DECISION SUPPORT INFORMATION SYSTEM FOR MODELING GREEN PEA YIELD

UDK 004:519.81

DOI: https://doi.org/10.35546/2313-0687.2019.26.55-62

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Abstract. In Ukraine, among leguminous crops, pea occupies one of the leading places. Modeling as an integral part of yield programming involves the development of a forecast, i.e. a probable idea of the theoretically possible yield, which is provided by various agrobiological indicators. One of the main conditions for increasing the efficiency of production and increasing the gross harvest of green pea is the development and implementation of the latest techniques to increase its productivity in agricultural practice, which is an important and urgent problem. A highly effective modern tool for mathematical modeling, forecasting, situation recognition and decision support are Bayesian networks (BN), which have a number of advantages over other modeling methods.

The goal of the research is to study the possibilities of using the apparatus of Bayesian networks to build an information system for decision support (DSS) to model the yield of green pea.

Research methods. The paper considers the possibility of using Bayesian networks in the information DSS in planning the yield of green pea at an agricultural enterprise. BNs provide the opportunity to take into account in one model of categorical and ordinary numerical variables, the number of variables reaching several hundred, the availability of alternative methods of forming a probabilistic inference and the correct representation of causal relationships.

The main results of the research. The BN apparatus allows combining the available statistical data on agrobiological characteristics of agricultural products in addition to the expert information provided by farmers. The use of DSS based on BN will allow farmers to make decisions under uncertainty of available information about the agrobiological characteristics of growing green pea.

Scientific novelty. BN is a powerful and effective mathematical tool for research and reproduction of the truthful overview of processes in DSS, which should be used to solve problems of probabilistic forecasting, modeling and risk assessment in yield planning.

Practical relevance. For practical confirmation of the obtained results, an experiment was conducted, the results of which confirmed the practical value of the proposed information technology, which can be used to model the green pea yield. The proposed structure of the database and DSS based on it, will support making of effective decisions on the organization of the harvesting campaign for green pea in different technological and weather conditions.

***Keywords*:** *increasing production efficiency, decision support, Bayesian network, yield modeling.*

Problem Statement. In Ukraine, among leguminous crops, pea occupies one of the leading places. Pea is a valuable food, forage and agrotechnical crop. High protein content, variety of uses, positive effect on soil fertility, expediency of sowing as a fallow, intermediate, post-harvest crop, the possibility of growing in different regions determine the significant economic importance of pea. Due to the high yield and forage value, pea has become widespread throughout Ukraine [1–2, 7].

Modeling as an integral part of yield programming involves the development of a forecast, i.e. a probable idea of the theoretically possible yield, which is provided by various agrobiological indicators [15].

One of the highly effective modern tools for mathematical modeling, forecasting, situation recognition and decision support is Bayesian networks (BN), which have a number of advantages over other modeling methods. In particular, the possibility of taking into account of categorical and ordinary numerical variables in one model, the number of variables reaching several hundred, the availability of alternative methods of forming a probabilistic inference and the correct representation of causal relationships [16].

One of the main conditions for increasing the efficiency of production and gross harvest of green pea is the development and implementation of the latest techniques to increase its productivity in agricultural practice, which is an important and urgent problem.

Review of the Literature. Important scientific developments in the technology of growing pea were made by well-known domestic and foreign scientists A.O. Babych, V.F. Petrychenko, A.V. Cherenkov, S.M. Kalenska, V.G. Mykhailov, M.I. Bakhmat, M.Ya. Shevnikov, O.M. Bakhmat, V.V. Lykhochvor, O.V. Ovcharuk, K. Novák, B. Furseth and others.

Analysis of the literature sources [8–12] shows that today Bayesian networks (BN) are widely used in information systems for analysis and processing of statistical data, presented in the form of time series, expert evaluation, interval values, etc. Moreover, BNs are used in decision support systems for forecasting and classification of data of different nature [3, 5, 14].

Decision support systems (DSS) are used in various fields of human activity, their basic components being the acquired experience and knowledge, which are organized in databases and knowledge bases. The tasks of data analysis are becoming increasingly relevant, especially in modern conditions, when significant amounts of information have been accumulated in almost all areas of human activity. Of particular practical importance is the assessment of the condition and forecasting of agricultural crop yields in the context of DSS implementation.

