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EXPERIENCE WITH FERTILIZER EXPERT SYSTEMS FOR BALANCED FERTILIZER RECOMMENDATIONS

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ABSTRACT: To evaluate soil fertility and to calculate fertilizer recommendations for different soil types and crop rotations, two expert systems were developed and are being used in Belgium and the Northern part of France. The BEMEX expert system (BEMEX, coming from BEMEstingsEXpertsysteem, Dutch for fertilization expert system) calculates field specific fertilizer recommendations for macronutrients and liming recommendations for crop rotations with arable crops and vegetable crops and for grasslands. The N-INDEX method is a field specific advice-system for N-fertilizer recommendation for most arable and vegetable crops. The knowledge base of BEMEX as well as of N-INDEX contains empirical and theoretical knowledge. The required information to run the expert systems consists of measurements of the chemical soil fertility on soil samples on the one hand and of information concerning the parcel and the crop on the other hand. The final output of the expert system is a two-to-five page bulletin, with the results of soil analysis and the fertilizer and liming recommendations. This bulletin is sent to the farmer. Additionally, an impressive database with soil fertility data is gathered annually. As a consequence presentation models such as choroplets, pie charts, etc. are useful tools to describe soil fertility on the basis of numerous soil analyses. Both the personalized advice bulletins and the general presentation models are the interface between the expert and the user of the expert system, which is commonly the farmer himself or extension staff members.

BEMEX and N-INDEX are useful tools for operational decision support on the subject of liming and fertilization.

INTRODUCTION

Automation is becoming more and more part of modern agriculture. To ensure production, to optimize productivity, and to promote quality it is desirable to adjust fertilization rate to field (parcel) and crop specific conditions. A good decision-making program could avoid miscalculations resulting in negative economic and ecological effects. For liming and fertilization recommendations two decision support systems, "BEMEX" and "N-INDEX" were developed and are successfully used.

BEMEX

Investigation of soil fertility levels for optimal economic benefits was started in Belgium in 1937 by Prof. J. Baeyens at the University of Leuven. Thousands of pot experiments and field trials are laid out and followed up to evaluate soil fertility and to adjust fertilizer and liming recommendations to soil fertility level. These empirical results are part of the knowledge base of the fertilization expert system BEMEX (1).

N-INDEX

An appropriate N-fertilization is faced with the challenge of a high economic return (high yield and high quality), low environmental hazards of residual N to the groundwater, and for some crops, a low nitrate content with regard to animal and human health. Preliminary field experiments showed a significant correlation between mineral N content (N-min) in the soil before the start of the vegetation period and the optimum N fertilization for agricultural crops (2, 3, 4). However, it appeared that the correlation between N-min and the optimum N fertilization rate was frequently insufficient for N-fertilization recommendation purposes. Fertilization experiments showed that the reliability of the former correlation could be greatly improved by taking into account a number of factors to determine the availability of

N during the growing season (humus content, pH, organic matter application, etc.). This empirical research resulted in 1980 in N-INDEX. Up to the present refinements are made according current experience (5).

EXPERT SYSTEMS

Decision support tools normally involve interactive inclusion of both objective data as well as subjective knowledge (expert) rules. The derivation of expert rules requires the structuring and intelligent use of accumulated information (6). Based on the classification of Jones (7), three types of expert systems used for decision support can be distinguished. First, *heuristic expert systems* based on the heuristic knowledge of an expert. Secondly, *model-based expert systems* that link simulation models and expert systems to facilitate the use of proven models through expert system parameterization and/or interpretation of results. Thirdly, *expert databases* that link databases and expert systems to facilitate the search for the most relevant information. The fertilization expert systems BEMEX and N-INDEX are a combination of the three types described by Jones (7). BEMEX and N-INDEX contain expert rules, simple simulation models (i.e., nitrate leaching), and expert databases (i.e., mineralization of organic manure).

Figure 1 gives a general structure of the fertilization expert systems consisting of input, knowledge base, and user interface. Necessary input is gathered from soil analysis and from an information form with specific information about the parcel and the crop. The information feeds the decision tree which is based on knowledge and reasons with this actual information. This is the knowledge base. The final output of the expert system is doublefold. First, a personalized advice bulletin which is send to the farmer. Secondly, a database with soil fertility data which can be used by the members of the extension staff.

