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SESSION V: AGRICULTURAL AND ENVIRONMENTAL HAZARDS

PAPER 8: AGRO-ENVIRONMENTAL EVALUATION OF ALTERNATIVE FARM MANAGEMENT SYSTEMS FOLLOWING THE EUROPEAN COMMUNITY REFORM OF AGRICULTURAL POLICY

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AGRO-ENVIRONMENTAL EVALUATION OF ALTERNATIVE FARM MANAGEMENT SYSTEMS FOLLOWING THE EUROPEAN COMMUNITY REFORM OF AGRICULTURAL POLICY

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ABSTRACT

The results of simulation modelling carried out with GLEAMS on hypothetical scenarios driven by the Reform of Common Agricultural Policy are presented. The model was set up with data collected in recent research projects to simulate a typical cultivated environment of the Venetian Plain (north east Italy) where field experiments are in progress. Agro-environmental simulations were conducted over a long period using a 30-year weather record. First single crops, then entire rotations and finally the whole farm production patterns were simulated, based on the present standard agrotechnologies of the study area and on proposed low input systems. The alternative farm scenarios were taken from those hypthesised by economists on the basis of the recent Common Agricultural Policy (CAP) Reform with multi-objective modelling.

Environmental evaluation of alternative scenarios was carried out with 6 proposed indexes quantifying water pollution due to nutrient and pesticide releases associated with leaching and runoff phenomena. The environmental indexes focus on the efficiency of applied agrochemicals, regulatory and toxicity limits for drinkable water and risks for aquatic ecosystems (fish toxicity and eutrophication).

The results confirmed the potential risks of intensive cultivation systems, in particular when livestock wastes are distributed, and the various levels of efficacy of proposed eco-compatible systems to mitigate water pollution phenomena.

INTRODUCTION

In recent years the growing interest and concern of public opinion for the environmental consequences of agricultural productions have led to increased financial support for specific research.

In Italy two main research projects have been established: R.A.I.S.A. (Advanced Research for Innovation in the Agricultural System), sponsored by the National Research Council, and P.A.N.D.A. (Agricultural Production in the Defence of the Environment), sponsored by the Ministry of Agro-Forestry and Food Resources. In both of these the University of Padova and the Authors of this paper are involved with experimental and modelling studies in the Venetian Plain, dealing with the environmental consequences of alternative agricultural systems, focusing in particular on water pollution.

A new research project sponsored by the European Union and titled "Soil and Water Quality as Affected by Agrochemicals under Different Soil Tillage Systems" started in 1993 at the experimental farm of the University of Padova. Six groups from Italy, Germany and Portugal are involved with the aim of improving knowledge on the understanding of qualitative and quantitative effects of different management systems on soil and water. Emphasis is on the effects of tillage on pesticide pollution in the different environments of the three European countries involved.

The three cited research projects have in common the use of modelling for the elaboration and extrapolation of experimental observations to compare agro-environmental effects of various types of management.

These multiannual studies with simulation tools, and in particular with the GLEAMS model (Leonard et al., 1987), permit the extrapolation of the acquired knowledge to evaluate the environmental significance in terms of nutrient and pesticide releases of hypothetical agricultural systems for the Venetian Plain.

Agronomists and economists have co-operated for long time in the identification of new agricultural systems: traditionally field research, oriented by the changing needs of society, produced new options in terms of new cultivars, technologies, etc. which were subsequently evaluated from an economic point of view. This has led the progress of agriculture during recent decades, but seems to be no longer sufficient to deal with socio-economic international scenarios in ever faster evolution. In fact field experiments always require multiannual trials to obtain results supported by a statistical significance.

When the need is for forecasting various hypothetical scenarios and evaluating their agronomic, economic and environmental aspects, field experiments become a too slow and too expensive solution. In these cases a crucial role is played by mathematical models simulating observed or hypothetical agricultural systems and estimating their agro-environmental and economic characteristics.