However, despite the presence of significant arrays of agricultural data on the green pea yield, which sufficiently characterize the processes under study, the use of DSS for modeling is quite limited. This is largely due to the lack of developed methods of agricultural data analysis and modeling at different management levels, the complexity of processing large amounts of heterogeneous input information, farmers' lacking skills of using integrated data analysis methods and modern information technology tools. Therefore, given the practical significance of the problem and the lack of methods for solving problems of this class, developed and adapted to domestic conditions, the task of developing a method for modeling the yield of green pea is relevant.

The aim of the paper is the research of the possibilities for using the apparatus of Bayesian networks for developing information DSS for modeling green pea yield.

Presentation of research material. Currently, various approaches are used to estimate agricultural crop yields, including statistical methods and assumptions about the relationship between environmental characteristics, fertilizer application and yield.

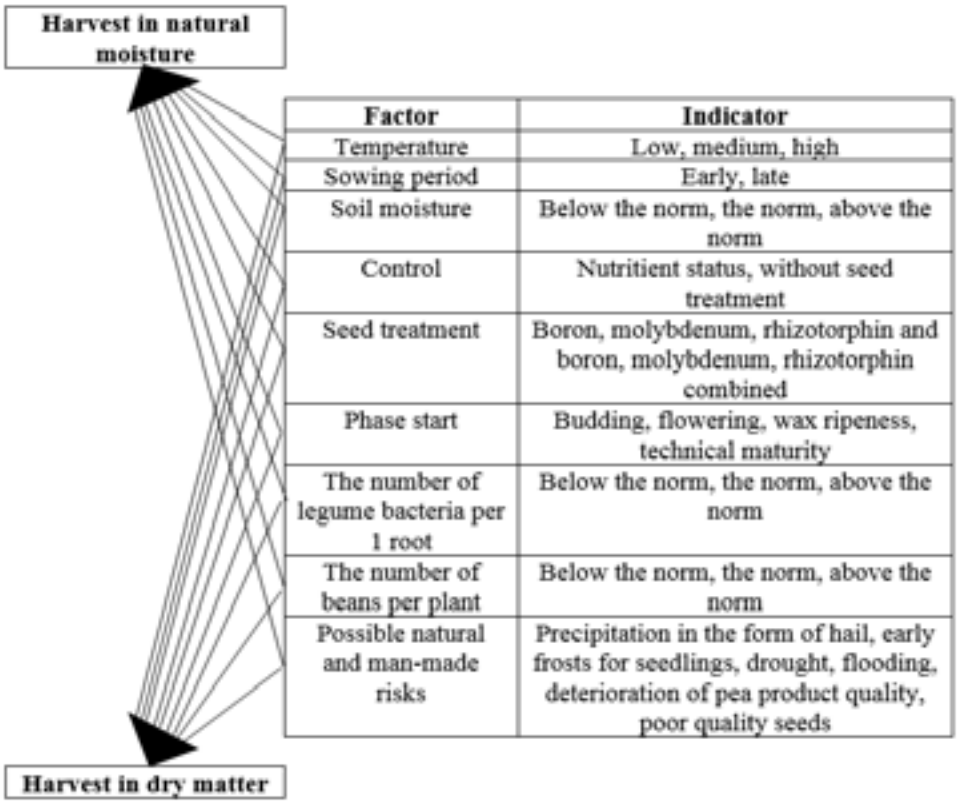
At the present stage of development of the Ukrainian agro-industrial complex, an important part is played by the introduction of new technologies and achievements of scientific and technological progress in order to increase the efficiency of agricultural production and adaptation of agricultural enterprises to changes in social, economic and political environment in the context of sustainable development. It is important to develop models and algorithms of decision support system (DSS) in crop yield modeling, which would provide decision support for modeling, planning and operational management in the cultivation of green pea.

Automation and introduction of modern information technologies in agricultural business, allowing to obtain a larger amount and variety of high-quality food products from each unit of used resources, is the most effective way to develop the agro-industrial complex [4, 6, 13].

