



Land-Water Linkages in Rural Watersheds Electronic Workshop 18 September – 27 October 2000

Case Study 1

Optimizing soil fertility and plant nutrition to prevent groundwater pollution

Peter Cepuder and Volker aus der Schmitten
Institute for Hydraulics and Rural Water Management
University of Agricultural Sciences
Muthgasse 18
Vienna, Austria
email: Cepuder@mail.boku.ac.at; H522t38@edv2.boku.ac.at

Abridged and changed version of the paper 'Optimizing soil fertility and plant nutrition to prevent groundwater pollution', P. Cepuder, M.K. Shukla, P. Liebhard and M. Tuller. 1988. Optimizing soil fertility and plant nutrition to prevent groundwater pollution. Proc. 15th World Congress on Soil Science, Montpellier, France

INTRODUCTION

Contamination of groundwater from point and non-point sources is one of the major pollution problems. The agricultural community has become keenly aware of the impact of irrigation and fertilization on groundwater quality. Agriculture in particular, is identified as a significant contributor to diffuse source contamination (Byrnes, 1990; Addiscott *et al.*, 1991; Goss and Gooraho, 1995). Excess use of chemicals, fertilizers increase the risk of groundwater contamination. Nitrates are the primary form of inorganic nitrogen within the soil, which are essential for the growth and development of a healthy crop. However, nitrates are very soluble in water and therefore, very mobile within soil solution. Nitrogen transformation in soils are also very complex and dynamic and have the potential to produce substantial N-losses via leaching, ammonia volatilization, denitrification, and runoff. N-losses not only result in lower production and subsequently increase in production costs but also lead to surface and groundwater pollution. Much effort has already been made for the optimum use of manure and fertilizers in such a way that sufficient food is produced without contaminating the groundwater quality.

In the plains of Austria, the nitrate concentration has increased very dramatically in the last four decades. The first objective was to quantify the ground water pollution by measuring the percolation and nitrate leaching. It is well known that simulation models may improve the ability to analyze soil nutrient transformations and losses and thereby can improve the fertilizer recommendation and management. Keeping this aspect in mind, the second objective was the simulation of the groundwater pollution caused by fertilizers using the physically based model EPIC. The crop cover has a substantial influence on nitrate leaching and percolation, therefore, the third objective was to find out the effect of cover crop on nitrogen leaching and percolation. The fourth objective was to explore the possibilities for recommending a sustainable combination of fertilizer and cover crop.

STUDY AREA

The present study is located in the west of Vienna. The total area under study is about 850 km². Agriculture is the principle land use of the area. The river Danube bisects Tullnerfeld in two parts, Tullnerfeld north and Tullnerfeld south. The area of the northern part is 46 932 ha while the southern is 38 167 ha. The land use classification of area shows that out of the total area of 85 099 ha, 51 628 ha is agricultural land, 25 733 ha is forests or woods and the rest 7738 ha has settlements. The soil of the area is a typical chernozem. The climate of the area is influenced by the continental and the pannonical climate. The average annual temperature of the area is about 9.5 °C and the average annual precipitation is about 570 mm.

MATERIALS AND METHODS

In order to measure the nitrogen leaching and percolation in Tullnerfeld, a small lysimeter and suction cups were installed below each parcel.

The Environmental Policy Integrated Climate Program (EPIC) developed by Williams *et al.* (1984) is a physically based field scale model. The model was originally developed to assess the effect of soil erosion on soil productivity. It is a continuous simulation model that can be used to determine the effect of management strategies on agricultural production and soil water resources. The major components of EPIC include weather simulation, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, crop management and growth, pesticide and nutrient movement with water and sediments, and field scale costs and returns.

EPIC Water Quality model can be used to simulate water and nitrogen transport in the unsaturated soil. The amount of NO₃-N contained in runoff, lateral flow, and percolation are estimated as products of volume of water and the concentration for a daily time step. The

calculations are started at the upper layer and the various processes are repeated layer by layer to the bottom of the soil profile (USDA, 1992). In order to operate the program for estimating nitrate leaching and percolation, various input parameters are necessary. Optimal results are achieved, when daily weather data are available.

The soil classification was carried out using the available textural classification, soil maps, and the various soil parameters estimated wide Baumer (1989). On the basis of weighted average plant available water storage capacity the soil was further classified as group 1, 2 and 3 or a very good, good and average soil respectively.