Today operational tools are available for modelling agro-ecosystems and integrating multidisciplinary approaches in the sectors of crop physiology, agro-climatology, chemistry, hydrology and environmental impact assessment

(Giupponi, 1994). Some are oriented towards the comparison of alternative management practices and their environmental effects such as soil erosion and water pollution (e.g. Arnold et al., 1990; Leonard et al., 1987; Sharpley and Williams, 1990). Those models can be coupled with socio-economic ones to produce comprehensive evaluations of agricultural systems (Giupponi and Rosato, 1993).

This paper presents the evaluation of the environmental impacts on water quality of possible alternative scenarios of farm production systems driven by the recent reform of the Common Agricultural Policy (CAP) (EC Reg. 92/1765 and 92/2078).

Detailed and cumulative indexes are proposed and discussed for comparing the water pollution effects of nutrient and pesticide releases from cultivated land: simulated concentrations and amount lost by leaching and runoff are analyzed with respect to the main sources for concern for water pollution: drinkability, mammal and non-mammal toxicity, and risks of eutrophication.

MATERIALS AND METHODS

The set of hypothetical alternative scenarios of production systems for small family farms on the Venetian Plain is taken from the work of Rosato and Stellin (1994). These Authors proposed two sets of alternative farm patterns (in terms of percentages of cultivated crops) driven by the EC reform of market prices (first) and the accompanying measures for the introduction of eco-compatible practices (second). The sets of efficient solutions were obtained with a multi-objective model, searching for optimal solutions for maximising the gross margin (income minus explicit costs) and minimising a risk index based on yield variability of crops.

The two extreme and two intermediate cases were taken from the two sets of 8 and 7 efficient solutions for agro-environmental evaluations. Production patterns were examined from an agronomic point of view to produce realistic specifications of the agricultural systems and their environmental consequences (Table 1):

- high input management practices were adopted for farm scenarios 1-4 based on the market reform (EC Reg. 92/1765), while low input techniques were used in those (5-8) based on eco-compatible agriculture (EC Reg. 92/2078);
- irrigation was introduced for scenarios 1-4, whose crop patterns include intercropping, which, in the study area, implies the availability of irrigation for spring and catch crops (soybean and maize);
- the application of standard amounts of livestock wastes (liquid manure) was introduced for farm scenarios 3 and 4, with crop patterns typical of stock farms: intercropping with forage maize and barley substituting wheat as the main crop;
- a set of possible crop rotations were hypothesised on the basis of the crop percentages of farm scenarios and of the current habits of the Venetian Plain: 4-year, 3-year or 2-year rotations were attributed to farm scenarios proposed by Rosato and Stellin (1994) to approximately meet these crop patterns. In this way it was assumed that a farmer wishing to adopt one of the proposed set of crop percentages must first organise his crop distribution into a rational scheme of rotations to obtain satisfactory yields with normal techniques.

Simulations were organised in a two step procedure: single crop (or combination of main and catch crop) and rotation. For both steps the GLEAMS model (Leonard et al., 1987) was implemented on the environment of the Legnaro experimental farm (see Table 2), where the EU research project is in progress, with a 30-year record of meteorological observations. GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) is a mathematical model which simulates the complex climate-soil-management interactions for field-size areas. It was developed to evaluate edge-of-field and bottom-of-root-zone loading of water, sediment, and agricultural chemicals from alternative management systems. Recently a component was added to the model to simulate relatively comprehensive nitrogen and phosphorus cycles in the soil (Knisel,1993). The objective of the model is to evaluate the differences among management systems and not to predict the absolute quantities of water, sediment, and chemicals lost from the field. There are numerous examples of GLEAMS applications to assess management alternatives in many parts of the world (e.g. Giardini et al., 1992 Leonard and Knisel, 1989).

As discussed below, the model application demonstrated the complexity of agro-ecosystem responses to changes in management practices, such as nutrient losses obtained with increased uses and losses of pesticides. This leads to the search for evaluation indexes allowing comparisons and judgements of various kinds of environmental impacts.

An examination of recent literature allowed the definition of a set of 6 evaluation indexes aimed at scoring and ranking the environmental impacts of alternative scenarios on water pollution, which is the major source for concern in the environmental consequences of agriculture in the study area (Berti et al., 1994; Marchetti, 1993; Wothing and Hance, 1991; Vismara, 1992). Water pollution was examined referring to the potential uses of this resource.

