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ANALYSIS OF ECONOMIC AND AGRICULTURAL INDICATORS UNDER SUSTAINABLE AGRICULTURE CONDITIONS WITH THE USE OF BAYESIAN MODELLING

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Key words: sustainable agriculture, mineral fertilization, stocking density, agri-economic indicators, Bayesian networks, model.

Abstract

Searching for relations between the level of production intensity, land efficiency and work performance, comparative analyses were carried out on international scale taking into consideration 45 countries from around the world with the use of the Statistical Yearbook (2013) and International Statistics Yearbook (2015). The research covered basic qualification criteria of sustainable agriculture, i.e. the level of mineral fertilization and stocking density as well as productivity rates, i.e. land efficiency and work performance and factors which shape them. The main aim of the research is the use of Bayesian modelling in order to predict the development of various economical and agricultural indicators and also show relationships between events basing on the theory of probability.

Introduction

Poland accession to the European Union obliged Member States to introduce assumptions of sustainable agriculture. Sustainable agriculture is one of main ideas of precise agriculture, consisting in achieving high crops with high quality at the simultaneous reduction of costs in an environmentally friendly manner. Using precise agriculture tools we decide, inter alia, on precise agri-technical treatments, suitable fertilization, crops protection or relevant

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amount of sowed seeds and efficient control of machines operation (KRASOWICZ 2005). In Poland, precise agriculture consists mainly in rational fertilization. Fertilization industry development is fundamental for ensuring food safety of a country and constitutes an indispensable condition for sustainable development of the world. Contrary, both in Europe and around the world it is more often applied for combating weeds, diseases and pests (BUJAK 2009). The main task of mineral fertilization is maintenance and increase of soil fertility. Based on the national and foreign research (BAUM 2006, KOPIŃSKI, TUJAKA 2009, TILMAN et al. 2002) it may be simultaneously stated that the increase of soil fertility and crops of cultivated plants ensures sustainable organic and mineral fertilization i.e. manure, mineral fertilizers NPK and calcium fertilizers Ca. One of the reasons of reduction of organic matter content in soil is intensification of agricultural production and inventory farming. According to the Main Statistical Office (2013) in 2005–2011 livestock of pigs in Poland reduced by over 4.5 million pieces contrary to cattle when in the same period an increase of livestock by approx. 300 thousand pieces was reported.

Lower content of organic matter weakens soil ability to accumulate water, reduces also its absorption ability which results in consequence in deterioration of soil structure and lower assimilability of nutrients. Therefore, mineral fertilizers, which boost growth and development of crops, are the only source of nutrients in agriculture. However, one should remember that their irrational use, through too high fertilization doses threatens soil and water. According to the Main Statistical Office (2013) in Poland in 2005–2011 an increase of mineral fertilizers use by 267 NPK per a hectare of agricultural land was reported.

The above mentioned issues concerning sustainable agriculture do not provide a full diagnosis with regard to precise agriculture, which requires from farm owners the use of modern technological solutions at relevant management of agricultural production. Therefore, there is a need to analyse and interpret agri-economic indicators and in particular land efficiency and work performance, which are the most universal, and as a result detailed productivity rates (GROTKIEWICZ, MICHAŁEK 2009). Both these rates considerably depend on the agriculture modernity degree thus they are derivatives of the level and efficiency of scientific progress. To take the best decisions within sustainable agriculture in order to achieve high indicators of land efficiency and work performance in an environmentally friendly manner, we may model farms based on international comparison and relevant statistical methods with the use of both quality and quantity data in order to present trends in changes of productivity rates on international scale in comparison to the criteria which meet the level of sustainable agriculture which decides on the productivity level and social efficiency in agriculture with regard to cognitive and application reasons. One of the most popular and used techniques for modelling are Bayesian networks (Bayesian Networks). Bayesian networks which are also called probabilistic graphical models, chains of cause and effect, they serve as a tool for knowledge representation under uncertainty and decision making process (APOLLO, MISZEWSKA-URBAŃSKA 2014). Systems which are based on Bayesian networks have found many practical applications not only in medicine, genetics or economics but also in agriculture and forestry (KUSZ 2015, MAKSYM 2011, OIJEN et al. 2005, SVENSSONA et al. 2008, SAGRADOA et al. 2016, WANG et al. 2009).

According to literature (ACHEL 2005, SUCHETA, PRAKASH 2004, BARTNIK, KUSZ 2005), Bayesian network is a non-oriented acyclic graph which reflects relations between variables and more precisely correlations between distributions of discreet variables basing on the probability calculus. Nodes of network are variables (properties with discreet values) and the connections of nodes (arches or vectors) reflect relations between properties and their direction. Thickness of connections between nodes on the graphs which present Bayesian networks symbolizes strength between variables (OLBRYŚ 2007). Each network includes a quality part, which constitutes a set of variables (graph nodes) along with relations between them and quantity part which represents distribution of probability for these variables (LUIS, JAVIER 2007, KUSZ et al. 2006). At the same time we should bear in mind that statistical methods used for research, mainly should be supported by knowledge in order to completely use information included in the analysed data and to carry out a detailed analysis.

