature and excessive rainfall suppress epidemics.
6	Alfalfa leafminers	May 1 – Jul. 20	(1) Temperature: Egg stage: The suitable range for the egg stage is 16 – 21 ℃. Larval stage: The optimal range is 20 – 25 ℃. Adult stage: The optimal range is 16 – 25 ℃. The pupal stage: The optimal temperature is 25 ℃. For all life stages, temperatures significantly higher or lower than these ranges adversely affect growth, development and reproduction. (2) Humidity: Egg stage: Relative humidity of 60% – 80% maximizes hatching rate. Below 40% or above 90%, the hatching rate declines sharply with humidity changes. Larval stage: Humidity > 80% is favorable. Below 40%, the survival rate drops drastically, especially for 1^{st}-2^{nd} instar larvae which are most humidity-sensitive. Adult stage: Optimal oviposition occurs at relative humidity of 50% – 70%. Egg production decreases significantly below 30% or above 90%. Pupal stage: Soil moisture of 50% – 70% is ideal. Excessive soil moisture causes dehydration and death. (3) Considering both temperature and precipitation conditions, higher temperatures combined with low humidity or prolonged rainy periods adversely affect their growth, development and reproduction. Conversely, warm and moderately humid environments favor population growth.

Table 3 Control countermeasures of "alfalfa brown spot, anthracnose, thrips, aphids, beet armyworms and alfalfa leafminers"

No.	Name of disease or pest	Control measures
1	Leaf spot	(1) Agricultural control: Disease-resistant varieties are selected, and mixed cropping or intercropping as well as burning are adopted to reduce the incidence and severity of the disease. Early harvesting is conducted to ensure yield and quality. (2) Chemical control: During the initial stage of the disease, 70% mancozeb at 600 times dilution, 75% chlorothalonil at 500 – 600 times dilution, or 50% benomyl at 1 500 – 2 000 times dilution can be applied. In severe cases, 5% kresoxim-methyl at 3 000 times dilution or 40% flusilazole at 7 500 times dilution is sprayed for 2 – 3 consecutive times at intervals of 7 – 10 d.
2	Anthracnose	(1) Agricultural control: Sowing is conducted at appropriate time with a suitable low density to improve ventilation and light penetration between plants. Field humidity is reduced to reduce the incidence and severity of the disease. Timely harvesting is carried out to ensure yield and quality. (2) Chemical control: During the initial stage of the disease, 75% chlorothalonil at 500 times dilution, or 80% mancozeb at 600 times dilution, or 250 g/L azoxystrobin suspension at 5 000 times dilution is applied. In severe cases, 450 g/L prochloraz emulsion at 1 000 times dilution is used for 1 – 2 consecutive times at intervals of 7 – 10 d.
3	Thrips	(1) Agricultural control: Crop residues are promptly cleared during rotation to eliminate thrips adults and nymphs. (2) Physical control: Blue sticky traps are hung to attract and trap thrips. (3) Biological control: A 200 times dilution of 1.5% pyrethrin emulsion and a 200 times dilution of mineral oil, as well as Beauveria bassiana and Metarhizium anisopliae, can be adopted for control. Alternatively, natural predators of thrips can be released. (4) Chemical control: In the early stage of infestation, 70% imidacloprid water-dispersible granules is applied at a rate of 30 g/hm^2. It can be mixed with 50 g of sugar per spray tank as an attractant, and then diluted for spraying. During peak infestation periods, a combination of contact and systemic insecticides is used, with appropriately increased application frequency.
4	Aphids	(1) Agricultural control: Aphid-resistant alfalfa varieties are selected. Immediate harvesting is conducted during aphid outbreaks to maintain forage yield and quality. (2) Chemical control: A 1 000 times dilution of 40% dimethoate emulsifiable concentrate or a 3 000 times dilution of 50% pirimicarb wettable powder is applied by spraying.