Pollution potential through leaching was considered to affect the drinkability of water, since most drinking water in the Venetian Plain is taken from ground water. Instead, pollutants removed by runoff were considered to interfere with surface water ecosystems in terms of non-mammal toxicity and risk of eutrophication. The calculation of environmental impact indexes was conducted as follows:

1) Absolute losses (30-year averages) of nutrients and pesticides per crop (or main+catch crop) and their ratios to applied quantities (*agrochemical inefficiency index, AI*).

2) Number of leaching events exceeding drinkability limits for nitrates (50 mg NO_3 L^{-1}) and pesticides (0.1 μg L^{-1}) of every scenario (*regulatory drinkability index, RD*).

3) Health risk derived from total pesticide losses of each scenario, weighted on the basis of their toxicity for mammals, with a cumulative groundwater danger index (GWDI) proposed by Berti et al. (1994) as the ratio between the leached amount and the value of the guideline (see Appendix 1) (*mammal toxicity index, MT*).

4) Number of runoff events exceeding fish toxicity limits of each scenario (LC_{50} for rainbow trout) reported in the Pesticide Manual (Worthing and Hance, 1991) (*non-mammal toxicity index, NT*).

5) Number of runoff events exceeding thresholds of eutrophication risk reported in Marchetti (1993): 10 mg L^{-1} of total phosphorus and 30 mg L^{-1} of total N (*eutrophication risk index, ER*).

6) Cumulative index obtained by adding and rescaling the values of indexes 2 through 5 (*cumulative impact index, CI*).

RESULTS AND DISCUSSION

In the first simulation step, fifteen parameter files for the GLEAMS model were compiled, based on crop patterns of the alternative scenarios reported in Table 1, to represent annual modules of single crops, or main+catch crops, with the various alternative management systems.

Simulations were run on a 30-year period, to obtain multiannual averages of the contribution of various crops to the environmental consequences of alternative farm scenarios. This first set of simulations allowed estimates and comparisons of environmental impacts on water quality of crops and management and calculations of efficiency indexes for applied nutrients and pesticides, reported in Table 3. The magnitude and the general trends of those results are consistent with experimental observations (see for instance Borin et al., 1994a and b; Morari and Giupponi, 1994) and they have then been used as a basis for further elaboration.

For the average nutrient losses, the topography of the simulated environment typical of the alluvial Venetian Plain determined relatively intensive leaching phenomena and limited sediment losses, relevant only for phosphorus. For the same reason phosphorus losses are in general relatively low and do not show significant effects from changes of crops and management. As expected the maize crop shows the widest range and the highest values of nitrogen releases, confirming its role as a high risk crop when liquid manure is applied, but demonstrating also the big possibility of reducing water pollution with low input strategies. Sugar beet confirmed its capacity to take up large amounts of nutrients, which determines stable losses with changing management. It is also interesting to note the relatively high nitrogen releases of soybean (legume crop), which could be reduced, as shown in Table 3, with the reduced tillage depth simulated in low input management. The differences in set aside values are determined by the simulation of a winter cover crop in the low input system (treated with Glyphosate in early spring).

Cheching the agrochemical inefficiency index (AI) values for nutrients demonstrates the general trend of increasing efficiency (lower AI's) of cultivation systems which do not use liquid manure and eco-compatible ones. In some cases low input systems provide greater inefficiency due to lower yields which determine lower nutrient uptake. In general, higher AI's are for nitrogen (range 6.1-21.1) than for phosphorus (range 3.9-9.7), due to the greater mobility of nitrates and ammonium, with respect to phosphates. The agrochemical inefficiency index (AI) for nitrogen, was not calculated for soybean and set aside where no nitrogen fertilizers are applied.

