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Effect of subsurface drainage on nutrient pollution of surface waters in south eastern Albania

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Abstract

Those who are familiar with salt problems in semi-arid regions are accustomed to thinking of managing water for its quality, but in areas where drainage water is primarily a result of excessive rainfall, drainage water management is a recently discovered tool. Thus, there are many unknowns in this area and much potential for improvements. Information is needed on the effects of subsurface drainage on the environment. A study to obtain information concerning the effect of subsurface drainage on nutrient pollution of surface waters was conducted from 1992–1995 in the Korça region, south-eastern Albania. The objectives of this study were: (a) to evaluate the effectiveness of subsurface drainage on reducing soil and nutrient erosion and surface run-off, and (b) to identify and evaluate the best water management practices to minimize off-site environmental impacts of drainage on outflow water quality in south-eastern Albania.

Keywords: Subsurface drainage; Surface run-off; Soil erosion; Nutrient erosion; Outflow water; Albania

1. Introduction

Subsurface drainage is used in many areas of Albania to increase crop yields by lowering the water table (improving the soil environment for plant root development, vegetative growth and soil water quality, providing better trafficable conditions for tillage, planting and harvest, etc.). Subsurface drainage may influence surface run-off, and soil and nutrient erosion from cropland. Surface run-off also presents a greater potential for soil erosion and sediment transport.

Drainage waters present two particular problems to fresh water and marine estuaries: a reduction in salt concentration due to fresh water dilution and contamination due to nutrients and sediment in the run-off. Subsurface drainage systems tend to reduce peak flows when compared with surface systems on similar soils. The influence of a good subsurface drainage system is to lower the water table and increase the potential for infiltration and soil storage at the time of a

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rainfall event, thereby reducing surface run-off. Improved subsurface drainage can reduce surface run-off by 3-fold [1–4].

Subsurface drainage will not only reduce the impact of the first problem by reducing peak flow, but it can also influence the second problem as the nutrient concentration in subsurface flow is generally different from surface run-off. Surface run-off tends to be higher in phosphorus and organic nitrogen [5–7] while subsurface drainage tends to be higher in nitrate-N [6–11]. Surface run-off also presents a greater potential for soil erosion and sediment transport [12,13]. Bottcher et al. [14] and Schwab et al. [15] report that sediment, phosphorus and potassium losses from drain outflow were considerably less than from surface run-off. They recommended that, on suitable soil types, subsurface drainage may well be a preferred best practice for soil and nutrient conservation. However, it is not clear which of the above situations poses the greatest detrimental effect to receiving waters. Generally, subsurface drainage reduces soil erosion and the loss of most plant nutrients on medium to heavy texture soils.

The influence of subsurface drainage, combined with normal fertilizer and chemical applications for crop production, will affect the shallow groundwater quality and may influence the quality of our water resources. A comprehensive evaluation of the quality of water entering, residing in and exiting subsurface drainage can provide essential information for the best management of this system and our water resources.

2. Materials and methods

The experimental sites are located in two adjacent district (Lumalas and Drithas) farms in south eastern Albania. The soils are classified as calcic chernozem. Three field sites were selected for an evaluation of the effect of subsurface drainage on soil and nutrient erosion and water quality. Sites 1 (8 ha) and 2 (10 ha) are located in the Lumalas district farms. Soil was a silty clay type. Topography was relatively flat. Site 3 (5 ha) is located in the Drithas district farms. Soil was of clay loam type, and had been graded to 1.5% slope. At each site a subsurface drained and a non-drained plot ~ 200 m long were selected. Subsurface drainage consisted of tubes installed at a depth of 1 m below the soil surface. Drain spacing was 13, 9 and 11 m at sites 1, 2 and 3, respectively. Soil profile descriptions, texture, physical and chemical properties, hydraulic conductivity and soil-water characteristics were determined for all sites. Some selected soil properties of the experimental sites are give in Table 1.

Earth dikes at least 0.3 m high were constructed around each plot to define the plot boundaries and to insure that run-off passed through the flumes where it could be measured and sampled. The drain outflow was discharged into 1.2 × 1.2 × 3 m metal sumps and pumped into a surface drainage ditch with electric pumps. In summary, one plot contained both surface and subsurface drainage (drained plot) and one control plot contained surface drainage only (non-drained plot).

