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EFFECTS OF AGRICULTURAL ACTIVITIES ON WATER POLLUTION WITH NITRATES AND PESTICIDES IN THE CENTRAL VALLEY OF CHILE

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ABSTRACT

The objectives of this study are, first, to describe the present use of fertilisers between the Regions III and VIII of Chile, identifying the associated environmental impacts and their relationship with the predominant agricultural practices and climatic characteristics. Secondly, to simulate the transport of nitrates and pesticides in a dairy and breeding farm of the Central Valley of Chile, employing EPIC (USDA/ARS) in order to determine the importance of these contamination processes. In the North area of Chile, agricultural production generates soil and groundwater salinization problems due to low average rainfall and the use of highly efficient irrigation practices. In the Central zone, nitrate contamination due to agricultural diffuse pollution is evident; this is especially valid for groundwater contamination with nitrates. The South Central area suffers from eutrophication due to an increase in the nutrient levels in surface water. The simulation indicates that the dairy farm in the Central Valley of Chile has a soil loss of 5.02 tons/ha/year or of 14.67 tons/ha/year, based on MUSS or USLE estimates, respectively. It is important to point out that loss of NO_3 and pesticides estimated by MUSS and USLE do not exceed maximum allowable standards. © 1999 IAWQ Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Nitrates; pesticides; agricultural externalities; diffuse pollution; groundwater contamination.

INTRODUCTION

In Chile, the contamination processes associated with agricultural and forestry production systems have not been extensively measured. Several studies have been conducted to identify and quantify surface water quality (Vallejos, 1971; INIA, 1986; Alamos and Peralta, 1989; Lagos, 1990; González, 1990, 1992; and Peña, 1992). These studies indicate, without quantifying, the importance of diffuse sources of pollution such as agriculture.

In a more recent study, Steffen (1993) states that the use of water in agricultural and forestry activities has significantly increased the nitrate and phosphorus contamination of the lakes of the southern region of Chile, thus contributing to eutrophication processes. Additionally, inadequate faecal management of intense milk production systems and of feedlots (Pedraza, 1994), and the existence of salmon production sites (González, 1992) has decreased water quality due to the bacteriological, organic and physical-chemical contamination generated by the discharge of solid and liquid residues.

However, at present, it is possible to simulate the environmental implications of different agricultural practices with respect to soil erosion and nutrient and pesticide loss through surface runoff and leaching processes, with various computer simulation models such as EPIC, WEPP, RUSLE and OPUS. These models use specific farm data (soil, slope, climate, crop rotation and production management) to simulate erosion and crop production through one or more years. Furthermore, EPIC and OPUS can also simulate nutrient and pesticide loss through leaching and runoff. It is important to point out that all of these models assume constant production technology.

Considering that there are few studies that quantify erosion, the loss of nutrients and pesticide residues to groundwater and surface water systems, and the effect on productivity in the long run (as done by Faeth *et al.*, 1991), the objectives of this study are first to, describe the present use of fertilisers between the Regions III and VIII of Chile, identifying the associated environmental impacts and their relationship with the predominant agricultural practices and climatic characteristics. Secondly, to simulate the transport of nitrates and pesticides in a dairy and breeding farm of the Central Valley of Chile, employing EPIC (USDA/ARS) in order to determine the importance of these contamination processes. This area was chosen for the present study since intensive agricultural production systems are concentrated in this area.

IRRIGATION PRACTICES AND EFFICIENCIES IN THE STUDY AREA

The area between Regions III and VIII of Chile can be divided into three zones that are differentiated by rainfall and by irrigation efficiency: the North zone, Central zone and South Central zone. Regions III and IV are in the North zone. In this area, agricultural production is not possible without irrigation due to the hydrological deficit generated by low rainfall levels (see Table 1). The V, VI, and Metropolitan (RM) regions form the Central zone. This area is characterised by a slightly higher rainfall than the North zone; however, agricultural production in areas with eventual irrigation is restricted only to a few crops. Finally, the VII and VIII Regions are in the South Central zone, which is similar to the Central zone, but with a lower hydrological deficit.

As can be appreciated from Table 1, rainfall increases from Region III to Region VIII; that is, it increases from north to south. Irrigation requirements thus decrease in the same direction. Additionally, empirical evidence indicates that as water becomes less scarce, irrigation efficiency is reduced from a maximum of 90% in the North zone to 25% or less in the South Central Zone.

