Bayesian network for predicting the level of crops weediness with wild oat

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Abstract. The authors propose an approach for predicting the level of crops weediness with wild oats (*Avena fatua* L.), based on the implementation of Bayesian Belief Network. This approach is applicable for solving the problem of estimated growth and development probability of wild oat based on taking into account the prevailing conditions on a specific land plot in the current year, depending on the predecessor’s cultivation technology and weed seed stock. In the course of the work, the authors carried out a selection of factors affecting the level of wild oats weediness, they also identified the need to minimize the number of input parameters to achieve acceptable prediction accuracy. The proposed model allows calculating the probability of exceeding the economic threshold of harmfulness of wild oat in cultivated plants crops. The advantage of this approach and its versatility lies in the ability of Bayesian Belief Network to “discourse” with incomplete information and in the ability to include new information in the analysis.

1. Introduction

The application review of Bayesian Belief Networks (BBNs) in agriculture noted that machine learning is currently experiencing a “surge of interest” from the academic community as well as practitioners. This increased focus has led to a number of different approaches used within machine learning. Among these approaches BBN is especially relevant for agricultural research [1].

Weed vegetation is part of agrophytocenosis and, with a high degree of its development, becomes a limiting factor in agricultural yield. Annually, due to unfavorable phytosanitary conditions, yield losses are 25-30%. The ability to predict and control the level of crops weediness is one of the key factors in modern conditions of agricultural management.

On the territory of Western Siberia, common wild oat occupies a leading place among weeds in terms of biological mass, abundance, and prevails in crops. The dominant position among weeds is due to: ability to intensive tillering, sufficiently large seed fertility, ability to quick ripening and seed cast before harvesting. It is also characterized by the heterocarpy phenomenon, which contributes to extended emergence of weed seedlings and seeds preservation in the soil for up to three or more years. The need to control common wild oat is due to its high harmfulness. On the basis of numerous studies it has been established that in the presence of one wild oat stalk per square meter, the yield of spring wheat decreases by 10 kg/ha, and if there are more than 50 pcs/m², the yield of cereals decreases by 20% [2, 3]. The main task when working with a land plot with *Avena fatua* L. is to stop the reproduction of wild oats or to provoke early germination of seeds, which are often contained in large quantities in the soil. An
important area of crop management is the ability to anticipate the situation at the work site in advance and predict weeds growth and development. The use of chemical weed control agents should be limited due to the high environmental hazard of herbicide. Therefore, it is important for an agronomist to be able to apply predictive technologies that allow regulating the development of weed vegetation in the most economical ways. At the same time, the probability calculation of weed outbreak at a specific work site makes it possible to prepare in advance, for example, to control the weed development with agricultural methods or to purchase herbicides in the necessary amount and range in advance.

Classical methods of information processing, modeling and forecasting do not always provide the required accuracy, which justifies the relevance of searching for new ways to analyze information and build complex systems. An example of such methods of making a forecast can be BBN, which is based on the expert estimates method, the a priori and a posteriori probabilities [4]. This network is a joint probability distribution of random variables characterizing features that affect, for example, vegetation growth.

The examples of using the BBN apparatus in Russian-language publications are considered in medicine, ecology, risk analysis, sociology and other subject areas [5, 6], in the field of agriculture, BBN has very limited application [7, 8]. Modeling the situation with the help of BBN will make it possible to estimate the probability of exceeding the economic threshold of harmfulness of wild oats (>16 pcs/m²) and to control the weeds development more efficiently.

2. Materials and methods
To create a BBN the authors analyzed the literature on the results of long-term observations of wild oats growth and development in the south of Western Siberia. The proposed approach was implemented using the Netica software package. The studies were carried out at the Laboratory of Predictive Agricultural Technologies using artificial intelligence methods of Siberian Federal Scientific Centre of agrobiotechnology, Russian Academy of Sciences. We used the following research methods: analysis of literary sources and their synthesis, modeling, interpretation and comparison. To determine the excess of economic threshold of harmfulness of wild oats, the conditional probability formula was applied. Let us assume that there may be two possible outcomes according to which the degree of crops weedyness with wild oats exceeded the economic threshold of harmfulness, or there was no excess. Let us also assume that agricultural practices affect the potential for wild oat seedlings, and the spring weather determines the level of intensity of its seedlings and development rates. The situation can be represented by the BBN [9, 10]. Mathematically, Bayes’ theorem shows the relationship between the probability of the event “Exceeding the economic threshold of harmfulness” and the probabilistic ratio of events: “Spring weather scenario”, “Growth potential”, “Cultivation technology” (predecessor), “Seed stock”.