Pesticide losses have magnitudes from milligrams to grams per hectare per year (range 0.4-25450 mg ha^{-1} y^{-1}) which correspond to AI's from less than 0.001 % for MCPA to a maximum of 1-3 % for Terbuthylazine. Having constant pedo-climatic variables, differences in AI's are due to rates, timing and chemical properties of the molecules: water solubility, Koc and half life in particular (see Appendix 1).

Results of simulations conducted on single crops allowed comparisons among the potentials of various crops in determining environmental impacts, but can be affected in some cases by unrealistic long term effects over the 30-year period. For instance, the simulation of continuous set-aside for 30 years could produce a long term reduction in organic matter and nutrient pools, influencing the estimate of average releases.

To avoid this source of errors and represent more realistic cropping systems in the second step of model simulation, more complex parameter files were compiled for GLEAMS to represent the hypothetical farm scenarios proposed by Rosato and Stellin (1994), with a set of 15 crop rotations proposable for the Venetian Plain (Giardini, 1992).

The model output files were modified to allow the extraction of parameters needed to calculate the evaluation indexes previously presented. Thus, a complete list of leaching and runoff events with their respective chemical parameters was compiled for each rotation for the 30-year simulation period. The details of the indexes' results for each rotation are reported in Appendix 2. Index values of farm scenarios are graphically reported in figure 1.

The index values for the eight hypothetical farm scenarios were then calculated by weighting the rotation indexes on the basis of rotation percentages of each scenario reported in Table 1. Results of this last step are reported in Table 4. All the index values are rescaled between zero and one.

Simulation results demonstrated a potential risk of ground water contamination from leaching of Metolachlor, MCPA and Dicamba and very small amount of leachates were simulated also for Linuron and Terbuthylazine (Appendix 2).

Regulatory drinkability indexes (RD) of leaching water evidenced the high frequency with which drinkability standards are exceeded in farming systems where the spreading of livestock wastes and intercropping are adopted (scenarios G and L_∞). This is frequently due (Appendix 2) to excesses in nitrate concentrations when soybean is the catch crop, while maize forage produces more pesticide leaching events over 0.1 mg L^{-1}. Regarding this it is interesting to note that the low input systems are always below 50% of the value of scenario G and that the lowest RD is associated to scenario 5 (A, low input) which has 10% of cultivated land put to set-aside.
For the molecules simulated in the leachates the GWDI indexes were calculated on the basis of guideline values reported in Appendix 1 and total leaching losses (Appendix 2); a cumulative GWDI was calculated from the sum of GWDI's of each molecule for every rotation. After rescaling and weighting, scenario G (high input with liquid manure) resulted again as the worst in terms of potential health risks from drinking polluted water, while MT indexes of eco-compatible scenarios are always below 1 % of MT value for scenario G.
Calculation of NT indexes, demonstrating potential risks for fish in surface water receiving runoff from cultivated land, showed that even if, on average, about 20 runoff events per year are simulated, none of them in any rotation exceeds the concentration limits of LC_{50} for rainbow trout (see Appendix 1).
Nutrient concentrations in runoff water have been examined to calculate the index of eutrophication risk (ER). With reference limits set at 10 mg L^{-1} of total phosphorus and 30 mg L^{-1} of total N, the number of events exceeding these limits ranges from 83 (during the 30-year period) for rotation B-W-S-A with low input management system to a maximum of 238 (see Appendix 2) for rotation B-W/S-W/S-W/S (high input and liquid manure). After weighting and rescaling, scenario L_∞ (high input and liquid manure) had the highest ER value, and all high input scenarios have ER indexes close to 1, while low input ones range around 0.5.
The cumulative impact indexes (CI), obtained with a rescaled sum of the previous four, confirm the relatively high potential for water pollution from high input management systems utilising liquid manure. Significant impact reductions can be obtained with low input systems (CI ranging between 0.20 and 0.31), both with crop patterns privileging soybean (A and L_∞) and those with high maize hectarages (D/L_1 and F).

