УДК 631.58: 551.5

R.I. Khrabatyn, V.V. Bandura, O.V. Khrabatyn, M.C. Pasyeka

Decision-Making Support Systems in Agriculture. Algorithm, Principles of Construction and Functionality

Описана структура, принципы организации и функционирования системы производства и поддержки выполнения аграрных технологий в сельском хозяйстве с использованием передовых достижений в области компьютерных наук.

The structure, the organizational principles, the production and support system functioning required for agrarian technologies application in agriculture using the latest achievements in computer sciences and technologies are described.

Описано структуру, принципи організації та функціонування системи виробництва і підтримки виконання аграрних технологій у сільському господарстві з використанням передових досягнень в галузі комп'ютерних наук.

Introduction. The impact of agriculture on the environment is significant and diverse. It consists of a large number of factors, influencing plant growing and animal breeding depending on the specific physical-geographical regional features [1]. The significance and extent impact of some factors vary a lot due to a wide variety of kinds of agricultural land exploitation, natural and historical conditions, under which an ecological situation is formed in various regions.

The composition, location and alternation of crops largely characterize the degree of crop farming impact on natural environment. A method of crops treatment determines the degree of soil surface vulnerability and its propensity for water or wind erosion. The volume and type of applied fertilizers determine the level of pollution of ambient environment and agricultural products with nitrates and other highly toxic substances. In addition, fertilization leads to accumulation of other hazardous substances and elements in soils. For example, fluorine, strontium and uranium amass in soils due to phosphate fertilizers. Livestock farming causes degradation of pastures, worsening of soil-protective properties and development of erosion, as well as environmental pollution by sewage and fumes. Pesticides and insecticides have very bad effects too. Moreover, the influence of the certain factors of agricultural activity may be increased by some natural factors, such as active erosion and deflation.

The main research material

Taking into account the exceptional importance of agriculture in terms of the ecological safety and population provision with foodstuff, it is topical to ensure effective management at crop producing enterprises, in order to maximize productivity, on the one hand, and to minimize anthropogenic load on the biosphere, on the other hand. To achieve these goals, the manufacturers more or less often use innovations of scientists, machine constructors, economists and other professionals, serving the agricultural sector (AS).

The agricultural technological innovations, such as precision agriculture, open the wide possibilities for reaching an optimal result by the criterion «profit + ecological safety». Precision agriculture is a system of land management, using the latest achievements in informatics and technology, based on the computer systems, generating agrotechnological solutions, global positioning systems (GPS), geo-information technologies (GIT), advanced information technologies, remote and on-board sensors, automatic operating members of agricultural machinery [2].

The process of crop production is realized in space and time on a particular territory. This territory is not homogeneous even on one and the same field. In traditional crop farming, after certain agro-technical operations their parameters (conditions of their fulfillment and corresponding effects) turn out to be, as a rule, the same for all areas of the field. By contrast, precision agriculture provides for dynamic optimization of these parameters for each homogeneous area of the field, depending on complicated agro-chemical, agro-physical, phytosanitary factors. In other words, all technological operations, carried out in a field, are differentiated in terms of the weather conditions not only in time but also in space.

Modern agricultural machinery, controlled by on-board computers, hardware – automatic samplers, various sensors and measuring systems, harvesting machines that automatically weigh crops, remote sensing devices and multifunctional software, allowing to make optimal decisions in farm management, are all required to implement the technology of precision agriculture.

State-of-the-art information technologies can fundamentally change the process of making agro-technological management solutions. The recent advances in telecommunications and systems, based on computer methods of decision-making support, objectively contribute to creation of innovative software systems, which can integrate knowledge and experience of many specialists in agronomy, biology, agriculture, economy and related spheres. In particular, the existing information and technical potential allow to develop, create a computer system, the most effective and, at the same time, environmentally friendly adaptive agro-technology for each field, taking into consideration the variability of the natural conditions and economic constraints in a specific farm. The solution of this problem, in turn, is connected with a need in presentation, formalization and clear synthesis of scientific knowledge and information, accumulated in agronomy. Implementation of computer systems of agro-technological decisions support depends on a conceptual framework (i.e. definitions), ensuring electronic submission, integration of descriptive and procedural knowledge in agronomy, based both on natural-lingual communication with computers and specialized knowledge processing. It has been thoroughly studied for a long time by the Agro-Physical Research Institute, which worked out the theoretical and methodological foundations for common computerized technological space in agronomy, offered a conceptual framework of computer description of technological operations and agro-technologies in whole. The creation and operation of agro-technological decisions support systems have been practiced with the help of computer-aided systems [3].