Table 1. Average monthly rainfall by region (mm)

Region	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOT
III	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IV	0.2	1.0	0.6	3.6	17.5	24.6	26.5	18.6	7.5	3.5	1.9	0.8	106.3
V	5.4	5.7	8.7	20.5	70.7	84.0	70.3	58.9	25.4	15.2	9.1	6.5	380.4
RM	4.4	4.7	7.2	17.0	58.6	69.6	58.3	48.8	21.1	12.6	7.5	5.4	315.2
VI	9.2	9.9	15.2	35.7	123.0	146.1	122.4	102.5	44.3	26.4	15.9	11.2	661.9
VII	11.7	12.5	19.2	45.2	155.5	184.8	154.7	129.6	56.0	33.4	20.1	14.2	837.0
VIII	26.3	25.9	42.0	77.8	206.8	236.2	204.6	167.4	92.4	57.0	41.9	31.9	1210.1

Source: Based on Santibañez and Uribe (1990).

Due to the important relationship between irrigation efficiencies and nitrate and pesticide contamination processes, it is important to determine the irrigation practices and efficiencies for each agricultural zone. The main irrigation practices that are in use in the different zones are identified, and for each of these an efficiency is assigned based on national information (Comisión Nacional de Riego, 1982; Dirección General de Aguas, 1994; Gurovich, 1989), in order to estimate the weighted average irrigation efficiencies. The standard efficiencies associated with each irrigation practice, which includes conduction efficiency within the farm, are presented in Table 2.

Table 2. Irrigation efficiency for different irrigation practices in different zones (%)

Irrigation Practice	Zone		
	North	Central	South Central
Flood	30	30	20
Furrow	50	50	43
Technical systems	80	70	

Source: Based on different National Studies (Comisión Nacional de Riego, 1982; Dirección General de Aguas, 1994; Gurovich, 1989).

Considering that in the North zone water is scarcer, flood and furrow irrigation were assigned efficiencies of 30% and 50%, respectively. Technical irrigation systems, on the other hand, were assigned an average efficiency of 80% for the North.

In the Central zone, technical irrigation systems present an average efficiency of 70% since water scarcity is not as high as in the North zone and, thus, the relative importance of drip irrigation is reduced while Californian irrigation systems are more important.

Finally, in the South Central zone, as Table 3 shows, there are no technical irrigation systems (Dirección General de Aguas, 1994). Additionally, flood and furrow irrigation systems present an average efficiency of 20% and 43%, respectively. These values are lower than in the North and Central zones due to the edaphic and topographic characteristics of the area; a high proportion of undulated red clays and ñadis soils that result in higher surface runoff.

Table 3. Cultivated land and land irrigated with technical systems by region

Region	Land irrigated with technical systems (ha)	Cultivated Land (ha)
III	6.061	14,793
IV	5.048	56,482
V	2.995	72,371
RM.	792	155,472
VI	742	212,454
VII	n.a.	457,367
VIII	n.a.	178,201

Source: Dirección General de Aguas (1994).

Once irrigation efficiencies have been determined, each agricultural production system must be assigned a specific irrigation system. The methodology employed to estimate irrigation technology allocation considers that: i) cereals and prairies are irrigated with flood systems, ii) horticultural crops and a large proportion of fruit-growing areas are irrigated by furrows, and iii) a large proportion of technical irrigation systems are employed in fruit production.

Thus, the weighted average irrigation efficiencies for each zone were estimated based on the standard efficiency of each irrigation method using the water demand of each crop as weights. The land assigned to each irrigation method was not taken into account as weights, given that this presupposes that each hectare irrigated with the same technology applies the same amount of water; an assumption which does not represent reality.

The weighted average irrigation efficiencies for each Region and zone are presented in Table 4. It is important to note that the estimates presented in Table 4 are validated by actual irrigation efficiencies. For example, in Regions VII and VIII irrigation efficiencies are approximately 25%, in the Metropolitan Region they are 36%, and in Region IV irrigation efficiency reaches 42% (Table 5).