CONCLUSIONS

Model simulations of agricultural diffuse pollution, based on observations from multiannual field experiments, allows evaluations of possible environmental consequences of alternative farm scenarios previously defined with an economic approach.
Changes in crop patterns can determine significant changes in water pollution potentials. Low input practices can in general produce beneficial effects on the environmental impact of agricultural systems. However, the effects of alternative systems are complex and can give contradictory information: changes in nitrogen, phosphorus and pesticide releases are not always correlated and sometimes can also show opposite trends.
For this reason, the evaluation of alternatives should be based on comparative indexes permitting the definition of the environmental meanings of various types of pollution (different nutrients and pesticides) for defined potential uses of water resources: drinkability, recreation, etc.
The proposed indexes are all indirect measures of potential impacts (e.g. drinkability of water is estimated at the bottom of the root zone instead of in the aquifer), but are considered to be strictly related to water pollution risks associated with agricultural production and useful for comparing alternative management systems, at least in the same environment.
Other indexes could be calculated to add the evaluation of impact on soil and air and then combined in a cumulative one.
While in this work all the indexes have been added and given the same weight in the calculation of CI, more complex algorithms can be proposed to meet economic evaluations of alternative uses of polluted resources, or orientations of public opinion.
A detailed evaluation of model results for alternative management systems can give useful information about the environmental role of single practices or crops, such as the effects of set-aside and legumes on nutrient balances.
The results presented above can only be utilised for the comparison of the tested alternatives, as the absolute values reported in the tables must be considered incorrect given the adopted methodology. Moreover two important sources of errors in estimating should be pointed out.
The first is that the evaluation of pesticide pollution is at present strongly affected by the wide variability in the literature of values for key parameters (Koc, Lg, etc.) used by the model and in the index calculations.
The second is that the present version of the adopted model presents new routines for nutrient cycling, which have already been extensively tested and validated (Knisel, 1993), but the results still have to be considered with prudence.

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Table 1: Alternative productive scenarios for small family farms of the Venetian Plain (from Rosato and Stellin,. 1994; modified), irrigation, use of liquid manure and crop rotations.

	FARM SCENARIOS							
	1	2	3	4	5	6	7	8
	A	E/L$_1$	L$_\infty$	G	A	L$_\infty$	D/L$_1$	F
CROP PERCENTAGES								
Soybeans (S1)	14.0	0.0	0.0	0.0	32.5	25.0	18.0	9.0
Soybeans (catch crop) (S2)	39.0	50.0	42.2	0.0	0.0	0.0	0.0	0.0
Maize (M1)	0.0	25.0	25.0	25.0	0.0	22.0	32.0	33.0
Maize (catch crop) (M2)	0.0	0.0	3.8	50.0	0.0	0.0	0.0	0.0
Winter wheat (W)	49.0	50.0	0.0	0.0	32.5	28.0	25.0	33.0
Winter barley (Y)	0.0	0.0	50.0	50.0	0.0	0.0	0.0	0.0
Sugar beet (B)	23.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Set-aside (A)	10.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0
INPUT LEVEL	H	H	H	H	L	L	L	L
IRRIGATION	Y	Y	Y	Y	N	N	N	N
LIVESTOCK WASTE	N	N	Y	Y	N	N	N	N
CROP ROTATIONS (%)								
B-W-S-A	40.0	0.0	0.0	0.0	40.0	0.0	0.0	0.0
B-W/S2-W/S2-W/S2	52.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B-W/S2-M1-W/S2	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
B-Y/S2-M1-Y/S2	0.0	0.0	84.8	0.0	0.0	0.0	0.0	0.0
B-Y/S2-M1-Y/M2	0.0	0.0	15.2	0.0	0.0	0.0	0.0	0.0
B-Y/M2-M1-Y/M2	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
B-S-M1-W	0.0	0.0	0.0	0.0	0.0	88.0	72.0	36.0
B-W-S-W	0.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0
B-W-M1-M1	0.0	0.0	0.0	0.0	0.0	0.0	28.0	0.0
B-W-S	0.0	0.0	0.0	0.0	45.0	0.0	0.0	0.0
B-W-M1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.0
W-S	8.0	0.0	0.0	0.0	15.0	0.0	0.0	0.0
W-M1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0

Table 2: Main pedo-climatic characteristics of the experimental farm of the University of Padova at Legnaro (north-east Italy).