Bayesian belief networks, or simply Bayesian networks (BNs), consist of a plurality of nodes and a set

of directional edges that connect these nodes together (Bayesian networks are discussed in more detail in the next section of this paper). The edges define cause-and-effect relationships in a subject area that are largely unambiguous. The likehood of a statement (or action) is represented by probability. The concept of BN lies in updating the probabilities when additional information is received. Information can be received by each node (variable) of the network, because the method of updating the probabilities is invariant with respect to the direction of information dissemination along the edges of the network [16]. Thus, BN, as the basis of DSS, significantly expands the possibilities of analysis and decision-making, as it allows making both direct and inverse inference at the same time. Moreover, the simultaneous input of information about the states of several nodes does not change the network processing algorithm, which makes it possible to eliminate situations of logical inconsistency, which often occur for other methods in similar cases. BNs in DSS have such significant advantages as the ability of computational interpretation of inference algorithms, the flexibility of the process of information dissemination and adaptation to new data [3, 5, 16]. It follows from the above that DSS for agricultural business should be developed on the basis of Bayesian networks.

The application of BNs to the analysis of processes of different nature, human activities and the functioning of engineering systems enables taking into account and using any input data in the form of expert evaluations and statistical information. In turn, the variables can be discrete and continuous, and the nature of their receipt in the analysis and decision-making can be in real time and in the form of static arrays of information and databases. Herewith, due to the use of the representation of the interaction between process factors in the form of cause-and-effect relationship, the network achieves the highest level of visualization and a clear understanding of the nature of the process factors interaction. Other advantages of BNs are the ability to consider the uncertainties of statistical, structural and parametric nature, as well as the inference formation using different methods – approximate and accurate ones [16].



Factor	Indicator
Temperature	Low, medium, high
Sowing period	Early, late
Soil moisture	Below the norm, the norm, above the norm
Control	Nutritient status, without seed treatment
Seed treatment	Boron, molybdenum, rhizotorphin and boron, molybdenum, rhizotorphin combined
Phase start	Budding, flowering, wax ripeness, technical maturity
The number of legume bacteria per 1 root	Below the norm, the norm, above the norm
The number of beans per plant	Below the norm, the norm, above the norm
Possible natural and man-made risks	Precipitation in the form of hail, early frosts for seedlings, drought, flooding, deterioration of pea product quality, poor quality seeds

Fig. 1 – Factors influencing the formation of green pea yield

The use of DSS based on BBN will allow agrarians to make decisions under conditions of uncertainty of available information about the agrobiological characteristics of growing green pea. The BBN apparatus allows combining the available statistical data on agrobiological characteristics of agricultural products in addition to the expert information provided by agrarians. The structure of the network is often determined by subject matter experts, but there are methods of structural MB training based on statistics. This makes it possible to adapt the BN structure to new data. However, it should be emphasized that the fundamentally subjective Bayesian approach does not require "objectivity" of probabilities, and therefore allows the formation of tables of conditional probabilities based on subjective expert evaluations. It should also be noted that the inference results are more sensitive to the BN qualitative structure than to the quantitative values of the probabilities.

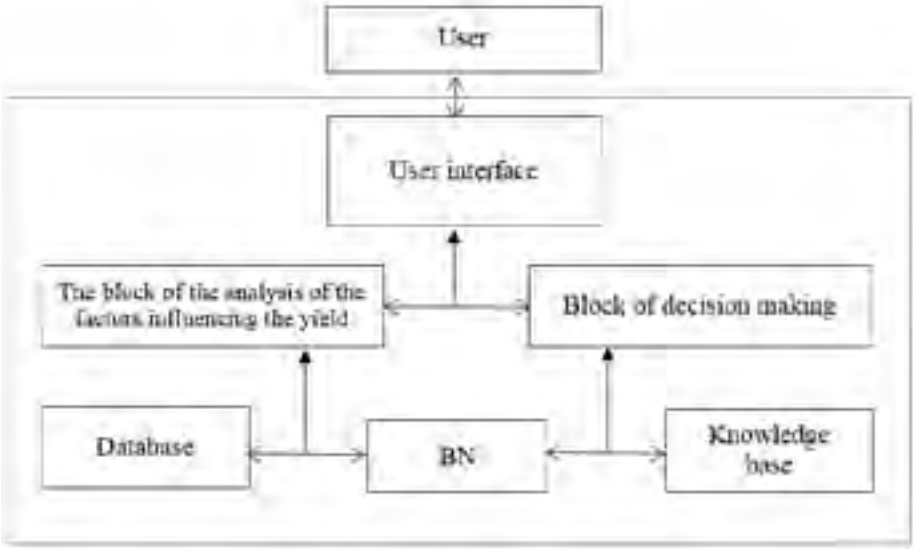


Fig. 2 – Conceptual scheme of information DSS for modeling the yield of green pea using BN

The structure of BBN for yield modeling is given by factors (Fig. 1) that affect the process of green pea cultivation and the relationships between them. The basis for the formation of relationships is expert information; available agrobiological research aimed at identifying such relationships between factors, and accumulated statistical data.