Table 4. Weighted average irrigation efficiency

Region	Cultivated Land by Region or Area (ha)	Efficiency
III	14,793	0.45
IV	56,482	0.43
V	72,371	0.46
RM	155,472	0.43
VI	212,454	0.41
VII	457,367	0.28
VIII	178,201	0.30
North Area	71,274	0.43
Central Area	440,297	0.42
South Central Area	635,568	0.28

Table 5. Irrigation efficiency by zone

	Area			
	North	Central	South Central	Total
Actual Efficiency (%)	42	36	25	30

Source: Modified from Valenzuela *et al.* (1991).

Table 6. Historic consumption of nitrogenous fertilisers in Chile (tons)

Year	Tons of nitrogen	Sodium nitrates	Potassium nitrates	Urea	Total	Nitrates (%)	Urea (%)
1975	36,693	14,466	32,930	11,747	59,143	0.80	0.20
1976	48,545	168,507	39,473	21,583	229,563	0.91	0.09
1977	37,105	114,526	38,159	22,624	175,309	0.87	0.13
1978	49,336	123,570	53,634	32,666	209,870	0.84	0.16
1979	56,722	110,818	42,767	54,184	207,769	0.74	0.26
1980	50,836	83,186	41,899	51,566	176,651	0.71	0.29
1981	47,733	84,546	39,015	48,164	171,725	0.72	0.28
1982	48,056	165,024	47,478	23,378	235,880	0.90	0.10
1983	64,871	177,804	39,072	53,461	270,337	0.80	0.20
1984	86,290	232,021	46,073	74,945	353,039	0.79	0.21
1985	104,465	286,359	40,912	99,796	427,067	0.77	0.23
1986	135,978	256,753	43,360	179,361	479,474	0.63	0.37
1987	140,800	220,000	50,000	190,000	460,000	0.59	0.41
1988	150,400	220,000	48,000	210,000	478,000	0.56	0.44
1989	156,030	190,000	42,000	230,000	462,000	0.50	0.50
1990	150,498	135,000	37,000	240,000	412,000	0.42	0.58
1991	164,492	138,178	51,789	269,397	459,364	0.41	0.59
1992	181,604	165,473	52,908	292,351	510,732	0.43	0.57
1993	180,281	176,620	51,452	293,493	521,565	0.44	0.56
1994	165,240	105,201	66,084	277,916	449,201	0.38	0.62
1995	186,071	148,161	57,281	311,046	516,488	0.40	0.60
1996	182,344	141,316	55,918	304,831	502,065	0.39	0.61

Source: Ministerio de Agricultura.

NITROGEN CONSUMPTION IN THE STUDY AREA.

In 1996, as shown in Table 6, the domestic consumption of nitrogen fertilisers reached approximately 567 thousand tons, which is equivalent to approximately 182 thousand tons of nitrogen. Of this total nitrogen fertiliser consumption, 35.2% was in the form of nitrates, 11.4% as phosphate ammonium, and 53.4% as urea.

The significant increase in the consumption of nitrogen fertilisers can be explained, in part, by the introduction of high yielding varieties with high nutrient demands during this period. It is important to point out the increase in the relative importance of urea with respect to the use of nitrates. The relative importance of urea as a source of nitrogen increased from 15% in the seventies to approximately 60% in the last few years. This increase became significant in the eighties due to the liberalisation of the nitrogen fertiliser market.

It is interesting to analyse the nitrogen fertiliser consumption for the different agricultural sectors. This consumption of nitrogen fertiliser for each sector is estimated based on cultivated land and on the standard doses for each agricultural product. The results of this estimation are presented in Table 7. The estimates indicate that in 1996 annual crops consumed approximately 66% of the total nitrogen consumption, while the fruit and horticultural sectors consumed 13% and 7%, respectively.

Table 7. Estimated nitrogen consumption by sector (tons)

Year	Annual Crops	Flowers	Fruits	Vineyards
1994	116926.0	144.0	24551.0	3086.0
1996	119779.1	169.8	22968.2	2945.2

Year	Horticultural	Prairies	Forestry	Total
1994	11935.0	14952.0	3000.0	174594.0
1996	11944.9	19536.8	5000.0	182344.1

With respect to the regional distribution of nitrogen consumption, it is important to point out that 90% of the total consumption is concentrated between the Metropolitan Region and Region X. However, the relative importance of the source of nitrogen varies throughout this area. The consumption of urea is concentrated in the northern regions while the southern regions consume primarily nitrates. This is due to the natural acidity of the soils in the southern regions and to the acidifying nature of urea.

