DECISION SUPPORT SYSTEM FOR APPLICABILITY OF LOW QUALITY WATER FOR IRRIGATION

SYSTEME D'AIDE A LA DECISION POUR L'APPLICATION DE L'EAU MARGINALE EN IRRIGATION

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ABSTRACT

The decision support system of the applicability of low quality water for irrigation is needed to avoid emerging problems associated with using such waters for agricultural crop production. The research objectives are directed towards the protection of: water resources, soil fertility, crop production and consumers' health. The system is based on FAO methodology on water quality for agriculture and on the other research results and expertise. The system recommends how to use the available water on the basis of its quality parameters and on the information of cultivated crops, soil and agro-climatic characteristics of the region and irrigation technology.

To fulfil the stated objectives, a computer programme was developed comprising two basic structures: (1) input and updating of initial data and (2) results and recommendations. The input data are divided into three basic groups depending on the information source and its nature. The results and recommendations on water quality are divided depending on the information groups which are processed taking into consideration the data interrelation of each group.

The system could be applied not only for recommendations towards the direct users: farmers, irrigation societies and laboratories how to use successfully the irrigation water of lower quality, but also for further research.

Key words: *Poor quality water, decision support system, irrigation suitability, Bulgarian National Science Fund.*

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RESUME ET CONCLUSIONS

Le système d'aide à la décision pour l'applicabilité de l'eau marginale en irrigation est nécessaire pour éviter les problèmes émergents de l'utilisation de l'eau d'une qualité insuffisante pour la production agricole. Les objectifs de recherche sont orientés vers la protection des ressources en eau, la fertilité des sols, la production agricole et la santé des consommateurs. Le système est basé sur la méthodologie de la FAO sur la qualité de l'eau pour l'agriculture et sur les résultats de la recherche menée par les auteurs et leur expertise. Le système recommande d'utiliser l'eau disponible sur la base des paramètres de qualité et des informations disponibles sur les cultures, les sols et les caractéristiques agro-climatiques de la région et de la technologie d'irrigation.

La méthodologie présentée montre les principales idées en vue de déterminer l'applicabilité de l'eau d'irrigation pour les cultures différentes sur la base d'évaluation de la qualité. La méthodologie comprend les éléments suivants:

- *la conception d'une base de données des indicateurs de qualité de l'eau d'irrigation;*
- *l'évaluation de la qualité de l'eau d'irrigation;*
- *les recommandations pour l'utilisation de l'eau d'irrigation.*

La base de données contient des informations permanentes sur l'impact de la qualité de l'eau d'irrigation sur la production agricole, des renseignements personnels sur les usagers de l'eau, les données sur les sources d'eau et des échantillons d'eau, les indicateurs de l'eau à partir des analyses de laboratoire.

La recommandation est une conclusion de l'évaluation de la qualité de l'eau d'irrigation. Sur la base de l'évaluation de chaque indicateur de qualité de l'eau d'irrigation, il est recommandé aux agriculteurs de considérer les caractéristiques du sol, les méthodes d'irrigation, etc. Après l'évaluation de la qualité de l'eau d'irrigation selon plusieurs indicateurs, les évaluations générale peuvent être faites.

Le logiciel utilisé se base sur la méthodologie décrite en format Visual Basic. Suivent les principaux éléments du programme :

- *une base de données contenant des informations préliminaires;*
- *un formulaire et le traitement préliminaire de l'information sur les résultats de l'analyse chimique de l'eau;*
- *la recommandation sur la façon d'utiliser l'eau d'irrigation.*

Le programme comporte deux structures de base: (i) données initiales et leur mise à jour, (ii) résultats et recommandations. Les données initiales sont divisés en trois groupes principaux selon le type de source d'information, les données sur l'utilisation de l'eau, les informations générales sur le champ irrigué, et les données de l'analyse en laboratoire. Les résultats et les recommandations sur la qualité de l'eau sont répartis selon le groupe d'informations établi compte tenu de l'interrelation des données entre les groupes.