(Continued)

(Table 3)

No.	Name of disease or pest	Control measures
5	Beet armyworms	(1) Agricultural control: Crop rotation and intertillage are implemented to eliminate pupae, while manual egg removal and field cleaning are also conducted. Timely harvesting is carried out. (2) Physical control: Thirty to forty five sex pheromone traps are deployed for control of beet armyworms per hectare, and water pans or sticky traps can be used in combination to enhance trapping efficiency. Additionally, 2 – 3 frequency-vibrancy pest-killing lamps are mounted per hectare to attract and kill adult pests. (3) Biological control: Natural predators such as frogs and birds are utilized and conserved. During the early larval stage (1^{st}-2^{nd} instar), *Bacillus thuringiensis* (Bt), *Beauveria bassiana*, or *Spodoptera exigua* nucleopolyhedrovirus (NPV) are applied by spraying. (4) Chemical control: Spray applications include 20% chlorantraniliprole suspension concentrate, 10% cyantraniliprole suspension concentrate, and 15% indoxacarb suspension concentrate.
6	Alfalfa leafminers	(1) Agricultural control: Fields are cleared to reduce pest sources. (2) Physical control: Utilizing the phototaxis of adult insects, 450 – 600 yellow sticky traps and 2 – 3 frequency-vibrancy pest-killing lamps are deployed per hectare to attract and trap adults. (3) Biological control: Natural enemies of alfalfa leafminers such as *Diglyphus* spp. and Opius sp. are utilized for control. (4) Chemical control: A 3 000 – 5 000 times dilution of 75% cyromazine wettable powder is sprayed on leaf undersides, with a follow-up application after 7 d. Alternatively, a mixture of 1 000 times dilution of 1.8% abamectin emulsifiable concentrate and 5 000 times dilution of 75% cyromazine is applied to thoroughly cover both leaf surfaces.

To reduce data redundancy, meteorological data will be directly extracted from local specialized meteorological database and intelligently processed to generate relevant meteorological data products for alfalfa pest and disease services, eliminating the need for a dedicated database. The data attributes of other databases are shown in Table 4.

Table 4 Data attribute list content

Data attributes	List content
Pest and disease database data attributes	Alfalfa variety name; alfalfa growth stage; pest and disease name; pest and disease growth state; pest and disease severity level
Enterprise information database data attributes	Company name; contact person; phone number; name of planted alfalfa variety; name of required service product; information delivery method
Expert consultation database data attributes	Expert name; contact person; phone number; specialization; alfalfa varieties for consultation; consultation availability period; consultation method
Countermeasure and suggestion database data attributes	Alfalfa variety name; pest and disease name; damage symptoms; severity level; physical control; biological control; chemical control

The main information of monitoring and forecasting service products for the six major pests and diseases of alfalfa is shown in Table 5.

Table 5 Detection and forecast of six major pests and diseases in animal husbandry

No.	Name of product	Main content	Release time	Release object	Release method
1	Alfalfa brown spot monitoring product	Current status of alfalfa brown spot occurrence (images and textual descriptions), analysis of concurrent meteorological conditions, and recommended countermeasures	May 21 – Oct. 30	Alfalfa production enterprises	WeChat push
2	Alfalfa brown spot assessment product	Assessment of damage severity from alfalfa brown spot, assessment of concurrent meteorological conditions, future risk analysis, and recommended countermeasures	May 21 – Oct. 30	Alfalfa production enterprises	WeChat push
3	Alfalfa brown spot forecast product	Forecast of alfalfa brown spot occurrence, forecast of concurrent meteorological conditions, and recommended countermeasures	May 21-Oct. 30	Alfalfa production enterprises	WeChat push
4	Alfalfa anthracnose monitoring product	Current status of alfalfa anthracnose occurrence (images and textual description), analysis of concurrent meteorological conditions, and recommended countermeasures	Jun. 20 – Sept. 20	Alfalfa production enterprises	WeChat push
5	Alfalfa anthracnose assessment product	Assessment of alfalfa anthracnose severity, assessment of concurrent meteorological conditions, future risk analysis, and recommended countermeasures	Jun. 20 – Sept. 20	Alfalfa production enterprises	WeChat push

(Continued)

(Table 5)