The data collected from the experimental sites includes climatic, run-off, sediment and water quality information. The climatic data illustrated in this paper includes average monthly rainfall from 1992–1995 (Fig. 1). Rainfall was measured at a meteorological station near the experiment sites. Surface run-off was measured with H-flumes (the older and more familiar short-throated flumes for measuring open-channel flow) and water stage recorders. Drain outflow was measured with a utility-type meter as outflow was pumped from the sumps.

Surface run-off was sampled at 60-min intervals with an automatic water sampler installed at each flume. Outflow from the center drains of drained plots was sampled. Run-off and drain outflow samples were analyzed in the laboratory for sediment, nitrogen, phosphorus and potassium.

The water quality sampling procedure was designed to provide an estimate of subsurface and surface water quality. All samples were collected using grab techniques on approximately a 2-week interval. The apparatus used to collect the in-field samples consisted of a peristaltic pump, a filtering flask and a Teflon sampling tube inserted into a 1.5-m monitoring pipe at each site. This pumping system helped reduce the potential for contamination of the samples. The pumping procedures for

Table 1
Some selected soil properties of experimental sites

Sampling depth (cm)	Horizon	Texture (ISSS) (%)						Hydraulic conductivity (md^{-1})	pH	Bulk density (g/cc)
		Clay	Silt	Sand	Total N	Total P	Total K			
Site 1										
0–20	Ap	59.8	27.8	12.4	0.49	0.081	1.88	0.683	7.4	1.05
20–42	Bw1	63.5	26.0	10.5	0.38	0.073	1.76	0.476	7.4	1.10
42–73	Bw2	58.2	33.8	8.0	0.22	0.060	1.63	0.282	7.3	1.25
73–95	2Bd	71.8	16.5	12.4	0.09	0.042	1.32	0.154	7.1	1.43
95–110	3Bd	62.9	20.8	16.3	0.11	0.040	1.41	0.051	7.1	1.48
Site 2										
0–20	Ap	69.6	24.4	6.0	0.44	0.072	2.12	0.560	7.5	1.10
20–37	Bw1	87.0	8.3	4.7	0.42	0.068	1.94	0.429	7.3	1.15
37–65	Bw2	56.4	30.2	13.4	0.33	0.053	1.35	0.231	7.3	1.15
65–81	2Bd	75.6	19.9	4.5	0.28	0.057	1.52	0.118	7.3	1.62
81–104	3Bd	72.6	14.8	12.6	0.16	0.038	1.30	0.042	7.2	1.58
Site 3										
0–20	Ap	65.7	30.3	4.0	0.39	0.060	1.72	0.273	7.4	1.05
20–42	Bw1	66.6	29.5	3.9	0.31	0.062	1.65	0.209	7.4	1.05
42–62	Bw2	45.2	46.0	8.8	0.29	0.043	1.53	0.113	7.3	1.00
62–77	2Bd	65.2	32.0	2.8	0.11	0.036	1.23	0.058	7.2	1.58
77–95	3Bd	66.3	27.6	6.1	0.06	0.020	1.05	0.021	7.0	1.51

each well sample required that the shallow well be pumped out prior to collection of the sample to remove any foreign objects which may have entered the well since the last sample was taken. The samples collected at each site were stored on ice and treated with phenyl mercuric acetate (PMA) as a preservative. The water samples were analyzed for nitrates (NO_3-N), ammonium (NH_4-N) and ortho phosphate (PO_4-P) concentrations. The number of samples analyzed from selected sites varied due to the inability to obtain a sample during the dry periods. The data for each water quality parameter of the samples were statistically analyzed.

Peizometers were installed at several locations at each site to evaluate the quality of shallow groundwater and potential seepage. Samples were collected once each month from the tile depth (1 m) down to ~5 m at intervals based on the composition of the sediments at each site. Typical sampling depths were: 0.5–1 m, 1.5–2 m, 2.5–3 m and > 3 m. The desired sample depths were controlled by installing peizometers to the required depth. To collect the sample for water quality analysis, the peizometer was pumped from the bottom, then a sample taken as soon as the water level rose to the upper limit of the desired zone.

The magnitude and direction of the seepage flux was estimated at the site by monitoring the movement of a concentrated calcium chloride solution injected into the seepage zone at several locations in the field. A battery of observation wells were installed around a calcium chloride source well and the time variant hydraulic gradient and calcium chloride concentration were measured.

