Effect of Drainage on Agricultural Erosion and Water Quality

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Abstract

A proper design and operation of a drainage system could satisfy both off-site environmental concerns and on-site agricultural requirements. The objective of this research was to evaluate the effectiveness of subsurface drainage on reducing soil and nutrient erosion and surface runoff. A study for obtaining the information about the effect subsurface drainage on soil and nutrient erosion and water quality was conducted from 2002 to 2005 in Korça province, southeastern Albania [40^0 35' N, 20^0 46' E, elev. 899 m]. The results taken by this study show that drainage system affects the proportions of water leaving the field via surface and subsurface flow. Systems that depend on surface drainage tend to have higher rates of runoff (~54%) with more sediment (~28%), phosphorus (~48%) and potassium (~37%) than do systems with good subsurface drainage. Subsurface drainage systems may be also a preferred water table management practice for improving the water quality of water leaving agricultural fields reducing the ammonium-N (~25%) and ortho-P (~20%) concentrations. Thus, subsurface drainage can be managed to reduce their potential for agricultural erosion and contamination of groundwater and surface water resources.

Key words: soil erosion, nutrient erosion, subsurface drainage, Albania.

Introduction

Due to land degradation by erosion some areas will suffer from food shortages while other areas will be subject to environmental problems. Erosion has both physical and chemical aspects. Till recently, physical aspects, such as soil loss from agricultural fields and sediment load in streams received most attention. Less obvious and therefore hidden for a long time is the enormous amount of plant nutrients and other chemicals that are lost with the runoff and in the eroded material. In high-input agriculture, practiced in most developed countries, the most attention is focused on the off- site effects of nutrient loss while in low-input agriculture the interest lies in the on - site effects. The release and migration of plant nutrients and other chemicals is considered both an economic loss and a threat to the quality of water resources.

Recently is seen a rapid acceptance of water table control via controlled drainage and subirrigation (*Evans et al.,* 1989; *Thomas et al.,* 1990). Water table management (subsurface drainage, controlled drainage-subirrigarion, etc.) systems are designed to provide a soil and water environment for enhancing crop growth conditions. Lowering the water table (drainage mode) removes excess water; raising the water table (subirrigation mode) helps supply water to the crop. Subsurface drainage and controlled drainage systems have an effect on the rate, the route and the quality of drainage water leaving a field. *Skaggs et al.* (1982), *Bengston et al.* (1984) and *Thomas et al.* (1987) found wide variabilities in natural losses from drainage system on clay soils. *Bottcher et al.* (1981) and *Schwab et al.* (1982) reported that sediment, phosphorus, and potassium losses from tile outflow were considerably less than from surface runoff. They recommended that on suitable soil types, subsurface drainage might well be a preferred practice for soil and nutrient conservation. Surface runoff tends to be higher in phosphorus and organic nitrogen (*Deal et al.*, 1986), while subsurface drainage tends to be higher in nitrate-nitrogen (*Gilliam et al.,* 1985; *Deal et al.,* 1986,). Generally, subsurface drainage reduces soil erosion and the loss of most plant nutrient on medium to heavy texture soils.

Many studies by environmentalists have identified and evaluated the nature and extent of non-point sources of pollution (*Ahuja, 1986*). The concentration at which nitrate-N constitutes a problem is a function of water use, but the environmental constraints indicate that a concentration of 10 mg L^{-1} NO_3-N is a primary upper limit for drinking water standards. Unionized ammonia (in solution) is a poison that may be hazardous to animal (fish) life. Rainbow trout, for instance, have a documented sensitivity to ammonium-N when concentrations exceed 2 mg L^{-1}. Ortho-P is one of the most detrimental nutrient in lakes and smaller impoundments due to its promotion of eutrophication (*Chapra, 1996*).

The increasing amount of nutrients in groundwater in certain area of Korça region has led to a research to address the problem. Leading issue was centered around a strategy to identify those alternatives that will satisfy agricultural requirements while minimizing detrimental effects on the receiving waters. This study illustrates how soil and nutrient erosion and water contamination can be reduced using subsurface drainage systems. The purposes of this study was to evaluate the effects of subsurface drainage systems on reducing surface runoff, soil and nutrient erosion, and improving groundwater and surface water quality.

