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AN EXPERT SYSTEM TO PREDICT CLIMATE CHANGE INDUCED SALINIZATION PROCESSES IN SALT-AFFECTED SOILS

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A b s t r a c t. Changes in climate will alter natural processes in the environment, and it is expected that one consequence will be that salinization processes in salt-affected soils will be modified. An expert system, called SALINEXP, was developed to assist the prediction of climate change induced salinization processes in salt-affected soils. The paper discusses the considerations used in the construction of the knowledge base, the state and objective variables, and the rules and decision making processes of the system. Results of a scenario analysis are also discussed when the system is applied to the Middle-Tisza Region of Hungary.

K e y w o r d s: expert system, soil salinity, climate change

INTRODUCTION

There is growing concern about the possible effects of climate change on the environment and the economy, it being more and more accepted that global warming will result, for Europe as a whole, in a mean rise in temperature of about 3 °C over the next 50 to 100 years. In addition, precipitation is expected to increase by about 10 per cent, although the seasonal and spatial distribution are expected to change in ways that are currently little known, and extremely difficult to predict. Winter will probably become wetter, and summer drier, although the severity of summer convection rainfall (thunderstorms, etc.) might increase.

One of the principle tasks of the Hungarian contribution to the ACCESS project was to develop an expert system program to predict salinity processes in salt-affected soils caused by possible climate change. The paper first briefly reviews research activities concerning salt-affected soils in Hungary, then discusses the construction of the knowledge base for the expert system, the state and objective variables used, and the rules and decision making processes of the system. Results of a scenario analysis are also discussed when the system is applied to the Middle-Tisza Region of Hungary.

SALT-AFFECTED SOIL RESEARCH IN HUNGARY

In Hungary, more than 1 mln ha of soils are salt-affected. The 10% ratio of salt-affected soils in Hungary is the highest in Europe [30]. This is why the effect of soil salt content on plant production had already been discussed in the paper by Teschedik [33]. Following this, Irinyi [17] discussed soda formation and relationships between this and the effect of salts on soil properties, as well as the amelioration of salt-affected soils. Since the second half of the last century papers have been published about the type, behaviour, characteristics, formation, extension and areal distribution of salt-affected soils and landscapes in Hungary [19,26,29,34,36]. In a recent review Darab [7] evaluated the historical development of world-wide research history of salt-affected soils. The Hungarian contribution to that development is also included. We focused our attention on the Hungarian contribution to the following: 'Sigmond [27] found that salt-affected soils contain high amount of exchangeable Na. Utilizing the illuviation theory of Gedroitz, he developed a classification system for salt-affected soils and presented it to the First International Congress of Soil Science, and developed it further [27,28]. The international consequence of 'Sigmond's work can be illustrated by the Riverside salt classification system. Even the later Hungarian classification work on salt-affected soils [3,31] were based on 'Sigmond's results, and were completed using the results of later surveys of a particular district in Hungary [32]. 'Sigmond's work also stimulated research regarding chemical and colloid-chemical properties [14], and soil formation processes of salt-affected soils [2,18].

Since the early 1950's, the amelioration and utilization of salt-affected soils has received more attention. The soil formation processes of the Trans-Tisza Region were elaborated by Szabolcs and Jassó [32]. The salt accumulation processes of the Danube Valley were studied by Várallyay, [38], whilst the application of different amelioration techniques are illustrated by the publications of Arany [3], Herke and Harmati [16], Prettenhoffer [21], Ábrahám and Bocskai [1]. The control of amelioration and irrigation has been based on measurements and calculation of the salt- and ion-balance of soils [7,9,31]. A part of this task was to determine the critical depth of saline ground-water. One of the results of this research period was the delineation of the area in Hungary where the danger of salinization exists due to the rise of ground-water above this critical level. The process is called 'secondary salinization' [31].

In the last 20 years research on salt-affected soils in Hungary has had two main branches. The first was a more practical approach dealing with amelioration and utilization of salt-affected soils and landscapes, coordinated by the Research Institute of the Debrecen Agricultural University in Karcag (e.g., Nyiri and Fehér, [20]; Blaskó, [5]). The other approach dealt with the physico-chemistry of the liquid phase of salt-affected soils and the mapping of salt-affected landscapes belonging to National Parks and Nature Reserves.

The research on physico-chemistry of the soil solution is illustrated by the papers of Rédly and Darab [24], Darab *et al.* [8,11] and Csillag *et al.* [6], whilst that related to increasing the effectiveness of chemical amendments of salt-affected soils is demonstrated by the papers of Darab and Rédly [10], Rédly and Darab [24], and Darab *et al.* [12]. The survey of salt-affected soils was made between 1978 and 1984 in the Kiskunság National Park at 1:25 000 scale by the staff of the Institute for Soil Science and Agricultural Chemistry of Hungarian Academy of Science, Budapest. In this mapping work not only soil types were identified, but also the characteristic plant communities of the soils [38], as well as the soil-plant correlations of different sites [23]. In addition, the spatial pattern of the soils and vegetation of salt-affected grassland in Hortobágy has been studied [22,25].