Le programme est composé de deux formulaires, trois formes des résultats de l'analyse et l'évaluation, et une forme de recommandations. Il est prévu de transférer les ressources en

eau à un contrôle précédent, d'ajouter les nouvelles données de recherche et de supprimer les données inutiles. Les formes d'évaluation de la qualité de l'eau et de recommandations illustrent les résultats de l'évaluation des problèmes d'irrigation potentielle, la toxicité et les effets secondaires spécifiques et les recommandations à l'utilisateur. Les recommandations à l'utilisateur contiennent non seulement l'évaluation du programme mais aussi les données de base et les résultats préliminaires pour sensibiliser l'utilisateur.

Le système (façon d'utiliser avec succès l'eau marginale en irrigation) pourrait être utilisé par les utilisateurs, les agriculteurs, les sociétés d'irrigation, les laboratoires, ainsi que dans d'autres recherches.

Mots clés: *Eau marginale, Système d'aide à la décision, convenable pour l'irrigation, Fonds bulgare des sciences nationales.*

1. INTRODUCTION

The drying up and the intensive usage of almost all water reserves of good quality has shown that the new and part of the available set up irrigated area should use water of poorer quality. The irrigation of agricultural crops with water of unsuitable quality, besides decreasing the crop yield, will also affect its quality. A decision support system of the applicability of low quality water for irrigation to meet the crop water demand is under development through research cooperation and partnership of Dr. Athanasios Panoras, Land Reclamation Institute of NAGREF (Thessaloniki-Sindos, Greece) (Panoras at al, 2009, 2007). Specific characteristics of the regions, where the system will be applied, as well as the relevant laws in force, have been considered in the system development. The project contributes to the implementation of the EU Water Framework Directive 2000/60 in the field of agricultural water management and will enable the decision makers to make decisions about the best practices in irrigated agriculture for various cultivated crops vis-a-vis, the water quality. The system is based on FAO methodology on water quality for agriculture (Ayers & Westcot, 1985) and the other research results (Kazandzhiev at Dimitrov, 2010, Pescod, 1992, Zhivkov at al, 2010). The system issues recommendations how to use the available water on the basis of laboratory analysis of water for irrigation and on the information of cultivated crops, soil and agro-climatic characteristics of the region and irrigation technology.

The objectives of the development are:

- Protection of water resources – assessment of the available water resource quality indicators for efficient use of water in accordance with the requirements of the water consumers;
- Protection of the soil – knowing the quality of the irrigation water and the soil, as well as of the applied water quantities the farmer should predict the water impact on the modification of the soil characteristics;
- Protection of the crops – avoiding crop quality and yield reduction by optimizing the quality and quantity of the irrigation application such that irrigation is economically attractive and crop yields are stable; and
- Protecting of the consumers – the sustainable agricultural development is a precondition for the crop production output, which eliminates the health risks for the consumers.

The system algorithm focuses on the process of issuing recommendations for irrigation water considering qualitative parameters of the available water. The computer programme is written in Visual Basic environment. It will be used not only as recommendations for the direct users, i.e. farmers, irrigation societies and laboratories, which perform the water chemical analysis but also for further research.

2. DESCRIPTION OF METHODOLOGY

2.1 Database for quality of irrigating water

The database for the quality of the irrigation water comprise:

- Information about: water users, water sources, type of water, soil characteristics, methods of irrigation, cultivated crops, water sampling date for laboratory analysis; and
- Laboratory analysis results of the irrigation water.

The personal information of water users is not required. The suitable information concerns their identification code, name, address and other information data for a direct contact with them.

The information of the available water sources contains data about water source and its region. The information of the soil characteristics, water quality and irrigation method is necessary for the water applicability assessment for the preparation of recommendations and suggestions.

The information of the results from the laboratory water analysis contains: pH, electrical conductivity, BOD, COD, suspended solids, bacterial populations, anions and cations. The main trace elements are also reported.