Materials and Methods

a. Experimental fields

Experimental fields are located in three adjacent Counties in southeastern Albania. For the evaluation of the effect of subsurface drainage on soil and nutrient erosion and water quality six field sites were selected. Sites 1 (13 ha), 2 (15 ha) and 3 (9 ha) are located in Lumalas County (Vertisol soil-FAO). Sites 4 (8 ha), 5 (10 ha) and 6 (5 ha) are located in Drithas County (Fluvisol soil-FAO). At each site a subsurface drained and a non-drained plot ~ 200 m long were selected. Subsurface drainage consisted of the tile tubes (100 mm diameter and 300 mm length, local production) installed at a depth of 1 m below the soil surface. Drain spacing was 13, 9, 11, 12, 10 and 8 m at sites 1, 2, 3, 4, 5 and 6, respectively. The soils were graded to 3% slope. Thus, one plot in each site contained both surface and subsurface drainage (drained plot) and another plot contained surface drainage only (non-drained plot). Earth dikes at least 0.3 m high were constructed around each drained and non-drained plot to define the plot boundaries and to insure that all the runoff passed through flumes where it could be measured and sampled. Drainage outflow was discharged into 1.2 x 1.2 x 3 m metal sumps and pumped into a surface drainage ditch with electric pumps. Corn was planted in April each year and was harvested for silage in August. It was fertilized with 120 kg ha^{-1}, 40 kg ha^{-1} and 75 kg ha^{-1} of nitrogen, phosphorus and potassium, respectively. The plots were cultivated from harvest until frost to control weeds. Monitoring pipes were installed near the center of each drained and non-drained plot to evaluate the quality of shallow groundwater.

b. Soil sampling

A comprehensive sampling of the soils was conducted only once in March 2002 prior to starting erosion and water quality-monitoring period (April 2002 to December 2005). Four replicate soil cores were randomly collected, in three different soil depths, from each experimental site. Immediately after sampling the soils were taken to laboratory and stored at 4^0 C in aerated plastic bags. The soil samples were analyzed mainly for total N, P, and K content. Other analyses included the soil texture, hydraulic conductivity, pH and soil bulk density. Conventional methods were implemented for the soil analysis. Hydraulic conductivity was measured by the single auger hole method described by van Beers (1979). Some selected properties of experimental sites are given in Table 1.

c. Soil erosion-sampling procedure

The data being collected from the experimental sites dealing with soil and nutrient erosion included rainfall, runoff, and drain outflow, amount of sediment in the runoff and concentrations of nitrogen, phosphorus and potassium in sediment. The rainfall data illustrated in this paper include average monthly rainfall from 2002 to 2005 years. Rainfall was measured with a weighing-type recording gage (SIAP type) installed at each experimental site. Surface runoff from drained and non-drained plots was measured with H-flumes (the older and more familiar short-throated flume for measuring open-channel flows) and water stage recorders (GEIB type). Drain outflow was measured with flowmeters (Albinson type) as outflow was pumped from the sumps. Outflow from the center drains from drained plots was sampled, too. Surface runoff and drain outflow was sampled at 60 minutes intervals with an automatic water sampler installed at each flume. Samples were collected at times when flow was occurring. Runoff and drain outflow samples were analyzed in the laboratory for sediment, nitrogen, phosphorus, and potassium. Sediment concentration was determined by oven drying the suspension at 105^0 C. Soil loss was estimated as the product of measured runoff volume and sediment concentration of the total runoff. Mineral nitrogen was determined by Kjeldahl procedures (*Bremner, 1965*). Total organic nitrogen of the plant was determined by a modified Kjeldahl procedure as published by *Guiraud and Fardeau* (1977). Sample preparation for phosphorus and potassium were done by method 2.020 (*Horwitz, 1980*). Phosphorus was determined by method 2.025 and potassium was determined by the atomic absorption method 3.006 described in *Horwitz* (1980).

d. Water quality-sampling procedure

The water quality sampling procedures were designed to provide an estimate of shallow subsurface and surface water quality. In this study were used two water sampling types: Grab and well. All samples using grab techniques were collected at approximately a two-week interval. The grab samples were obtained with a 1, 000 ml glass bottle. After sampling, the water was transferred to a 500-ml nalgene sample bottle and placed on ice.