The above brief review highlights that there are deep historical roots to the knowledge of salt-affected soils, which could be utilized for building an expert system to predict the likely consequences of climate change on the extent and productivity of salt-affected soils in Hungary. Such a system would be the first attempted of this kind, and would serve as a fundamental reference point for the extension of this work to salt-affected soils elsewhere in the world.

EXPERT SYSTEM APPROACH

Expert systems are 'computer programs that have built into them the knowledge and capacity that will allow them to operate at an expert's level'[15]. As pointed out by Denning [13] these programs are designed to simulate the problem-solving behavior of humans who are experts in a specialized area. Expert systems differ from conventional computer programs since knowledge, which is usually represented in the form of rules in the expert system, is treated separately from the problem-solving mechanism (called the inference engine). Because of their non-algorithmic, modular structure, expert systems are also much easier to develop, maintain, or modify. The rules in an expert system are text representations of knowledge, and are structured in the form of conditional 'If-Then' logical decisions. The rules allow a program to arrive at its conclusion (decision) when the inference procedure executes (fires) them. The inference procedure can be of the backward- or forward-chaining type. In backward-chaining, the inference engine automatically checks all rules to see if there is one that could provide the required information. By contrast, forward-chaining can only be used as a method for testing rules that are not goal driven. Rules in this case are simply tested in the order in which they were implemented. Detailed discussions of expert systems and artificial intelligence are given by Barr et al. [4] and Shapiro [25], among others. Four major tasks had to be carried out in the development of an expert system to predict the probable consequences induced by climate change on the extent and productivity of salt-affected soils:

- First, determine those parameters which largely describe the salinity/alkalinity status of a soil;
- Second, identify those parameters which characterize climate change scenarios;
- Third, establish a knowledge-base and relevant rule base;
- Fourth, write the actual program.

Variables

Based on several decades of research experience, five state variable groups were distinguished for the system in order to characterize the initial state of the salt-affected soil.

Group A. Soil characteristics: soil type, soil sub-type, depth of the maximum value of the exchangeable Na%, cation exchange capacity, texture, organic matter content, bulk density, hydraulic conductivity of the B horizon, maximum value of the exchangeable Na% of the B horizon, total salt content, depth of the maximum value of the salt content, pH of the B horizon, critical ground water depth, total porosity, field capacity water content, wilting point water content.

Group B. Ground water parameters: average depth, annual fluctuation, total salt content, Na content (%), sodium adsorption ratio, pH.

Group C. Initial climate characteristics: seasonal average air temperature, seasonal average potential evapotranspiration, and seasonal average precipitation.

Group D. Plant characteristics: type of plant grown, and average expected yield.

Group E. Irrigation water parameter: annual average amount of water added.

Three soil types were considered in the system: meadow solonetz, meadow soil and meadow chernozem, while four soil sub-types were identified: medium, deep, steppe, solonetz-like and deep-salt. The characteristic soil textures considered were sand, loamy sand, sandy loam, loam, clay loam, loamy clay and clay. The plant types considered in the system were: wheat, maize, sunflower, sugar-beet, oilseed rape and soybean.

In SALINEXP, climate change is characterized by four parameters: (a) change in seasonal average air temperature; (b) change in seasonal average potential evapotranspiration; (c) change in seasonal average precipitation, and (d) change in average ground water depth.

From the initial state parameters, SALINEXP predicts the new salinity/alkalinity state, which is represented by five objective variables: (i) change of the amount of exchangeable Na%, (ii) change in depth of the maximum value of the exchangeable Na%, (iii) change in the total amount of salt at the salt accumulation level, (iv) change in depth of total salt content, and (v) change in average expected yield.

Considerations in the system

Several assumptions are made when the prediction is evaluated:

a) The maximum depth of the pedon (soil profile) is 1.5 m or down to permanent ground water level if this is shallower than 1.5 m.

b) A pedon consists of layers, and each layer is regarded homogeneous. It is assumed that a larger region can be characterized by horizontally homogeneous, vertically layered soil profiles or, in other words, by pedons.

c) The change in salinity/alkalinity of a soil and the probability that these changes are dependent only on climate change phenomena. No salinization/alkalinization is considered in the program due to the effect of irrigation water; this means that no secondary salinization was taken into account.

d) The long-term effect of soil cultivation is also not considered in the program. It is assumed that all parameters characterizing the soil layers are characteristic of naturally settled layers. Artificial compaction is not considered.

e) It is also assumed that the new climate situation will effect the soil for at least 15 years continuously, and that the given scenario parameters represent an average value for the entire period.

Rules of the knowledge base

As part of knowledge base, the characteristic range of dominant parameters were compiled for Middle-Tisza Region soils which are subject to salinization. Table 1 summarizes the results for meadow solonetz, meadow soil and meadow chernozem. Other soil types were not considered, because either those were not characteristic of the region investigated or not considered to be salt affected soils.

