Phosphorus transport through surface runoff and sub-surface drainage from regular free drainage and controlled drainage with sub-irrigation systems in corn and soybean production

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Abstract

Majority of the field water discharge was from sub-surface tile drainage for both CDS and RFD systems. Controlled drainage with sub-irrigation reduced the flow volume of and the P content in tile drainage water, and consequently the total soil P loss, relative to RFD. Along with the enhancement of crop production due to timely supply of soil moisture, CDS can be recommended as a beneficial management practice.

Key Words

Phosphorus transport, surface runoff, sub-irrigation systems, corn and soybean production

Introduction

It is understood that non-point sources of agricultural lands have increasingly become important as sources of phosphorus (P) pollution to the water resource. The regions in southern Ontario are dominated with annual crops that are grown in soils which have a high risk of P loss due to both long-term build-up of P in soils and high volume water discharge from the farm lands. The effects are especially apparent in the Lake Erie basin, where some of Canada's most intensive agricultural activity combines with growing urbanization. The majority of soils in the region are tile drained and also prone to preferential flow through cracks, earthworm and root channels, and that can funnel water from the surface to the tile drainage, especially after a heavy rainfall.

Conservation tillage or no-tillage has been widely adopted for highly erodible soils in the Midwest of United States, and has been considered as best management agricultural practices for reducing soil erosion, which reduces soil P loss accordingly. On the other hand, other studies have reported that dissolved reactive P concentrations and losses increase in no-till fields. While conservation tillage reduces soil erosion and surface runoff, it also enhances infiltration. As a result, more nutrients, such as nitrate and P, and/or herbicides would find their way down to the sub-surface drainage and eventually to the groundwater. Agricultural sub-surface drainage is necessary for economical and efficient crop production in Southern Ontario. Unfortunately, such an approach can also increase non-point source agricultural pollution by enhancing the movement of agricultural sediment, nutrients and pesticides into surface and ground water resources. Research results indicated that controlled drainage provided some reduction in nitrate-N losses over conventional free drained crop land. With controlled drainage/sub-irrigation system, water is pumped back into the tile drains during water deficit periods to provide irrigation water directly to the crop root zone. This innovative water management system has both economic and environmental benefits.

The objectives of this research were to compare the effectiveness of the regular free tile drainage and controlled drainage-subsurface irrigation systems for: i) mitigating P losses from agricultural fields; and ii) assessing and identifying the proportions of soil P loss in surface runoff and sub-surface tile drainage flow.

Materials and methods

The experiment was initiated in the spring of 2000 and continued till the December of 2004 on a Perth clay soil (Gleyed Grey Brown Luvisol) that is located on the Essex Region Conservation Authority Demonstration Farm at Holiday Beach, Ontario, Canada. Cropping system was corn-soybean rotation. Corn was planted on May 26, 2000, May 20, 2001 and May 15, 2003. Fertilizer was applied pre-plant at 17.7 kg N/ha, 76.8 kg P/ha and 17.7 kg K/ha. Urea-Ammonium Nitrate (UAL 28% liquid) was added as a side-dress application in June at 150 kg N/ha. Soybeans were planted on June 1, 2002 and June 15, 2004.

The treatments included two water management systems: controlled tile drainage/sub-irrigation (CDS) and regular free tile drainage (RFD). Each plot was 25 m wide by 131 m long, and linked to a central automated monitoring station. The plot was tile-drained by six 104-mm diameter subsurface drains (4.6 m spacing, 0.6 m average depth). Each plot was equipped with a 0.6 m diameter catch basin at its lower boundary to collect surface runoff water. The sub-surface tile drainage at the CDS plot was routed to a control drainage structure before linked to central monitoring station. The control structure was used for both controlled drainage and subsurface irrigation. For controlled drainage, a “riser” within the structure increases the elevation of the tile outflow, thereby effectively raising the elevation of the tile and encouraging water retention within the soil profile. For subsurface irrigation water was pumped into the control structure, thus creating a pressure head that forces water back up the tile lines and into the crop root zone. The control structure was used primarily for subsurface irrigation during the growing season and primarily for controlled drainage during the fall, winter and spring.