2.2 Assessment of quality of water used for irrigation

The degree of restriction on the usage of irrigation water has been presented in conformity with FAO methodology on water quality for agriculture (Ayers & Westcot, 1985). The parameters are, as follows:

- Salinity;
- Infiltration. Assessment of the infiltration water quality are based on EC, SAR when fresh water is used for irrigation, and the adjusted SAR when waste water is used;
- Specific ion toxicity. Sodium – for surface and sprinkler irrigation; Chloride – for surface and sprinkler irrigation; Boron; Trace elements – arsenic, cadmium, chromium, copper, iron, manganese, lead, zinc, etc;
- Miscellaneous effects: Nitrogen (NO_3-N); Bicarbonate (overhead sprinkling only); pH; Clogging problems in the case of drip irrigation: Langelier saturation index, suspended solids, bacterial population, etc.; and
- Suggestions about suitability of the available irrigation water, taking into consideration the previous estimates, BOD, COD and other factors.

2.3 Recommendations for irrigation water use

The recommendation on how to use the irrigation water follows from the assessment of the irrigation water quality. During the assessment of each indicator of water quality, the user of the system gets acquainted with the recommendations, which take into consideration soil characteristics, irrigation methods, etc.

3. DESCRIPTION OF ALGORITHM

The algorithm of the assessment of irrigation water quality has been developed on the basis of a methodology. The degree of restriction on the usage of irrigation water has been presented as a remark for all analyzed parameters of the algorithm.

3.1 General instructions on water suitability for irrigation

Guidelines for evaluation of water quality for irrigation are given in Ayers & Westcot, 1985 (Ayers & Westcot, 1985: page 8, Table 1; page 10, Table 2). The guidelines are practical and have been used successfully in general irrigated agriculture for evaluation of the common constituents in surface water, groundwater, drainage water, sewage effluent and wastewater. They are the first step in pointing out the quality limitations of the water supply, but this alone is not enough; methods to overcome or adapt to them are also needed. The specific impact of every one of the problematic factors on separate groups of crops and their limitation is presented at detailed algorithm of the system.

Ordinarily, no soil or cropping problems are experienced or recognized when the water parameters are lower than those shown for 'no restriction on use'. With restrictions in the slight to moderate range, gradually increasing care in selection of crop and management alternatives is required if full yield potential is to be achieved. If water quality values are found to approach or exceed those given for the severe restriction category, it is recommended that before initiating the use of the water in a large project, a series of pilot farming studies are conducted to determine the economics of the farming and cropping techniques that need to be implemented.

The research has to comply with the Bulgarian Ordinance on Water Quality for Irrigation of Agricultural Crops. Its main requirements are, as follows:

Indicator	Measure	Limit
A. Salinity (Salt Content)		
Electrical Conductivity (water), EC_w	µS/cm	2000
B. Infiltration		
Sodium (Na^+)	mg/dm^3	300
Calcium (Ca^{++})	mg/dm^3	400
Magnesium (Mg^{++})	mg/dm^3	300
Potassium (K^+)	mg/dm^3	350
C. Toxicity		
Boron (B)	mg/dm^3	1,0
Chloride (Cl^-)	mg/dm^3	300
Manganese (Mn)	mg/dm^3	0,2
Iron (Fe)	mg/dm^3	5,0
Copper (Cu)	mg/dm^3	0,2
Cobalt (Co)	mg/dm^3	0,05
Zinc (Zn)	mg/dm^3	2,0
Molybdenum (Mo)	mg/dm^3	0,01
Lead (Pb)	mg/dm^3	0,05
Mercury (Hg)	mg/dm^3	0,001
Aluminum (Al)	mg/dm^3	5,0
Beryllium (Be)	mg/dm^3	0,01
Nickel (Ni),	mg/dm^3	0,2
Vanadium (V)	mg/dm^3	0,1
Cadmium (Cd)	mg/dm^3	0,01
Selenium (Se)	mg/dm^3	0,01
Arsenic (As)	mg/dm^3	0,1
Chromium - hexavalent (Cr^{+6})	mg/dm^3	0,05
Chromium - triad (Cr^{+3})	mg/dm^3	0,5
Fluoride (F)	mg/dm^3	1,0
Lithium (Li)	mg/dm^3	2,5
Г. Sanitary - hygiene indicators		
Total Colly-titre	cm^3	<0,1
Esherihia Colly-titre	cm^3	<1,0
Intestinal Pathogenic Microorganisms	cm^3	Not allowed
E. Miscellaneous effects		
Ammonium-Nitrogen (NH_4-N)	mg/dm^3	5
Nitrate-Nitrogen (NO_3-N^-)	mg/dm^3	20
Carbonate (CO_3^{--})	mg/dm^3	200
Bicarbonate (HCO_3^-)	mg/dm^3	300
Sulphate ($SO4^{--}$)	mg/dm^3	300
Phosphate (PO4)	mg/dm^3	3
pH (hydrogen-ion activity, acidity/alkalinity)		6 - 9
Phenols (volatile)	mg/dm^3	0,05
Cyanides (CN) - total	mg/dm^3	0,5
Petroleum	mg/dm^3	0,3
Detergents	mg/dm^3	1,0
COD	mg/dm^3	100
BOD5	mg/dm^3	25
Extractable Substances with Carbon Tetrachloride	mg/dm^3	5,0
Temperature	°C	28
Dissolved Oxygen	mg/dm^3	>2,0
Hardness	$mgeqv/dm^3$	14
Non-dissolved Substances	mg/dm^3	50
F. Radioactivity		
Radium 226 (Ra 226)	mBq/dm^3	150
Total Beta Radioactivity	mBq/dm^3	750

3.2 Elaboration of recommendations for irrigation water use

The recommendation on how to use the irrigation water is the result of running the algorithm for assessment of the irrigation water quality. During the assessment of each indicator, the relevant recommendations will be displayed on the screen for the guidance of the farmers.

4. SOFTWARE DEVELOPMENT

4.1 General description of computer programme

The computer programme is based on the described algorithm and is written in Visual Basic. The main elements of the programme are as follows:

- Establishing an initial database connected to the programme, containing preliminary information, i.e.
  - information about: water users, water sources, type of water, soil characteristics, methods of irrigation, cultivated crops, date of water sample, taken for laboratory analysis,
  - results of the chemical analysis of the water samples, accompanied by supplementing information about water users, water sources, soil characteristics, cultivated crops, etc.;
- Input form and preliminary processing of the information about the results of chemical analysis of the water. The form contains the following elements:
  - control on the input of the chemical analysis data and the identified data input,
  - ActiveX Data Object control (to quickly create connections between data-bound controls and data provider) for navigating in the database,
  - command buttons and menus for correcting, adding and erasing records from the record-set, and for moving between input data pages and the recommendation pages.
  - establishing a record-set (to manipulate data in a database at the record level) based on available criteria,
  - menus to manage different aspects of the user's interface;
- Recommendation and suggestion forms on how to use the irrigation water. The forms contain the following groups of elements:
  - control over the information coming from the chemical analysis,
  - ActiveX Data Object control for navigating into the records,
  - remarks about the impacts of the irrigation water parameters on the crops,
  - menu and command buttons for managing the different aspects of the user interface of the implementation.

The present programme version implies basic elements of the algorithm:

- A database to have results from the chemical analysis of the water samples;
- The preliminary version of the input and preliminary processing for identifying the input data and the data on the chemical analysis;

- Module for assessing irrigation water quality. It helps for determining how to use the irrigation water. During the next work phases of the software development the module should be completed with the improved algorithm for processing, taking into account the results from the testing of the programme and the additional research of the bibliographic sources on theoretical and practical results;
- Forms, showing on the monitor screen the recommendations and suggestions how to use the available irrigation water, through different windows.