No.	Name of product	Main content	Release time	Release object	Release method
6	Alfalfa anthracnose forecast product	Forecast of alfalfa anthracnose occurrence severity, forecast of concurrent meteorological conditions, and recommended countermeasures	Jun. 20 – Sept. 20	Alfalfa production enterprises	WeChat push
7	Alfalfa thrips monitoring product	Current status of alfalfa thrips infestation (images and textual description), analysis of concurrent meteorological conditions, and recommended countermeasures	Mar. 21 – Sept. 20	Alfalfa production enterprises	WeChat push
8	Alfalfa thrip assessment product	Assessment of alfalfa thrips' damage severity, assessment of concurrent meteorological conditions, future risk analysis, and recommended countermeasures	Mar. 21 – Sept. 20	Alfalfa production enterprises	WeChat push
9	Alfalfa thrip forecast product	Forecast of thrip infestation severity, forecast of concurrent meteorological conditions, and recommended countermeasures	Mar. 21 – Sept. 20	Alfalfa production enterprises	WeChat push
10	Alfalfa aphid monitoring product	Current status of aphid occurrence (images and textual description), analysis of concurrent meteorological conditions, and recommended countermeasures	Apr. 21 – Sept. 20	Alfalfa production enterprises	WeChat push
11	Alfalfa aphid assessment product	Assessment of aphid damage severity, assessment of concurrent meteorological conditions, future risk analysis, and recommended countermeasures	Apr. 21-Sept. 20	Alfalfa production enterprises	WeChat push
12	Alfalfa aphid forecast product	Forecast of aphid infestation severity, forecast of concurrent meteorological conditions, and recommended countermeasures	Apr. 21 – Sept. 20	Alfalfa production enterprises	WeChat push
13	Alfalfa beet armyworm monitoring product	Current status of alfalfa beet armyworm occurrence (images and textual description), analysis of concurrent meteorological conditions, and recommended countermeasures	Jan. 1 – Sept. 10	Alfalfa production enterprises	WeChat push
14	Alfalfa beet armyworm assessment product	Assessment of alfalfa beet armyworm damage severity, assessment of concurrent meteorological conditions, future risk analysis, and recommended countermeasures	Jan. 1-Sept. 10	Alfalfa production enterprises	WeChat push
15	Alfalfa beet armyworm forecast product	Forecast of alfalfa beet armyworm occurrence severity, forecast of concurrent meteorological conditions, and recommended countermeasures	Jan. 1 – Sept. 10	Alfalfa production enterprises	WeChat push
16	Alfalfa leafminer monitoring product	Current status of alfalfa leafminer occurrence (images and textual descriptions), analysis of concurrent meteorological conditions, and recommended countermeasures	May 1 – Jul. 20	Alfalfa production enterprises	WeChat push
17	Alfalfa leafminer assessment product	Assessment of alfalfa leafminer damage level, assessment of concurrent meteorological conditions, future risk analysis, and recommended countermeasures	May 1 – Jul. 20	Alfalfa production enterprises	WeChat push
18	Alfalfa leafminer forecast product	Forecast of alfalfa leafminer occurrence level, forecast of concurrent meteorological conditions, and recommended countermeasures	May 1 – Jul. 20	Alfalfa production enterprises	WeChat push

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This 'knowledge-values-responsibility' integrated approach not only enables students to master technical skills, but also establishes a modern scientific research consciousness of serving the country through science and technology, serving the society, making rational judgments and complying ethics, which provides a solid ideological foundation for them to move towards the academic frontier or the front line of industry in the future.

Table 2 Teaching reform effects of the *Genetic Engineering Principles* course %

Class	Pass rate	Excellent rate	Curriculum satisfaction
Bioengineering 18 – 1 (reform class)	96.00	32.00	96.00
Bioengineering 18 – 2 (control class)	88.89	18.52	92.59
Bioengineering 19 – 1 (reform class)	95.83	29.17	95.83
Bioengineering 19 – 2 (control class)	91.30	26.09	91.30
Bioengineering 20 – 1 (reform class)	92.00	28.00	96.00
Bioengineering 20 – 2 (control class)	89.29	21.43	92.86

Effects of the Teaching Reform

As a core fundamental course for life science majors, *Genetic Engineering Principles* directly impacts students' comprehension and mastery of related subjects like genetics and specialized experiments, while serving as a crucial component for developing their research literacy and innovation capability. In recent years, addressing issues such as outdated content systems, monotonous teaching methods, and low student engagement, we have implemented comprehensive teaching reforms including modular curriculum restructuring, flipped classroom approaches, blended online-offline instruction, and competency-oriented diversified evaluation systems. Since implementation, our bioengineering students have demonstrated significant improvements in theoretical knowledge mastery, research awareness, experimental skills, and social responsibility consciousness (Table 2). Classroom interactions have significantly increased, with students demonstrating deeper content understanding and markedly enhanced learning motivation and active participation. Although the reform is ongoing, practice demonstrates that student-centered teaching innovation effectively enhances course quality and promotes holistic development, offering a valuable model for high-quality undergraduate education.

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