A multi-dimensional decision space was established showing the direction of the changes in the state variables, should a climate change scenario occur. Table 2 shows the results of verbal predictions that the expert team agreed on. The verbal evaluation of the direction of the changes representing the objective variables are as follows:

Scenario 1. This case is the theoretical initial condition and absolutely no change would occur. The result is: no change will occur in salinity/alkalinity level; the risk will not change.

Scenario 2. Only the ground water level will increase; no change in climate parameters. The expected direction of changes: the salinity/alkalinity level will increase in the soil profile; cropping potential deteriorates.

Scenario 3. Only the ground water level will decrease; no change in climate parameters. The expected direction of changes: the salinity/alkalinity level will decrease in the soil profile; cropping potential improves.

Scenario 4. Average air temperature and potential evapotranspiration will increase, precipitation will decrease, no change in ground water level. The expected result: the salinity/alkalinity level will increase slightly; cropping potential deteriorates.

Scenario 5. Average air temperature and potential evapotranspiration will increase, precipitation will decrease, but the decrease will be compensated by irrigation; no change in ground-water level. The expected result: the salinity/alkalinity level will not change; cropping potential improves, and the expected yield will be higher.

Scenario 6. Average air temperature and potential evapotranspiration will increase, precipitation will decrease, but the decrease will be compensated by irrigation. The ground water level will increase. The expected result: the salinity/alkalinity level will increase; cropping potential deteriorates, and the expected yield will be lower.

Scenario 7. The average air temperature and the potential evapotranspiration will increase, the precipitation and ground water level will not change. The expected result: the salinity/alkalinity level will not change, but the plant growing potential will decrease; cropping potential deteriorates, and the expected yield will be lower.

Scenario 8. Average air temperature and potential evapotranspiration will increase, precipitation does not change. The ground water level will decrease. The expected result: the salinity/alkalinity level will decrease, but less intensively than in *Scenario 3*; cropping potential will not change.

Table 1. Characteristic range of dominant parameters of Middle-Tisza Region soils subject to salinization

A.1	Soil type, verbal	Meadow solonetz	Meadow solonetz	Meadow solonetz	Meadow soil	Meadow chernozem
A.2	Soil subtype, verbal	Medium	Deep	Steppe	Solonetz-like	Deep salt
A.3	Depth of max. exch. Na% in H hor, cm	10-30	15-40	30-60	30-40	80-120
A.4	Cation exchange capacity, mg eq/100	20-40	20-40	20-40	25-40	20-30
A.5	Texture, verbal	Clay loam	Clay loam	Clay loam	Loamy clay	Loam
A.6	Organic matter content, %	1.5-2.0	1.5-2.0	1.5-3.0	2-4	2.5-5.0
A.7	Bulk density, g/cm^3	1.4-1.6	1.4-1.6	1.4-1.6	1.3-1.45	1.3-1.45
A.8	Hydraulic conductivity, cm/d	<0.01	<0.1	<1.0	<1.0	1-10
A.9	Max. of exch. Na% in B horizon, %	25-70	25-65	25-40	5-15	1-5
A.10	Total salt content, %	0.2-0.7	0.2-0.7	0.1-0.4	0.05-0.2	0.05-0.2
A.11	Depth of max. of salt content, cm	25-50	50-70	70-140	50-100	100-150
A.12	pH in B horizon	>8.5	7.5-9.0	7.5-9.0	7.5-8.5	7.0-8.0
A.13	Critical ground water depth, cm	calculated	calculated	calculated	calculated	calculated
A.14	Total porosity, vol. %	55-65	50-60	50-60	50-55	45-50
A.15	Field capacity water content, vol. %	40-45	35-40	25-40	40-45	35-40
A.16	Wilting point water contetn, vol. %	30-35	25-30	25-30	30-35	20-25
B.1	Average ground water depth, cm	100-200	150-250	200-300	300-400	300-500
B.2	Annual ground water fluctuation, cm	80-120	80-120	100-120	100-120	60-80
B.3	Total salt content of ground water, mS/cm	3-8	3-8	2-7	1-5	1-5
B.4	Na% of ground water, %					
B.5	SAR of ground water, $mg/eq/l^{1/2}$	0.5-4.0	0.5-4.0	1.5-2.5	0.5-2.0	0.5-2.0
B.6	pH of ground water	>8.5	8.0-8.5	7.5-8.5	7.0-8.0	7.0-8.0

T a b l e 2. Soil salinization/alkalinization changes due to different climate change scenarios

