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MEASURED EFFECT OF AGRICULTURAL DRAINAGE WATER MANAGEMENT ON HYDROLOGY, WATER QUALITY, AND CROP YIELD

M. SUNOHARA[1], M. YOUSSEF[2], E. TOPP[3], D.R. LAPEN[4]

[1] M. SUNOHARA, Physical Scientist, Agriculture and Agri-Food Canada, Ottawa, Ontario, K1A 0C6, Mark.Sunohara@agr.gc.ca.
[1] D.R. LAPEN, Research Scientist, David.Lapen@agr.gc.ca.
[2] M. YOUSSEF, Assistant Professor, Dept. of Biol. and Ag. Engineering, NC State University, Raleigh, NC- 27695, mohamed_youssef@ncsu.edu.
[3] E. TOPP, Research Scientist, Agriculture and Agri-Food Canada, London, Ontario, N5V 4T3, edward.topp@agr.gc.ca.

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ABSTRACT A field scale experiment has been initiated in 2006 to study the effects of controlled drainage on drain flow, nutrient export, and crop yield for a subsurface drained site in eastern Ontario, Canada. Eight paired fields of comparable size (2 to 7 ha), soil (Bainsville silt loam), crop rotation (corn-soybean), and drainage system (subsurface drains 100 cm deep and spaced 15 m apart) were evaluate in the study. For each field pair, controlled drainage (CD) is implemented on one field and conventional (uncontrolled) drainage (UCD) is implemented on the other field. The results of the study showed that controlled drainage substantially reduced subsurface drainage and nutrient (nitrogen and phosphorus) export with drain flow, compared with conventional drainage. On average over the four field pairs and the three-year period, controlled drainage reduced the May-to-November drain flow by 50%, nitrate-nitrogen export by 47% and total phosphorus export by 56%. These results support the contention that nutrient reductions are controlled primarily by reduced drain flow. The results suggest the May-to-November nutrient mass losses were, overall, modest. A very modest increase in crop yield was observed with implementing drainage water management, although results were not statistically significant. Nevertheless, the results do show that controlled drainage does not have an adverse effect on crop yield.

Keywords: Controlled drainage, Nitrogen, Phosphorus, Water quality, Crop yield.

INTRODUCTION Agricultural drainage is essential for crop production on millions of acres of farmland in Canada. It improves trafficability for timely planting and harvesting and removes excess water from the root zone (Evans and Fausey, 1999). However, drainage can impair surface water quality. Nitrogen losses from drained cropland have been identified as one of the major sources of N leading to hypoxic conditions in several major water bodies of the world.

Controlled drainage (CD), also referred to as drainage water management or managed drainage, is a management practice that have been proven effective in reducing nutrient losses from drained lands to surface waters (Skaggs, 1982 ; Drury et al., 1996; Wesström and Messing, 2007). It regulates the amount of drainage water that can leave a subsurface drained field (Gilliam et al., 1979).Drainage water control structures are used to raise the water level in the drainage outlet and reduce drain flow when intensive drainage is not needed. In addition to the water quality benefits, CD has the potential to conserve water and improve crop yields, especially during dry years. Since CD works by substantially reducing drainage volumes, it increases groundwater recharge, raises the water table, and increases soil water in the root zone. All of these factors can alleviate dry period stresses on crops. Controlled drainage has been shown to increase crop yields (Mejia et al., 2000; Ng et al., 2002; Ma et al., 2007). In many temperate regions, tile drains are allowed to freely drain in spring periods in order to facilitate normal and timely spring field operations. Tile drainage is often restricted at or just after planting by a water flow control structure installed at the drainage outlet. The water flow control structures that regulate discharge from a subsurface drainage network can be carefully managed to reduce the potential risk of excess water stresses to crops. Overall, CD is a flexible management system that can be set to accommodate specific crop, topographic, and field soil characteristics (ASABE, 1990; Madramootoo et al., 1993; Evans et al., 1995; Drury et al., 1996; Paasonen-Kivekas et al., 1996).