In summary, total nitrogen consumption has significantly increased over the past few years in Chile and the main agricultural sectors, which consume nitrogen, are, in order of significance, annual crops, fruit, and horticultural crops. The importance of annual crops is due to the extensive area they cover and to the fact that some annual crops are fertilised with high doses; corn, for example, in some areas of the Central zone, is fertilised with 450 kg N/ha. Fruit production also employs high nitrogen doses, but these are less significant with respect to total nitrogen consumption since the area dedicated to their production is lower than for annual crops. Finally, even though horticultural crops represent an intensive agricultural activity, they are restricted to reduced areas.

AGRICULTURAL DIFFUSE POLLUTION IN CHILE

Based on the analysed climatic characteristics, irrigation practices and nitrogen consumption, it is possible to foresee the major environmental impacts due to agricultural diffuse pollution. In the North area agricultural production generates soil salinization problems due to low average rainfall and the use of highly efficient irrigation practices. The low water input in conjunction with high evapotranspiration rates produces accumulation of salts. At the same time, this problem of soil salinization leads to the agricultural practice of periodically flooding the production fields in order to reduce the salt content. This in turn leads to the salinization of groundwater (see Tables 8 and 9). Additionally, nitrate contamination is not expected to be an important agricultural diffuse pollution problem in the North zone because of the restricted transport of the contaminant due to the hydrological deficit, which characterises this area.

In the Central zone, on the other hand, there is an increased transport of nitrates through surface runoff and percolation due to the fact that average rainfall increases, irrigation practices are characterised by lower efficiencies, and nitrogen consumption is greater, in relation to the North zone. Thus, nitrate contamination due to agricultural diffuse pollution is seen in the Central zone; this is especially valid for groundwater contamination with nitrates (see Table 9).

The South Central zone presents the lowest hydrological deficit due to increased average rainfall and the lowest irrigation efficiency; in some areas irrigation efficiency is less than 30%. Despite these facts, nitrate contamination of groundwater is expected to be lower than in the Central zone due to the edaphic and topographic characteristics of the area which favour surface runoff over lixiviation processes. For the same reasons, in this area agricultural diffuse pollution is associated with nutrient increase in surface waters, which accelerates eutrophication problems.

Table 8. Agricultural diffuse problems in chile

Region	Environmental Problem	Importance	Number of Environmental. Problems	Ranking*
I	1) Water Pollution caused by pesticides	3	118	88
II	N.P.			
III	1) Water pollution with agrochemical products	3.9	117	34
	2) Surface and Groundwater pollution caused by agricultural chemicals	3.8		36
	3) Groundwater pollution due to agricultural disinfectants	3.2		64
IV	1) Water Pollution caused by pesticides	3.7	115	54
	2) Water pollution caused by excess fertilisation	3.8		56
	3) Pesticide pollution	3.7		58
V	1) Chemical pollution due to agricultural pesticides	4.1	132	27
	2) Biological pollution due to agriculture	3.9		42
R.M.	1) Groundwater pollution	3.8	136	68
VI	1) Water Pollution caused by pesticides	3.5	99	43
VII	N.P.			
VIII	1) Chemical pollution of surface and groundwater	3.6	112	55

* This ranking corresponds to the relative importance with respect to the other environmental problems of the region.

Source: Espinoza, Gross and Hajek (1991).

Table 9. Pollutants which exceed environmental standards for groundwater, by region