The meteorological data used in this estimation were provided by eight weather stations located in the observed area. Based on the statistical cropping pattern for last five years, a crop rotation of corn (C), winter wheat (W), barley (B), sugarbeet (S), and again W, was considered for simulation. The simulation was carried out for three combinations of crop rotation viz. S-W-C-W-B, C -W-B-S-W, and B-S-W-C-W, for a standard fertilizer application with and without cover crop. For tillage data, actual tillage operations as practiced by the farmers of the study area were considered for the simulation.

During the period from 1992 to 1995 a four year crop rotation of rye - corn - winter wheat - sunflower was considered at the lysimeter site. The weekly measurement of percolation and nitrogen leaching was made for two levels of nitrogen fertilizer i.e. no fertilizer application (0 N) and standard application (100% N). The weekly amounts of nitrogen obtained in this way were summed up to get the annual amounts. The annual crop yield from the area was also obtained. In order to validate the EPIC model, the measured data were compared with the results of the simulation for lysimeter site.

RESULTS AND DISCUSSION

Measured and simulated data on crop yield, percolation and nitrogen at the lysimeter site:

These data are presented in Table 1. The results on measured and simulated yields show a very good agreement. In the first year when no fertilizer was applied in the parcel, crop yield remained almost unaffected. However, from the second year the yield from the unfertilized plot decreased between 35 and 45 percent both for measured and simulated data.

TABLE 1
Measured and simulated results

Year	crop	Rainfall [mm]	yield [t.ha ⁻¹]		Percolation [mm]		Nitrogen-leaching [kg.ha ⁻¹]	
			0 N	100% N	0 N	100% N	0 N	100% N
Measured data								
1992	rye	520	6.0	4.9	85	88	58	85
1993	corn	484	6.4	9.5	96	67	38	67
1994	w-wheat	477	3.3	6.1	52	46	3	52
1995	sunflower	684	1.8	2.7	58	25	2	23
Simulated data								
1992	rye	520	5.2	5.2	81	69	59	29
1993	corn	484	6.7	9.0	83	36	1	21
1994	w-wheat	477	3.2	6.1	80	80	3	40
1995	sunflower	684	2.0	2.6	112	48	2	23

The measured percolation as shown in Table 1 was higher for the first two years of measurement. This is probably due to the disturbances in soil caused by the lysimeter installation and refilling. However, the measured percolation is lower than the simulated percolation for year 1994 and 1995. This is probably due to the delay in emptying the lysimeter after dry periods. The measured nitrogen leaching was higher for year 1992 and 1993 than the simulated values. But for the year 1994 and 1995 these results are almost same. These measurements will be continued till year 2001.

Use of the EPIC model: The model was used for the earlier mentioned crop rotation for all three soil groups to obtain yield, percolation and nitrogen leaching from the entire area with and without cover crop. The simulation for this crop rotation was carried out for a forty year period. In order to reduce the impact of climatic conditions on a particular crop, three different starting crops namely, corn, barley and sugarbeat were chosen. During the winter period between barley and sugarbeat alpha-alpha and during the winter period after winter wheat a combination of mustard, vetch and peas were planted as cover crop. Because of space limitation, only one simulation result for soil group 2 and one crop rotation with and without cover crop is presented here. Table 2 also contains the average annual arial rainfall, yield, percolation and nitrogen leaching. The nitrate concentration in the percolated water was calculated from nitrogen leaching and percolation.

TABLE 2
Average annual results for soil group 2

crop	Rainfall [mm]	yield (dry matter) [t.ha ⁻¹]	Percolation [mm]	Nitrogen – leaching [kg.ha ⁻¹]	NO ₃ concentr. [mg.l ⁻¹]
Without cover crop					
corn	465	8.2	53	10	85
winterwheat	514	5.4	76	9	53
barley	509	3.9	78	17	99
sugarbeat	494	13.3	75	15	89
winterwheat	499	5.5	33	8	106
With cover crop					
corn	465	7.9	34	9	120
winterwheat+cc	514	5.4	45	13	124
barley+cc	509	3.9	56	21	166
sugarbeat	494	13.1	51	8	67
winterwheat+cc	499	5.5	27	6	99

cc = cover crop

Due to the fact that cover crop transpire water, percolation was always lower for simulation with cover crop. However, it is clear from the above table, that there is no direct relationship between percolation and nitrogen leaching.

The Table 3 shows the results for the three soil groups and for the chosen crop rotation starting with sugarbeat (S-W-C-W-B), corn (C-W-B-S-W), and barley (B-S-W-C-W).