Average annual rainfall (mm)	802.3
Average annual temperature (°C)	11.74
Average slope of the fields (%)	1.5
Average surface areas of the fields (ha)	0.5
Range of shallow water table depth (m)	0.4-2.0
Gravel (%)	0
Sand (%)	56
Silt (%)	30
Clay (%)	14
pH	8.05
salinity (ECe, mS cm^{-1})	224
Total carbonates (%)	18.6
Organic matter (%)	1.6
Cation exchange capacyty (meq 100 g^{-1})	21.57

Table 3: Estimated losses of nutrients and pesticides and their Agrochemical Inefficiency (AI) indexes.

Crop Management		W H	W L	M1 H_w	M1 H	M1 L	B H_w	B H	B L	S1 H	S1 L	Y/S2 H_w	Y/M2 H_w	W/S2 H	A H	A L
Nitrogen	runoff	5.05	3.11	12.41	10.93	6.03	4.73	3.25	3.18	2.32	2.60	6.60	16.37	5.42	0.81	0.96
	sediment	0.41	0.31	0.86	0.92	0.88	0.86	0.69	0.69	0.93	0.93	1.33	1.07	1.10	1.63	1.40
	leaching	26.05	9.96	82.33	44.03	6.98	3.52	2.51	2.65	40.89	22.00	29.30	48.47	13.70	5.10	1.40
	AI	15.32	21.10	20.56	18.63	6.90	6.10	6.44	6.52	--	--	--	15.9	--	--	--
Phosphorus	runoff	2.40	1.66	1.63	2.03	0.81	1.36	1.73	0.97	1.83	0.65	2.23	2.50	2.13	0.70	0.87
	sediment	1.54	1.41	2.00	2.47	1.97	2.20	2.21	1.82	2.47	1.80	4.00	3.17	4.00	3.50	0.93
	leaching	1.30	1.29	1.73	1.73	1.31	1.17	1.17	1.16	1.37	1.30	0.73	1.27	0.70	0.78	2.07
	AI	5.23	4.36	9.74	7.79	5.83	4.72	3.93	6.58	8.10	6.25	4.00	3.96	3.90	--	--
Bromoxinil	runoff	134.3										264.7	167.7	173.0		
	sediment	1.5										2.4	2.0	1.8		
	leaching	0.0										0.0	0.0	0.0		
	AI	0.03										0.06	0.04	0.04		
Dicamba	runoff			14.4	14.4											
	sediment			0.0	0.0											
	leaching			165.1	166.0											
	AI			0.05	0.05											
Ethofumesate	runoff						12475.3	12475.3	6232.3							
	sediment						30.7	30.7	16.7							
	leaching						0.0	0.0	0.0							
	AI						1.39	1.39	1.39							
Fluazifop-P	runoff						551.7	551.7	551.7	390.3	378.0	727.3		533.3		
	sediment						16.0	16.0	16.0	20.8	20.7	21.9		31.0		
	leaching						0.0	0.0	0.0	0.0	0.0	0.0		0.0		
	AI						0.44	0.44	0.44	0.30	0.31	0.58		0.37		
Glyphosate	runoff															5780.0
	sediment															116.7
	leaching															0.0
	AI															0.78
Lenacil	runoff						5336.7	5336.7	2660.1							
	sediment						58.3	58.3	30.0							
	leaching						0.0	0.0	0.0							
	AI						1.50	1.50	1.49							
Linuron	runoff									3689.2	3720.7					
	sediment									14.2	14.3					
	leaching									0.1	0.0					
	AI									1.02	1.04					

Table 3: Continued.