The apparatus used to collect the in-field (shallow-well) samples consisted of a peristaltic pump (12 VDC type), a filtering flask, and dedicated Teflon sampling tubes inserted in PVC monitoring pipe at each site. The monitoring pipe (50 mm diameter and 1.6 m length) had 0.5 mm slots around the pipe to within 0.15 m of each end. All monitoring pipes were installed to 1.50 m below the surface. The water samples were analyzed for nitrates (NO_3-N), ammonium (NH_4-N) and ortho phosphate (PO_4-P) using standard colorimetric techniques with a TECHNICON Flow Analyzer (*Guiraud and Fardeau, 1977*).

e. Statistical analysis

The sample data were statistically analyzed between sites with new Duncan multiple range test (*SAS, 1985*) at the 0.05 level of significance. Some important characteristics must be emphasized when interpreting the statistical results. The first, the sample size was relatively small due to the sampling interval and dry periods. The second, the concentrations would be expected to vary between sampling intervals. A decrease in the sampling interval may have produced different results.

Results and Discussion

1. Runoff, soil and nutrient losses from subsurface drainage system

The rainfall distribution during this period (Table 2) was unusual compared to the 40 yr averages. The rainfall data for a 40-yr period (1965-2005) were taken from a meteorological station near the experimental sites. Rainfall in April and May exceeded the 40 yr averages by about 80 mm, with several storms. April was an unusually wet month with total rainfall about 120 mm. The rainfall during the fall was below normal with about 65 mm.

Table 2. Average monthly rainfall (mm) at experimental sites (Lumalas and Drithas Counties), 2002 – 2005.

Month	40 yr average	Experimental Sites					
		1	2	3	4	5	6
January	78.1	53.8	55.4	54.9	52.6	50.1	55.9
February	73.4	56.6	58.3	57.2	56.2	55.4	58.8
March	59.3	65.4	67.4	66.3	64.3	64.1	68.3
April	60.8	120.5	124.1	121.8	119.7	118.6	125.3
May	73.6	92.6	95.4	93.5	94.3	90.7	96.3
June	42.5	39.3	40.5	38.7	38.6	37.5	40.3
July	32.2	26.5	29.7	26.4	27.7	25.6	26.1
August	31.0	30.6	31.8	30.9	30.8	29.1	31.2
September	47.8	32.3	33.5	34.6	31.6	31.7	33.5
October	85.4	54.1	55.7	54.5	53.0	52.2	56.3
November	109.3	89.9	92.6	90.6	88.3	87.1	93.4
December	97.5	91.8	94.3	92.7	90.8	89.3	95.5
Total	790.9	753.4	778.7	762.1	748.3	731.4	780.9

The analysis showed that the losses of surface runoff, sediment and nutrients were reduced by subsurface drainage. The data indicate that the subsurface drainage reduced surface runoff by 54% (Table 3). Total water left from drain plots was increased as a result of reduced peak runoff. Also, 30% more water left the drained plots than the non-drained plots.