TABLE 3
Summary of average annual results for three soil groups and for different crop rotations without cover crop

Crop rotation	Yield (dry matter) [t.ha ⁻¹]			Percolation [mm]			Nitrogen – leaching [kg.ha ⁻¹]			NO ₃ concentration [mg.l ⁻¹]		
	sg1	sg2	sg3	Sg1	sg2	sg3	sg1	sg2	sg3	sg1	sg2	sg3
S-W-C-W-B	6.8	7.1	3.9	67	68	189	8	12	74	55	78	175
C-W-B-S-W	6.9	7.3	4.2	66	63	180	10	12	70	65	84	173
B-S-W-C-W	7.1	7.4	4.5	61	60	175	7	8	63	48	61	159

sg = soil group

Water storage capacity: The water storage capacity is one of the most important parameter for plant growth in regions with dry periods extending more than a week. The difference in the water storage capacity between soil group 1 (232 mm) and 2 (198 mm) is only 34 mm). Therefore, the plants in these soil groups should always have a good water supply. The organic substance of soil group 2 is little higher than soil group 1 and probably, this is the reason that soil group 2 always shows higher yields and nitrogen leaching. The yield of soil group 2 is about 5% higher and varies between 7.1 t.ha⁻¹ to 7.4 t.ha⁻¹ dry matter for the chosen crop rotation. Soil group 3 has the lowest yield varying between 3.9 to 4.5 t.ha⁻¹. Though this soil group contains a high organic substance, the plant available water is only 50 mm which results in reduction in the yield quite substantially.

Percolation from soil group 2 is nearly the same like soil group 1 and varies between 60 mm to 68 mm. Due to the higher content of organic matter and higher mineralisation the leached

nitrogen is found between 8 and 12 kg.ha⁻¹ and the nitrate concentration is about 75 mg.l⁻¹, which exceeds the limit for drinking water. The worst results were obtained in soil group 3. Though the average percolation is nearly 180 mm per year, the nitrogen leaching is the highest due to the reduced plant uptake. Therefore, the nitrate concentration of the percolation water reaches as high as 170 mg.l⁻¹.

The following table contains the **effect of cover crop in the crop rotation**. It shows that the crop yield is maximum from soil group 2, followed by soil group 1. The nitrogen leaching is minimum from the soil group 1 followed by group 2. Soil group 3 presents the worst results with the minimum crop yield and maximum nitrogen leaching.

TABLE 4
Summary of average annual results for three soil groups and for different crop rotations with cover crop

crop rotation	yield (dry matter) [t.ha ⁻¹]			Percolation [mm]			Nitrogen – leaching [kg.ha ⁻¹]			NO ₃ concentration [mg.l ⁻¹]		
	sg1	sg2	sg3	sg1	sg2	Sg3	sg1	sg2	sg3	sg1	sg2	sg3
S-W -C-W -B	6.3	6.8	4.0	53	47	155	7	15	72	55	145	205
C-W -B -S-W	6.7	7.1	4.5	52	42	151	6	11	67	51	118	196
B -S-W -C-W	6.8	7.2	4.8	51	41	146	6	9	61	51	93	185

* + cover crop, sg = soil group

A comparison between Tables 3 and 4 shows about 5% decrease in crop yield for soil group 1 and 2 with cover crop. In the soil group 3, use of cover crop result in a 5% increase in crop yield. This is probably due to the uptake of nitrogen by cover crop and subsequent release for the following crop.

Table 3 and 4 show a 30% reduction in percolation which amounts to 52 mm in soil group 1 and 43 mm in soil group 2 with cover crop which is clearly due to the additional transpiration taking place from the cover crop. The reduction in percolation was only 17% from soil group 3. In case of nitrogen leaching a reduction of 25% was observed in soil group 1 and 2% in soil group 3. An increase of 8% was measured for soil group 2. Depending on the reduction of percolation and partly nitrogen leaching the nitrate concentration increases in soil group 2 and 3. In soil group 1 a reduction from 56 mg.l⁻¹ to 52 mg.l⁻¹ was reached.

The above **results were extended to the entire area of Tullnerfeld**. These are presented in Table 5. Soil group 1 and soil group 2 covers nearly 52% and 44% of the total area respectively. It is clear from the table 5 that with an average percolation of 52 mm and 6kg.ha⁻¹ leached nitrogen per year soil group 1 with cover crop results in the minimum contamination of groundwater. The average annual nitrate concentration of the water passing through the root zone is about 52 mg.l⁻¹ and closely correspond to the nitrate concentration of 50 mg.l⁻¹ recommended by the European Community for drinking water.

