2015

Comparison of Timing and Volume of Subsurface Drainage under Perennial Forage and Row Crops in a Tile-Drained Field in Iowa

Ryan J. Goeken
Iowa State University, rgoeken@iastate.edu

Xiaobo Zhou
Iowa State University

Matthew J. Helmers
Iowa State University, mhelmers@iastate.edu

Comparison of Timing and Volume of Subsurface Drainage under Perennial Forage and Row Crops in a Tile-Drained Field in Iowa

Abstract

Subsurface drainage systems in Iowa increase the productivity of annual row crops, such as corn and soybeans, but also contribute to alterations in the hydrological balance of the region and leaching of nutrient pollutants, such as NO3-N. This study's objective was to determine whether perennial forage orchardgrass can reduce the volume and change the timing of subsurface drainage in tiled fields in Iowa, thereby contributing to reductions in NO3-N leaching and moderating changes in the hydrology. Research was conducted at Iowa State University's Agricultural Drainage Water Research Site, located in northwest Iowa. Six 0.05 ha plots (three control and three treatment plots), each including subsurface drainage with continuous flow monitoring, were planted to row crops (RC) consisting of either a corn-soybean rotation or continuous corn from 1990-2004 (the pretreatment period). During the treatment period (2006-2011), control plots remained in RC while treatment plots were planted to perennial forage (PF), a mixture of orchardgrass, red clover, and ladino clover, succeeding to a monoculture of orchardgrass. During the pretreatment period, control and treatment plots showed no difference in subsurface drainage. During the treatment period, over the entire drainage season (March to November), PF did not decrease subsurface drainage; however, during the month of May, PF decreased subsurface drainage by 32% ($p < 0.05$). Early spring, including May, is a critical period for drainage in Iowa, as wet field conditions and a lack of vegetative cover contribute to a majority of the drainage and leaching of NO3-N from row crop fields during this period. Further research including different perennial species is needed, and investigations in different geographical regions are needed, as differences in precipitation and weather will affect the timing and volume of subsurface drainage.

Keywords

Nitrate, Orchardgrass, Perennial forage, Row crop, Subsurface drainage

Disciplines

Agriculture | Bioresource and Agricultural Engineering | Water Resource Management

Comments

This article was published in *Transactions of the ASABE* 58(5): 1193-1200 (doi: 10.13031/trans.58.10054).

Comparison of Timing and Volume of Subsurface Drainage under Perennial Forage and Row Crops in a Tile-Drained Field in Iowa

R. J. Goeken, X. Zhou, M. J. Helmers

Abstract. *Subsurface drainage systems in Iowa increase the productivity of annual row crops, such as corn and soybeans, but also contribute to alterations in the hydrological balance of the region and leaching of nutrient pollutants, such as NO_3-N. This study's objective was to determine whether perennial forage orchardgrass can reduce the volume and change the timing of subsurface drainage in tiled fields in Iowa, thereby contributing to reductions in NO_3-N leaching and moderating changes in the hydrology. Research was conducted at Iowa State University's Agricultural Drainage Water Research Site, located in northwest Iowa. Six 0.05 ha plots (three control and three treatment plots), each including subsurface drainage with continuous flow monitoring, were planted to row crops (RC) consisting of either a corn-soybean rotation or continuous corn from 1990-2004 (the pretreatment period). During the treatment period (2006-2011), control plots remained in RC while treatment plots were planted to perennial forage (PF), a mixture of orchardgrass, red clover, and ladino clover, succeeding to a monoculture of orchardgrass. During the pretreatment period, control and treatment plots showed no difference in subsurface drainage. During the treatment period, over the entire drainage season (March to November), PF did not decrease subsurface drainage; however, during the month of May, PF decreased subsurface drainage by 32% ($p < 0.05$). Early spring, including May, is a critical period for drainage in Iowa, as wet field conditions and a lack of vegetative cover contribute to a majority of the drainage and leaching of NO_3-N from row crop fields during this period. Further research including different perennial species is needed, and investigations in different geographical regions are needed, as differences in precipitation and weather will affect the timing and volume of subsurface drainage.*