		Climate change scenarios										
		1	2	3	4	5	6	7	8	9	10	11
	CH. 1 AIR temp	Same	Same	Same	+2.5°C	+2,5°C	+2,5°C	+2,5°C	+2,5°C	+2,5°C	No change	No change
	CH.2 PET	Same	Same	Same	+25%	+25%	+25%	+25%	+25%	+25%	?	?
	CH.3 Precipn	Same	Same	Same	-25%	±25% IR	±25% IR	Same	Sam	Sam	+25%	+25%
	CH.4 G/ water depth	Same	Decr.	Incr.	Same	Same	Decr	Same	Incr	Decr	Decr	Incr
A.1	Soil type,verbal	No						No	No		No	
A.2	Soil subtype, verbal	No						No	No		No	
A.3	Depth of max. exch. Na% in H hor, cm	No	Decr	Incr	No	No	Decr	No	No	Decr	Decr	Incr
A.4	Cation exchange capacity, mg eq/100	No	No	No	No	No	No	No	No	No	No	No
A.5	Texture, verbal	No	No	No	No	No	No	No	No	No	No	No
A.6	Humus content, %	No	Decr	Incr	Decr	No	Decr	No	No	Decr	Decr	Incr
A.7	Bulk density, g/cm^3	No	Incr	Decr	No	No	Incr	No	Decr	Incr	Incr	Decr
A.8	Hydraulic conductivity, cm/d	No	Decr	Incr	No	No	Incr	No	Incr	Decr	Decr	Incr
A.9	Max. of exch. Na% in B horizon, %	No	Incr	Decr	No	No	Incr	No	Decr	Incr	Incr	Decr
A.10	Total salt content, %	No	Incr	Decr	No	No	Incr	No	No	Incr	Incr	Decr
A.11	Depth of max. of salt content, cm	No	Decr	Incr	No	No	Decr	No	Incr	Decr	Decr	Incr
A.12	pH in B horizon	No	Incr	Decr	No	No	Incr	No	No	Incr	Incr	Decr
A.13	Critical ground water depth, cm	No	No	No	Incr	No	No	No	No	No	No	No
A.14	Total porosity, vol. %	No	Incr	Decr	No	No	Incr	No	Decr	Incr	Incr	Decr
A.15	Field capacity water content, vol. %	No	Incr	Decr	No	No	No	No	Decr	Incr	Incr	Decr
A.16	Wilting point water, vol. % contetn	No	Incr	Decr	No	No	No	No	Decr	Incr	Incr	Decr

Table 2. Continuation.

B.1	Average ground water depth, cm	No	Incr	Decr	No	No	Incr	No	Decr	Incr	Imcr	Decr
B.2	Annual ground water flucuation, cm	No			Decr	No		Decr	Decr			
B.3	Total salt content of ground water, mS/cm	No										
B.4	Na% of ground water, %	No										
B.5	SAR of ground water, mg $eq/l^{1/2}$	No										
B.6	pH of ground water	No										
D.1	Cropping potential, verbal	No				Incr	Decr	Decr	No	Decr	Decr	Incr
D.2	Average expected yield, t/y	No	Decr	Incr	Decr	Incr	Decr	Decr	Decr	Decr	Decr	Incr
E.1	Annual average irrigation, mm/y	No										
OV.1 (A.9)	Change in exchangeable Na%	No	INCR	decr	No	No	INCR	No	decr	**INCR**	INCR	**decr**
OV.2 (A.3)	Change in the depth of maximum value of the exchangable Na%	No	DECR	incr	No	No	DECR	No	incr	**DECR**	DECR	**incr**
OV.3 (A.10)	Change in the total amount of salt at the salt accumulation level	No	INCR	decr	No	No	INCR	No	No	**INCR**	INCR	**decr**
OV.4 (A.11)	Change in the depth of total salt content	No	DECR	incr	No	No	DECR	No	incr	**DECR**	DECR	**incr**
OV.5 (D.2)	Change in the average expected yield **(maize)**	No	DECR	incr	DECR	incr	DECR	DECR	DECR	**DECR**	DECR	**incr**
OV.5 (D.2)	Change in the average expected yield **(wheat)**	No	No	incr	No	incr	No	No	No	No	No	incr
OV.5 (D.2)	Change in the average expected yield **(oilseed rape)**	No	No	incr	No	incr	No	No	No	No	No	incr
OV.5 (D.2)	Change in the average expected yield **(sunflower)**	No	No	incr	DECR	incr	No	No	DECR	No	No	incr

Legend: CH1-CH4: Same=no change; A.1-OV.5: No=no change; Decr=decrease; Incr=increase; OV.1-OV.5: all capital letters=the direction of change enlarges the salinization processes; all lower case letters=the direction of change reduces the salinization processes.

Scenario 9. Average air temperature and potential evapotranspiration will increase, precipitation does not change. The ground water level will increase. The expected result: the salinity/alkalinity level will greatly increase - more so than in *Scenario 2*; cropping potential will not change.

Scenario 10. Average air temperature will not change, and precipitation will increase. Potential evapotranspiration will probably increase slightly. The ground water level will increase. The expected result: the salinity/alkalinity level will increase in the soil profile. The effect is similar to *Scenario 2*; cropping potential will decrease.

Scenario 11. Average air temperature will not change, but precipitation will increase. Potential evapotranspiration will probably increase slightly. The ground water level will decrease. The expected result: the salinity/alkalinity level will greatly decrease in the soil profile. The effect is more intensive than in *Scenario 3*; cropping potential will increase greatly.