4.2 Program structure

Program structure of the system corresponds to the algorithm developed in accordance with the agreed methodology and contains two basic structures:

- input and updating of initial data,
- results and recommendations.

Each of these structures envelops some program blocks.

Input and updating of the initial data

The input data are divided into 3 basic groups depending on the information source and its character, i.e.:

- data for the water user,
- general information about irrigated field,
- data from laboratory analysis.

Results and recommendations

Results and recommendations on water quality are divided depending on information groups which are processed taking in into account the data interrelation in each group. This is important for the expert system to be developed in the future. There, the information will be monitored and processed even before the specific analysis. The groups are, as follows:

- potential irrigation problems,
- specific toxicity,
- miscellaneous effects,
- recommendations.

4.3 System operation algorithm

The basic steps at the operation of the system at its launching are, as follows:

- Input data uploading, i.e. forms on the specific water user and general information about the irrigated field are being uploaded. The data from the last processing are available because significant part of the information about the water user at the last service provided is the same. The data is being updated with the uploading of the new ones;

- Uploading of data from laboratory analysis. If the water source coincides with the source from the last processing, then the previously processed data are also shown because it is likely that some of them will be the same;
- Processing the laboratory analysis information and preserving the results. The achieved results will be processed together with the data of sensitivity and tolerance of the crop and also with the information on irrigated field;
- Results divided into three groups: potential problems at irrigation, specific toxicity and side effects;
- Recommendation choice according to the chosen indicators. Recommendation information is kept as a permanent information of the algorithm; and
- Results carried out from the recommendation analysis.

5. SYSTEM BLOCKS ALGORITHMS

5.1 Information uploading

In this part, data uploading means data uploading at system exploitation at user level, as well as data blocks input into the algorithm structure and their consequent updating regardless the fact that they are visible or not for the user while he is working with the system.

Personal and operational information

Personal information input is done consequently. If there is a coincidence with the database data shown on the screen, the information will be accepted as granted. Part of the information, which is not significant for the identification of the research subject, can be omitted while some information like code of the target subject, crop cultivated, etc. shall be upload obligatorily, i.e. it is not allowed to go further towards assessment without this information. The same rule is valid even more for the operational information, i.e. for the laboratory chemical analysis results of a specific water sample.

Permanent information

Permanent information is presented mostly in table forms. It shows the crop sensitivity towards water quality indicators, soil characteristics and methods of irrigation. Its main role is in the assessment process. Changes, updating and additional information will be applied only if there are accumulation of new knowledge from some sources. That is why it can be upload only by the system maintaining specialist who has access to it. Source of this information could be own research, FAO methods and recommendations and analysis of other bibliographic sources.

5.2 Information processing and results

Information processing means not only its reliability and correctness but also a follow-up complex analysis of the uploaded data for assessment achievement of the irrigation water indicators and the follow-up formulation of the user recommendation done on the basis of them.

Input data control envelops an assessment of its structure (digital, text and other type of information), as well as data validity check. If there is discrepancy among data concerning their structure/format or inconformity with their admissible range which has been taken in consideration from the other available information, the reason of specific data rejection should be said and the user gets revised recommendation in such cases.

The next is data complex analysis. Firstly, an assessment of potential irrigation problems is done (Fig. 3). As a result of this, if there are likely potential irrigation problems with the cultivated crop, the user will be given relevant information, which contains a short description of the problem and how it could be solved. If data are analyzed for specific toxicity and side effects, the approach is the same (Figs. 4 & 5). During the water quality assessment the system user can look through the information concerning the reflection of the specific indicator on the crop yield and its development, i.e. crop sensitivity and the quality indicators of the output.

User recommendations are formulated on the basis of data analysis. They are based on the practical experience to a great extent and they are combination of the knowledge included in the methodology.

5.3 Present version of the software

The programme is developed in Visual Basic. First, the programme version will be tested for laboratory condition and its development as independent working programme out of Visual Basic environment will lead to control texts in real circumstances with specific water users.

