EXPERT EVALUATION SYSTEM FOR ASSESSING FIELD VULNERABILITY TO AGROCHEMICAL COMPOUNDS IN MEDITERRANEAN REGIONS

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An expert evaluation system (named ARENAL) has been developed using a knowledge-based approach that allows estimation of the relative vulnerability of soil and groundwater to diffuse agrochemical contamination. ARENAL interprets groundwater vulnerability at the field scale especially from nitrate and pesticide leaching. Soil properties and related agricultural land-features are combined with management system criteria for Mediterranean regions. The Automated Land Evaluation System (ALES) was used to acquire this computer-captured expert knowledge and allied data. The ARENAL expert system uses basic input data or "key" parameters from existing soil and land survey information. Such an evaluation approach can be the basis for estimation of the environmental impact of agricultural activities, with reference to chemical degradation of soil and water resources.

1. Introduction

Agricultural production within the European Community has increased strongly during the last decades as a result of, among other factors, increased use of agrochemical compounds such as fertilizers and pesticides. This increase has been beneficial in many ways, but there is increasing evidence of adverse effects of modern agricultural practices on soil and water quality. In Spain, 70% or urban centres consume fresh water from underground aquifers, and 72% of agricultural water is also from groundwater supplies. More than 11% of these aquifers are presently overexploited, increasing greatly their salinization and contamination risks. Nitrate is the major source of groundwater contamination, frequently surpassing the drinking water limit[1] of 50 mg/l.

The major causes of chemical degradation of soil and water quality are natural and agricultural hazards, along with urbanization and industrialization, with concomitant emissions and dumping of all kinds of products, residues and wastes. There is increasing concern, not only about the deterioration of soil and water quality, but also about the accumulation of pollutants in soil and their transfer to surface/ground water and the food chain. Because of the capacity of soils and sediments to store and immobilize toxic chemicals, the direct effects of pollution may not be seen in the short term.[2] This positive function of soils and sediments does not guarantee, however, that the chemicals are stored safely forever. Factors influencing the storage capacity of soils and sediments or the bioavailability of the stored chemical can change and indirectly cause sudden and often unexpected mobilization of chemicals in the environment. Because loading of the chemical to the environment can occur long before effects are observed, the term "chemical time bomb" (CTB) has been coined to describe such phenomena. CTBs are triggered by a chain of events that are often difficult to anticipate. However, there are ways of developing anticipatory strategies that foresee such problems before they become critical.

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As pointed out by Wagenet and Rao,[3] computer simulation models have become a useful tool in understanding and combatting environmental problems caused by the migration of agrochemical compounds, especially nitrates and organic pesticides, through soil into groundwater. The leaching of agricultural chemicals results from a complex interaction of physical, chemical and biological processes and attempts have been made to model these by equations based on classical mechanistic physics, in a statistical or stochastic framework (see, for example, Addiscott[4]). However, models are not yet reliable enough to predict accurately the behaviour of agrochemicals in the field. Soils are heterogeneous, climate and management factors vary, both in the short and long-term, and so on. The development of expert systems as aids to decision making on land use and land management strategy is thus justified in terms of providing a tool with which to assess large amounts of soil information, such as that obtained from soil surveys, in order to yield the most practicable strategy for environmental protection.

The objectives of this paper are: to illustrate the development of a computer-based expert knowledge system for the evaluation of field vulnerability to significant agrochemical compounds; and to apply the expert system, through a microcomputer programme, to selected agricultural areas within Andalucia (Spain).

2. Mediterranean agriculture

After many years of intensive cultivation in Mediterranean regions, the best agricultural soils are becoming degraded and water resources increasingly polluted. In many irrigation areas, mineral nutrients are causing pollution of groundwater, surface water and air by leaching, runoff and volatilization of NH_3–N. Past and present influxes of chemical compounds are modifying and reducing the initial buffering capacity, filtering and transforming soil functions. However, crops continue to enjoy maximum protection by chemicals, and there is little obligation to protect the environment. The most important agrochemical degradation processes of soil and water are shown in Table 1.