A field scale experiment has been initiated in 2006 to study the effects of CD on drain flow, nutrient export, and crop yield for a subsurface drained site in eastern Ontario, Canada. This paper presents three years of preliminary hydrology (drain flow) and water quality (nitrogen and phosphorus loads) data and four years of crop yield data

METHODOLOGY

Site Description and Experimental Procedure The study was conducted on privately owned tile-drained agricultural fields in eastern Ontario, Canada from 2006-2008. Precipitation over the agronomically active months (May to October) was 627 mm in 2006, 316 mm in 2007, and 471 mm in 2008. The soil on the site is classified as Bainsville series, characterized by layered silt and fine sand overlying clayey deposits, with poor natural drainage. The surface topography is generally flat (average slope <1%). Eight paired fields of comparable size, soil type, and cropping management were evaluated in this study. For each field pair, controlled drainage (CD) is implemented on one field and conventional (uncontrolled) drainage (UCD) is implemented on the other field Monitored fields were planted with corn or soybean from May to October. Areas of individual fields varied from 2 to 7 ha. The drainage system on the site consists of lateral subsurface drains (102 mm in diameter) installed at an average depth of 100 cm and a spacing of 15 m with an average slope of 0.1%. The lateral drains are connected to a main drain line and an outlet, which was retrofitted with an inline water level control structure (Agri Drain Corporation, Adair, USA). Water overflow depth in the water level control structures of the CD fields was set conservatively at a depth of 0.6 m below the soil surface. The water table depth was not managed in the UCD fields permitting free drain flow. Fertilizer application rates were 3.4 kg N ha^{-1} for soybean and 177 kg N ha^{-1} for corn. In the beginning of May, paired fields received the same amount and type of fertilizer prior to and at planting. Urea fertilizer was broadcast prior to planting. Urea-ammonium-nitrate (UAN) fertilizer was applied at planting as a starter for corn.

Drain flow, nitrogen, and phosphorus loads of CD and UCD fields were measured during May and November of each year. Calibrated ISCO 6712 automatic water samplers (ISCO

Inc., Lincoln, NE) with ISCO 730 bubbler flow modules were used in 22° V-notch weir boxes installed at each outlet or directly in the water level control structures to obtain continuous tile discharge. ISCO water sampling programs were set to collect composite water samples twice weekly during continuous tile flow and set to trigger intensive non-uniform time-paced sampling routines during rain event flow to capture hydrograph events.

Nitrate and ammonia/ammonium were analysed colourimetrically with a TrAAcs 800 autoanalyzer (Bran and Luebbe Analyzing Technologies, Inc., Elmsford, NY, USA) using the cadmium reduction method for nitrate and the phenate method for ammonia. Dissolved reactive phosphorus was analyzed with a Lachat QuikChem FIA+8000 series autoanalyzer (Zellweger Analytics, Inc., Lincolnshire, IL, USA) using the ascorbic acid method, while total phosphorus was analyzed with the Smart Spectro spectrophotometer from LaMotte Company (Chestertown, MD, USA) using the same method, preceded by a persulfate digestion.

RESULTS AND DISCUSSION

Hydrology The results of this three-year experiment showed that controlled drainage substantially reduced subsurface drainage, compared with conventional drainage (Table 1 and Figure 1). The three-year average reduction in May-to-November drain flow because of implementing controlled drainage ranged from 22% for field pair 4 to 71% for field pair 1. On average over the four field pairs and the three-year period, controlled drainage reduced the May-to-November drain flow by 50%, compared to conventional drainage. In 2006, the May-to-November drain flow of the controlled plot of field pair 4 was unexpectedly higher by 15% than the flow of the uncontrolled plot.

Table 1. Drain flow during May-November of 2006-2008 for the four field pairs managed using controlled drainage (CD) and conventional drainage (UCD).

Year	Field Pair 1			Field Pair 2			Field Pair 3			Field Pair 4			All Field Pairs		
	CD	UCD	Rd	CD	UCD	Rd	CD	UCD	Rd	CD	UCD	Rd	CD	UCD	Rd
	mm/ha		%	mm/ha		%	mm/ha		%	mm/ha		%	mm/ha		%
2006	34	101	*66.4*	106	140	*24.0*	153	258	*40.5*	90	78	*-15.4*	384	576	*33.4*
2007	00	19	*99.5*	01	13	*94.8*	27	34	*20.2*	09	24	*64.1*	37	89	*58.7*
2008	35	119	*70.2*	08	127	*93.4*	97	219	*55.8*	47	84	*44.1*	187	548	*65.8*
Avg.	**23**	**79**	***70.7***	**39**	**93**	***58.7***	**92**	**170**	***45.7***	**49**	**62**	***21.8***	**203**	**405**	***49.9***