Knowledge Base

Both expert systems have their own knowledge base which contains expertise coming from long- and short-term field trials. This expertise is integrated in

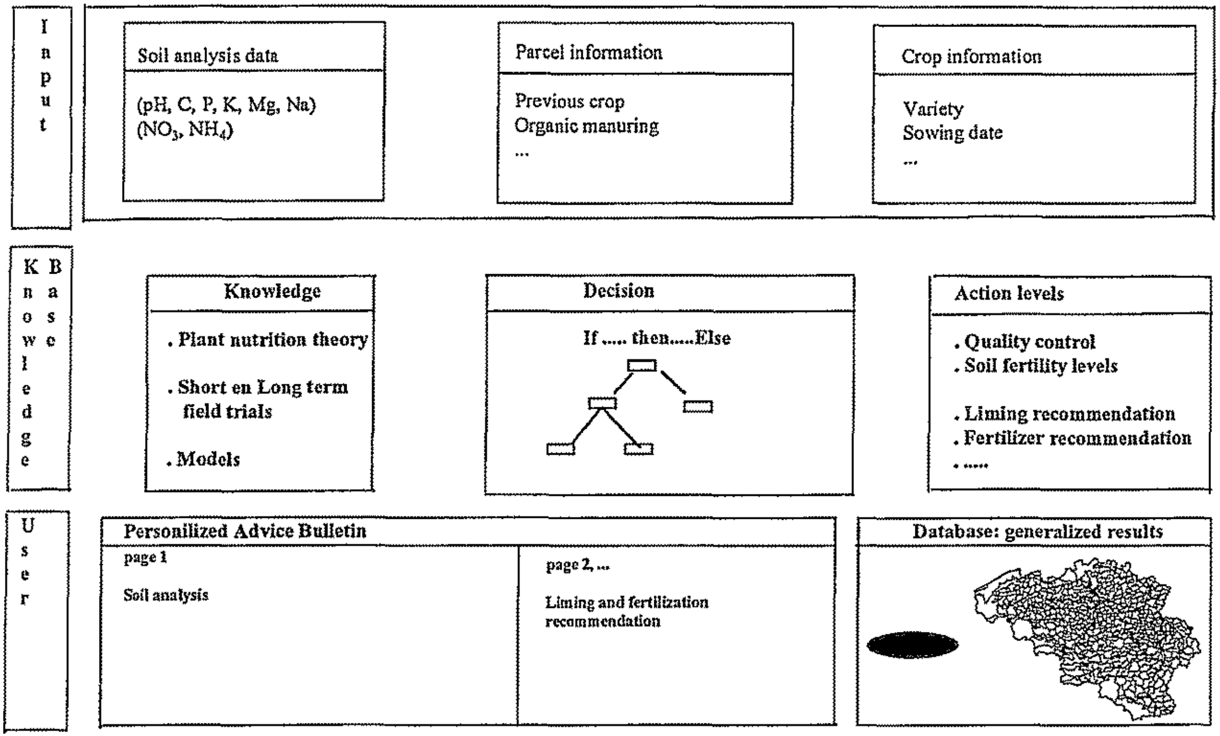

FIGURE 1 : Outline of the fertilization expert system BEMEX and N-INDEX

response and surplus functions. Response functions investigate the yield responses to fertilizer application. This results in the optimal rate of fertilizer application to a crop to achieve maximum economic returns, which is the first goal of the expert systems. The second goal is to guarantee long-term optimal soil fertility conditions. This is especially the case for soil pH, plant available phosphorus, potassium, magnesium, and calcium and for a good equilibrium between those available nutrients. The first and the latter goals include avoidance of unnecessary high residues of nutrients not used by the crop. Therefore the empirical surplus functions are part of the knowledge base to evaluate soil fertility to fertilizer applications.

How these fertilization expert systems work is best explained using the N-INDEX. The knowledge base is built like a decision tree. Most decisions are taken on the basis of "if...then...else" rules. Real parcel data are necessary input for the tree, the expertise is used to make the decision, and the output is the N-INDEX-value. N-INDEX is a calculated measure of available mineral N for a specific crop on a well determined field (5). Nitrogen-index is the sum of a maximum of 18 factors, some of which may be zero for some crops or situations:

$$\textbf{N-index} = \mathbf{x_1 + x_2 + ... + x_{18}} \qquad [1]$$

These factors may be divided in three groups:

- Factors which are determined by the amount of mineral N in the soil available for the crop and the amount of N, already taken up by the crop at the time the samples are taken. The amount of available mineral N in the soil is measured (see input).
- Factors determining the mineral N which will be supplied by the soil. The mineralization process is assessed by the summation of several subprocesses which will contribute to the total mineralization. Each subprocess is treated as a factor in the calculation of N-INDEX (5).
- The last factors taken into account are losses, e.g. leaching, volatilization, denitrification, and run off, resulting in a diminished availability of mineral N.