Mineral nutrients and organic pesticides seem to be the most significant potential pollutants. Impurities in fertilizers can also be an important source of toxicity from heavy metals and radionuclides, as pointed out by Bonson[5] from the chemical analysis of raw

Table 1
Agricultural chemical degradation of soil and groundwater

Source	*Major derived pollutants*	*Dominant degradation process*
Water	Soluble salts	Salinization Alkalinization
Mineral fertilizers and natural reserves	P, NO_x, K_2O Heavy metals Radionuclides	Eutrophication Acidification Toxicity
Organic pesticides	Halogenated organic compounds Heavy metals	Toxicity Acidification
Manure of animal and human wastes	Organic compounds P, NO_x Heavy metals	Eutrophication Toxicity

Table 2
Estimated inputs of agrochemical compounds to agricultural crops in Andalucia (per year and crop)

Tillage, number of operations	*Fertilizers kg/ha*	*Herbicides* 1/ha*	*Pesticides* kg/ha*	*Water needs† m^3/h*
		Traditional crops		
Primary	8-15-15	Treflan#	Lindane#	4500–8000
(1–2)	(300–600)	(1·5)	(25–50)	
Secondary	Urea 46%	2,4 D	Folidol M2	
(2–4)	(150–500)	(1·0)	(20–30)	
		Permanent fruit crops		
	15-15-15	Paraquat	Malathion#	5000–8500
	(400–600)	(3·0)	(20–25)	
Secondary	Urea 46%	Trifluraline#	SO_4Cu	
(3–4)	(100–200)	(4·5)	(15–20)	
		Vegetable crops		
Primary	Manure	Biodac#	Mocap 10G#	4000–7000
(1–2)	(50,000)	(7–12)	(40–60)	
Secondary	2 –1 –2	Fusilade	Malathion	
(3–5)	(500–600)	(1·5)	(20–25)	
		Flooded crops		
Primary	Super	Basagran#	Sumithion	(Q = 1 l/s.ha)
(3–4)	(300–500)	(4·0)	(20–30)	
Secondary	Urea 46%	Stam	Dipterex 5	
(1–2)	(300–400)	(3·0)	(20–30)	

Traditional crops: wheat, sunflower, sugar beet, cotton, corn, potatoe.
Permanent fruit crops: olive, citrus, peaches, nectarines, plums, grapes.
Vegetable crops, in controlled and semi-controlled environments: strawberry, asparagus, lettuce, cauliflower, spinach, celery, broccoli.
Flooding crops: rice.
* All product names are trademarks of the respective manufacturers.
# Product normally applied directly to the soil.
† Crop available water, and hence irrigation requirements.

phosphates for fertilizer production. Many raw phosphates from Morocco contained about 2 ppm of Pb, 21 ppm of Cu and 22 ppm of Ni and Cd; and the radionuclide content reached 150 ppm, expressed in U_3O_8. The toxicity of organic pesticides is very variable and is usually measured in water to humans and aquatic species, being the organic carbon adsorption coefficient, the biological degradation half-life, the lifetime health advisory level, and the aquatic toxicity, the parameters considered for selecting pesticides to minimize water quality impacts.[6]

Table 2 illustrates the current intensity of farming, through estimates of inputs of agrochemical compounds in the Andalucia region. This information was acquired through a study of published agricultural statistics, farmer contacts and discussion with extension personnel. Besides the traditional crops (wheat, sunflower, alfalfa, cotton, potato), other permanent fruit crops (citrus, olive, grapes, peaches, nectarines, plums), vegetable crops, winter and spring planting (celery, broccoli, Brussels sprouts, cauliflower, lettuce, spinach, strawberry), and flooded crops (mainly rice), are currently grown in intensively managed fields. Agrochemical inputs increase in the order: traditional crops, fruit crops, vegetable crops and flooded crops.

3. The expert evaluation approach

The ARENAL system is a qualitative biophysical interpretation procedure for assessing the relative field vulnerability of soil and groundwater by diffuse contamination. The main process considered was the leaching of nitrogen and pesticides into groundwater. ARENAL does not consider run-off or soil erosion because these processes are discrete (event-based) and affect surface-water only. The physical evaluation procedure indicates the degree of vulnerability for the most representative agricultural land uses (Table 2) without reference to economic factors.