Corn was planted in April each year when it was fertilized with 96 kg/ha, 40 kg/ha and 75 kg/ha of nitrogen, phosphorus, and potassium, respectively. The corn was cultivated each year to control weeds and was harvested for silage in July. The plots were cultivated periodically from harvest until frost to control weeds.

3. Results and discussion

The results presented in this section are based on the data obtained from 1992–1995. The aver-

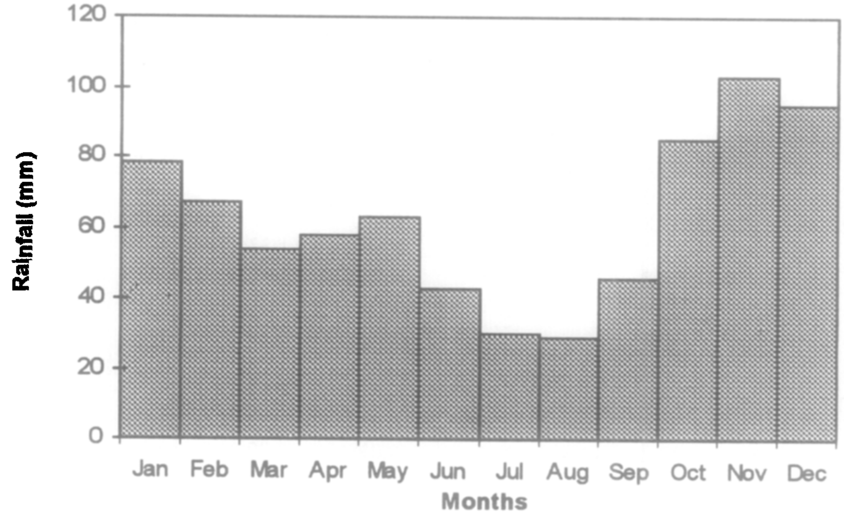

Fig. 1. Average monthly rainfall.

age annual surface run-off for sites 3, 2 and 1 were 76 and 172 mm, 168 and 253 mm and 146 and 211 mm for drained and non-drained plots, respectively (Table 2). The subsurface drainage reduced surface run-off by 30%, 34% and 56%, respectively. Also, 31%, 28% and 42% more water left the drained plots than the non-drained plots. The surface run-off accounted for 19%, 22% and 10%, and 17%, 21% and 23% of the rainfall from the drained and non-drained plots, respectively.

Subsurface drainage also reduced soil and nutrient losses with the exception of nitrogen. From 1992–1995, surface run-off at sites 1, 2 and 3 carried an annual average of 2543, 2992 and 1752 kg/ha of soil from the non-drained plots (Table 3). The drained plots lost 1761, 2088 and 1340 kg/ha of soil, i.e. a 31%, 30% and 24% reduction due to subsurface drainage. Subsurface discharges accounted for 203, 219 and 215 kg/ha or 12%, 10% and 16% of the total loss, respectively. The largest portion of the soil was lost during the October–December period, when ~35% of the average annual loss left the fields.

The average annual total nitrogen losses from the drained and non-drained plots at sites 1, 2 and 3 were 15.00, 17.53 and 11.42 kg/ha, and 11.98, 14.36 and 8.68 kg/ha (Table 4), respectively, i.e. a 25%, 22% and 24% increase due to subsurface drainage. The subsurface discharges contained 7.68, 9.22 and 4.32 kg/ha or 51%, 52% and 38% of the nitrogen lost from the drained plots. The majority of the nitrogen (56%) was lost in March and April, the period of intense rainfall, soon after the application of nitrogen fertilizer.

Table 2
Average annual runoff, 1992–1995 (in mm)

Site no.	Drained plot			Non-drained plot
	Surface	Subsurface	Total	Total
1	146	130	276	211
2	168	156	324	253
3	76	169	245	172

Table 3
Average annual soil loss, 1992–1995 (in kg/ha)

Site no.	Drained plot			Non-drained plot
	Surface	Subsurface	Total	Total
1	1558	203	1761	2543
2	1869	219	2088	2992
3	1125	215	1340	1752

Table 4
Average annual nitrogen losses, 1992–1995 (in kg/ha)

Site no.	Drained plot			Non-drained plot
	Surface	Subsurface	Total	Total
1	7.32	7.68	15.00	11.98
2	8.31	9.22	17.53	14.36
3	7.10	4.32	11.42	8.68

The average annual phosphorus losses from the drained and non-drained plots at sites 1, 2 and 3 were 3.15, 3.65 and 2.54 kg/ha, and 4.65, 5.58 and 3.56 kg/ha, respectively, i.e. a 32% 35% and 29% reduction due to subsurface drainage (Table 5). The subsurface discharges contained 0.22, 0.26 and 0.36 kg/ha or 5% 7% and 14% of the lost phosphorus. The phosphorus losses for the drained plots are evenly spaced throughout the year. For example, 39% (drained) and 34% (non-drained) of the phosphorus was lost during the winter.