The decision making process in the SALINEXP expert system goes through three levels of evaluations. In Level One the program checks the input file content. First, the range of parameters is checked, especially the soil type and climate change scenario parameters.

- If the SALINEXP.IN input file is not available in the current directory SALINEXP gives a warning and creates an empty input file to facilitate the use of the system.
- The data in the input file is checked and an error message is displayed if any input parameter has a negative value.
- If the climate change scenario values are not specified properly an error message is displayed.
- If the soil type is missing in the input file, the program tries to determine it from other state variables.
- If the available information is insufficient to determine the soil type, the program gives an error message, as also happens if the climate change scenario data are missing. The program is terminated at this point.
- If the soil type is given, the program compares other given initial state variable values with the range of the parameters listed in Table 1. If incompatible information is encountered the program gives an error message and the program terminates.

If Level One checking finishes without error, SALINEXP starts Level Two checking. If the given climate change scenario is not feasible then an error message is given and the program terminates.

Finally, Level Three of the decision making is carried out with the evaluation of input data according to the content of Table 2. The SALINEXP program determines the direction of changes for the state variables and describes verbally the expected new salinity/alkalinity status, and the expected cropping potential changes. This information is written into the output file, called SALINEXP.OUT.

Approximately 0.8 Mbyte hard-disk space is required to set up the system on a PC running under DOS. A minimum of 550 KB of free RAM memory is required to run the program. However, if the user does not want to use the auxiliary text editor, then only 290 KB of free RAM memory will be enough.

RESULTS OF SCENARIO ANALYSES

A scenario analysis was carried out for the Middle-Tisza Region in Hungary in order to predict the effect of a feasible climate change scenario on the expected yield of corn (maize) and wheat. Based on the analysis of 50-year climate records, it was assumed that the average air temperature and - as a consequence - potential evapotranspiration would increase, precipitation would decrease, and the ground water level would not change significantly.

After running the expert system program for the Middle-Tisza Region soils, the prediction in the majority of the cases was as follows:

- the salinity/alkalinity level will increase only slightly, but the cropping potential will decrease. The expert system predicted that there would not be significant change in the state of salinity/alkalinity in the soils located in the region. The expected cropping potential decrease will occur as a consequence of water and soil moisture shortage in the soils. It can be compensated by irrigation, but this will increase production costs and raise the likelihood of secondary salinization of the soils.

In Hungary, until recently, an extensive data collection system operated giving field-by-field information about the variation of crop yields. Using these base for comparison purpose, yield data for two meteorologically significantly different years were evaluated statistically for maize and wheat. In 1983 there was severe drought in the Middle-Tisza Region in Hungary, but in 1988 the meteorological records show that the weather was similar to the long term average. Figures 1 and 2 show the yield frequency distributions for the meteorologically average year (1988, as present curve) and a warm, dry year (1983, as predicted curve) for maize and wheat, respectively. The difference between the two curves clearly shows the significant decrease in crop yields. The results were also presented as 1:750 000 scale maps showing the spatial variation of expected yield losses for these crops (Figs and 4).