The field, as the study unit of this work, is considered to be the total natural and socio-economic environment within which agricultural production takes place. Therefore, land and management factors were combined as diagnostic criteria to develop the expert evaluation system. The general rules for this interpretion approach were based on:

(1) the criteria for assessing soil sensitivity in the European Community;[7]
(2) vulnerability test data given for aquifers in irrigated areas from Spain;
(3) field experience from experts in Andalucia.

Following these criteria a first approximation to the ARENAL system was previously developed by De la Rosa *et al.*[8]

The Automated Land Evaluation System[9] (ALES), was used to develop computer-based decision trees based on expert knowledge. The ALES system is a framework for evaluators to build their own expert systems in accordance with the FAO Land Evaluation Guidelines.[10] ALES was used to estimate the relative field vulnerability, in four steps (*Fig. 1*) as follows.

(1) Formulation of field limitations in relation to the processes of agrochemical soil and groundwater pollution.
(2) Selection of relevant land and management characteristics, which have an important influence on the process being considered.
(3) Definition of land and management factors, "key" parameters, and deduction of these from the relevant characteristics or diagnostic criteria using decision trees. Severity levels of the criteria were determined for each field unit.
(4) Combination of land and management factors using a decision tree to infer relative vulnerability for each field unit. Field units are allocated to one of four vulnerability classes.

The ARENAL expert system considers land factors derived from climate, hydrogeological situations and soil physical characteristics, to determine the size and type of the reservoir accumulating polluting agrochemical compounds. In addition, intensity of management is used to determine the level and type of inputs of these compounds.

3.1. *"Climate" factor*

The precipitation was considered as one of the relatively permanent aspects of land vulnerability. In Mediterranean regions the climate is characterized by low and variable rainfall and high temperatures during much of the growing season. Virtually all precipitation occurs from October to May. In Andalucia, the historical average of total precipitation is 630 mm, with a spatial variation between provinces of 250 to 910 mm. Precipitation effects the leaching of agrochemicals within the soil and their concentration

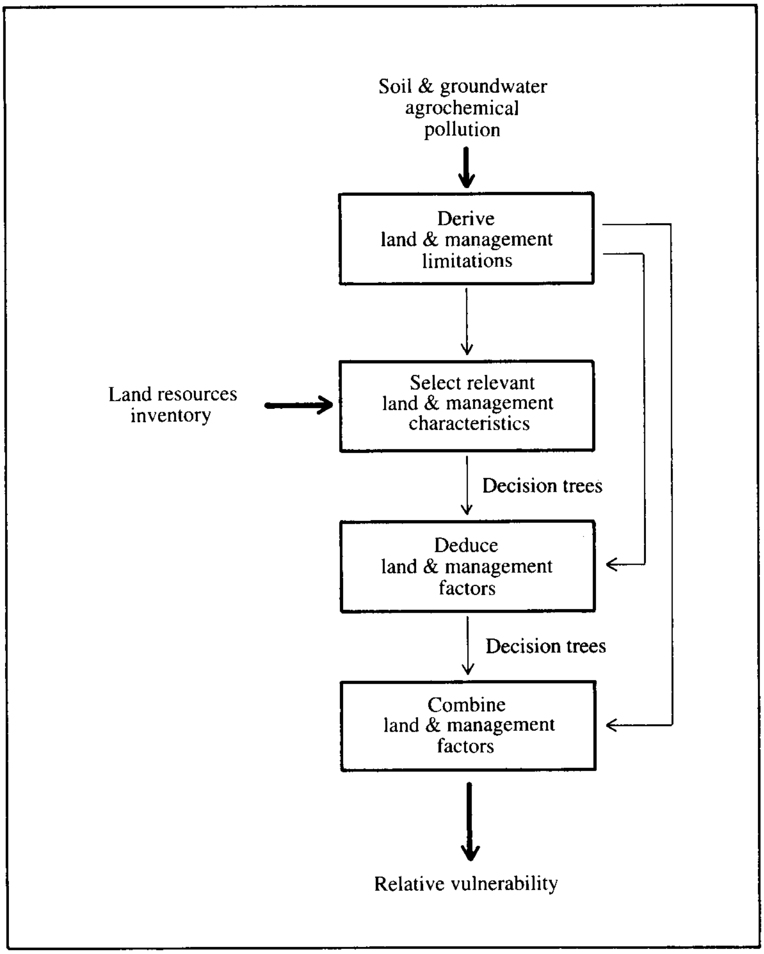

Fig. 1. Relational diagram for assessing the relative field vulnerability using ALES system