Table 1. Some selected soil properties of experimental fields

Sampling depth (cm)	Texture (ISSS) ($g\ kg^{-1}$)			Nutrients (‰)			Hydraulic Conductivity ($m\ d^{-1}$)	pH (water)	Bulk density (g/cc)
	Clay	Silt	Sand	Total-N	Total-P	Total-K			
Site 1									
0-30	645	248	107	0.51	0.062	1.84	0.683	7.4	1.05
30-60	682	252	66	0.42	0.037	1.70	0.572		1.27
60-100	674	273	53	0.38	0.041	1.16	0.237		1.43
Site 2									
0-30	593	174	233	0.44	0.051	2.15	0.560	7.5	1.12
30-60	644	192	164	0.41	0.042	1.86	0.420		1.34
60-100	652	245	103	0.27	0.031	1.32	0.230		1.47
Site 3									
0-30	672	214	114	0.37	0.050	1.72	0.273	7.4	1.05
30-60	741	192	67	0.22	0.037	1.57	0.214		1.18
60-100	559	273	168	0.19	0.032	1.23	0.113		1.37
Site 4									
0-30	447	325	228	1.07	0.113	1.56	0.613	6.8	1.28
30-60	521	341	138	0.82	0.103	1.24	0.384		1.44
60-100	453	302	245	0.67	0.087	1.07	0.418		1.46
Site 5									
0-30	397	401	202	1.12	0.147	1.65	0.792	7.2	1.32
30-60	424	375	201	0.72	0.114	1.19	0.609		1.37
60-100	462	382	156	0.60	0.072	1.00	0.574		1.33
Site 6									
0-30	517	221	262	1.48	0.184	1.46	0.612	7.0	1.25
30-60	532	245	223	1.02	0.109	1.30	0.478		1.32
60-100	614	217	169	0.84	0.092	1.10	0.329		1.39

Table 3. Average annual runoff (mm) from drained and non drained at experimental sites (Lumalas and Drithas Counties), 2002 – 2005.

Site	Drained Plot						Non drained Plot	
No.	Surface		Subsurface		Total		Total	
1.	161[1]	4.3[2]	143	5.5	304	10.7	232	6.9
2.	185	5.6	172	3.3	357	9.1	278	5.8
3.	84	2.5	186	4.2	270	6.9	189	6.3
4.	146	4.4	130	4.3	276	8.1	211	4.7
5.	168	2.3	156	5.1	324	6.1	253	7.6
6.	76	4.2	169	4.7	245	8.2	172	5.2
All sites	137	3.9	159	4.5	296	8.2	222	6.1

[1]. Mean, [2]. Standard error of mean.

Subsurface drainage also reduced soil and nutrient losses with the exception of the nitrogen. From 2002 to 2005, surface runoff carried an annual average of 2550 kg N ha^{-1} of soil for the non-drained plots (Table 4). The drained plots lost 1816 kg N ha^{-1} of soil for a 28% reduction due to subsurface drainage. Average annual soil losses of 223 kg N ha^{-1} or 12% of the total loss occurred with subsurface drainage only. This study showed that the variations in the soil losses reflect seasonal precipitation patterns. The largest portion of the soil was lost in October-December period, when about 38% of the average annual loss left the fields.

Table 4. Average annual soil loss (kg ha^{-1}) from drained and non drained at experimental sites (Lumalas and Drithas Counties), 2002 – 2005.

Site	Drained Plot						Non drained Plot	
No	Surface		Subsurface		Total		Total	
1.	1714[1]	51.4[2]	223	6.6	1937	57.4	2797	82.3
2.	2056	42.9	241	7.1	2297	48.4	3291	70.1
3.	1238	30.9	237	7.2	1475	40.2	1927	76.3
4.	1558	55.4	203	5.7	1761	36.9	2543	48.2
5.	1869	46.7	219	5.2	2088	52.8	2992	89.8
6.	1125	33.7	215	5.4	1340	62.6	1752	52.6
All sites	1593	43.5	223	6.2	1816	49.7	2550	69.9

[1]. Mean, [2]. Standard error of mean.

The average annual total nitrogen losses from the drained and non-drained plots were 14.09 kg N ha^{-1} and 11.08 kg N ha^{-1} (Table 5), respectively, for a 21% increases due to subsurface drainage. The amount of nitrogen lost in drainage water is increased by subsurface drainage. It represented about 6% of the applied fertilizer N. The subsurface discharges contained 6.72 kg N ha^{-1} or 47% of the nitrogen lost from the drained plots. More than 70% of the N lost in the drainage water was in the nitrate form. The majority of the nitrogen (48%) was lost in April and May, the period with intense rainfall, soon after the application of nitrogen fertilizer.