Keywords. *Nitrate, Orchardgrass, Perennial forage, Row crop, Subsurface drainage.*

The use of subsurface drainage systems in Iowa has assisted in greatly increasing the productivity of annual row crops such as corn and soybeans (Baker et al., 2004). To harness the productive potential of the land, subsurface drainage was installed extensively in Iowa in the late 19th and early 20th centuries to drain somewhat poorly to poorly drained soils. In Iowa alone, approximately 3.6 million ha of cropland are estimated to be artificially drained, amounting to 25% of the state's agricultural land (Baker et al., 2004). These drainage systems allow timely seedbed preparation, planting, and harvesting, and they protect crops from periods of flooded soil conditions, allowing gas exchange between crop roots and the soil, which is crucial to plant metabolic processes. However, the widespread use of subsurface drainage coupled with changes in land use and vegetative cover may be impacting the hydrological balance of the region (Asbjornsen et al., 2007). Changing the landscape from perennial prairie to annual row crops changes water uptake patterns (Asbjornsen et al., 2007) because annual row crops grow for a shorter period of the year as compared to perennial plants. Evapotranspiration and water uptake occur mostly during the late spring and summer for row crops, while evapotranspiration and water uptake occur for a larger part of the year, including the early spring, for perennials (Hatfield et al., 2009). The switch from perennial to annual landscapes can increase the amount of water lost to subsurface drainage, contributing to an increase in the baseflow of Iowa's rivers (Schilling, 2005). In addition, most of the NO_3-N that enters streams in Iowa is from subsurface flow pathways (Schilling, 2005). Therefore, there is a double effect increasing the amount of NO_3-N in waterways: subsurface drainage increases the amount of subsurface water that flows into streams, and this greater amount of water has a relatively high concentration of NO_3-N. Changes in cropping practices (changing the landscape from predominantly small grains, grass. and hay to row crops) have a more significant effect on NO_3-N concentrations in streams than nitrogen fertilizer use, timing, or even historical precipitation differences (Hatfield et al., 2009). At recommended nitrogen application rates in corn-soybean rotations and in continuous corn, the NO_3-N concentrations in subsurface drainage water commonly exceed 10 mg L^{-1}, the U.S. public health drinking water standard (Helmers et al., 2012). High concentrations of NO_3-N in drinking water can have adverse effects on human health,

Submitted for review in November 2012 as manuscript number NRES 10054; approved for publication by the Natural Resources & Environmental Systems Community of ASABE in June 2015.

The authors are **Ryan J. Goeken,** Former Graduate Student, **Xiaobo Zhou,** Former Assistant Scientist, and **Matthew J. Helmers, ASABE Member,** Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa. **Corresponding author:** Matthew J. Helmers, 4354 Elings Hall, Iowa State University, Ames, IA 50011; phone: 515-294-6717; e-mail: mhelmers@iastate.edu.

and the large volumes of this nutrient that enter streams in the Mississippi River basin contribute to the hypoxic zone in the Gulf of Mexico (Mitsch et al., 2001).

The timing and volume of subsurface drainage are dependent on many factors, including precipitation timing and intensity, soil moisture conditions, and crop water demand (Lawlor et al., 2008). Lawlor et al. (2008) showed that drainage volumes from a single field can be significantly different between years, even with years of equal rainfall. This variation in drainage volume is due in large part to the timing and intensity of specific rainfall events and the resulting soil moisture conditions. Crop water demand is also important in determining subsurface drainage volumes. In addition to the duration of the growing season, the root depth, type, and density also affect a crop's water use. Perennial grass species most likely take up a larger percentage of water from soil layers near the surface, as compared to corn (Dong et al., 2010; Kranz et al., 2008; Nippert and Knapp, 2007), so water use varies greatly, both spatially and temporally, between different cropping systems. Many relatively short-term studies have shown a decrease in subsurface drainage flow with perennial crops and CRP grasses (Huggins et al., 2001; Oquist et al., 2007; Randall et al., 1997). A previous study at the site used in this study found no change in annual or drainage season flow volume due to different perennial crops or cover crops (Qi et al., 2011). However, that study did not examine variability in drainage over shorter periods. In addition, because about 70% of NO_3-N losses through subsurface drainage in the Midwest occur before row crops are established in the early spring (Randall and Vetsch, 2005), an analysis of drainage over this short but crucial period is warranted. In light of this, the objective of this study was to determine the timing and volume of subsurface drainage occurring in two different cropping systems: perennial forage (PF), which included pasture plots planted to orchardgrass (*Dactylis glomerata*), red clover (*Trifolium pretense*), and ladino clover (*Trifolium repens*), succeeding to predominantly a monoculture of orchardgrass, and row crop (RC) (either continuous corn or a corn-soybean rotation).