in the groundwater. This effect was estimated here by the method of Arkley[11] which considers that the degree of leaching is characterized by either the annual sum of monthly precipitation minus potential evapotranspiration for those months when precipitation is greater than potential evapotranspiration, or from the amount of precipitation in the wettest month, whichever is greater. In building the expert system, three severity levels of leaching degree were estimated according to the Arkley index values, <300, 300 to 500, and >500. These index values were found to be most appropriate in explaining the spatial variation in Andalucia conditions. The leaching degree severity levels were then used in the determination of the vulnerability classes.

3.2. "*Landform*" *factor*

Hydrogeology was rated according to landform, and was derived from the physiography and the hydrological conditions.

Major Mediterranean agricultural lands are located in four physiographic units: recent

Holocene plains, older terraces of Pleistocene age, Plio-pleistocene surfaces, and rolling Tertiary hills. According to Vanney and Menanteau,[12] the following summary definitions can be made.

Recent Holocene plains include lower alluvial terraces, littoral dunes and marshlands. The parent materials of the soils are deep, unconsolidated Quaternary deposits characterized by a flat or slightly sloping terrain (slopes are 0 to 2%). Dominant soils in this physiographic unit are Typic Xerofluvents, Typic Xeropsamments and Salorthidic Fluvaquents. The vulnerability of these soils to chemical compounds depends on the particular properties of the soil profile. Soils of the flood alluvial plains can also be recipients of surface water enriched with pollutants and soluble salts.

Pleistocene terraces include upper glaciers eroding the Quaternary deposits and middle river terraces with calcareus crusts. Rubification, clay translocation and formation of concretions are prominent features of these smooth and gentle slope soils (slopes range from <2 to 6%). There are also flat areas where claypans and fragipans, formed in the subsurface horizons, impede the internal soil drainage. Dominant soils in this physiographic unit are Aquic Haploxeralfs, Calcic Rhodoxeralfs and Calcixerollic Xerochrepts. The damaging processes are the same as those described for the recent Holocene plains soils, although their respective influences are different.

Plio-pleistocene surfaces include sandy and conglomerate formations, which frequently have erosive forms and estuarine origens. Slopes are smooth or convex and range from <2 to 8%. Dominant soils in this physiographic unit are Grossarenic Fragixeralfs, Aquic Palexeralfs and Aquic Xeropsamments. Most of the littoral irrigation zones are located on these formations, with high vulnerability to agrochemical compounds.

Rolling Tertiary hills correspond to moderately sloping terrains and unconsolidated deep late-Tertiary sediments. Slopes are complex and range from 4 to 16%. The parent material of the soils is mostly a deep, friable and carbonate-rich sediment. Dominant soils in this physiographic unit are Typic Chromoxererts, Typic Rhodoxeralfs and Calcic Xerochrepts. The main cause of degradation of these types of soil is erosion because water is more likely to run-off, with only a low risk of chemical contamination.

Hydrological conditions relate soil infiltration and percolation processes to groundwater recharge. The maximum water-table position has been chosen as an indicator of the effective depth of groundwater and its consequent recharge or discharge. This seasonal position is the highest surface of the saturated zone in the soil in most years. A detailed study on optimal water-table levels for crop yield and ground water quality, along with the effects of soil drainage and water extraction, was reported by Steenvoorden & Bouma.[13] Shallow groundwater is more vulnerable to contamination, and water-tables with intervening impermeable layers are much less vulnerable. Three severity levels of the water-table depth were considered: shallow, <50 cm; moderate, 50 to 150 cm; and deep, >150 cm; measured in the winter season.

3.3. "*Soil profile*" *factor*

Specific soil properties clearly affect soil and groundwater vulnerability to chemical compounds, and are also related to land productivity. In this sense, soil profile is analysed through a control section, including horizon differentiation and lithological stratification. Organic matter, which is important for the adsorption of agrochemical compounds and increased opportunities for degradation by soil microorganisms, was not considered because of its low content (usually less than 2%) in most Mediterranean agricultural soils. The rating of the soil profile factor was derived from the textural class, salinity, pH and cation exchange capacity.