Table 5. Average annual nitrogen losses (kg ha^{-1}) from drained and non drained at experimental sites (Lumalas and Drithas Counties), 2002 – 2005.

Site	Drained Plot						Non drained Plot	
No	Surface		Subsurface		Total		Total	
1.	6.59[1]	0.22[2]	6.91	0.17	13.50	0.39	10.55	0.31
2.	7.48	0.21	8.30	0.21	15.78	0.41	12.73	0.32
3.	7.39	0.18	3.89	0.10	11.28	0.28	8.15	0.29
4.	7.32	0.17	7.68	0.23	15.00	0.44	11.98	0.24
5.	8.31	0.24	9.22	0.28	17.53	0.46	14.36	0.22
6.	7.10	0.20	4.32	0.13	11.42	0.29	8.68	0.43
All sites	7.37	0.20	6.72	0.19	14.09	0.38	11.08	0.30

[1]. Mean, [2]. Standard error of mean.

This study showed that the system, which tended to increase N losses in drainage water decreased the losses of P. Concentrations of dissolved P were higher in surface runoff than in subsurface drainage. The low level of P loss reinforces the potential water quality benefit of subsurface drainage because the loss of P in surface runoff is considered a major threat to many water bodies. The average annual phosphorus losses from the drained and non-drained plots were 3. 30 kg P ha^{-1}, and 4. 88 kg P ha^{-1}, respectively, for a 48% reduction due to subsurface drainage (Table 6). Phosphorus losses in subsurface drainage were very small. The subsurface discharges contained 0.33 kg P ha^{-1} or 10% of the lost phosphorus. The phosphorus losses for the drained plots were evenly spaced throughout the year. For example, 36% (drained) and 31% (non-drained) of the phosphorus was lost during the winter. Approximately 90% of the phosphorus loss was associated with sediments compared to ~50% for nitrogen.

Table 6. Average annual phosphorus losses (kg ha^{-1}) from drained and non drained at experimental sites (Lumalas and Drithas Counties), 2002 – 2005.

Site	Drained Plot						Non drained Plot	
No	Surface		Subsurface		Total		Total	
1.	3.22(1)	0.09(2)	0.24	0.011	3.46	0.13	5.02	0.14
2.	3.73	0.08	0.39	0.007	4.12	0.11	6.24	0.12
3.	2.40	0.06	0.48	0.014	2.88	0.10	4.22	0.11
4.	2.93	0.05	0.22	0.006	3.15	0.09	4.65	0.12
5.	3.39	0.04	0.26	0.008	3.65	0.12	5.58	0.10
6.	2.18	0.07	0.36	0.010	2.54	0.08	3.56	0.13
All sites	2.98	0.07	0.33	0.009	3.30	0.11	4.88	0.12

(1). Mean, (2). Standard error of mean.

Although subsurface drainage increases N losses, there was a tendency to decrease the discharge of potassium. We found lower potassium losses from subsurface drained plots. The average annual potassium losses from the drained and non-drained plots were 22. 31 kg K ha^{-1} and 30.58 kg K ha^{-1}, i.e. a 37% reduction due to subsurface drainage (Table 7). The subsurface discharges contained 2.69 kg K ha^{-1} or 12% of the total of drained plot. The largest monthly losses were in November when about 23% (drained) and 26% (non-drained) of the annual total was lost. However, unlike nitrogen, the losses of potassium occurred throughout the year. For example, 32% (drained) and 34% (non-drained) of the total potassium was lost during the winter as opposed to only 15% (drained) and 14% (non-drained) of the nitrogen.

Table 7. Average annual potassium losses (kg ha^{-1}) from drained and non drained at experimental sites (Lumalas and Drithas Counties), 2002 – 2005.

Site	Drained Plot						Non drained Plot	
No	Surface		Subsurface		Total		Total	
1.	18.23(1)	0.66(2)	2.97	0.08	21.20	0.75	27.88	0.69
2.	21.88	0.55	3.12	0.09	25.00	0.53	32.00	0.81
3.	15.67	0.51	1.56	0.05	17.23	0.59	23.09	0.98
4.	20.26	0.47	3.29	0.08	23.55	0.43	32.66	0.58
5.	24.31	0.73	3.47	0.10	27.78	0.57	39.19	0.72
6.	17.41	0.44	1.73	0.05	19.14	0.83	28.64	1.03
All sites	19.62	0.56	2.69	0.08	22.31	0.62	30.58	0.80

(1). Mean, (2). Standard error of mean.