MCPA	runoff	0.2						2.7	0.4	0.4
	sediment	0.0						0.0	0.0	0.0
	leaching	2.2						5.5	0.2	0.9
	AI	0.00						0.00	0.00	0.00
Metolachlor	runoff		3854.0	4198.8	1927.0	4194.3	4196.7		4476.7	
	sediment		4.3	4.6	2.1	7.7	7.7		2.8	
	leaching		0.4	0.4	0.1	0.0	0.0		11.2	
	AI		0.26	0.28	0.26	1.02	0.31		0.30	
Terbuthylazine	runoff		10183.3	10651.3	5133.3				25449.7	
	sediment		37.4	38.4	18.9				41.7	
	leaching		0.0	0.0	0.0				0.0	
	AI		1.36	1.43	1.36				3.40	

Nutrient losses expressed as kg ha^{-1} , pesticide losses as mg ha^{-1} , AI as percentage of applied amounts.

For crop acronyms see table 1. Management: H = high input; Hw = high input with livestock wastes; L = low input.

Table 4: Evaluation indexes of water pollution potential of alternative productive scenarios for small family farms of the Venetian Plain.

	FARM SCENARIOS							
	1	2	3	4	5	6	7	8
	A	E/L$_1$	L$_\infty$	G	A	L$_\infty$	D/L$_1$	F
INDEXES								
Regulatory drinkability (RD)	0.26	0.40	0.61	1.00	0.16	0.41	0.35	0.20
Mammal toxicity (MT)	0.31	0.44	0.39	1.00	0.00	0.00	0.00	0.00
Non-mammal toxicity (NT)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eutrophication Risk (ER)	0.87	0.97	1.00	0.98	0.45	0.52	0.52	0.46
Cumulative impact (CI)	0.48	0.60	0.66	1.00	0.20	0.31	0.29	0.22

Appendix 1: Pesticide parameters.

Molecule	Water solubility (mg L^{-1})	$t_{1/2}$ soil (days)	Koc (l g^{-1})	Lg (mg L^{-1})	LC$_{50}$ for rainbow trout (mg L^{-1})
Bromoxinil	0.08	7	10000	18.0	0.15
Dicamba	400000.00	14	2	105.0	135.00
Ethofumesate	50.00	30	340	--	180.00
Fluazifop-P-butyl	2.00	15	5700	17.5	13.70
Glyphosate	900000.00	47	24000	1050.0	86.00
Lenacil	50.00	3	50	--	10.00
Linuron	75.00	60	400	31.5	16.00
MCPA	5.00	25	1000	0.5	117.00
Metolachlor	530.00	90	200	5.o	2.00
Terbuthylazine	130.00	64	645	12.0	4.60

From: Knisel. 1993; Berti et al., 1994; Zanin and Berti, 1992.

Appendix 2: Details of index calculation of simulated rotations.

					RD (n/30y)			
input	liv_w		events	tot_exc	pest_exc	nutr_exc	INDEX	RESC_I
H	-	B-W-S-A	509	110	62	48	110	0.20
H	-	B-W/S-W/S-W/S	480	160	147	36	160	0.29
H	-	B-W/S-M-W/S	598	221	161	110	221	0.40
H	W	B-Y/S-M-Y/S	488	326	84	293	326	0.59
H	W	B-Y/S-M-Y/M	562	418	287	308	418	0.75
H	W	B-Y/M-M-Y/M	599	557	513	274	557	1.00
L	-	B-W-S-A	568	43	34	9	43	0.08
L	-	B-W-S	528	90	12	78	90	0.16
L	-	W-S	539	207	0	207	207	0.37
L	-	B-S-M-W	528	238	51	192	238	0.43
L	-	B-W-S-W	521	160	10	154	160	0.29
L	-	B-W-M-M	553	80	29	54	80	0.14
L	-	B-W-M	536	8	3	5	8	0.01
L	-	W-M	771	123	0	123	123	0.22