The average annual potassium losses from the drained and non-drained plots at sites 1, 2 and 3 were 23.55, 27.78 and 19.14 kg/ha, and 32.66, 39.19 and 28.64 kg/ha, respectively, i.e. a 30%, 29% and 33% reduction due to subsurface drainage (Table 6). The subsurface discharges contained 3.29, 3.47 and 1.73 kg/ha or 14%, 12% and 10% of the total from drained plots, respectively. The largest monthly losses were in November when ~ 18% (drained) and 21% (non-drained) of the annual total was lost. However, unlike nitrogen, the losses occurred throughout the year. For example, 35% (drained) and 32% (non-drained) of the total potassium was lost during the winter as opposed to only 17% (drained) and 16% (non-drained) of the nitrogen.

Table 5
Average annual phosphorus losses, 1992–1995 (in kg/ha)

Site no.	Drained plot			Non-drained plot
	Surface	Subsurface	Total	Total
1	2.93	0.22	3.15	4.65
2	3.39	0.26	3.65	5.58
3	2.18	0.36	2.54	3.56

Table 6
Average annual potassium losses, 1992–1995 (in kg/ha)

Site no.	Drained plot			Non-drained plot
	Surface	Subsurface	Total	Total
1	20.26	3.29	23.55	32.66
2	24.31	3.47	27.78	39.19
3	17.41	1.73	19.14	28.64

The characteristics of the water quality measurements (maximum, mean and standard deviation) are shown in Table 7 for each site. Statistical analysis of the results are shown for each individual water quality parameter; sampling points in Fig. 2 do not imply that the concentration between the sampling points fell on that line. The concentration would be expected to vary between the sampling intervals.

In the statistical analysis, the subsurface drainage samples from non-drained plot samples contained significantly higher nitrate-N concentrations (~ 30%). Changes in concentration occurred gradually during the year with the highest nitrate concentrations observed during the summer to early autumn, then decreasing gradually to their lowest levels by early spring. Similar results have been reported by [4,5,7]. There were nine samples which had ammonium-N concentrations > 2 mg/l. The subsurface drainage systems (sites 1, 2 and 3) had ammonium-N concentrations which reached 2.27, 1.82 and 2.93 mg/l, respectively. The non-drained plots' samples showed the highest concentrations at 3.55 mg/l. Thus, subsurface drainage reduced the ammonium-N concentrations (~ 25%).

Surface run-off increases sediment losses and sediments contain absorbed P — as well as organic N. Concentrations of dissolved P are also much greater in surface run-off than in subsurface drainage. Phosphorus losses in subsurface drainage water are very small. Hence, the larger the percentage of drainage water removed through subsurface flow, the lower the loss of P in the drainage water. Subsurface drainage has the potential to reduce phosphorus concentrations (~ 20%) due to its potential to reduce run-off and erosion.

Table 7
Maximum, mean and standard deviation values for the nutrient concentrations

Site	Sample size	NO_3-N (mg/l)			NH_4-N (mg/l)			PO_4-P (mg/l)		
		Max.	Mean	S.D.	Max.	Mean	S.D.	Max.	Mean	S.D.
1[a]	65	51.15	23.68	12.35	2.27	0.98	1.23	0.25	0.098	0.087
1[b]	63	40.84	16.58	9.68	2.66	1.18	0.95	0.36	0.124	0.126
2[a]	64	48.15	19.03	10.63	1.82	0.84	0.56	0.24	0.086	0.964
2[b]	60	37.69	13.32	14.27	2.09	1.12	0.84	0.33	0.107	0.118
3[a]	62	63.56	30.26	16.19	2.93	1.25	1.08	0.47	0.105	0.123
3[b]	61	46.75	22.95	13.52	3.55	1.58	1.46	0.54	0.129	0.185

[a]Drained plot.
[b]Non-drained plot.