Physical and chemical soil properties can be inferred from the soil texture. In particular, high clay and calcium carbonate contents result in good soil buffering capacity and transfer processes. Most calcaric soils have properties which favour the complex processes of adsorption and degradation of pesticides. A sandy texture, resulting in high hydraulic permeability, favours the leaching of agrochemical compounds and groundwater contamination. Fine textured soils, with irrigation and without adequate drainage, have high sensitivities to salinization–alkalinization and surface contamination processes. Three severity levels of soil texture (clay plus silt percentage) were considered: coarse, <35%; medium, 35 to 65%; and fine, >65%.

The salinization–alkalinization process is a world-wide problem for irrigated soils in climatic zones where evapotranspiration exceeds precipitation. High soil salinity mitigates against a well-functioning soil and effective transfer processes, such as evaporation, leaching, erosion, deposition and plant uptake. The soluble salt content of the water used in irrigation systems and from deep soil layers are the major primary sources of salinization. Three severity levels of soil salinity measured in extracts of saturated pastes were considered: null or light, <4 dS/m; moderate, 4 to 8 dS/m; and high, >8 dS/m.

The soil properties alkalinity (pH) and cation exchange capacity (CEC) are associated with soil loading capacity. The soil loading capacity is a measure of the retention and degradation of contaminants by the soil. Basic or nearly neutral soil with high cation exchange capacity, which usually corresponds with the montmorillonite group of clays, have a high waste loading capacity. On the contrary, in agricultural semi-arid regions the somewhat acid soils with low CEC correspond to sandy formations with low loading capacity. Three severity levels were considered by combining both pH and CEC: pH <7; pH >7 and CEC <0·35 mol/kg; and pH >7 and CEC >0·35 mol/kg.

3.4. "*Management intensity*" *factor*

Intensively managed Mediterranean farming systems, usually including irrigation, were selected to determine the level and type of inputs of polluting agrochemicals. Soil and groundwater pollution can be restricted by reducing fertilization and pesticide application rates, as well as by intensifying agricultural practices such as irrigation, drainage and manipulation of water table levels.[13] The rating of this factor was derived from the farming system, artificial drainage, and water extraction.

On the basis of present Mediterranean agricultural practices, four types of farming systems were considered, namely: (1) traditional crops such as wheat, sunflower, cotton, potato, sugar beet and alfalfa; (2) permanent fruit crops such as citrus, olive, grapes, peaches, nectarines and plums; (3) vegetable crops (winter and spring planting) such as celery, broccoli, Brussel sprouts, cauliflower, lettuce, spinach and strawberry; and (4) flooded crops, that is, rice (Table 2). Much of the management information used here was local, acquired over many years by the experience of local experimental stations and agriculturalists as well as by farmers. Information describing these farming systems has also been taken from the scientific literature, technical manuals, and company product literature. The farming systems have been ranked in the following order according to agrochemical inputs: flooded crops > vegetable crops > fruit crops > traditional crops.

Soil drainage practices, refering to drain depth and soil type, are important for groundwater pollution. Fields with artificial drainage will present a smaller risk of aquifer contamination than those without drainage. Irrigation can also wash off significant quantities of pesticides from foliage immediately after application. In addition, irrigation without adequate drainage and with water applications below the leaching requirement can lead to a slow but progressive salinization of the soil in semi-arid zones. Two severity levels were considered, namely, fields with artificial drainage and fields without artificial drainage.