Based on this N-INDEX a N-fertilizer recommendation is calculated which is generally formulated as:

$$\textbf{N-recommendation} = \textbf{A} - \textbf{b} \times \textbf{N-INDEX} \qquad [2]$$

The value of A and b for each arable crop are derived from field experiments. For some crops also an advice for split application of nitrogen may be given.

An example of an if...then...else decision tree is given in Figure 2 for the factor counting for the mineral nitrogen which will be delivered from applied animal manure x_{15}. From the information form, the system knows if there is a yes or no application of animal manure. If no, the factor x_{15} is zero and doesn't count in N-INDEX. If yes, the system wants to know which kind of animal manure is used, when is it applied, and in what quantity. With this information the knowledge base calculates the value of x_{15} which will of course be greater than zero.

Besides the evaluation of soil fertility and the calculation of fertilizer rates, the knowledge base has an important function in the quality control of the input data (given later).

Input

Concerning the input necessary to run the expert system, three parts may be distinguished:

- Soil analysis data which deliver the status of the soil fertility of the parcel.
- Parcel information to evaluate the nutrient dynamic in the soil
- Information about the crop for which fertilizer recommendation is wanted.

Soil fertility. For BEMEX soil samples are taken down to a depth of 23 cm for arable land and 6 cm for grassland and are analyzed for pH, carbon content, and levels of phosphorus, potassium, magnesium, calcium, and sodium. Besides the value of soil fertility factors, the ratio of these values is also a very important element in evaluating the adjusted recommendation. To run BEMEX, soil sampling is necessary every four years, preferably at the start of the crop rotation.

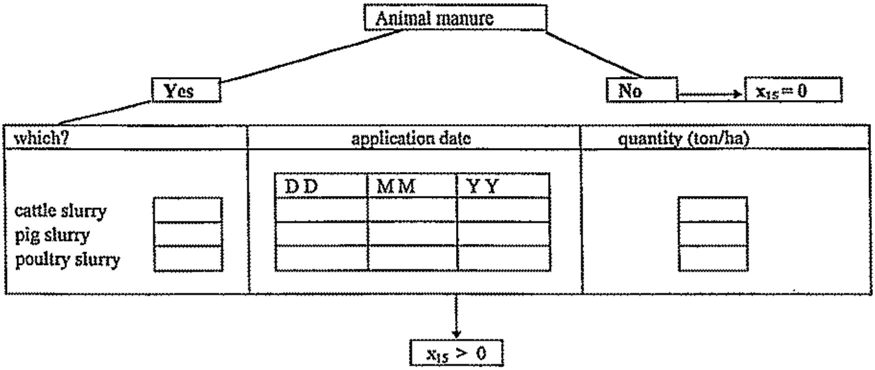

FIGURE 2 : Decision tree for factor x_{15} of N-INDEX

For N-INDEX, the soil is sampled with a steel gouge auger to a depth of 90 cm for most agricultural crops and to 60 cm for potatoes and most vegetables. In contrast to BEMEX, which requires one soil sample at the start of the crop rotation, N-INDEX requires a soil sample for every crop and to greater depths. In the laboratory, each soil layer of 30 cm is analyzed separately for nitrate and ammonium. Carbon content and pH are measured in the topsoil.

Parcel information. Every soil sample is accompanied with an information form concerning the necessary field and crop technical information. The delegate of the Soil Service who has taken the soil samples completes this form in conjunction with the farmer. Examples of questions on this form are: "did you apply organic manure ? If yes, type, quantity, and application date" (Fig.2). "Is there green manure on the field, if yes type development and what will be done with the green manure?" "Simply ploughed, or cut, or grazed".

Crop information. Significant information is type of the crop and, depending on the crop, variety, sowing data, sowing density, application of a growth regulator, harvest date, etc. All these questions and measurements supply the required information to the knowledge base to calculate N-INDEX.