The response of field pair 3 was quite different from the other three field pairs. The minimum and maximum reductions in drain flow, on percentage basis, occurred in 2006 and 2007, respectively, for field pairs 1, 2, and 4. The minimum and maximum reductions in drain flow for field pair 3 occurred in 2007 and 2008, respectively. More importantly, the subsurface drainage rates from field pair 3, under both conventional and controlled drainage, are significantly higher than the drainage rates from the other three field pairs. Thus the overall average reduction in drain flow over the three year period and four field pairs was closest to the recorded reduction in drain flow for field pair 3 (46% vs. 50%)

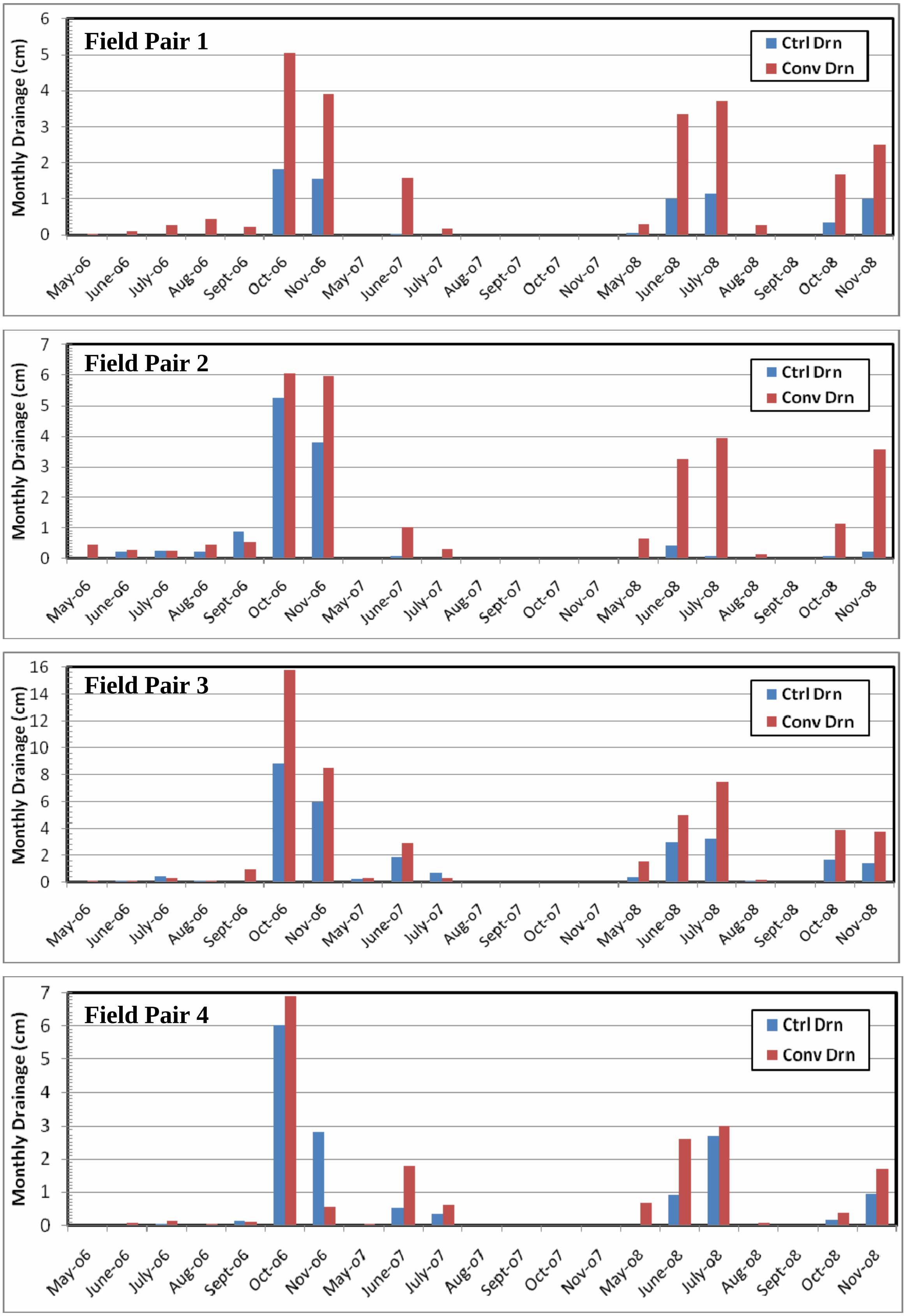

Figure 1. Monthly drain flow during May-November of 2006-2008 for four field pairs managed using controlled drainage (Ctrl Drn) and conventional drainage (ConvDrn).