Input data forms

Input data forms are divided in two groups according to the above grouping of the database: form of personal information about water users and water sources, and form of the laboratory analysis data.

Each form contains some information and there is envisaged a transfer towards:

- the other input form,
- three forms for results from analysis-assessment,
- the form on recommendations.

It is envisaged a transfer to a previous inspection of this water source, new research data (Add Record) to be added, as well as data about research available in the database to be deleted (Delete Record). These opportunities are included in the forms bellow.

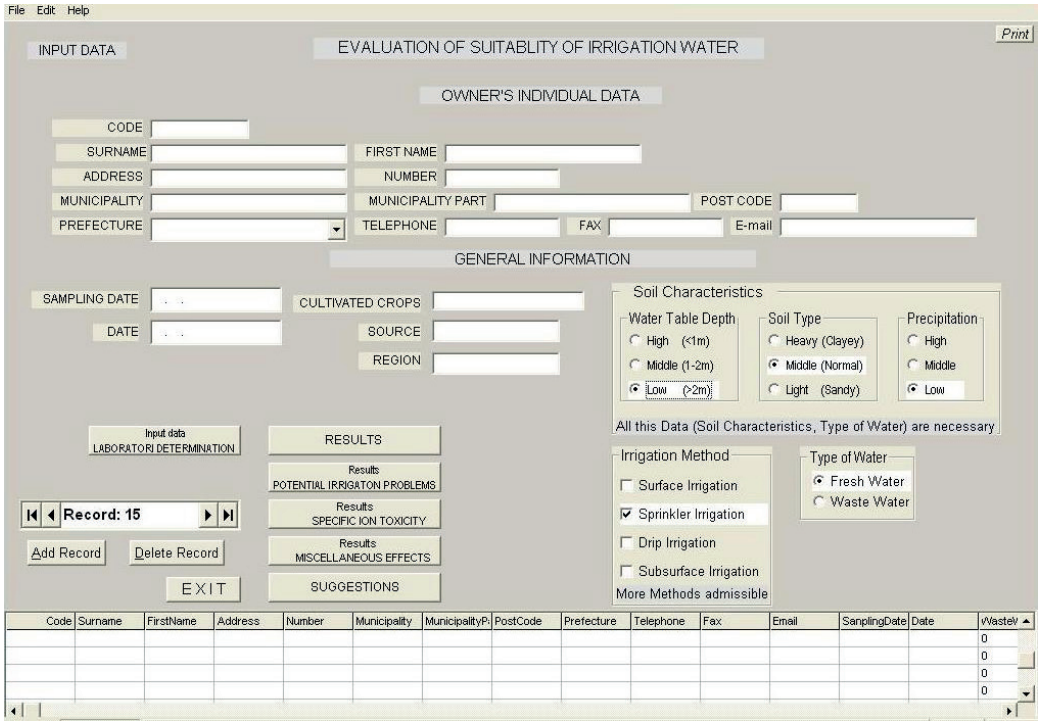

Fig. 1. Input form - water users, type of water, etc. (Formulaire de saisie - usagers de l'eau, le type d'eau, etc.)