Each of the variables (seed stock, growth potential) can take only one of two possible values: Low and High.

3. Findings and discussion
Weed plants are the most dynamic element of agrophytocenosis, and weather fluctuations significantly complicate the work of protecting crops from weeds. Lack of heat and moisture are the basic factors that limit not only the yield of crops, but also the growth potential of weeds. It has been established that in highly humid years, weed infestation of agricultural lands increases. The increase in fields weedyness in humid years occurs due to cold spring, with a relatively large amount of precipitation, when at the sowing time weed vegetation has not yet emerged and mechanical tillage practice for weed control is ineffective [11,12]. The competition of wild oats with cultivated plants for light, moisture and minerals is especially noticeable with moisture deficit, as well as in years with abundant precipitation and low temperatures. The weedyness in these cases increases due to a decrease in the competitiveness of cultivated plants crops. Low air and soil temperatures do not significantly affect the germination process, but determine the intensity of growth. An extreme situation occurs in conditions of heat weather and lack of moisture for plants, where the assessment of each of the influencing factors is individual. In this
regard, the assessment of a priori probability of exceeding the economic threshold of harmfulness of wild oats, depending on the spring weather scenario, was one of the most difficult.

Along with soil and climatic conditions, the level of intensification of agricultural technologies has a significant impact on the level of crops weediness. Effective weed management should aim not only to decrease their role in a given crop planting to reduce yield losses, but also to minimize the soil seed stock. The factors that can significantly affect the weed seed stock in the soil are tillage, crop rotation and herbicides using. All these factors can be combined into one big concept – “cultivation technology”, which is implemented in practice at different intensification levels: extensive, normal and intensive.

It is known that minimal tillage without the herbicides introduction has most often the least inhibiting effect on the weeds development. The use of herbicides reduces the weediness by several times. Minimization of the main soil treatment leads to an increase in the weed component, but the systematic use of herbicides helps to reduce the flow of weed seeds into the soil. The use of intensive treatments, both with herbicides and without them, against the background of deep plowing, preserving some of the seeds in the lower layers, significantly reduces the total weediness during the growing season.

Consequently, we assume that the factors such as cultivation technology of the predecessor (crop, agricultural practices), scenario (weather) of spring and weed seeds stock in the soil have the greatest influence on the weediness level with wild oats of the working area (a priori probability of wild oats amount is higher than the economic threshold of harmfulness).

The assessment of a priori probabilities of the cultivation technology influence on the seed stock is given in Table 1, and Table 2 shows the a priori probability of the spring weather scenario influence on the excess of the economic threshold of harmfulness of wild oats. Tables 1 and 2 illustrate the theory of conditional probability for two vertices of the BBN [13,14]. Note that the tables show the probability of a certain vertex being in a certain state, due to the state of its parent vertices. Such vertices as: “Spring weather scenario”, “Cultivation technology” do not have parent vertices, their probabilities do not depend on anything.

| Table 1. A priori probability (“Seed stock”) |
|---------------------------------------------|
| Seed stock       | High | Low |
|------------------|------|-----|
| Intensive        | 20   | 80  |
| Extensive        | 80   | 20  |
| Normal           | 60   | 40  |

| Table 2. A priori probability (“Spring weather scenario”) |
|------------------------------------------------------|
| Spring weather scenario* | High, % | Low, % |
|--------------------------|---------|--------|
| H_S                      | 20      | 80     |
| H_V                      | 30      | 70     |
| T_S                      | 40      | 60     |
| T_V                      | 60      | 40     |

* Spring weather scenarios: H_S – cold, humid; H_V – cold, dry; T_S – warm, dry; T_V – warm, humid.

Five vertices of a simple acyclic graph are shown in Figures 1 and 2. In the given examples, two opposite scenarios of spring weather are considered with intensive and extensive cultivation technologies of the previous crop.
Figure 1. Scenario of the belief network (cold, dry spring, intensive cultivation technology).