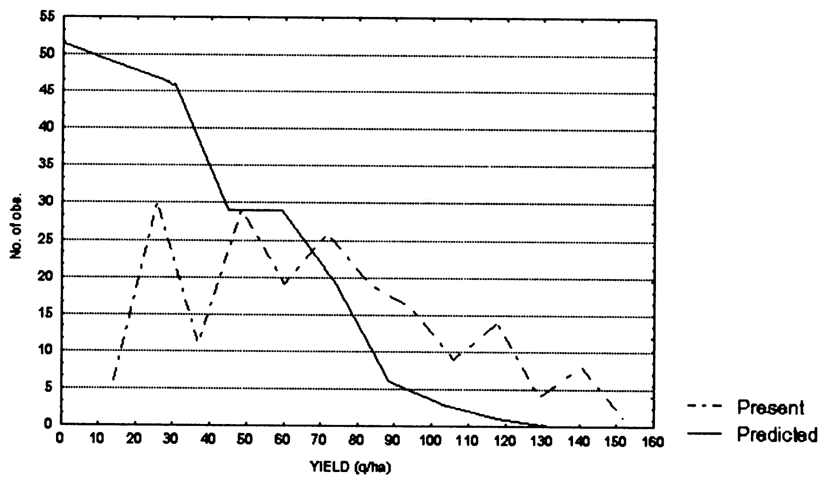


Fig. 1. Comparison of an average and a dry year maize yield distribution

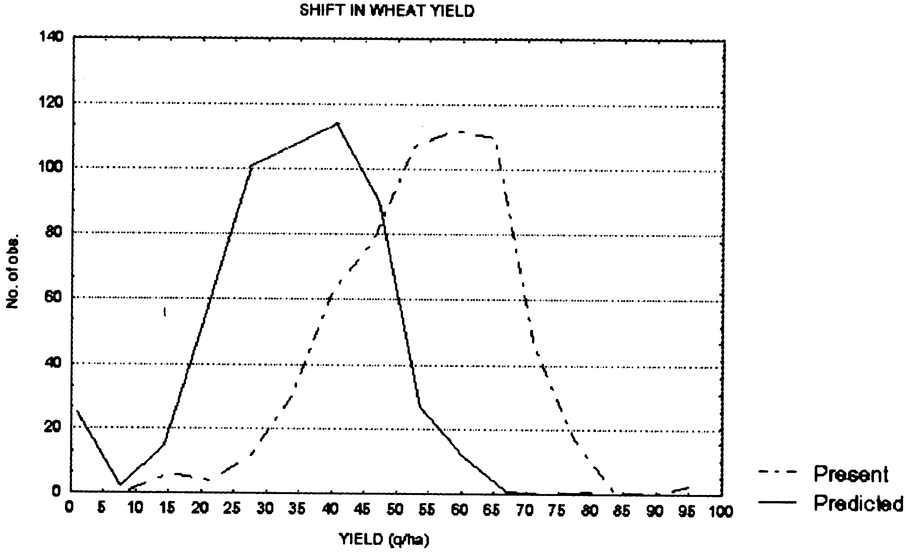


Fig. 2. Comparison of an average and a dry year wheat yield distribution.

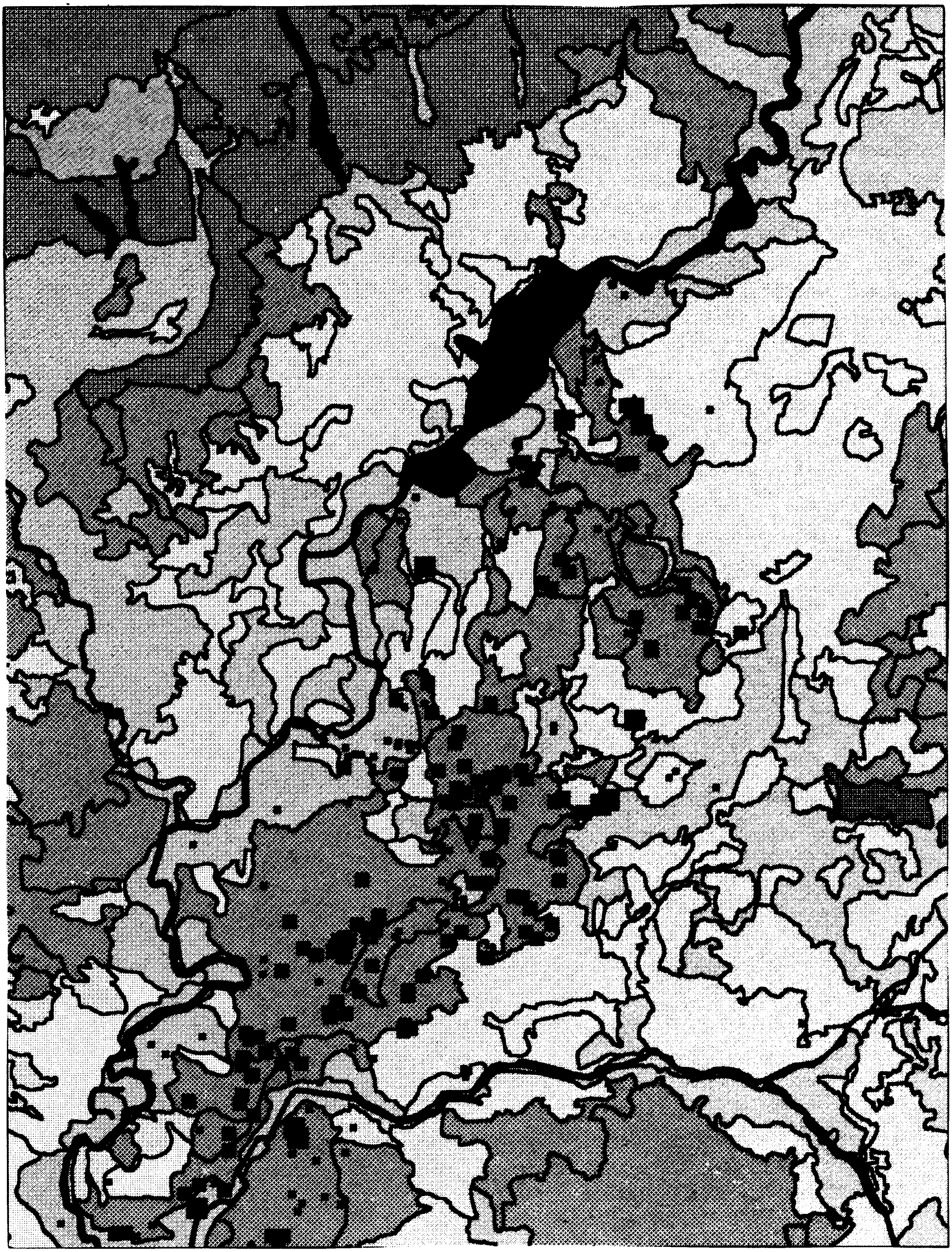
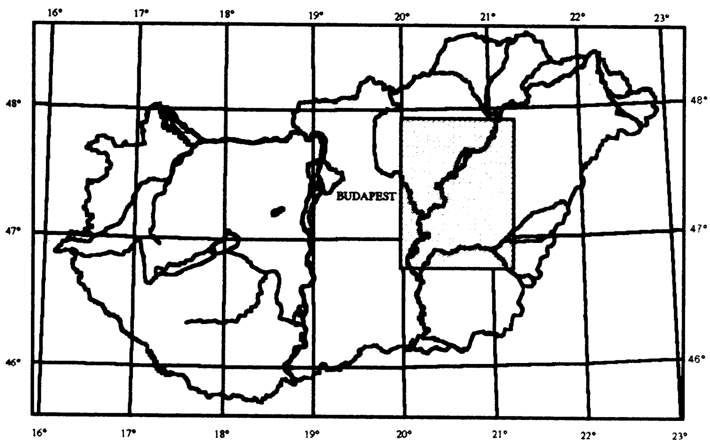