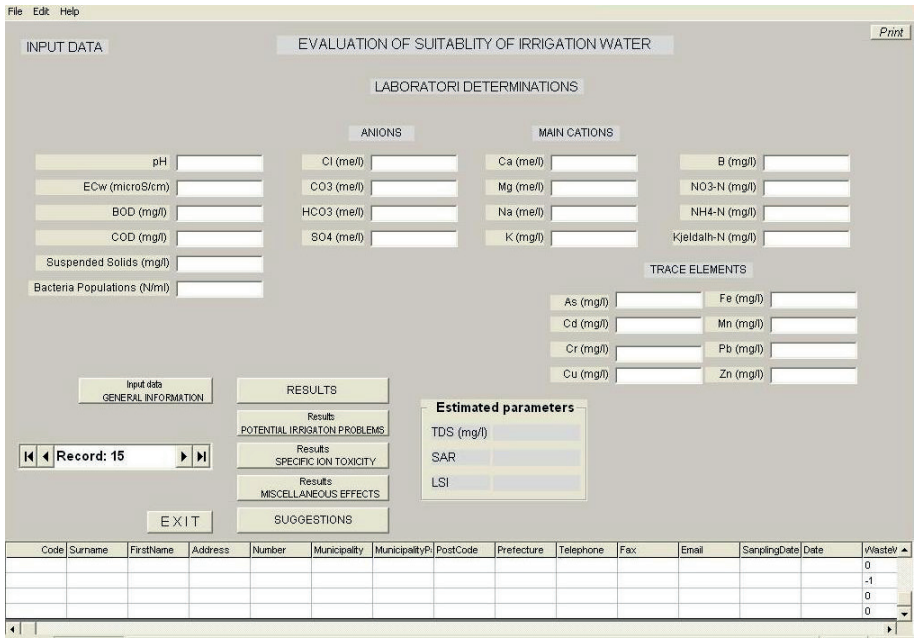

Fig. 2. Input form - results of the water chemical analysis (Formulaire de saisie - résultats de l'analyse chimique de l'eau)

Forms for water quality assessment and for recommendations

These forms illustrate results from assessment of the potential irrigation problems, specific toxicity and side effects and the form of issuing user recommendations.

Figure 3 illustrates a part of a table which could be activated by the user, i.e. it can be shown in the form, in this way, possible negative consequences for the crop in the table using irrigation water could be assessed (Figs. 4 & 5).

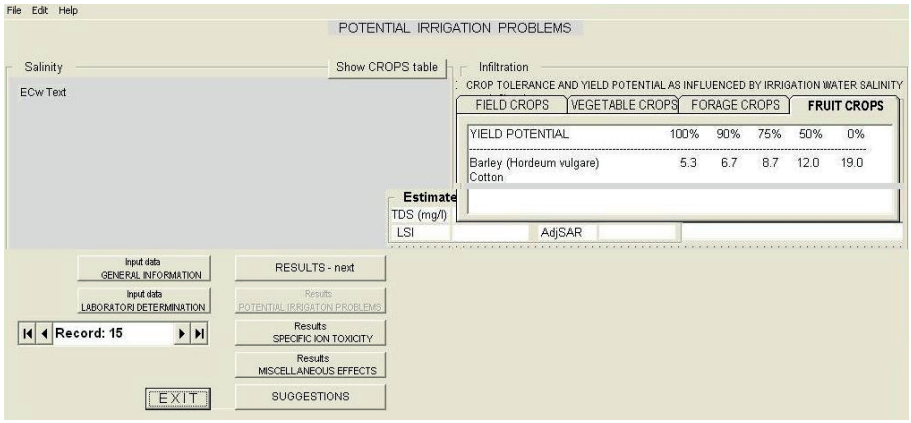

Fig. 3. Form Potential irrigation problems assessment (Formulaire Le potentiel d'irrigation des problèmes d'évaluation)

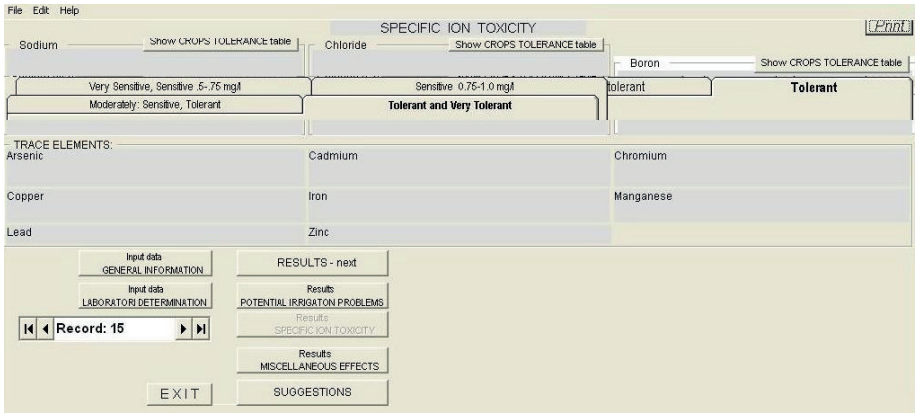

Fig. 4. Form Specific toxicity assessment (Formulaire Évaluation de la toxicité spécifique)