Region	Pollutant Exceeding the Standard (mg/l)	Level	Area
I	Chlorides	352-493	Arica, Iquique, La Tirana
	Arsenic	0.13	Pisagua, Chapiquiña
	Manganese	0.39	
II	Arsenic		Taltal
	Sulfates		
III	Sulfates	600	
	Fe-SO4	0.34-427	
IV	Sulfates	533	
	Iron	0.56	
	Manganese	0.328	
V	Manganese	0.17	
	Sulfates	300	San Antonio, Cartagena, El quisc
	Iron	0.32	
	Chlorides	344	Papudo, Zapallar
VI	Manganese	0.18	Rengo
	Lead	0.08	Malloa
	Mercury	0.002	Pelequén
VII	Iron	0.33	Curanipe
VIII	Iron	0.4	Coronel
	Iron	0.4	Florida
	Iron	0.35	Bulnes
	Iron	0.48	Coelemu
	Manganese	0.28	Quillón
	Iron	0.36	Santa Clara
	Iron	0.38	Nacimiento
	Iron	0.6	Cabrero
	Manganese	0.25	Cabrero
	Iron	0.7	Monte aguila
	Manganese	0.16	Monte aguila
	Mercury	<.005	Celulosa Baja
IX	Iron	0.48	Galvarino
	Iron	0.85	Carahue
	Iron	0.44	Chol Chol
	Iron	0.34	Quitratue
	Iron	0.44	Angol
	Iron	0.46	Lumaco
X	Iron	0.34	Osorno
RM	Sulfates	259-390	Maipo, Laguna Negra
	Sulfates	300-380	Talagante, Peñaflor
	Sulfates	310	Melipilla
	Sulfates	280-400	Buin
	Sulfates	330	Paine
	Sulfates	280	Isla de maipo
	Sulfates	280	Pomaire
	Sulfates	280	Valdivia de Paine
	Sulfates	652.5	Melipilla Norte
	Sulfates	266-290	Maipú-Cerrillos
	Chlorides	258-270	Maipú-Cerrillos
	Nitrates	12.3 mg N-NO_3/lt	Maipú-Cerrillos
	Sulfates	266-290.5	Maipú-San José
	Chlorides	282.9	Maipú-San José
	Nitrates	13 mg N-NO_3/lt	Maipú-San José
	Sulfates	317	Maipú-El Abrazo
	Sulfates	290	Maipú-Aras Figuron
	Sulfates	279	COOPSAP-La Puntilla
	Fe-Mn	3.5-0.14	COOPSAP-La Puntilla
XI	No Problems		
XII	No Problems		

Source: Superintendencia de Servicios Sanitarios.

SIMULATION OF AGRICULTURAL DIFFUSE POLLUTION FROM A DAIRY AND BREEDING FARM IN THE CENTRAL VALLEY OF CHILE

Methodology

Based on an analysis of the characteristics of the EPIC, WEPP and RUSLE models, EPIC was considered to be the most complete of the three and the most suitable for the study due to its capacity to simulate erosion, loss of productivity, nutrients and pesticides which contaminate water. Since its creation in 1985, EPIC has demonstrated its utility in several studies in different parts of the world (Magri, 1996).

The USDA/ARS team in Temple, Texas, which developed the program, kindly provided EPIC version 5125, used in this study to simulate the contamination processes which occur on a dairy and breeding farm near the city of Melipilla, in central Chile.

Locality and soils. The farm is located 20 km from Melipilla and is composed of 125 ha of two different soil series; 87.5 ha of the series Piedmont Lo Vasquez that has an average slope of 5%, and 37.5 ha of the series Pomaire that has a slope of 3%. Soil data for each series, presented in Tables 10 and 11, were obtained from the National Irrigation Commission (1981).

Table 10. Description of soil series Piedmont Lo Vasquez

Soil layer	1	2	3	4	5	6
Depth (m)	0.16	0.31	0.55	0.72	1.05	1.20
Density (T/m^3)	1.4	1.3	1.3	1.3	1.2	1.2
Wilting Point (m/m)	0.09	0.08	0.10	0.13	0.18	0.18
Field Capacity (m/m)	0.18	0.15	0.18	0.28	0.27	0.26
Sand (%)	54.5	56.0	52.1	51.6	39.6	44.1
Silt (%)	31.5	3.70	26.9	12.1	23.0	19.8
Soil pH	7.8	7.7	7.6	7.6	7.6	7.5
Organic C (%)	1.10	0.20	0.20	0.20	0.10	0.10
$CaCO_3$ (%)	0.10	0.30	0.10	0.10	0.20	0.20

Table 11. Description of the series Pomaire

Soil layer	1	2	3	4
Depth (m)	0.23	0.50	0.78	1.25
Density (T/m^3)	1.3	1.3	1.3	1.3
Wilting Point (m/m)	0.13	0.07	0.14	0.14
Field Capacity (m/m)	0.23	0.12	0.25	0.25
Sand (%)	38.2	63.0	32.0	33.9
Silt (%)	37.8	19.9	42.7	42.0
Soil pH	7.2	7.2	7.5	7.5
Organic C (%)	2.30	1.00	1.90	1.70
$CaCO_3$ (%)	0.10	0.10	0.10	0.10