Table 3

Pathway of the decision trees constructed to develop Arenal Expert System

Evaluation		*Severity level*			
Step	*Variable*	*1*	*2*	*3*	*4*
A	Physiography	>B	>D	>D	>R
B	Water table depth	>S	>D	>C	—
C	Leaching degree	Class S1	>D	>D	>D
D	Texture	>E	>F	>G	—
E	Salinity	>K	>S	>S	—
F	Salinity	>J	>I	>H	—
G	Salinity	>M	>J	>S	—
H	pH & CEC	>S	>K	>K	—
I	pH & CEC	>L	>L	>M	—
J	pH & CEC	>L	>M	>M	—
K	Farming system	>T	>N	>N	>S
L	Farming system	>T	>O	>O	>S
M	Farming system	>R	>U	>O	>O
N	Artificial drainage	>U	>P	—	—
O	Artificial drainage	>T	>Q	—	—
P	Water extraction	Class S4	>S	—	—
Q	Water extraction	>S	>U	—	—
R	Leaching degree	Class S1	Class S1	Class S2	—
S	Leaching degree	Class S3	Class S4	Class S4	—
T	Leaching degree	Class S1	Class S2	Class S3	—
U	Leaching degree	Class S2	Class S3	Class S4	—

Under each severity level the symbol > followed by a letter (B to U) is used to direct the user to the next step of the decision tree. The path is followed until a vulnerability class is encontered.

Extraction of groundwater for agricultural, industrial or municipal use often results in lower water tables and an increase of pollutant concentration in the groundwater. Also, the risk of groundwater salinization will be greater. Two severity levels were considered, namely, fields with water extraction and fields without water extraction.

3.5. *Field vulnerability classes*

In the estimation process for interpreting the field vulnerability of groundwater to contamination, the characteristics discussed above were combined in decision trees, and these were used to infer factor limitations. As presented in Table 3, the severity levels of each land and management factor were derived from the relevant characteristics according to relatively simple decision trees. Finally, another decision tree was built to combine the trees previously developed. Four vulnerability classes were determined: S1 None, S2 Slight, S3 Moderate and S4 Severe, defined in the following terms.

The *Class S1* (*None*) is not vulnerable to chemical contamination through agricultural activities, and the risks of soil and groundwater diffuse pollution are very low. The representative soils have a very big storage capacity for chemical compounds and the leaching is very low. These soils are developed on rolling Tertiary hills with carbonate-rich parent material, or more recent physiographic positions with deep and fine textured parent material. The management intensity is not considered to be a controlling factor and any of the defined farming systems can be implemented.

The *Class S2* (*Slight*) represents a low vulnerability to agrochemical compounds in terms of soil and groundwater diffuse contamination. Pollutant storage capacity of the representative soils is high, and the leaching ranges from low to moderate. The effect of management system changes on the vulnerability classes could be important.

The *Class S3* (*Moderate*) represents a moderate vulnerability to agrochemical compounds in terms of soil and groundwater diffuse contamination. The pollutant storage capacity of the representative soils is low, and leaching ranges from moderate to high. The more intensive farming systems can have adverse effects on the environment.

The *Class S4* (*Severe*) is very vulnerable to chemical contamination through agricultural activities, and the risks of soil and groundwater diffuse pollution are high. The representative soils have a very small storage capacity for agrochemical compounds, and therefore the leaching can be very rapid. Also, some clayey soils with a high retention capacity and low permeability which are very sensitive to pollutant concentration on the surface, were included in this class. Water management and the quantity and toxicity of pollutants must be carefully applied.

4. Application of the system

In order to allow an easy application of the ARENAL system, a Basic program was elaborated from the ALES expert system built previously. The compiled program, has been incorporated as an environmental impact module within a new version of MicroLEIS,[14] and runs on IBM PC XT, AT, or compatible microcomputers, following an easy-to-use menu system.

A representative example to illustrate the utility and applicability of ARENAL was developed using published land resource inventory information from Andalucia.[15,16] Table 4 shows the dominant or most representative field factors corresponding to 11 selected agricultural areas from this Mediterranean region. Table 5 shows the data for all the field characteristics analysed using the ARENAL program for one of the selected field units. Mean values of soil characteristics were calculated for a control section from the

Table 4

Field units to be evaluated in the example of ARENAL application. Benchmark agricultural areas from Andalucia region