Fig. 1 depicts a general block diagram, according to which the agro-technological decisions are generated in agronomy, including realization of agro-techniques of the information technology of precision agriculture (PA). This diagram provides for diverse data and knowledge collection, their analysis and formalization, as well as making agro-technological differentiated solutions on basis of the information gathered, including performing the agro-techniques in a field by one of the two main modes of their implementation in precision agriculture (offline or online).

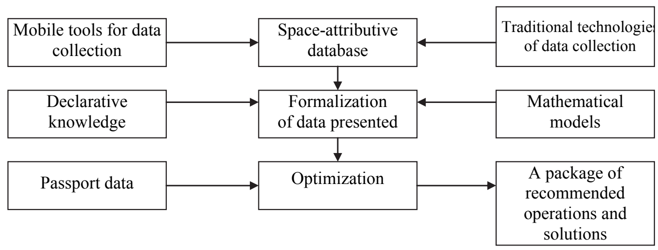

Fig. 1. Block diagram, showing generation and realization of technological solutions

The block of agro-technologies generation and optimization is the core of this diagram, as it accumulates knowledge of specialists (experts), who develop the basic agro-technologies and technology adapters. Using an appropriate program-mathematical software, any user (agronomist, farmer) will be able to synthesize the optimal agro-technology to treat a given breed on a particular field, taking into account the peculiarities of his own farm and experience. This very agro-technology is regarded by us as a fundamental element of any agriculture, including precision one. The quest for synthesis of the optimal agro-technology is the main purpose of any user of a decision-making support system (DMSS).

It is important to remark, that functional capabilities of the whole diagram (Fig. 1) are considerably determined by the scope, frequency and quality of directly measured, calculated information, that was used in DMSS in agro-technologies synthesis. Efficiency of the implemented information technology of precision agriculture, particularly, depends on the content and principles of organization/improvement of databases and knowledge in DMSS. Consequently, the issue of information support of the precision agriculture technology should be viewed as a task, aimed at improving databases and knowledge within the frame of DMSS [1].

The decision-making support systems (DMSS) or decision support systems (DSS) emerged as a result of natural development, generalization of management information systems and database control systems (DCS) towards their greater suitability and adaptability to the challenges of daily management activity.

The term «decision-making support system» appeared in the early 70s, but till now neither scientists nor developers have given a generally accepted definition to it.

A sufficient number of domestic and foreign experts' papers on various subjects are dedicated to DMSS application and functional purpose definition. The scope of DMSS application covers, first of all, lowly structured problems. The tasks, attributed by us to the scope of DMSS application, are characterized with uncertainty, that makes practically impossible to find the sole objectively optimal solution. Therefore, taking decisions in such situations shall be accompanied by a finer toolset of defining a system of advantages, a deeper comparative analysis of alternatives, corresponding dataware for decision-makers [4].

The research work [5] describes DMSS as a means of «calculating solutions», based on «usage of models of a number of data/assertions processing procedures, helping a decision-maker (DM) in his management», while the research work [6] suggested considering DMSS as «interactive automated systems, helping a decision-maker to use data and models to solve non-structured problems». In the rest of sources, DMSS is defined as «a computer information system, applied to support different kinds of activity, if a decision is taken in situations, when it is impossible or undesirable to use automated systems, executing the full process of decision-making». DMSS does not substitute the decision-makers by automating the decision-making process, it just assists them in solving a problem [7].

Starting from the first definitions of DMSS, a circle of tasks, solved with their help, has emerged: they were non-structured and lowly structured. The classification of problems, offered in [8, 9], had a great impact on such tendency of DMSS; according to it, non-structured tasks have only a qualitative description, grounded on decision-makers' opinion, while quantitative dependences between the main task characteristics are not known. As for the well-structured tasks, essential dependences can be expressed quantitatively in them. Lowly structured tasks fall in between them, «they combine both quantitative and qualitative dependences, while little-known, undefined task elements tend to prevail» [8].

Despite the lack of a generally accepted definition, researchers are unanimous in the opinion, that DMSS are computerized assistants, helping a manager to transform information into the actions, that are effective for the system under control. These systems must have such features, which make them not only helpful, but also indispensable for a decision-maker. Like any information systems, they shall satisfy a specific need of decision-making process in information. DMSS must be capable of adapting to changing computer models, to communicating with a user in a language, specific for the sphere of management (ideally – in a natural language), to present the results in the form, that would facilitate understanding of the results.