Objective and scope of the study

The main aim of the research is to analyse the current problems of fertilization on the background of the concept of sustainable agriculture, using modelling based on Bayesian networks.

The effect of the research will consist in obtaining information on probability distribution where each node of a network is related to conditional distribution of probability that a given component (feature, variable) is in a given state (group or the value class), preconditioned with the state of components (factors) represented by components related to them (BARTNIK et al. 2006).

Based on network topologies and the conditional probability distribution, in the work will be presented the modelling method of the farm which operates in sustainable agriculture, with a special emphasis on information that concerns the indicators of economic and agricultural performance according to the used doses of mineral and organic fertilization.

Data from the Main Statistical Office (2013) and International Statistics Yearbook (2015) which covers 45 world countries were used for the research. The analysis concerns 2010–2012.

Methodology

When searching for relations between the production intensity level, land efficiency and work performance, comparative analyses on international scale were carried out. The analysis covered the basic qualification criteria of sustainable agriculture, i.e. the level of mineral fertilization: nitrogen, phosphorus, potassium (NPK) and stocking density as well as productivity rates, i.e. land efficiency (WZ) and work performance (WP) and factors which shape them (gross national product in agriculture (PKBR), professionally active people in agriculture (LAR)).

For calculating indicators of performance of land and labour were used the following formulas:

$$W_P = \frac{\mathrm{PKB}_R}{L_{\mathrm{AR}}} \ [\mathrm{USD} \cdot \mathrm{man}^{-1}]$$

where:
W_P – work productivity [USD · man^{-1}],
PKB_R – gross national product in agriculture [USD],
L_{AR} – people professionally active in agriculture [man].

$$W_Z = \frac{\mathrm{PKB}_R}{Z_{\mathrm{UR}}} \ [\mathrm{USD} \cdot \mathrm{ha}^{-1}]$$

where:
W_Z – land productivity [USD · ha^{-1}],
PKB_R – gross national product in agriculture [USD],
Z_{UR} – area of agricultural land [ha].

A detailed methodology concerning productivity measures were presented also in the monograph „Scientific and technical progress in the process of modernization of Polish agriculture and rural areas” (GROTKIEWICZ et al. 2013).

Based on the collected figures of characteristics on economic and agricultural indicators, and subsequently accomplishing the objective of the project, the quantitative variables which were analyzed were then subjected to the data exploration by eliminating unusual data from the set of data, and then values have been grouped by using the method TwoStep Cluster Analysis.

Based on the undertaken statistical analysis and existing cause and effect relationship between quantitative variables the modelling process started using the Bayesian networks and also done an analysis of the conditional relationships between quantitative variables (economic and agricultural indicators), i.e. stocking density, NPK, WP, WZ, PKBR, LAR.

By taking into account the parametric models it was possible to obtain a posteriori probability distribution of single variable model or the cumulative distribution of conditional probabilities and thus find the most likely configuration variables, as well as to estimate the probability of the hypothesis, taking into account the specific observations.

GeNie program will be used for Bayesian analyses. This program serves for construction and testing of predictive models which base on various algorithms of Bayesian networks (JONGSAWAT i in. 2010). IBM SPSS Statistics 23 is the program which was used for analysis of basic descriptive analyses and TwoStep Clustering analysis.

Research results

Based on the review of the analysed data from 45 countries from around the world their average values were presented on maps. Data show both the stocking density and consumption of mineral fertilizers i.e. nitrogen, potassium and phosphorus.

Fig. 1. Stocking density in the worldwide countries [SD · ha^{-1} AL]

Fig. 2. Consumption of mineral nitrogen fertilizers in the world [kg · ha^{-1} AL]

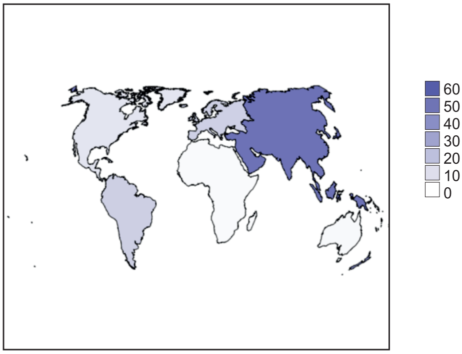

Fig. 3. Consumption of mineral phosphorus fertilizers around the world [kg · ha^{-1} AL]

Fig. 4. Consumption of mineral potassium fertilizer around the world [kg · ha^{-1} AL]

In case of European countries, which constitute the most numerous group of information in the analysed data, the situation is as presented on the European maps. Russia was excluded from analysis despite data for this country (which concern a summary region of Euroasia).