TABLE 5
Total groundwater contamination with nitrogen for the entire Tullnerfeld

Soil group	Area [ha]	yield (dry matter) [t.ha ⁻¹]	Percolation [mm]	Nitrogen – leaching [kg.ha ⁻¹]	NO ₃ concentr. [mg.l ⁻¹]
without cover crop					
1	26694	6.9	65	8	56
2	22631	7.3	64	11	74
3	2302	4.2	181	69	169
weighted avg.		7.0	70	12	77
with cover crop					
1	26694	6.6	52	6	52
2	22631	7.0	43	12	119
3	2302	4.4	151	67	195
weighted avg.		6.7	52	11	95

Table 5 also points out the fact that the difference in crop yield between soil group 1 and 2 is not very significant but the nitrogen leaching from 1 is considerably less than 2 and therefore, soil group 1 presents the best results in both cases. Perhaps better results may be obtained if the cover crop does not contain legumes or alpha-alpha so no nitrogen can be collect from air.

The average percolation and nitrogen leaching are higher from the whole area without cover crop (table 5). But the average nitrate concentration of the water that leaves the root zone and reaches groundwater is lower in this case. However, combination of soil group 1 with cover crop and soil group 2 and 3 without cover crop is resulting in higher percolation, lower nitrogen leaching and concentration annually from the entire area. However, in our opinion this result needs to be evaluated further in order to arrive at a final conclusion.

In the present study area groundwater can be recharged either by rainfall (percolation) or by seepage from river or both. In the case when groundwater is mainly recharged by percolation, the use of cover crop can not be recommended as it is resulting in less annual percolation and consequently less recharge with higher nitrate concentrations. On the other hand, if seepage from river is the principle source of groundwater recharge, cover crop could be recommended as annual nitrogen leaching is less. As regards the best combination of soil, crop rotation, cover crop and weather conditions no definite conclusions could be arrived at this stage.

INTEGRATION OF GIS

Currently, at the Institute for Hydraulics and Rural Water-Management another project („Spatial modeling of nitrogen leaching with EPIC“) is worked on which tries to integrate the EPIC model into a GIS – platform. A main task is to investigate a complete area, modeling nitrogen leaching spatially. This may improve conclusions from other projects already worked on. A GIS – platform has been established that integrates all needed data and methods used to run an EPIC – simulation. Soil data are estimated with the empiric formula of BAUMER, the result of the Austrian Soil Map Survey serves as input for these formula. Daily weather data from different stations are spatially linked over THIESSEN-polygons. Croprotection is investigated for each community. On this platform, multiple scenarios can be run easily and the output viewed. Further information on this project can be achieved from our homepage: <http://ihlww.boku.ac.at/interreg/interreg2c.htm>

REFERENCES

- ADDISCOTT, T.M, et al., 1991:Farming. Fertilizers and the Nitrate Problem. CAB International. UK.
- BAUMER, O.W., 1989: Predicting Unsaturated Hydraulic Parameters. In van Genuchten M, Th. Und F.J. Leij. Indirect Methods for Estimating the Hydraulic Properties of Unsaturated Soils. - Proc. Of the Int. Workshop on Indirect Methods for Estimating the Hydraulic Properties of Unsaturated Soils. Riverside. California. October 11 - 13.
- BYRNES, B.H., 1990: Environmental Effects of N Fertilizer Use - An Overview. Fert Res 26. 209 - 215
- CEPUDER, P., M. TULLER; 1996: Simple field testing sites to determine the extent of nitrogen leaching from agricultural areas. Fertilizer Research 0, 1-11, Kluwer Academic Publishers, Netherlands
- CEPUDER, P.; M. TULLER; M.K. SHUKLA; H. MÜLLER, E. KORTSCHAK, P. LIEBHARD, H. HAGER, S. HUBER, R. HABERL, 1997: Estimation of ground-water contamination by various land uses with the simulation model EPIC and GIS. Proceedings of the 11th World Fertilizer Congress. Gent, Belgium.
- GOSS, M.J, and GOORAH, D., 1995: Nitrate contamination of groundwater; Measurement and prediction. Fert Res 42. 331 - 338
- USDA-ARS GRASSLAND SOIL AND WATER RESEARCH LABORATORY, 1992: EPIC User's Guide - Draft. Version 3270
- WILLIAMS, J. R. et al., 1984: A modeling approach to determining the relationship between erosion and soil productivity. Transactions, American Society of Agricultural Engineers 27, 129 – 144