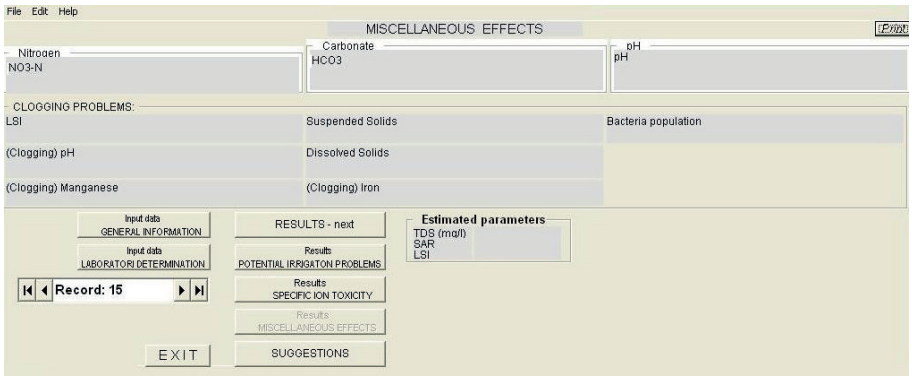

Fig. 5. Form Side effects assessment (Formulaire Les effets secondaires d'évaluation)

The form, recommendations for the user (Fig. 6), contains not only the recommendation formulated in the result of the complex assessment but also on the basis of basic data and preliminary results. In this way, user education is helped for better interpretation of information and if the user is knowledgeable it means qualified usage of the recommendations.

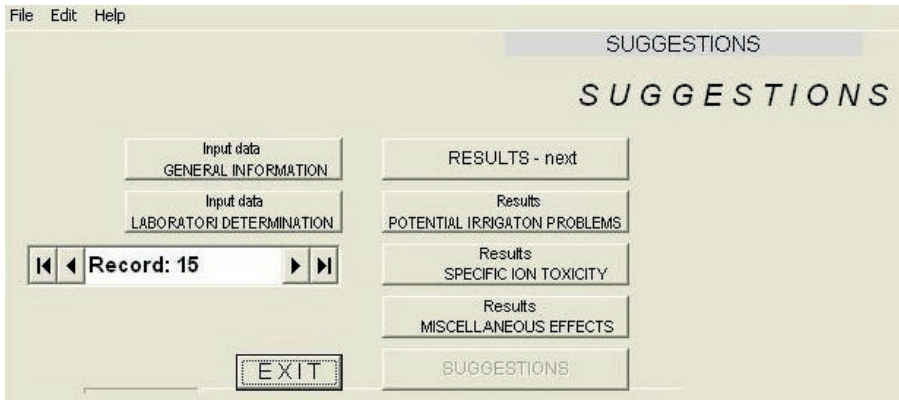

Figure 6. Recommendation and suggestion form (Formulaire Recommandation et suggestion)

5. CONCLUSIONS AND RECOMMENDATIONS

The results of the research are as follows:

- Formulation of a methodology on determining usability of the irrigation water for differing crops on the basis of the results of chemical analysis for its quality;
- An algorithm for recommendation on the usage of the irrigation water taking in consideration its quality parameters; and
- Software, i.e. a programme on recommendations issue and provisions to the users of how to use the irrigation water.

The software helps to achieve the main objectives of the research. However, for testing the relevant versions longer time period is needed besides selection of suitable data.

The present software addresses the main objectives of the model. For developing of the next versions of the software, it is necessary to take into consideration not only the worldwide experience but to update the methodology and the algorithms as well.

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