Surface runoff and sub-surface tile drainage were directed to a central monitoring station. Four stainless steel custom fabricated tipping buckets were used to measure surface runoff and tile drainage volume on a year-round continuous base. The tipping buckets were calibrated individually to determine the relationship between flow rate and tip rate. The data logger was used with tipping buckets to measure flow volume on a continuous base. Samples of surface runoff and tile drainage water from each plot were collected using two separate ISCO auto-samplers. Sample collection was based on flow volume. After volume recording and sampling, water was pumped into a constructed reservoir, and then used for subsurface irrigation of the CDS plot during the growing season.

The water samples were analyzed for dissolved reactive P (DRP) and total dissolved P (TDP), which was performed by digesting vacuum-filtered sub-samples with acidified ammonium persulphate ($(NH_4)_2S_2O_8$) oxidation in an autoclave. Total P (TP) in water samples was measured by digesting a sub-sample of unfiltered water using the H_2O_2-H_2SO_4 method. Phosphorous concentrations in all solutions were determined using a QuikChem Flow Injection Auto-Analyzer with the ammonium molybdate ascorbic acid reduction method. Dissolved un-reactive P (DURP) was determined as the difference between TDP and DRP. Particulate P was determined as the difference between TP and TDP. Flow weighted mean (FWM) P concentrations for each plot were calculated as cumulative loss (on mass basis) from June 1, 2000, to December 31, 2004, divided by the corresponding cumulative water outflow from the plot.

Results

The CDS system produced greater surface runoff but much less sub-surface tile drainage relative to the RFD system over a 5-yr period from June 1, 2000 to December 31, 2004. Sub-surface tile drainage accounted for 80 and 97% of total flow volume for the CDS and RFD systems, respectively.

For RFD, FWM of DRP, DURP, PP and the total P (TP) concentrations over the 5-yr period were averaged at 0.057, 0.057, 0.627, and 0.741 mg P/L in surface runoff water and at 0.034, 0.053, 0.393, and 0.480 mg P/L in tile drainage water, respectively (Table 1). Controlled drainage with sub-irrigation increased FWM of most forms of P and the TP concentrations in surface runoff water, but decreased the FWM of DURP, PP and the TP concentrations in tile drainage water.

Cumulative total DRP, DURP, TDP, PP and TP losses were attributed to sub-surface tile drainage at 65 to 71% for the CDS system and at 95 to 97% for the RFD system (Table 2). The CDS system produced greater cumulative DRP, DURP, TDP, PP and TP losses in surface runoff but much large reduction on cumulative DRP, DURP, TDP, PP and TP losses in sub-surface tile drainage relative to the RFD system. The cumulative total PP losses accounted for more than 80% of total TP losses for both the CDS and RFD systems. Combined with surface and sub-surface water, the CDS system reduced PP and TP losses by 15 and 12 %, respectively relative to the RFD system. Since the major soil P losses pathway was through sub-surface tile drainage, the CDS water management system that enhance crop growth and nutrient uptake and alter the hydrology of surface runoff and tile drainage flow can be used to reduce off-field movement of soil P loss. The effectiveness of the CDS system for soil P transport reduction in our soil and climate conditions may be further modified and improved by optimizing the tile spacing and depth.

Conclusions

Majority of the field water discharge was from sub-surface tile drainage for both CDS and RFD systems. Controlled drainage with sub-irrigation reduced the flow volume of and the P content in tile drainage water, and consequently the total soil P loss, relative to RFD. Along with the enhancement of crop production due to timely supply of soil moisture, CDS can be recommended as a beneficial management practice.

Table 1. Flow weighted mean (FWM) P concentration for dissolved reactive P (DRP), dissolved un-reactive P (DURP), total dissolved P (TDP), particulate P (PP), and total P (TP) from surface runoff and tile drainage under controlled drainage/sub-irrigation (CDS) and regular free drainage (RFD) systems from June1, 2001 to December 31, 2004.