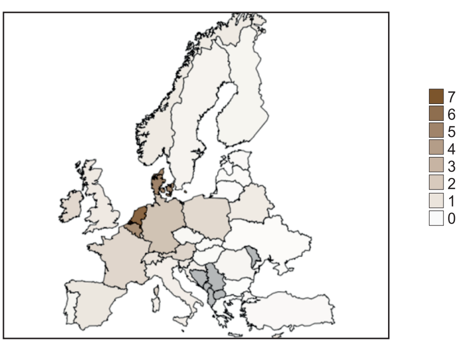

Fig. 5. Stocking density in the European countries [SD · ha^{-1} AL]

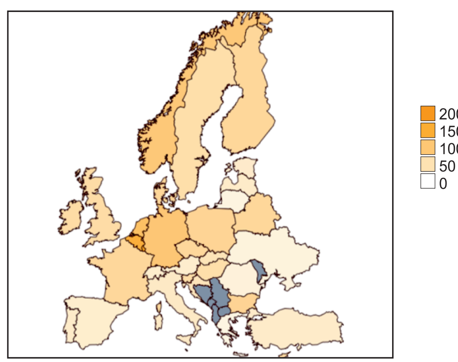

Fig. 6. Consumption of mineral nitrogen fertilizers in the European countries [kg · ha^{-1} AL]

Nitrogen is a basic crop factor. Based on the analyses from the Statistical Yearbook (2013) and International Statistics (2015) from among the analysed countries of the world the highest level of nitrogen fertilization occurs in the Republic of South Korea, Japan and China and their fertilization level per hectare of AL is respectively: 125.3 [kg · ha^{-1} AL], 96.4 [kg · ha^{-1} AL], 73.7 [kg · ha^{-1} AL]. On the other hand, the lowest demand of mineral nitrogen fertilization per one hectare of AL was reported in Australia (2.7), Republic

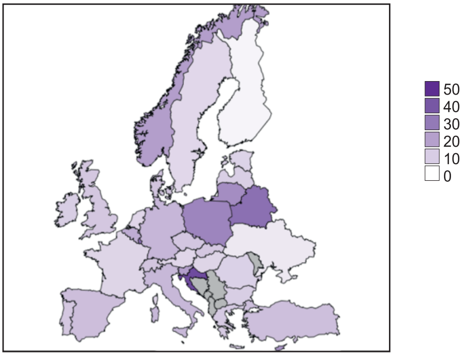

Fig. 7. Consumption of mineral phosphorus fertilizers in the European countries [kg · ha^{-1} AL]

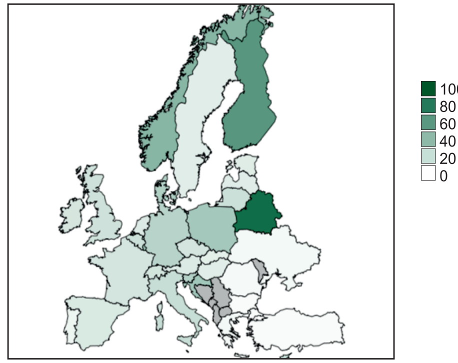

Fig. 8. Consumption of mineral potassium fertilizers in the European countries [kg · ha^{-1} AL]

of South Africa (4) and Russia (5.9). From among the European countries, countries located in the Western Europe prevail. They include: Luxembourg 165.7 [kg · ha^{-1} AL], Belgium 142.8 [kg · ha^{-1} AL] and the Netherlands 112 [kg · ha^{-1} AL]. The list of data concerning mineral nitrogen fertilization as well as remaining minerals prove high variability of the analysed countries of the World and Europe resulting from, inter alia, the area of agricultural land and the condition of soil as well as the number of people and economic reasons.

The essence of sustainable agriculture means not only the use of rational mineral fertilization but also stocking density which does not exceed 1.2 SD per one hectare of fodder surface area (MICHAŁEK et al. 2010). According to the Main Statistical Office (2013) from among 45 world countries the highest stocking density occurs in the countries with moderate climate, i.e. in the Netherlands 6.45 [SD · ha^{-1} AL], the Republic of South Korea 5.48 [SD · ha^{-1} AL] and Denmark 5.06 [SD · ha^{-1} AL], while we have a reverse situation in case of such countries as: Australia 0.07 [SD · ha^{-1} AL], Greece 0.83 [SD · ha^{-1} AL] and Bulgaria 0.12 [SD · ha^{-1} AL].

After the analysis was carried out on the data from economic and agricultural base from 45 countries of the World according to the assumed objective of this paper, the research with the use of Bayesian modelling algorithms was initiated. However, before formation of the network had begun, an exploratory review of available data including basic qualifying criteria of sustainable agriculture, i.e. the level of mineral fertilization NPK and stocking density as well as productivity rates, such as land efficiency and work performance was carried out. Necessity of carrying out the analysis of this type results from the process of data preparation for Bayesian modelling (MORZY 2007). The exploratory analysis is also justified by assumptions referring to data that may be used by Bayesian network.