Climate. Climatic data necessary for EPIC simulations were obtained from the climatic monitoring station in Melipilla. Data collected from 1980 to 1995 were used to calculate the required averages, variances and standard deviations. Only the historic maximum intensity for 0.5-hr rainfall was not obtained from the climatic station and was estimated using values for 1, 2, 24, 48 and 72 hr maximum rainfall intensities registered from 1980 until 1995. Exponential curves were adjusted to these values in order to estimate the maximum historical values for 0.5-hr rainfall intensity. The curves adjusted well for each month's historical data, obtaining an R^2 from 0.8777 to 0.9994.

Crop rotation and management. The farm produces alfalfa for 4 years (for hay and silage), ryegrass in winter (for hay) and maize in summer (for silage) in a crop rotation that lasts 5 years. This allows a stable production of 100 ha of alfalfa, 25 ha of ryegrass and 25 ha of maize each year. This crop rotation offers adequate soil cover all year round, which is important, as the soils have slopes of 3% and 5%.

Dairy. The dairy farm is stabilised with 225 milk producing cows. Animals on the farm were separated into 9 groups according to age, sex and stage of milk production. Normal growth rates and lengths of lactation were assumed.

Epic simulations

A series of EPIC simulations were used to estimate initial soil productions for each of the two series of soils, long term erosion, pesticide fate and nutrient loss that would occur under the present management scheme of the farm, and to estimate the productivity of the soil after erosion.

The following simulations were made using EPIC:

1. Complete crop rotation (excluding seedbed preparation for ryegrass) for 21 years, using static soil and 12 different climatic sequences.
2. Ryegrass alone (with complete management) for 21 years, using normal winter growth, static soil and 12 different climatic sequences.
3. Complete rotation (excluding seedbed preparation for ryegrass) for 61 years, using a normal soil profile (that suffers erosion) and 12 different climatic sequences.
4. Complete crop rotation (excluding seedbed preparation for ryegrass) for 21 years, using static soil, 12 different climatic sequences and final soil data from simulation No. 3.
5. Ryegrass alone (with complete management) for 21 years, using normal winter growth, static soil, 12 different climatic sequences and final soil data from simulation No. 3.

These 5 series of simulations were run for each soil, using both MUSS and USLE as erosion estimator equations. Simulation 1 gives the initial productivity of alfalfa and maize on the 2 soils. Simulation 2 indicates the initial productivity of ryegrass (grown under normal management and soil preparation) for the 2 soils. Simulation 3 estimates the magnitude of erosion, loss of nutrients and pesticides. It should also determine the soil's productivity loss due to erosion, but this was not the case. This is presumably due to the high amount of nitrogen in the crop rotation (from fertilisation and atmospheric fixation by alfalfa) and to the fact that irrigation was set so that the plants would not suffer from water stress. The same problem was found by Faeth *et al.* (1991) in their simulations using EPIC. Their solution to the problem was to input final soil data estimated by EPIC and to rerun the simulations so as to estimate the productivity of the eroded soil. The same solution was used in this case so as to include the soil's decline in productivity in the investigation. Final soil data is obtained from the results of simulation 3 and is employed in simulations 4 and 5, which indicate the soil's productivity of alfalfa, maize and ryegrass after 61 years of erosion.

Results and discussion

This section presents the results obtained from the EPIC simulations. The results indicate that there exists a high correlation between superficial runoff estimated by EPIC and irrigation. However, runoff due to irrigation does not have an important impact on soil erosion; the major factor affecting soil erosion is rainfall, which occurs when plant ground cover is low (in winter).

Of the 5 possible equations EPIC can use to quantify erosion, MUSS is the one that predicts less soil loss, whereas USLE is the one which predicts the most, as shown in Table 12. MUSS and USLE were selected so as to compare their results and indicate the range of possible results.