The monthly drain flow from controlled plots was consistently less than the monthly drain flow from uncontrolled plots with only two exceptions; in September 2006 the drain flow from the controlled plot of field pair 2 was slightly less than the flow from the uncontrolled plot and in November 2006 substantially higher subsurface drainage was recorded for the controlled plot of field pair 4 (Figure 1). At present, there is no explanation for the large difference in measured subsurface drainage for field pair 4 during November 2006, but results could have been related to field monitoring problems.

It should be mentioned that the two paired fields, managed using conventional and controlled drainage, are adjacent to each other. The borders of these field plots are not hydraulically isolated. This might cause the groundwater to move laterally from the controlled plot to the conventional plot. This lateral seepage (groundwater flow) from/to field plots due to differences in water table management treatments might increase the "apparent" effectiveness of controlled drainage in "controlling" drain flow. As of yet, we have not made any measurements to assess the significance of the hydraulic interaction between plots under different drainage water management and its implications on lateral seepage.

The significance of vertical seepage was not assessed in this study. Field investigations showed that a clayey layer with relatively low hydraulic conductivity is present at a shallow depth of 100 cm. This might indicate that the vertical seepage is not an important component of the water balance for the site. The hydrology of the site will be simulated using the DRAINMOD model to study the importance of both lateral and vertical seepage as factors affecting the measured reduction in drain flow because of implementing controlled drainage.

Nutrient Export from Subsurface Drain The results of the study indicated that drainage water management substantially reduced nutrient export via subsurface drainage. As expected, nitrogen lost with drain flow was mostly in the nitrate form (NO_3^-). Since the nitrogen losses in the ammonium (NH_4^+) form were very small, the NH_4-N are not present and discussed in this paper.

The reductions in NO_3-N loads (Table 2) due to the implementation of drainage water management closely followed the reductions in drain flows (Table 1). This phenomenon was clearer for field pairs 1 and 2. On percentage basis, the three year average reduction in May-to-November NO_3-N export via subsurface drainage ranged from 30% for field pair 3 to 74% for field pair 1. Over the three-year period and the four field pairs, controlled drainage reduced NO_3-N export with drain flow by 47%. This closely matched the 50% reduction in drain flow. These results mean that controlled drainage works primarily by reducing drain flow. This finding supports previously published studies on controlled drainage (Skaggs and Youssef, 2008).

Similar to drain flow, the response of field pair 3 was different from the other three field pairs. Field pair 3 has the highest nitrogen loss (7 and 10 kg N/ha, for controlled and uncontrolled fields, respectively) and the lowest percent reduction in NO_3-N loading because of controlled drainage (30%). The maximum percent reduction in NO_3-N loading occurred in 2007, the driest year, for field pairs 1, 2, and 4, whereas almost no reduction was observed during this year for field pair 3.

Table 2. NO_3-N losses in drain flow during May-November of 2006-2008 for the four field pairs managed using controlled drainage (CD) and conventional drainage (UCD).

Year	Field Pair 1			Field Pair 2			Field Pair 3			Field Pair 4			All Field Pairs		
	CD	UCD	Rd	CD	UCD	Rd	CD	UCD	Rd	CD	UCD	Rd	CD	UCD	Rd
	Kg NO_3-N/ha		%	Kg NO_3-N/ha		%	Kg NO_3-N/ha		%	Kg NO_3-N/ha		%	Kg NO_3-N/ha		%
2006	2.6	9.3	*72.5*	5.3	7.0	*24.4*	10.9	14.9	*27.1*	3.2	4.2	*23.0*	21.9	35.4	*38.0*
2007	0.0	1.3	*99.6*	0.0	0.8	*94.5*	2.5	2.4	*-3.6*	0.3	1.3	*76.3*	2.8	5.8	*51.5*
2008	2.2	7.7	*70.9*	0.4	4.6	*91.8*	7.5	12.5	*39.7*	1.3	2.0	*37.5*	11.4	26.8	*57.4*
Avg.	**1.6**	**6.1**	***73.8***	**1.9**	**4.1**	***53.9***	**7.0**	**9.9**	***29.9***	**1.6**	**2.5**	***36.3***	**12.1**	**22.7**	***46.8***