The role of DMSS does not consist of replacing a manager, but of increasing effectiveness of his work. The aim of ordinary DMSS is not so much automating the process of decision making, as a system and a person's cooperating, interacting to take a solution. In comparison with the typical schemes, DMSS with extended functions is required for effective precision agriculture implementation.

Speaking of DMSS with extended functions, we mean quite a complicated architecture of a system created, which includes an expert system, mathematical models, geo-information system (GIS), interfaces of data transfer between DMSS, on-board systems of agricultural machinery and mobile workstations. Along with the usual functions of decision-making support, the DMSS under review also ensures an automatic procedure of forming an electronic map-task for implementation of agro-techniques owing to precision agriculture. All the listed modules, as a rule, are applied and worked out as separate programs, but we combine them into one program-apparatus complex (Fig. 2). We hope, that the DMSS, created by us, will become irreplaceable in developing and making solutions at the plan/operation levels of farm management. The possibility of procedural knowledge usage (algorithms of analysis and ways of problem solving) along with declarative (descriptive) knowledge is one of the most valuable qualities of this system. Procedural knowledge is the mathematical models of different complexity and purpose, presented as a variety of computer models, designed by certain software modules.

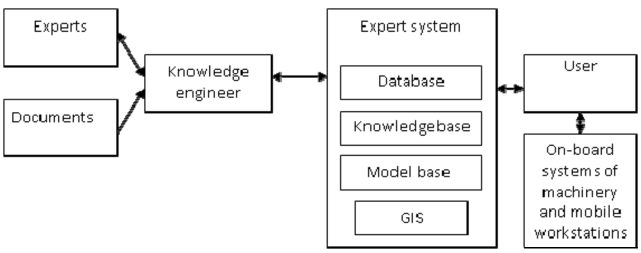

Fig. 2. Structure of DMSS

Let us have a deeper look at each block of DMSS structure.

The term «expert» roots from Latin word «expertus» (experienced) – a carrier of specialized, hardly available or formalized knowledge, so-called deep knowledge [10]. There are different definitions of the notion «expert». So, for instance, to Yu.V. Sydelnykov's mind, an expert is a person, who is a specialist and (or) has practical experience, who:

• has and provides objective, full knowledge about the peculiarities/properties of an external object and (or) recommendations as for the desired (better) variants of solutions concerning the given object;

• has rights, duties and responsibilities for his expert opinion pursuant to regulatory documents;

• is involved in making-decisions process by performing a special function and is obliged to scientifically ground these decisions;

• expresses his opinion on a question, posed to him by any person, within the scope of his competence and (or) practical experience, irrespectively of external effects and his own benefit.

In our case, they are people with solid practical experience in development of agro-technologies and technology adapters. They may be the scientists, agronomists, farm managers.

A knowledge engineer is a specialist, who withdraws and structures knowledge. He is usually an intermediary between an expert and a knowledge base, which is to be created. Knowledge engineering is a subject, associated with the below-listed issues:

• withdrawing knowledge from the experts and/or literature, Internet;

• structuring, forming and processing knowledge to create databases, knowledge bases, expert systems, decision-making support systems.

The term «knowledge engineering» was suggested by E. Feigenbaum. Knowledge withdrawal is interpreted as the procedure of knowledge engineer's interacting with a knowledge source, resulting in more explicit process of experts' reasoning in the course of making professional decisions and clearer structure of their views on the knowledge domain.

A variety of effects have been described in relation to knowledge withdrawal from experts:

• existence of so-called informal, implicit or implied knowledge under the following circumstances: unconscious nature of expert skills; difficulty of verbalization and expert's underestimation of importance of some knowledge, used in solving professional problems;

• special form of expert knowledge organization in comparison with beginners' knowledge organization;

• quite a short period of time, needed by the expert to solve a certain number of the professional tasks;

• limited short-term memory of a man;

• incorrectness of some methods of information obtaining;

• availability of psycho-lingual problems. Thus, distinction between a communicative language and a language of intellectual process can lead to significant loss of knowledge, after a knowledge engineer communicates with an expert [3, 8, 11, 12].

The experts and knowledge engineers are the key men, that determine DMSS fullness with knowledge and data.