Table 1

Descriptive statistics of the investigated quantity variables

Economic and agricultural indicators	*N*	Range	Minimum	Maximum	Average	Standard deviation	Skewness		Kurtosis	
	statistics	statistics	statistics	statistics	statistics	statistics	statistics	standard error	statistics	standard error
1	45	6.380	0.070	6.450	1.159	1.479	2.391	0.357	5.308	0.702
2	45	163.000	2.700	165.700	54.537	37.163	0.999	0.357	0.944	0.702
3	45	95.500	1.700	97.200	18.111	18.929	2.662	0.357	8.154	0.702
4	45	86.000	0.400	86.400	18.211	19.345	2.114	0.357	4.648	0.702
5	45	16.900	0.300	17.200	3.684	3.240	2.184	0.357	6.189	0.702
6	45	35.900	0.300	36.200	4.090	6.119	4.109	0.357	19.076	0.702
7	45	89.280	0.540	89.820	17.574	16.500	2.119	0.357	7.242	0.702
8	45	16,224.940	91.500	16,316.440	2,334.498	3,334.537	3.304	0.357	11.521	0.702

1 – Stocking density SD · ha AL^{-1}, 2 – Consumption of mineral nitrogen fertilizers, kg · ha AL^{-1}, 3 – Consumption of phosphorus mineral fertilizers, kg · ha AL^{-1} , 4 – Consumption of potassium mineral fertilizers, kg · ha AL^{-1}, 5 – gross national product in agriculture, %, 6 – professionally active people in agriculture, %, 7 – Work performance, thous PLN · mhr^{-1}, 8 – Land efficiency, thous PLN · LAR^{-1}

On the example of this analysis a uniformity of values distribution for the investigated properties was reported. Any of the variables does not have a regular distribution and the basic descriptive statistics for the investigated variables were set in Table 1.

Grouping values in the analysed variables

All analysed variables have values measured in the quantity scale. Nevertheless, Bayesian networks require properties with discreet values in the analysis. Discretization of constant values may be carried out arbitrary or analytically. Division into categories (discreet values) consists in grouping constant values and assigning to these groups values that represent them. Discreet values for variables were formed in a result of analysis which uses a two-step cluster technique (TwoStep Cluster Analysis). The advantage of this method in comparison to other grouping methods is an assumption of independence of variables which enables the analysis of variables with combined multi-normal distributions (PARK et al. 2006). For assessment of the number of clusters Schwarz's information criterion (BIC) was used. It enables adjustment of a model to data (RAFTERY 1999, GROTKIEWICZ et al. 2016). Values of Schwarz'z Bayesian criterion in case of all variables provided in the analysis indicate the best model which adjusts to data when values are divided into 3 clusters (groups). However, at such division grouping is not justified since clusters have a varied number. Majority of observations is only in one group (93.2%). Confirmation of these results was also obtained when the algorithm of hierarchical cluster analysis was used. On account of absence of natural clusters of values in data, which would serve as an element of representation of data group in the discretization process (categorization) of quantity variables, arbitrary division of values was applied for further analyses.

Due to absence of natural clusters of values in the analysed quantity variables constructed Bayesian networks will be based on discreet values which are formed from the conversion of constant values of the investigated quantity variables. Quality variables (categorial) will be formed as a result of division. New variables which have discreet values result from the application of arbitrary determined criteria of division in comparison to quantity variables. Each of quantity variables was divided into several value ranges. Arbitrary determined value ranges, which describe cluster (groups) with their borders, do not have a balanced number. It will of course affect distribution of initial probabilities in Bayesian network nodes but it will not influence the occurrence of relations and the power of relations between the network nodes.