	CDS					RFD				
Year	DRP	DURP	TDP	PP	TP	DRP	DURP	TDP	PP	TP
	FWM P in surface runoff (mg P/L)									
2000	0.010	0.131	0.141	1.573	1.714	0.014	0.023	0.037	1.076	1.113
2001	0.102	0.067	0.169	0.450	0.619	0.076	0.093	0.169	0.597	0.766
2002	0.059	0.063	0.123	0.527	0.650	0	0	0	0	0
2003	0.151	0.117	0.268	0.324	0.592	0.065	0.027	0.092	0.350	0.442
2004	0.119	0.042	0.161	0.406	0.567	0.110	0.056	0.166	0.669	0.835
FWM Ave	0.094	0.090	0.184	0.620	0.804	0.057	0.057	0.114	0.627	0.741
	FWM P in tile drainage(mg P/L)									
2000	0.022	0.088	0.110	0.293	0.403	0.029	0.023	0.052	0.440	0.492
2001	0.040	0.040	0.080	0.301	0.381	0.050	0.042	0.092	0.399	0.491
2002	0.064	0.077	0.141	0.367	0.508	0.039	0.061	0.100	0.430	0.530
2003	0.036	0.026	0.062	0.370	0.432	0.040	0.067	0.107	0.310	0.417
2004	0.042	0.037	0.079	0.418	0.497	0.020	0.051	0.071	0.411	0.482
FWM Ave	0.043	0.045	0.087	0.370	0.457	0.034	0.053	0.087	0.393	0.480

Table 2. Dissolved reactive P (DRP), dissolved un-reactive P (DURP), total dissolved P (TDP), particulate P (PP), total P (TP) and percentage of P loss from surface runoff and tile drainage under controlled drainage/sub-irrigation (CDS) and regular free drainage (RFD) systems from June1, 2001 to December 31, 2004.

	CDS					RFD				
Year	DRP	DURP	TDP	PP	TP	DRP	DURP	TDP	PP	TP
	P loss in surface runoff (g P/ha)									
2000	3.3	42.7	46.0	514.1	560.1	1.2	2.0	3.1	91.6	94.8
2001	70.0	45.2	115.2	307.2	422.4	12.9	15.9	28.8	101.9	130.7
2002	15.8	16.8	32.6	140.2	172.8	0.0	0.0	0.0	0.0	0.0
2003	77.0	59.5	136.5	165.0	301.5	5.8	2.4	8.2	31.2	39.4
2004	10.9	3.8	14.7	37.1	51.8	1.4	0.7	2.1	8.3	10.3
Total	177.0	167.9	344.9	1163.6	1508.5	21.3	21.0	42.2	232.9	275.1
	P loss in tile drainage(g P/ha)									
2000	7.5	29.8	37.3	99.5	136.9	12.5	9.7	22.2	189.5	211.7
2001	82.8	84.4	167.1	630.5	797.6	120.1	102.1	222.2	962.6	1184.8
2002	64.7	78.8	143.5	373.2	516.7	71.7	112.1	183.8	795.1	978.8
2003	18.6	13.6	32.2	391.5	423.7	88.1	147.0	235.1	682.9	918.0
2004	152.1	136.4	288.5	1332.2	1620.7	89.7	223.5	313.3	1821.3	2134.6
Total	325.7	343.0	668.7	2826.8	3495.5	382.1	594.4	976.6	4451.4	5428.0
	P loss in both surface runoff and tile drainage (g P/ha)									
2000	10.8	72.6	83.4	613.6	697.0	13.7	11.7	25.4	281.1	306.5
2001	152.8	129.5	282.3	937.6	1219.9	133.0	118.0	251.0	1064.5	1315.5
2002	80.5	95.6	176.1	513.4	689.5	71.7	112.1	183.8	795.1	978.8
2003	95.6	73.1	168.7	556.5	725.2	93.9	149.4	243.3	714.1	957.4
2004	163.0	140.2	303.2	1369.3	1672.5	91.1	224.2	315.3	1829.6	2144.9
Total	502.7	510.9	1013.6	3990.5	5004.1	403.4	615.4	1018.8	4684.3	5703.1
	Percentage of P loss									
Surface	0.35	0.33	0.34	0.29	0.30	0.05	0.03	0.04	0.05	0.05
Tile	0.65	0.67	0.66	0.71	0.70	0.95	0.97	0.96	0.95	0.95