An expert system is a computer-aided system, using one or more experts' knowledge, expressed in a formal form, as well as the logic of decision-making in the tasks, formalized in a difficult way or not formalized at all. In a complicated situation (lack of time, lack of information or experience), expert systems can give a competent consultation (advice, prompt), that would help a professional come to an informed decision. The basic idea of these systems is that less qualified specialists, when facing any problems, should use knowledge and experience of highly qualified professionals, specializing in the same knowledge domain.

Typically, expert systems are created in narrow knowledge domains. The first models were created in the mid-70s: MYCIN system was used in medicine to diagnose diseases, DENDRAL – in exploration of mineral deposits to analyze chemical composition of soils. An expert system includes the following subsystems: a knowledge base, inference engine (solver), intelligent interface and subsystem of explanations. The knowledge base contains a formal description of experts' knowledge, presented as a set of facts and rules. The mechanism of withdrawal (or solver) is a block, i.e. a program, realizing a forward or reverse chain of reasoning as a general strategy for building an inference. Using an intelligent interface, the expert system asks its user questions and reflects conclusions, as a rule, by presenting them in a symbolic form [13].

These are the advantages of expert systems over a human expert:

• hey have no prejudice, they are resistant to various obstacles;

• they do not jump to conclusions;

• these systems give out not the first-found, but optimal (by appropriate criteria) solution;

• a knowledge base can be very vast. The knowledge, set once into a computer, is stored there permanently. By contrast, a man has a limited knowledge base, so, if some data are not used by him for a long time, they are forgotten and lost forever.

The first research works, dedicated to expert estimates, appeared in the former USSR in the late 60s. V.M. Glushkov, a well-known cyberneticist, was one of the first researchers, who realized the viability and importance of expert assessment technology. After early technologies of expert evaluation were developed and led to the first essential results, the potential of their practical application has been overestimated. Even now professionals are often misled by this illusion.

Upon an initiative of the country government, in the early 70s a series of experiments were made to test actual capabilities of practical application of the expert evaluation methods. The offered research objects were linked to the situation in the Middle East, the region of chemical tests etc. The results were not satisfactory, it subsequently had a negative impact on the development of expert evaluation methods in the country.

It is necessary to understand properly the real capabilities of these methods. Of course, not all the existing problems can be solved by expert opinion. Although in many cases correct usage of expert technologies is the only real way to prepare and make informed management decisions [4], expert systems do not replace a specialist, they are his emotionless adviser, intellectual partner.

An expert system, being an intellectual core of DMSS, using formalized knowledge of experts, farm database, strategy of farm development and integrated models in an interactive mode, lets its user synthesize optimal agro-technologies for his farm. The optimal agro-technology is synthesized by adapting the basic agro-technology to the existing farm resources and chosen strategy of farm development.

An inference mechanism (or a solver) is the basic software module of the expert system. Based on formalized knowledge, it synthesizes the optimal agro-technology by documenting the chain of reasoning with the corresponding subsystem.

The database contains all attributive information, used in DMSS operation at all stages, i.e. at the stage of basic agro-technology description, adaptive agro-technology generation and subsequent analysis of generated technology. Apart from that, a database stores the results of applied agro-technology, which can also become input data in case of generation of further agro-technologies for a specific field.

The data, stored in the database, must be strictly typified. It is necessary for their subsequent correct processing by the system. Data typification is organized by us in such a way, that we can describe almost any object. To do so, an editor of data types was designed, helping a user to create new types or edit the existing ones. Figure 3 shows a diagram of simple example, describing the type «Breed». As you see here, the type «Breed» has five properties, which, in turn, are typified too: «string», «real» and «list». At the same time, the type «Breed» is also a property of parent type «Crop».

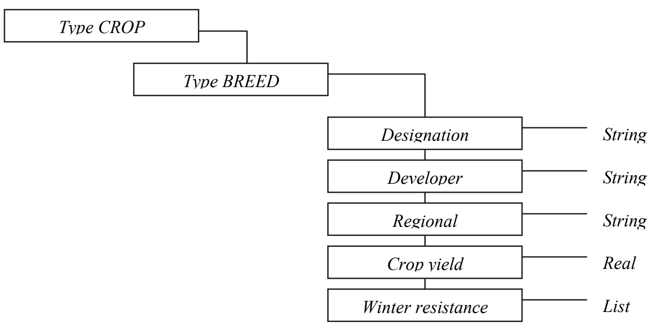

Fig. 3. Diagram of description of an attribute type in the database

Filling the database is nothing but copying this or that type. Thus, we describe and fill all attributes with the specific values, the attributes, needed by us for the basic agro-technology description [3].