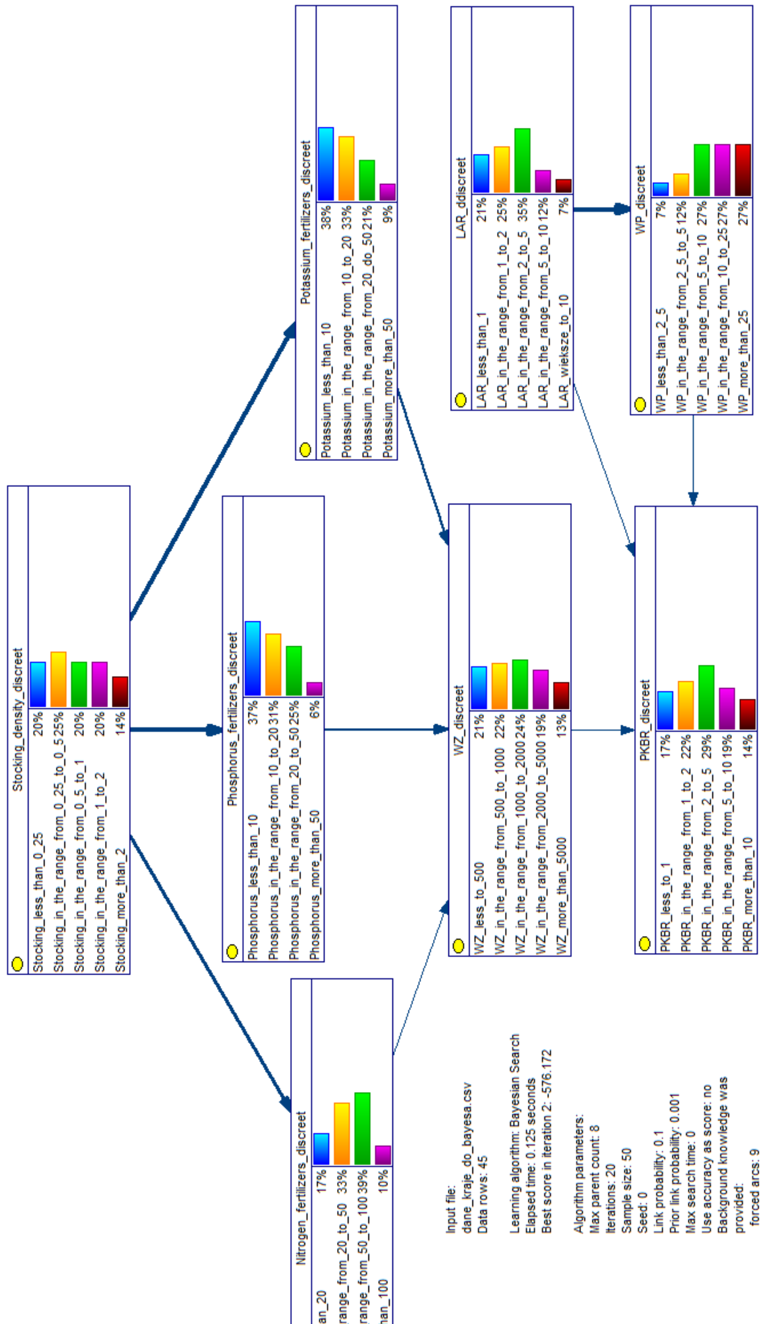

Fig. 9. Distribution of conditional probabilities for agri-economic indicators

Basing on the knowledge and experience some relations between particular indicators are already known. Before construction of network, which uses discretized variables (Stocking_density_discreet, Nitrogen_fertilizers_discreet, Potassium_fertilizers_discreet, Phosphorus_fertilizers_discreet, PKBR_discreet, LAR_discreet, WP_discreet and WZ_discreet), was initiated, it was decided to check whether there are any correlations between them. Person's correlation proved significant relations between professionally active people in agriculture and the gross national product in agriculture and work performance. Moreover, a relation between stocking density and consumption of mineral fertilizers (for all groups of fertilizers, although correlation is significant at various levels) is noticeable. Stocking density and fertilization have a significant impact on shaping the values of the indicator that describes land efficiency. The knowledge resulting from the correlation which was carried out and based on the developed methodology (GROTKIEWICZ et al. 2013, GROTKIEWICZ, KOWALCZYK 2015) was used during construction of Bayesian network as well as at the construction of bindings between nodes.

Based on the data exploration and arbitrary determined value criteria, based on the discreet values, finally for further analyses the network takes the form which was presented on the Figure 9. This network presents the system of relations between the investigated properties (discretized agri-economic indicators) and power of relations between these properties which represent basic qualification criteria of sustainable agriculture in the world agriculture. Probability of occurrence of values in a particular cluster of variables values (continuous) and its percentage value were presented in the nodes of the network in the form of a bar chart. In the description of the network, also algorithm parameters for which network was searched, are provided (Bayesian Search).

Then, analysis of conditional probabilities was carried out in secondary nodes for the obtained network. These analyses may be carried out straight on the Bayesian network diagram basing on the possibility of checking conditional probabilities on condition that a specific event will take place.

For example, if we assume that the value of the discretized variable *Stocking_density_discreet* takes the second value, it means then that stocking density belongs to the second range of values (from 0.25 to 0.50 [SD · ha^{-1} AL]). At such assumption, probability of such occurrence is 100% (for the node *Stocking_density_discreet*), but in the secondary nodes which depend on this node, probabilities of particular events will also change. Distribution of conditional probabilities of particular values occurrence in the network nodes is the same as on Figure 10.