The structure of the developed BN's relations is shown in Fig. 3. The expert knowledge in this field was used to generate the structure of BN relations.

GeNie 2.0 software package was used for calculations, which is a software implementation of decision-making system based on BBN, allowing to determine variables and relationships between them, to learn parameters and network structure, as well as to make probabilistic inference based on the obtained data.

It is proposed to use BN as a basis of the information system, which incorporates expert evaluations of factor indicators in the form of tables of BN conditional probabilities.

The information system, which is based on the model of the subject area in the form of BN, can be used to solve the problem of yield modeling.

The DSS, which implements the use of BN, the conceptual scheme of which is shown in Fig. 2, gives a finite set of recommendations to agrarians on the appropriateness of the impact of agrobiological factors on yields. An agrarian must use such a system as a means of partial automation of the complex process of yield modeling.

The results of the evaluation of BN parameters are shown in Fig. 3.

Based on the research performed, it was found that the formation of the maximum yield of vegetable peas (in terms of dry matter) for the first sowing period was against the background of N30 P40 for seed treatment with boron and molybdenum – 2,650 kg / ha, and for the second one – 2,490 kg / ha when using for the treatment molybdenum and rhizotorphin at 2,050 and 1.870 kg / ha in the control.

Fig. 3 – The structure of BN relations for DSS in modeling the yield of green pea (initial state of evaluation (on the left), example of modeling according to the specified parameters) (on the right)

The proposed IT enables quick identifying of the most significant causes for reducing the likelihood of high yields. As a result of computer simulation, the probabilistic characteristics of achieving the final result are obtained and the best indicators of factors for specific yield conditions are determined.

BN is a powerful and effective mathematical tool for research and reproduction of the truthful overview of processes in DSS, which should be used to solve problems of probabilistic forecasting, modeling and risk assessment in yield planning.

Conclusions. Modern information technologies allow storing a huge amount of data, their analysis and, on the basis of the obtained results, offering solutions to problems that would minimize costs and maximize profits of agricultural enterprises. The use of information technology will significantly improve the information support system of agricultural enterprises, which will be accompanied by increased competitiveness.

The proposed structure of BN and DSS based on it, will support effective decision making on the organization of the harvesting campaign for green pea in different technological and weather conditions.

For practical substantiation of the obtained results, an experiment was conducted, the results of which confirmed the practical value of the proposed information technology, which can be used to model the green pea yield.

The degree of success of this method of modeling and making a statistical inference depends on the ability to correctly formulate the problem, select process variables that sufficiently characterize its dynamics or statics, collect statistical data and use them to train the network, and correctly form the result – inference using the developed network.

Based on the proposed methods and algorithms, a conceptual scheme of the decision support system based on BN has been developed. Herewith, it is possible to quickly modify computational procedures due to the open modular architecture of the computer system for decision support in modeling and forecasting yields.

Further development of the work involves the expansion of modeling by introducing additional criteria and factors that affect yields.

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ІНФОРМАЦІЙНА СИСТЕМА ПІДТРИМКИ ПРИЙНЯТТЯ РІШЕНЬ ДЛЯ МОДЕЛЮВАННЯ ВРОЖАЙНОСТІ ГОРОХУ ОВОЧЕВОГО

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Анотація. В Україні серед зернобобових культур одне з провідних місць належить гороху. Моделювання як складова частина програмування врожаю передбачає розробку прогнозу, тобто ймовірного уявлення про теоретично можливу врожайність, яка забезпечується різними агробіологічними показниками. Одна з головних умов підвищення ефективності виробництва і збільшення валових зборів гороху овочевого є розробка та впровадження у сільськогосподарську практику новітніх прийомів підвищення його продуктивності, що є важливою і актуальною проблемою. Високоефективним сучасним інструментом математичного моделювання, прогнозування, розпізнавання ситуацій та підтримки прийняття рішень є байєсівські мережі (БМ), які мають ряд переваг перед іншими методами моделювання.