Fig. 3. Spatial variation of expected yield losses for maize.

Loss of corn yield in case of the climate scenario No. 4



N

Hungarian Unified Map Projection System

0 10 20 30 40 Kilometers

Main genetic soil type
- Alluvial soils
- Bog soils
- Brown forest soils
- Chernozem soils
- Lithomorphous soils
- Meadow soils
- Salt-affected soils
- Skeletal soils

Degree of yield loss
- 10%
- 20%
- 100%

GIS Lab
RISSAC

Complied in RISSAC GIS Lab in 1995

Fig. 3. Continuation.

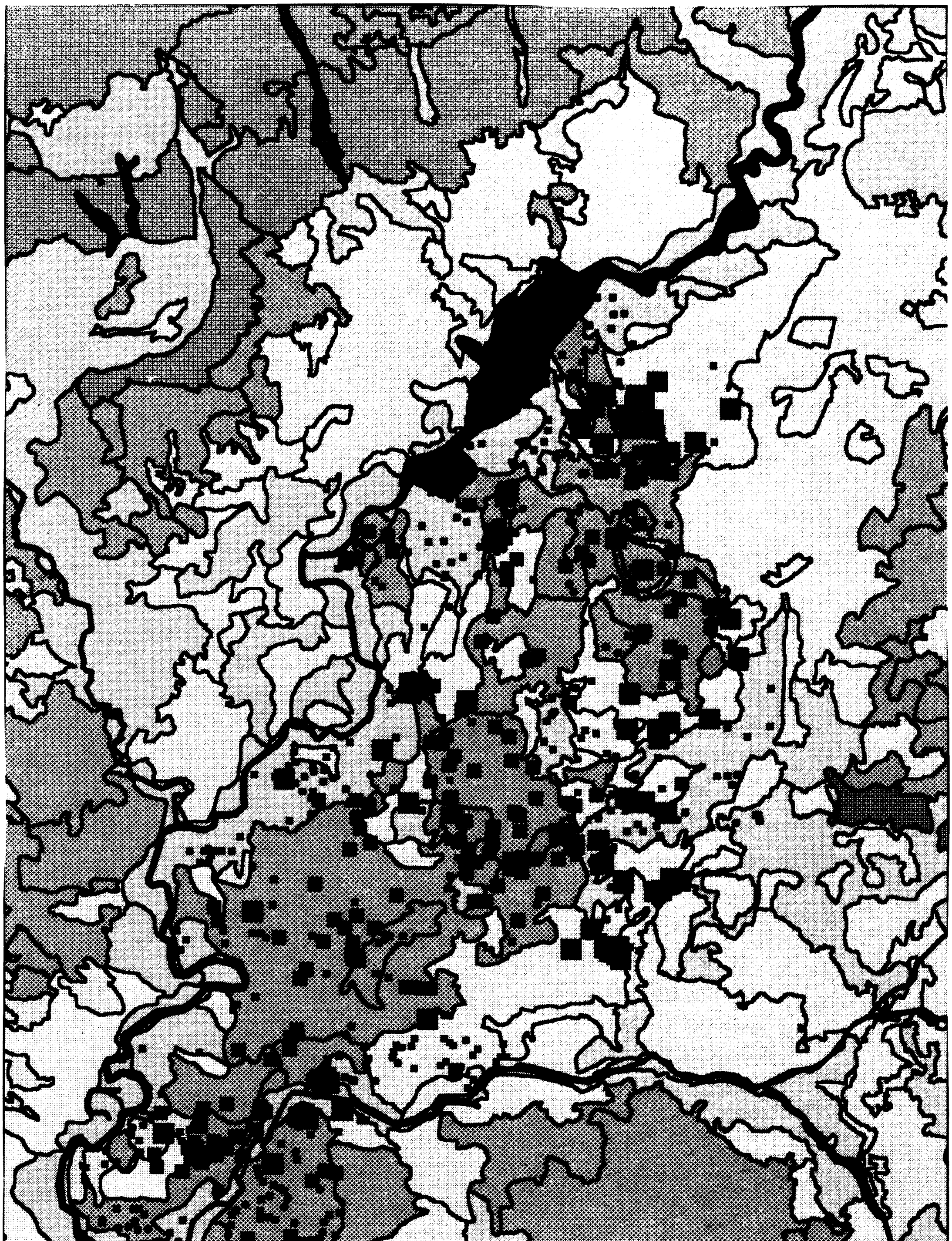


Fig. 4. Spatial variation of expected yield losses for wheat.