Occurrence of the above described event results in the probability change only in the node networks which depend on the node *Stocking_density_discreet*

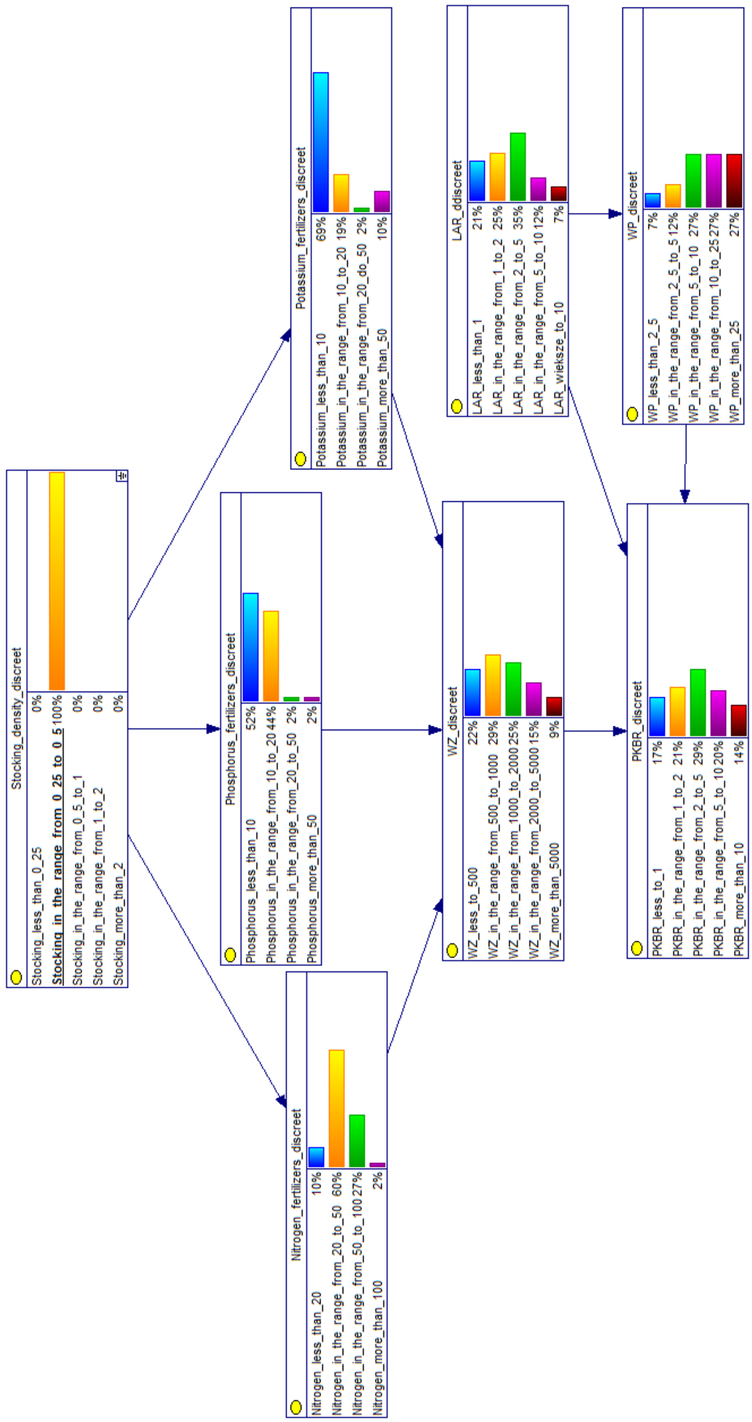

Fig. 10. Distribution of conditional probabilities for variables if the event Stocking_density_discreet takes place, belongs to the second cluster