2. Water quality of subsurface drainage system

Statistics of the water quality measurements at each experimental site are presented in Table 8. In the statistical analysis, the subsurface drainage samples had significantly higher (~25%) nitrate-N concentrations compared to non-drained plot samples. Increase or decrease in concentration occurred gradually during the year with the highest nitrate concentrations observed in the summer to early fall events then decreasing gradually to their lowest levels by early spring. *Deal et al.* (1986); *Grazhdani et al.* (1996) and *Evans et al.* (1989) have reported similar results. In the sample results, there were eleven samples which had ammonium-N concentration > 2 mg L^{-1}. The subsurface drainage systems had ammonium-N concentrations which reached 3.52 mg L^{-1}. The non-drained plots' samples showed the highest concentrations at 4.26 mg L^{-1}. Thus, subsurface drainage reduced the ammonium-N concentrations (~25%) in groundwater.

Concentrations of dissolved P were very low and would not be considered an environment concern. Subsurface drainage has also the potential to reduce phosphorus concentrations (~20%) in groundwater.

Conclusions

This research has shown that subsurface drainage system reduced surface runoff, soil (sediment), phosphorus and potassium loss by substantial amounts (54, 28, 48 and 37 %, respectively). It can control erosion and losses of sediment-associated nutrients and P in drainage water. More than 70 % of the N lost in the drainage water was in the nitrate form. Approximately 90 % of the P lost was in the form of sediment-bound P. Subsurface drainage system should be also considered a good water table management system for improving the quality of the water coming from watersheds with heavy texture soils and slopes less than 3 % with high water tables.

Table 8. Statistics values for the nutrients concentrations in groundwater at experimental sites (Lumalas and Drithas Counties), 2002 - 2005.

Site	Sample size	NO_3-N(mg L^{-1})				NH_4-N(mg L^{-1})				PO_4-P(mg L^{-1})			
		Max	Mean	SD	D[c]	Max	Mean	SD	D[c]	Max	Mean	SD	D[c]
1[a]	71	62.38	26.96	10.53	cd	2.72	1.08	0.32	b	0.33	0.132	0.078	ab
1[b]	68	46.21	21.18	9.86	cd	3.19	1.36	0.59	b	0.47	0.164	0.062	ab
2[a]	69	51.26	23.59	10.36	bc	2.18	1.01	0.65	b	0.31	0.118	0.469	ab
2[b]	70	41.69	18.05	11.72	bc	2.51	1.24	0.48	b	0.43	0.143	0.081	ab
3[a]	72	66.56	34.97	12.91	cb	3.52	1.56	0.84	b	0.62	0.136	0.098	ab
3[b]	71	48.57	27.93	10.25	cb	4.25	1.95	0.96	b	0.75	0.165	0.085	ab
4[a]	65	51.15	23.68	12.35	cd	2.27	0.98	1.23	b	0.25	0.098	0.087	cd
4[b]	63	40.84	16.58	9.68	cd	2.66	1.18	0.95	b	0.36	0.124	0.126	cd
5[a]	64	48.15	19.03	10.63	bc	1.82	0.84	0.56	b	0.24	0.086	0.964	ab
5[b]	60	37.69	13.32	14.27	bc	2.09	1.12	0.84	b	0.33	0.107	0.118	ab
6[a]	62	63.56	30.26	16.19	cd	2.93	1.25	1.08	b	0.47	0.105	0.123	cd
6[b]	61	46.75	22.95	13.52	cd	3.55	1.58	1.46	b	0.54	0.129	0.185	cd

[a] Drained plot.
[b] Non-drained plot.
[c] Duncan new multiple range test. Means followed by the same letter are not significantly different based on a 0.05 level of significance.

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