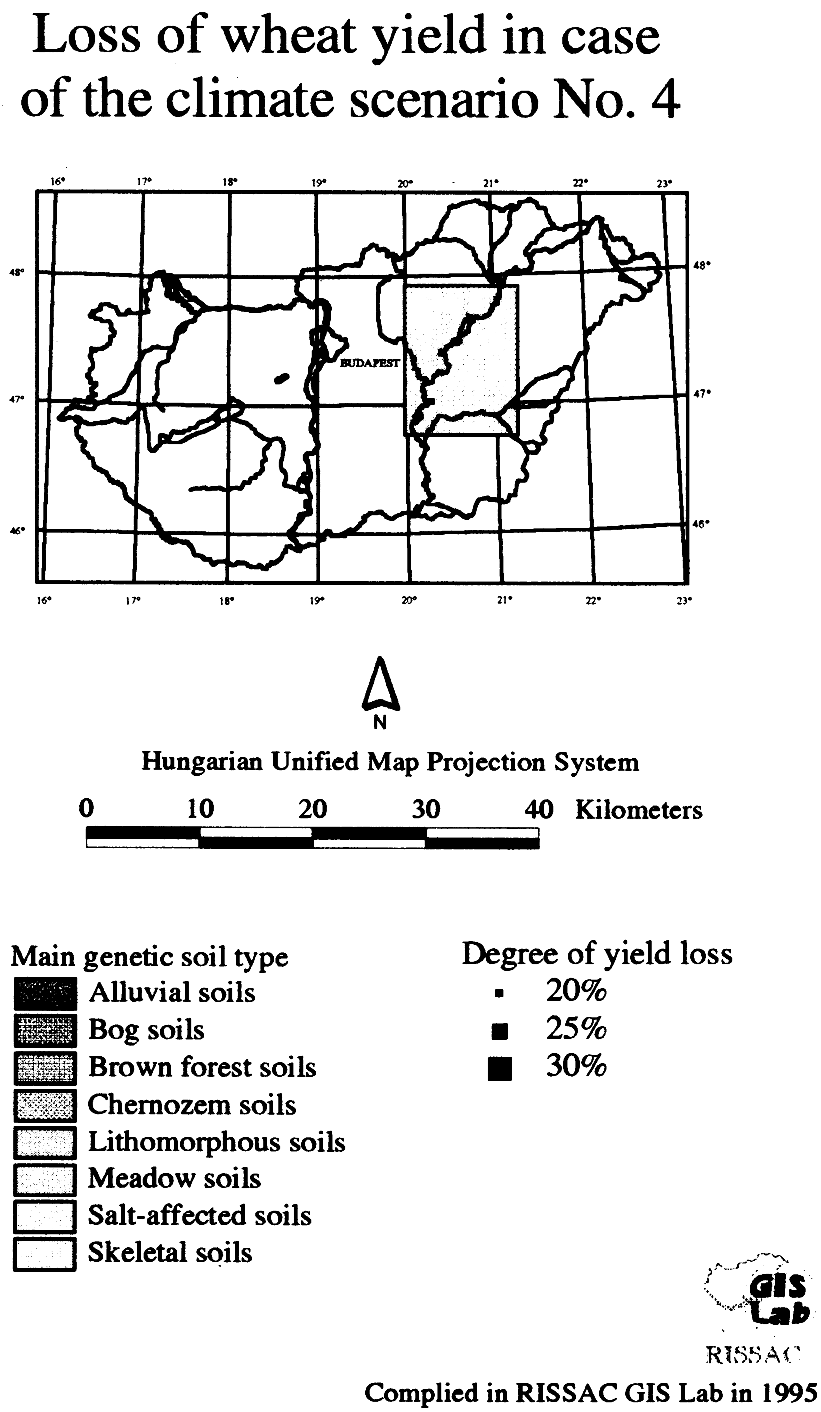


Fig. 4. Continuation.

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It is almost axiomatic that an expert system cannot be developed by a single person. An expert system should, by definition, incorporate and mimic the knowledge at least of a group of highly skilled experts who have specialized knowledge and experience in the domain of the expert system. When their knowledge is formulated logically into a compu- terized system by means of rules, formulae and functions, then that particular program can be called an expert system. The authors of this chapter acknowledge the very valuable contribution to the system of the expert group, whose knowledge is built in the SALINEXP program, namely:

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