*Field unit code**	*Physiographic unit*	*Dominant soil***	*Farming system*
CO-f07	Alluvial plains	Typic Xerofluvent	Fruit crops
H-f04	Littoral dunes	Typic Xeropsamment	Vegetable crops
SE-f05	Marshlands	Salorthidic Fluvaquent	Flooding crops
SE-f08	Pleistocene terraces	Aquic Haploxeralf	Traditional crops
GR-f05	Pleistocene terraces	Calcic Rhodoxeralf	Traditional crops
MA-f01	Pleistocene terraces	Calcixerollic Xerochrept	Fruit crops
H-f05	Plio-pleistocene surf.	Aquic Palexeralf	Traditional crops
H-f05a	Plio-pleistocene surf.	Grosarenic Fragixeralf	Vegetable crops
CA-f01	Rolling Tertiary hills	Typic Pelloxerert	Traditional crops
CO-f01	Rolllng Tertiary hills	Calcic Xerochrept	Fruit crops
SE-f02	Rolling Tertiary hills	Typic Rhodoxeralf	Fruit crops

* Reference symbol from "Catalogo de Suelos de Andalucía"[15] used to identify land map units.
** Taxonomic subgroup according to Soil Taxonomy.[19]

Table 5

Land and management information values for the field unit 'CO-f07' used as input to ARENAL

Field characteristic	*Value*
Climate factor	
Leaching degree	310
Landform factor	
Physiography	Alluvial plains
Water-table depth	Moderate
Soil factor	
Clay content, %	20
Silt content, %	18
Salinity, dS/m	<4
pH	7·5
CEC, mol/kg	8
Management factor	
Farming system	Fruit crops
Artificial drainage	No
Water extraction	No

surface to two meters depth, including horizon differentiation and lithological stratification.

Vulnerability classes for each of the selected field units were computed readily by application of the ARENAL program. Table 6 shows the results of the field vulnerability evaluation. A subset of four field units (36% of the total number of selected units) were evaluated as non-vulnerable, primarily because of the very large chemical storage capacities of the representative soils. On the contrary, five field units (45%) were evaluated as being moderately or severely vulnerability. As pointed out by Instituto Tecnologico Geominero de España,[17] in Spain more than 60% of agricultural soils have a

Table 6

Evaluation results by application of the ARENAL system: field vulnerability to agrochemical compounds

Field unit	*Vulnerability class*
CO-f07	S3. Moderate
H-f04	S4. Severe
SE-f05	S4. Severe
SE-f08	S1. None
GR-f05	S1. None
MA-f01	S3. Moderate
H-f05	S2. Slight
H-f05a	S4. Severe
CA-f01	S1. None
CO-f01	S1. None
SE-f02	S2. Slight

high vulnerability to chemical compounds. Most of the representative soils of the field units used here were sandy textured, although 'SE-f05' with a clayey texture was also included. Due to its high retention capacity and low permeability this clay soil is sensitive to pollutant concentration on its surface. For most of these vulnerable field units a change in the management system, for example from vegetable crops to traditional crops, can have a favourable effect on the vulnerability class.

Although an actual validation test of the evaluation results is not possible, the following general comments appear consistent with experience and local knowledge. The ARENAL expert evaluation system can be the basis for estimation of the environmental impact of agricultural activities, with reference to chemical degradation of soil and water resources. It can also help to develop new agricultural management systems which benefit environmental quality. Evaluating field vulnerability is of interest in order to plan the most efficient and successful clean-up management practices; to anticipate how the use of some practices may affect the aquifers in the future and possibly to recommend restoration practices in contaminated areas. There is an urgent need for research and education on farming systems which can increase productivity and profits without having adverse effects on the environment and ultimately our future survival. As pointed out by Van Lanen,[18] computer-captured expert knowledge in qualitative land evaluation methods appear to be useful in exploring land use options. General results can be obtained quickly, which reduces the number of possible land use options. Within a relatively short time-period policy-makers and researchers can focus on the remaining, more promising options.

Conclusions

The results of this work have shown the following.

(1) Simples classes of information describing soils, the climate and land management can be combined using expert knowledge to develop quantified land evaluation procedures for the prediction of soil and groundwater vulnerability to agrochemical compounds.
(2) Estimates using such a system (ARENAL) suggest that 45% of benchmark soils in Andalucia present at least a moderate risk of groundwater contamination by agrochemicals.
(3) Computerized expert land evaluation systems can provide an invaluable tool for policy-makers and land managers to predict the impact of agricultural practices on the environment.

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