The results generally suggest the May-to-November NO_3-N mass losses were, overall, modest. The highest NO_3-N loss of 15.0 kg N/ha was measured in 2006 for the uncontrolled plot of pair 3. Yet, in terms of percent reductions associated with CD, averages for NH_4-N and NO_3-N were respectively 58 and 54%

Phosphorus losses in drainage water were generally small. The highest May-to-November total P loading of 93 g P/ha was measured for the uncontrolled plot of field pair 3 in 2006. Over the three year period, the percent reduction in May-to-November total P loading ranged from 31% for field pair 4 and 73% for field pairs 1 and 2. Field pair 3 has the highest total P export among the four monitored field pairs. On average of the three year and four field pairs, controlled drainage reduced total P export via subsurface drainage by 56%. On percentage basis, the reduction in May-to-November P export was similar to the reduction in NO_3-N export and drainage outflows (Table 3).

Although the results presented here are for agronomically active months, they are supportive of other studies on the benefits of CD in the context of reducing mass losses of nutrients to the broader surface water environment (Lalonde et al., 1996; Drury et al., 1996; Tan et al., 1999; Wesström and Messing, 2007).

Crop Yield Theoretically, a portion of the nutrients not lost via subsurface drainage would be available for crop uptake; thereby enhancing crop production. A very modest increase in crop yield is observed with implementing drainage water management. It should be underscored that although these results are indeed modest and overall not statistically significant at the 0.05 level (t-test analyses), they do not suggest that controlled drainage as employed in this study, adversely affects crop performance (which can occur if waterlogging conditions occur at critical crop growth stages as a result of too

Table 3. Total phosphorus losses in drain flow during May-November of 2006-2008 for the four field pairs managed using controlled drainage (CD) and conventional drainage (UCD).

Year	Field Pair 1			Field Pair 2			Field Pair 3			Field Pair 4			All Field Pairs		
	CD	UCD	Rd	CD	UCD	Rd	CD	UCD	Rd	CD	UCD	Rd	CD	UCD	Rd
	g P/ha		%	g P/ha		%	g P/ha		%	g P/ha		%	g P/ha		%
2006	9	32	*72*	19	29	*35*	25	37	*32*	12	13	*8*	65	111	*41*
2007	0	9	*100*	0	7	*100*	14	14	*0.0*	4	9	*56*	18	39	*54*
2008	13	39	*67*	3	44	*93*	38	93	*59*	20	30	*33*	74	206	*64*
Avg.	**7**	**27**	***73***	**7**	**27**	***73***	**26**	**48**	***47***	**12**	**17**	***31***	**52**	**119**	***56***

Table 4: Field average crop yields for CD and UCD paired fields. Field pairs are associated with common agronomic practices.

Field Pair	Year	Crop	CD (kg ha^{-1})	UCD (kg ha^{-1})	CD-UCD (kg ha^{-1})
1	2005	Soybean	3299	3020	280
	2006	Corn	11278	11000	278
	2007	Corn	10474	9972	278
	2008	Soybean	3835	3725	0
2	2005	Corn	6591	8035	-1444
	2006	Corn	9783	8846	937
	2007	Corn	No Data	No Data	No Data
	2008	Soybean	3725	3675	0
3	2005	Corn	9792	9792	0
	2006	Soybean	3889	3633	256
	2007	Corn	11979	11979	0
	2008	Corn	8411	7344	1067
4	2005	Soybean	3477	3377	100
	2006	Corn	11497	11356	141
	2007	Corn	12041	11477	564
	2008	Soybean	3700	3650	50

aggressive water table management). Overall, irrespective of drainage management practice, the crop yields were considered excellent. Other studies found crop yield improvements associated with CD on similar soils to be somewhat higher (Kalita and Kanwar. 1993; Tan et al., 1999; Ng et al., 2002; Ma et al., 2007). Thus this data is supportive of these published findings and encouraging with respect to building lines of evidence that CD is both an environmentally and economically viable practice.

CONCLUSIONS This study demonstrated clear benefits of CD with respect to reducing the impact of agricultural pollution on the broader surface water environment, while at the same time modestly improving, or rather, not degrading, crop production. Nevertheless, CD in Canada is not readily employed irrespective of the positive documented research efforts to date. Clearly, while field studies are relevant for broadening the knowledge base of this drainage management practice, more concerted efforts need to be conducted on identification of adoption constraints.

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