Метою дослідження є вивчення можливостей використання апарату байєсівських мереж для побудови інформаційної системи підтримки прийняття рішень (СППР) для моделювання врожайності гороху овочевого.

Методи дослідження. В статті розглянута можливість використання байєсівських мереж у інформаційної СППР при

плануванні врожайності гороху овочевого на агропідприємстві. БМ надають можливість врахування в одній моделі категорійних і звичайних числових змінних, кількість змінних може сягати декількох сотень, наявність альтернативних методів формування імовірнісного висновку та коректне представлення причинно-наслідкових зв'язків.

Основні результати дослідження. Апарат БМ дозволяє комбінувати наявні статистичні дані про агробіологічні характеристики агропродукції у доповненні до експертної інформації, яку надають аграрії. Використання СППР на основі БМ дозволить аграріям приймати рішення в умовах невизначеності наявної інформації про агробіологічні характеристики вирощування гороху овочевого.

Наукова новизна. БМ – це потужний і ефективний математичний інструмент дослідження та відтворення реальної картини процесів у СППР, який доцільно застосовувати для розв'язання задач ймовірнісного прогнозування, моделювання та оцінювання ризиків при плануванні врожайності.

Практична значимість. Для практичного підтвердження отриманих результатів проведено експеримент, результати якого підтвердили практичну цінність запропонованої інформаційної технології, яка може бути використана для моделювання врожайності гороху овочевого. Запропонована структура БД, СППР на її основі, забезпечать підтримку прийняття ефективних рішень по організації збиральної кампанії гороху овочевого в різних технологічних і погодних умовах.

***Ключові слова*:** *підвищення ефективності виробництва, підтримка прийняття рішень, байєсівська мережа довіри, моделювання врожайності.*

ИНФОРМАЦИОННАЯ СИСТЕМА ПОДДЕРЖКИ ПРИНЯТИЯ РЕШЕНИЙ ДЛЯ МОДЕЛИРОВАНИЯ УРОЖАЙНОСТИ ГОРОХА ОВОЩНОГО

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Аннотация. В Украине среди зернобобовых культур одно из ведущих мест принадлежит гороху. Моделирование как составная часть программирования урожая предусматривает разработку прогноза, то есть возможного представления о теоретически возможной урожайности, которая обеспечивается различными агробиологическими показателями. Одним из главных условий повышения эффективности производства и увеличения валовых сборов гороха овощного является разработка и внедрение в сельскохозяйственную практику новейших приемов повышения его производительности, что является важной и актуальной проблемой. Высокоэффективным современным инструментом математического моделирования, прогнозирования, распознавания ситуаций и поддержки принятия решений являются байесовские сети (БС), которые имеют ряд преимуществ перед другими методами моделирования.

Целью исследования является изучение возможностей использования аппарата байесовских сетей для построения информационной системы поддержки принятия решений (СППР) для моделирования урожайности гороха овощного.

Методы исследования. В статье рассмотрена возможность использования байесовских сетей в информационной СППР при планировании урожайности гороха овощного на агропредприятии. БС предоставляют возможность учета в одной модели категорийных и обычных числовых переменных, количество переменных может достигать нескольких сотен, наличие альтернативных методов формирования вероятностного заключения и корректное представление причинно-следственных связей.

Основные результаты исследования. Аппарат БС позволяет комбинировать имеющиеся статистические данные про агробиологические характеристики агропродукции в дополнении к экспертной информации, которую предоставляют аграрии. Использование СППР на основе БС позволит аграриям принимать решения в условиях неопределенности имеющейся информации про агробиологические характеристики выращивания гороха овощного.

Научная новизна. БС – это мощный и эффективный математический инструмент исследования и воспроизведения реальной картины процессов в СППР, который целесообразно применять для решения задач вероятностного прогнозирования, моделирования и оценки рисков при планировании урожайности.

Практическая значимость. Для практического подтверждения полученных результатов проведен эксперимент, результаты которого подтвердили практическую ценность предложенной информационной технологии, которая может быть использована для моделирования урожайности гороха овощного. Предложенная структура БС, СППР на ее основе, обеспечат поддержку принятия эффективных решений по организации уборочной кампании гороха овощного в различных технологических и погодных условиях.

***Ключевые слова*:** *повышение эффективности производства, поддержка принятия решений, байесовская сеть, моделирование урожайности.*

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