The knowledge base contains data on certain technological operations, their characteristics, conditions, degree of impact on ecological environment, depending on operation parameters. The data, ensuring further formalization and generation of the agro-technology according to the given degree of differentiation, are set also into the knowledge base. For this purpose, for example, a certain compliance is established between a set of technological operations and their characteristics, on the one hand, and their parameters (conditions) – on the other hand. In this case, an appropriate description is «tied» to a particular object of agro-technology, i.e. to technological operations, their characteristics, and through them – to a specific field, crop, breed. This circumstance is extremely important, as inclusion of application models in the system, particularly the simplest regression ones, is connected with the certain conditions. These conditions can be spatio-temporal constraints, agro-physical, agro-chemical, biological, meteorological and other features of appropriate formulas application.

The base of models, integrated into DMSS, is used to calculate dosage of fertilizers, to forecast the start of phenological stages, to assess agro-technologies and some agro-technical operations by economic and environmental criteria. The strategy of mathematical models involves two modes of their application in DMSS: automatic and semi-automatic one. In the first case, the models (software modules) are automatically included in the control core of DMSS and use a common database. The semi-automatic mode involves automatic launch of various programs; the results of calculations are exchanged at the level of system files.

Geo-information system (GIS), being integrated into DMSS, can analyze and visualize spatial-oriented data, bound to coordinates by GPS-receivers (field contour, map of layout according to agro-chemical, agro-physical and agronomic indices, history of fields, yield maps etc.), can create map-tasks for agricultural machinery, equipped with on-board computers and GPS-receivers to perform agro-technical operations in a differentiated way, taking into consideration location of machines in a field. We should note, that DMSS uses different protocols of data exchange with on-board computers of agricultural machines and mobile workstations in order to carry out agro-technical operations in precision agriculture modes (gathering information about a field or fertilizing).

Conclusions

Thus, a user of DMSS (person who makes decisions) is provided with a wide range of functional capabilities to make the optimal solutions for farm management. Having synthesized an adaptive (applicable in a particular farm) agro-technology, the user can assess it by economic and ecologic criteria, from the point of the company's development strategy. It is important, that agro-technical operations, included in the agro-technology, could be performed in the mode of precision farming (in a differentiated way) through the realized mechanisms of generation of map-tasks and tables of agro-requirements. As the knowledge base is filled, via Internet in particular, such a system will be helpful for any agricultural enterprise and can become an irreplaceable consultant for agronomists and farm managers.

1. *Карпович Л.*, *Косиков А.* Построение синтетических карт оценки воздействия сельского хозяйства на окружающую среду с использованием Мастера пространственных операций ArcView GIS. – МГУ. – http://www.dataplus.ru/Industries/13Ecolog/AgryEco.htm
2. *Якушев В.В.* Программно-технические средства информационного обеспечения и реализации агроприемов в системе точного земледелия. Автореферат диссертации. СПб.: АФИ, 2005.
3. *Якушев В.П.*, *Якушев В.В.* Информационное обеспечение точного земледелия. – 2007.
4. *Литвак Б.Г.* Экспертные технологи в управлении. – М.: Дело, 2004.
5. *Поспелов Г.С.* Искусственный интеллект – основа новой информационной технологии. – М.: Наука, 1988.
6. *Форсайт Р.* Экспертные системы. – М.: Радио и связь, 1987.
7. *Наумов А.И.* Системы управления базами данных и знаний. – М.: Финансы и статистика, 1991.
8. *Гаврилова Т.А.*, *Хорошевский В.Ф.* Базы знаний интеллектуальных систем. – СПБ.: Питер, 2000.
9. *Керров Л.А.* и др. Экспертные системы: инструментальные средства разработки. – СПб.: Политехника, 1996.
10. *Сидельников Ю.В.* Теория и организация экспертного прогнозирования. – М.: ИМЭМОАН, 1990.
11. *Гаврилова Т.А.*, *Червинская К.Р.* Извлечение и структурирование знаний для экспертных систем. – М.: 1992.
12. *Хилл С.*. Шестьдесят трендов за шестьдесят минут. – СПб.: Крылов, 2004. – 107 с.
13. *Междисциплинарный* словарь по менеджменту / Под ред. С.П. Мясоедова. – М.: Дело, 2005. – С. 248–249.

Поступила 30.12.2014
E-mail: *leuro@list.ru*; *romankhr@yahoo.com*

●