There has been concern that controlled drainage practices that reduced drainage outflow might increase seepage and potential transport of nutrients to groundwater. Attempts were made in this study to quantify experimentally any increased seepage that might be occurring. Comparisons of nitrate/chloride ratios in time and with depth have been used to qualify nitrate movement in seepage water.

Nitrate/chloride ratios were measured in shallow groundwater wells. While nitrate levels and nitrate/chloride ratios at the lower depths were elevated immediately after well installation, there was no evidence of downward nitrate movement once the wells had recovered from apparent contamination during installation. This situation was observed in all wells.

Groundwater wells installed at the tile depth (1–1.5 m) indicated nitrate levels consistent with those measured in drainage outflow. Based on the rapid reduction in nitrate/chloride ratios below this depth, any nitrate movement below the tile depth was apparently denitrified and showed no evidence of potential groundwater contamination. While commercial fertilizer nutrients show no evidence of deteriorating groundwater quality, there

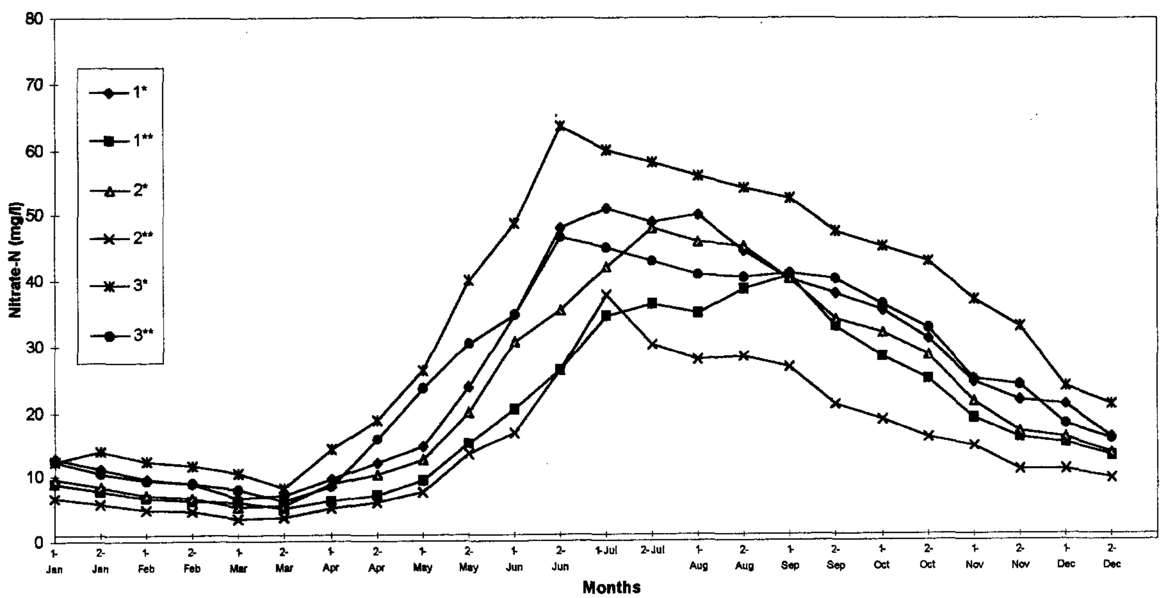

Fig. 2. Time variant NO_3-N concentrations at the Lumalas site.

may be potential problems associated with other agricultural chemicals that are removed from the soil solution, if controlled drainage increases vertical seepage.

4. Conclusions

The limited data presented in this paper is not meant to provide conclusive results on the effects of subsurface drainage systems on soil and nutrient erosion and surface water quality. Continued field monitoring and modelling can aid in the validation of the results presented.

Subsurface drainage reduces soil erosion and water pollution (loss of the most plant nutrients) by substantial amounts on medium to heavy texture soils on slopes of $< 2\%$.

On certain soil types, subsurface drainage may be the preferred best management practice for soil conservation and improving the quality of water leaving agricultural watersheds.

Nutrient concentrations did not appear to be significantly affected by the type of drainage system. Rather, drainage outflow volume was the most important factor affecting total nutrient transport.

Research has shown that drainage systems can be managed to reduce their potential for contamination of surface waters. Obviously there is no single water management practice which can be utilized for all situations, but evidence suggests that water management can be utilized almost everywhere to improve water quality.

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