With intensive cultivation technology, in the cold and dry spring of the current period (H_S), the economic threshold of harmfulness of wild oat will not be achieved with a probability of 78.4% (Fig. 1). The weed seeds stock is also insignificant by using this technology. In the second case, under conditions of warm and humid spring (T_V) with extensive cultivation technology of the predecessor, the probability of exceeding the economic threshold of harmfulness of wild oat will be 61.2% (Fig. 2). The high rate of excess of the economic threshold of harmfulness of wild oats is due to the favorable ratio of heat and moisture supply for wild oat growth and development, because its mass seedlings are observed at a soil temperature of 10-14°C and at high soil moisture [15].

Figure 2. Scenario of the belief network (warm, humid spring, extensive cultivation technology).

In a warm and humid spring (T_V), the probability of exceeding the economic threshold of harmfulness of wild oats with intensive cultivation technology of the predecessor will be 52.8% (Table 3). The presence of heat and moisture favorably affects the wild oats development, causing a high intensity of weeds germination and crops weediness. At the same time, the probability of exceeding the economic threshold of harmfulness of wild oat is not significant, which is associated with the cultivation technology type of the previous crop, with a high efficiency of wild oat plants control, and, therefore, the wild oat seed stock will most likely also be reduced. In other cases, it is more likely that the economic
threshold of harmfulness of wild oats will not be exceeded under the following spring weather scenarios: cold, humid (H_V) – 70.6%; warm, dry (T_S) – 62.8%. This occurs due to edaphic stress factors.

**Table 3.** Conditional probabilities (excess of the economic threshold of harmfulness).

| Cultivation technology | Spring weather scenario | Yes  | No  |
|------------------------|-------------------------|------|-----|
| Intensive              | H_S                     | 21.6 | 78.4|
|                        | H_V                     | 29.4 | 70.6|
|                        | T_S                     | 37.2 | 62.8|
|                        | T_V                     | 52.8 | 47.2|
|                        | H_S                     | 24.8 | 75.2|
|                        | H_V                     | 33.2 | 66.8|
| Normal                 | T_S                     | 41.6 | 58.4|
|                        | T_V                     | 58.4 | 41.6|
|                        | H_S                     | 26.4 | 73.6|
|                        | H_V                     | 35.1 | 64.9|
| Extensive              | T_S                     | 43.8 | 56.2|
|                        | T_V                     | 61.2 | 38.8|

Under conditions of a warm and humid spring (T_V), the probability of exceeding the economic threshold of harmfulness of wild oats with normal cultivation technology of the predecessor will be 58.4%. The prerequisites for this are weed seeds stock and suitable conditions for their growth. In the cold and dry spring weather scenario (H_S), the economic threshold of harmfulness will not be exceeded with a probability of 75.2%. In a cold and dry spring (H_S) with an extensive cultivation technology of the predecessor, an excess of the economic threshold of harmfulness will not occur with a probability of 73.6%. In both cases, the spring weather is the main limiting factor in wild oats growth and development. We would like to add that the forecast can be improved if the model takes into account a larger number of agricultural practices.

4. Conclusion
The authors proposed the method for predicting and assessing the level of crops weediness with common wild oats using BBN. They made a selection of limiting factors and introduced measures (a priori probability) that can be used to solve the problem of assessing wild oats growth and development on agricultural lands, taking into account the intensification level of the predecessor’s cultivation technologies and the features of agrometeorological resources in the spring of the current season (heat and moisture supply). It was found that the most significant factors are: spring weather, wild oat seeds stock in the soil, the potential for their growth and the cultivation technology of the previous crop. The simulation of BBN was carried out to test the hypothesis for each of the spring weather scenarios. Particular attention should be paid to the warm and humid scenario of spring weather, when, with all the considered cultivation technologies, the growth potential of wild oats and the exceedance probability of the economic threshold of harmfulness are quite high. The use of BBN makes it possible to foresee, with some degree of probability, the potential for crops weediness with wild oats and to substantiate recommendations for agricultural producers to make its control more economically effective.

The next stages of work will be: research results verification, accumulation of data and knowledge in the relevant databases on weed plants and their linking to climatic zones, creation of models for calculating probabilities using individual plant parameters, and development of a decision support system for controlling action in crop production.

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