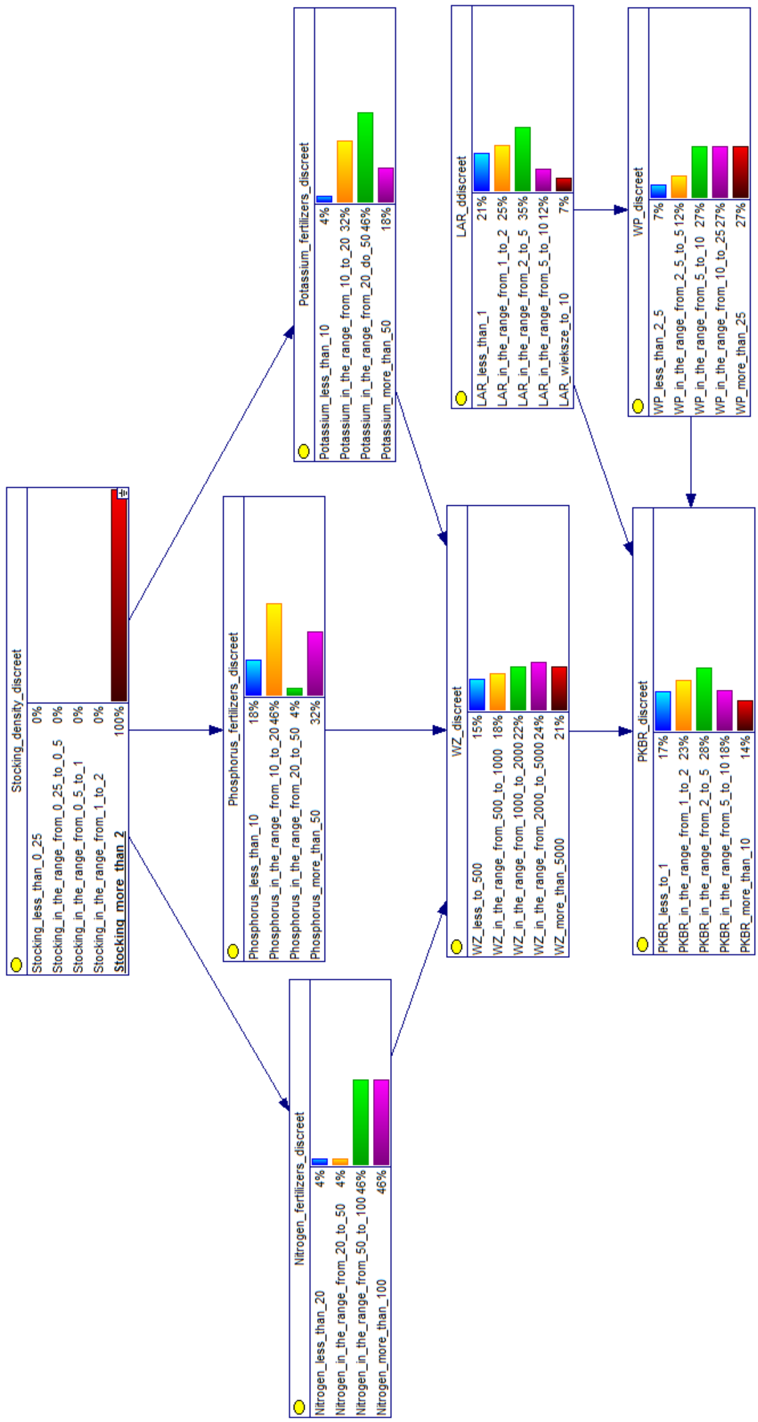

Fig. 11. Distribution of conditional probabilities for variables if the event Stocking_density_discreet takes place, belongs to the fifth cluster