					MT (mg/ha/y)					
input	liv_w		dicamba	linuron	MCPA	metolach.	terbuthyl.	GWDI tot	INDEX	RESC_I
H	-	B-W-S-A		0.003	57.1	5.3		115.5265	115.5	0.15
H	-	B-W/S-W/S-W/S			186.2			372.4	372.4	0.48
H	-	B-W/S-M-W/S	23.5		169.4	8.6		341.1738	341.2	0.44
H	W	B-Y/S-M-Y/S	23.4		129.7	3		260.3729	260.4	0.34
H	W	B-Y/S-M-Y/M	23.4		230.4	191.4	0.007	508.8734	508.9	0.66
H	W	B-Y/M-M-Y/M	16.41		328.7	464.7	0.01	773.7321	773.7	1.00
L	-	B-W-S-A				5.9		1.475	1.5	0.00
L	-	B-W-S				3.2		0.8	0.8	0.00
L	-	W-S		0.003		0.023		0.00725	0.0	0.00
L	-	B-S-M-W				9.4		2.35	2.4	0.00
L	-	B-W-S-W				3.3		0.825	0.8	0.00
L	-	B-W-M-M				12.4		3.1	3.1	0.00
L	-	B-W-M				1.3		0.325	0.3	0.00
L	-	W-M				0.003		0.00075	0.0	0.00

Appendix 2: Continued.

RD (n/30y)

input	liv_w			INDEX	RESC_I
H	-	B-W-S-A		0.00	0.00
H	-	B-W/S-W/S-W/S		0.00	0.00
H	-	B-W/S-M-W/S		0.00	0.00
H	W	B-Y/S-M-Y/S		0.00	0.00
H	W	B-Y/S-M-Y/M		0.00	0.00
H	W	B-Y/M-M-Y/M	ALWAYS BELOW VALUES	0.00	0.00
L	-	B-W-S-A	OF LC_{50} FOR RAINBOW TROUT	0.00	0.00
L	-	B-W-S		0.00	0.00
L	-	W-S		0.00	0.00
L	-	B-S-M-W		0.00	0.00
L	-	B-W-S-W		0.00	0.00
L	-	B-W-M-M		0.00	0.00
L	-	B-W-M		0.00	0.00
L	-	W-M		0.00	0.00

ER (n/30y)

input	liv_w		events	tot_exc	P_exc	N_exc	INDEX	RESC_I
H	-	B-W-S-A	584	157	141	28	157	0.66
H	-	B-W/S-W/S-W/S	521	238	211	59	238	1.00
H	-	B-W/S-M-W/S	562	220	177	75	220	0.92
H	W	B-Y/S-M-Y/S	570	226	181	78	226	0.95
H	W	B-Y/S-M-Y/M	558	225	176	81	225	0.95
H	W	B-Y/M-M-Y/M	565	221	153	93	221	0.93
L	-	B-W-S-A	592	83	77	11	83	0.35
L	-	B-W-S	535	111	106	12	111	0.47
L	-	W-S	616	117	114	12	117	0.49
L	-	B-S-M-W	535	115	103	30	115	0.48
L	-	B-W-S-W	532	128	121	17	128	0.54
L	-	B-W-M-M	551	125	104	30	125	0.53
L	-	B-W-M	537	97	92	13	97	0.41
L	-	W-M	594	106	97	19	106	0.45

INDEX SUMMARY

input	liv_w		RD	MT	NT	ER	CI
H	-	B-W-S-A	0.20	0.15	0.00	0.66	1.01
H	-	B-W/S-W/S-W/S	0.29	0.48	0.00	1.00	1.77
H	-	B-W/S-M-W/S	0.40	0.44	0.00	0.92	1.76
H	W	B-Y/S-M-Y/S	0.59	0.34	0.00	0.95	1.87
H	W	B-Y/S-M-Y/M	0.75	0.66	0.00	0.95	2.35
H	W	B-Y/M-M-Y/M	1.00	1.00	0.00	0.93	2.93
L	-	B-W-S-A	0.08	0.00	0.00	0.35	0.43
L	-	B-W-S	0.16	0.00	0.00	0.47	0.63
L	-	W-S	0.37	0.00	0.00	0.49	0.86
L	-	B-S-M-W	0.43	0.00	0.00	0.48	0.91
L	-	B-W-S-W	0.29	0.00	0.00	0.54	0.83
L	-	B-W-M-M	0.14	0.00	0.00	0.53	0.67
L	-	B-W-M	0.01	0.00	0.00	0.41	0.42
L	-	W-M	0.22	0.00	0.00	0.45	0.67

Figure 1

Environmental impact indexes