Table 12. Annual soil erosion estimates

Equation	Soil P. Lo Vasquez	Soil Pomaire	Farm Average
USLE	15.05	14.54	14.69
AOF	10.90	10.47	10.77
MUSL	7.88	7.52	7.77
MUST	6.13	5.85	6.05
MUSS	5.09	4.84	5.02

EPIC estimated a surface runoff of 7,073.157 m^3/ha/year, which is equivalent to 7,073,157 l/ha/year. MUSS estimated a soil loss of 5.02 tons/ha/year, which implies that sediment concentration was 709.7 mg/l in runoff water. Maximum sediment concentration allowed for drinking water is 1,000 mg/l (World Health Organisation, 1995) and 10,000 mg/l in drinking water for animals (Ayers and Weatcot, 1976); thus the farm's runoff water does not exceed the maximum permitted limits. Using the USLE estimation of 14.67 tons/ha/year however, the sediment concentration in runoff water increased to 2,077 mg/l, which exceeds the maximum allowed standard.

Other EPIC outputs (water contamination by pesticides, fertilisers and sediments) are presented in Tables 13 to 16.

Table 13. Pesticide fate estimated when using MUSS

	Kerb	Dyfonate	Basagran
Amount applied (g/ha)	101.0	280.0	90.0
Pesticide lost in runoff (g/ha)	16.08	70.06	49.09
Pesticide Leached (ppt)	0.0813	0.0014	0.1725
Pesticide in subsurface flow (ppt)	1.325	0.495	0.388
Pesticide in sediments (g/ha)	0.3	0.3	0.0
Pesticide Biodegraded on Foliage (g/ha)	0.0	1.0	0.0
Pesticide biodegraded in soil (g/ha)	83.84	208.32	40.12

Table 14. Pesticide fate estimated when using USLE

	Kerb	Dyfonate	Basagran
Amount applied (g/ha)	101.0	280.0	90.0
Pesticide lost in runoff (g/ha)	16.41	77.85	51.35
Pesticide leached (ppt)	0.0876	0.0018	0.1866
Pesticide in subsurface flow (ppt)	0.203	0.624	0.485
Pesticide in sediments (g/ha)	1.4	0.4	0.0
Pesticide biodegraded on foliage (g/ha)	0.0	1.0	0.0
Pesticide biodegraded in soil (g/ha)	78.11	201.11	37.88

Table 15. Loss of soil nutrients estimated using MUSS

Nutrients lost	Quantity (kg/ha)
NO_3 in runoff	21.4
Mineral N in subsurface flow	1.0
Mineral N leached	5.8
Organic N lost with sediment	15.4
P lost with sediment	2.2

Table 16. Loss of soil nutrients estimated using USLE

Nutrients lost	Quantity (kg/ha)
NO_3 in runoff	20.6
Mineral N in subsurface flow	1.0
Mineral N leached	6.0
Organic N lost with sediment	33.2
P lost with sediment	5.0

It is important to point out that loss of NO_3 and pesticides estimated by MUSS and USLE were also compared to the maximum permitted emission concentrations, but did not exceed them. This is due, in part, to the hydrological deficit, which characterises the area.

SUMMARY AND CONCLUSIONS

Total nitrogen consumption has significantly increased over the past few years in Chile and the main agricultural sectors which consume nitrogen, are, in order of significance, annual crops, fruit, and horticultural crops.

In the North area, agricultural production generates soil and groundwater salinization problems due to low average rainfall and the use of highly efficient irrigation practices. In the Central zone, nitrate contamination due to agricultural diffuse pollution is present; this is especially valid for groundwater contamination with nitrates. The South Central area suffers from eutrophication due to an increase in the nutrient levels in surface water.

The simulation indicates that the dairy farm of the Central Valley of Chile has a soil loss of 5.02 tons/ha/year or of 14.67 tons/ha/year, based on MUSS or USLE estimates respectively. It is important to point out that loss of NO_3 and pesticides estimated by MUSS and USLE do not exceed maximum allowable standards.

In view of agricultural diffuse pollution, there is an urgent need in developing countries to quantify these processes so as to minimise or revert the damage. Computer simulation models, such as EPIC, are a useful tool that allows the researcher to quickly quantify and simulate many productive options. Once the farm's database for EPIC has been input and the model calibrated and validated, modifications in farm management can easily be simulated in order to determine best management practices concerning erosion and nutrient and pesticide loss. This is a useful tool for the design of correct agricultural policies to regulate diffuse pollution caused by agricultural activities. Finally, these small-scale models must be integrated with larger scale watershed models so as to quantify the full effects of agricultural diffuse pollution.

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