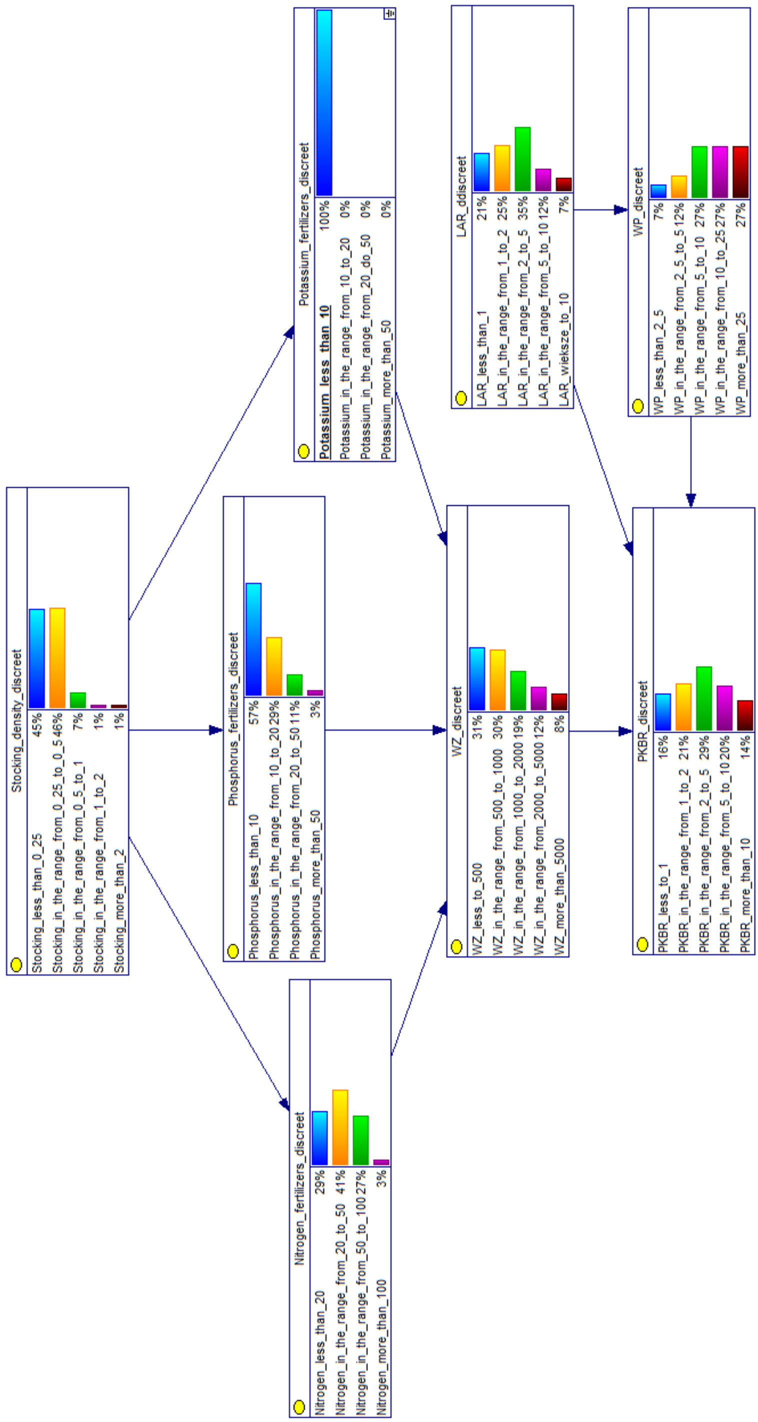

Fig. 12. Distribution of conditional probabilities of variables if the event Potassium_fertilizers_discreet takes place, belongs to the first cluster

in particular, the consumption of mineral nitrogen fertilizers. For example probability values in the nodes *LAR_discreet* and *WP_discreet* do not change. And thus, an increase of probability (from 38% to 69%) of occurrence of an event that the value of the node *Potassium_fertilizers_discreet* takes the first discreet value is reported (i.e. consumption of potassium fertilizers will be lower than 10 [$kg \cdot ha^{-1}$ AL]). In the same node *Potassium_fertilizers_discreet* probability decreases (from 21% to 2%) of the third value occurrence, namely, chances that consumption of potassium fertilizers consumption takes the value from the range from 20 [$kg \cdot ha^{-1}$ AL] to 50 [$kg \cdot ha^{-1}$ AL] fall down. At the same time it is noticed that probability changes for particular values of variables *WZ_discreet* and further *PKBR_discreet* but these changes are not as characteristic as for the node which describes a discreet level of mineral fertilization.

Another example of the change of probability in nodes takes place in case of an event that *Stocking_density_discreet* assumes the last value, which means that stocking density is higher than 2 [$SD \cdot ha^{-1}$ AL]. The following diagram presents distribution of probability in dependent nodes at such event (Fig. 11).

Moving on to this probability level for the node *Stocking_density_discreet* results in a noticeable change in the probability distribution for particular ranges of land efficiency (WZ_discreet) except for changes in the nodes which represent fertilization. This situation also influences, although to a smaller extent, the distribution of the value for the gross national product in agriculture (PKBR_discreet).

The analyses which were carried out with the use of Bayesian networks enable some conclusions. They concern mutual and significant relations of indicators which describe data referring to farms in the analysed countries of the World and Europe. A schematic representation (Fig. 12) which presents the change of probability distribution in the node which refers to the land efficiency indicator (WZ_discreet) in a situation when the level of mineral (potassium) fertilization is lower than 10 [$kg \cdot ha^{-1}$ AL], can serve as an example.

Conclusion

The analyses and economic experiments which were carried out prove that agriculture of EU and the world countries is considerably varied. The land efficiency indicator is mainly the rate which differentiates the analysed countries and at the same time decides on the competitiveness of agriculture. It depends on many factors, among which the most important are: soil quality, climatic conditions, fertilization, plant protection, timeliness of agri-technical treatments, level of inputs, production trend, selection of varieties. Based on the agri-economic analyses on account of the sustainable agriculture, networks were built based on the previous experiments which simultaneously reflect relations between the analysed variables (Fig. 9). Change of probabilities of the analysed variables in comparison to conditional probabilities proves mutual and significant relations of agri-economic indicators which describe the investigated World and European countries and in particular it proves sensitivity of some indicators, when others assume particular values.

On the basis of the completed studies, it could be stated that the appropriate tool which supports decisions under uncertainty, is the properly constructed Bayesian network, which enabling decision-making processes by taking into account information of various nature.

Using the tools of the theory of probability in accordance with the Bayesian law, creates a possibility to build a model of the farm, which is part of the strategies of the EU, whose main objective is to improve the competitiveness of agriculture, sustainable management of natural resources and climate action, and balanced territorial development of rural areas.

Additionally, capabilities of acquiring knowledge from the database of economic by using the new technology will enable the modification of such a model according to preferences and experts' ratings under uncertainty.

In summary, based on the knowledge obtained from the analyses, the analysed algorithm of Bayesian modelling could be used in further research and on other objects in direct practice for developing an optimal model of a farm located in a well-organized technical and economic and informative infrastructure which mainly meets the conditions of sustainable agriculture.

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