The measured soil fertility data and the parcel and crop information data are subjected to quality control. The soil fertility data are checked with the aid of reference samples running together in the laboratory chain with the real samples. The knowledge base contains heuristic rules to accept or reject the soil fertility data. In the latter case, BEMEX or N-INDEX refuses to calculate the fertilizer recommendation. Instead the expert systems automatically make a list of soil samples for re-analysis. Parcel and crop information are independently imported into the system. If a discrepancy is established in the information, this must be checked before the systems continue the calculation for those parcels.

User Interface

In general there are several possibilities to communicate with the user (user interface), such as: 1) personalized letters, 2) computerized systems, 3) telematic systems, and 4) generalized results. BEMEX and N-INDEX communicate in the first place by the use of personalized, field specific fertilizer recommendations. Secondly, generalized results are derived from the unique dataset with soil fertility data (BEMEX) and mineral nitrogen reserves in the soil layers (N-INDEX). The latter are very useful in training and advising individual farmers and extension agents. Some examples of generalized results are described by Geypens et al. (5), Vandendriessche et al. (8,9) for N-INDEX, Hendrickx et al. (10), and Vandendriessche et al. (11) for BEMEX.

Currently, the use of personalized advice bulletins is still a benefit. Farmers only have to read the bulletin and do not need a microcomputer. Nevertheless, the interest in telematic and computerized user interfaces is increasing (12).

Included in an appendix is a summary of a personalized advice bulletin generated with BEMEX for a pasture. The first part contains the soil analysis results. The second part contains the lime and fertilizer advice for the three years following soil sampling. The advice is given for "only grazing" and "first cutting followed by grazing", respectively. From the crop information (input) the knowledge base knows to calculate this type of advice. The third part of the advice bulletin contains specific and general remarks.

The reasons for success of these fertilization expert systems may be that they give advice which is right to the point, precise, easy to understand, and quick. From the arrival of the soil samples at the laboratory until a ready to send personalized bulletin, takes 10 days for N-INDEX and at maximum three weeks for BEMEX.

CONCLUSIONS

The fertilization decision support systems, BEMEX and N-INDEX, consist of a combination of data processing and knowledge rules. They are successful examples of expert systems within one aspect of farming, namely operational decision-making concerning the optimal fertilizer and lime rate. High attention is paid to follow-up, quality control, and easy-to-understand, personalized advice.

ACKNOWLEDGMENT

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APPENDIX

Example of a personalized advice bulletin as generated with BEMEX. The consecutive pages of the bulletin are overlaid for this figure

SOIL ANALYSIS RESULTS:

Parameter	Result	Target zone	
Soil type	35	-	Light loam
pH-KCl	5.7	5.5 - 5.8	Favourable
C (%)	6.0	2.6 - 4.2	Rather high
P (mg/100 g)	32	23 - 31	Rather high
K (mg/100 g)	45	14 - 25	High
Mg (mg/100 g)	29	20 - 31	Normal
Ca (mg/100 g)	215	219 - 489	Rather low
Na (mg/100 g)	3.7	4.8 - 7.4	Rather low Too low compared to K

FERTILIZER RECOMMENDATION: (kg/ha)

	FIRST YEAR : only grazing	first cutting, then grazing
Lime	0	0.
	SECOND YEAR : only grazing	**first cutting, then grazing**
Lime	0	0.
Nitrogen	80 kg N in spring and 40 kg N every 3 weeks until the end of August	80 kg N in spring and 40 kg N every 3 weeks until the end of August
P	35 kg P_2O_5	65 kg P_2O_5
	THIRD YEAR : only grazing	**first cutting, then grazing**
Lime	0	0
Nitrogen	80 kg N in spring and 40 kg N every 3 weeks until the end of August	80 kg N in spring and 40 kg N every 3 weeks until the end of August
P	35 kg P_2O_5	65 kg P_2O_5
K	0 kg K_2O in spring and 20 kg in June-July	80 kg K_2O in spring and 40 kg after cutting
Mg	40 kg MgO	50 kg MgO
Na	60 kg Na_2O	60 kg Na_2O

SPECIFIC REMARKS

During the growing season, adjust the N recommendation to the growth stage. In dry climatic conditions and on soils, susceptible to dehydration, reduce the recommended N fertilization. So nitrate accumulation in grass and soil is prevented and the risk of reduced growth, because of a too high salt concentration, is decreased.

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