Materials and Methods

Site Description

The field study was performed at the Agricultural Drainage Water Research Site in northwest Iowa near Gilmore City in Pocahontas County. The site is located in Garfield Township at SW 1/4, Section 27, T92N, R31W. The ubiquitous soils are Nicollet (fine-loamy, mixed, superactive, mesic Aquic Hapludoll) and Webster and Canisteo (fine-loamy, mixed, superactive, mesic Typic Endoaqualls) clay loams with 3% to 5% organic matter, having an average slope of 0.5% to 1.5%. They are naturally poorly to naturally somewhat poorly drained glacial till soils. An automatic on-site meteorological station monitored weather conditions, including rainfall. Rainfall patterns at the site were compared to long-term averages (27 years from 1984-2010) determined from readings at the National Climate Data Center station at Pocahontas (COOP ID 1367), located 19 km west of the research site.

The total research area is 4.5 ha, of which 3.8 ha are used as experimental plots; the remainder is border and buffer. There are seventy-eight 0.05 ha plots (15 × 38 m). In 1989, subsurface drainage lines were installed parallel to the long dimension through the center of each plot and on the borders between plots. Only the center drainage lines are monitored for drainage volume. The three center drainage lines from three adjacent plots drain into an aluminum culvert containing three separate sumps and sampling/monitoring systems. Backpressure diverts a small fraction of all drainage to a 20 L glass sampling bottle, allowing for continuously monitored flow volume measurement and flow-integrated sampling of subsurface drainage. A detailed description of the drainage monitoring design is presented by Lawlor et al. (2008). The drainage coefficient at the site is approximately 3.5 cm d^{-1} and is the same on all plots.

Study Design and Statistical Analysis

The analysis presented in this article is based on a blocked plot design including six plots in the research area. Monthly and drainage season (March to November) drainage volumes for 1990-2011 were determined for each of these plots. The study period was split into two periods: the pretreatment period (1990-2004) and the treatment period (2006-2011). Because 2005 was an establishment year for PF, that year was left out of the analysis. During the pretreatment period, all six plots were planted in RC. During the treatment period, three plots were left in RC while the remaining three plots were planted to PF. The six plots were grouped into three pairs; these pairs were chosen because they were the plots with the most similar average yearly drainage volume during the pretreatment period (table 1). Each of these pairs belonged to one block. In 2000, a blocking system was devised in which the plots at the research site were split into four blocks according to drainage volume (a low flow block, a medium-low flow block, a medium-high flow block, and a high flow block; Qi et al., 2011). A more detailed description of the blocking for the entire research site is presented by Qi et al. (2011). The plots used in this study were included in the three blocks with lowest flow; the highest flow block was excluded because its subsurface flow exceeded precipitation during the study period.

Crop planting and harvest dates during the treatment period are shown in table 2. These dates were similar to that of local producers in the area. The PF plots were mowed at least three times each year and baled once or twice each year from 2006 to 2010. The PF plots generally greened up in early April, and there was generally growth throughout the year until temperatures fell below freezing. An extend-

Table 1. Research plot setup (PF = perennial forage, RC = row crop).

Pair	Plot	Average Yearly Drainage (mm) for Pretreatment Period (1990-2004)	Cropping System for Treatment Period (2006-2011)
1	20-1	174	RC
	17-2	165	PF
2	20-2	235	RC
	19-1	234	PF
3	16-2	296	RC
	14-2	300	PF

Table 2. Crop planting and harvest dates during treatment period.

Year	Corn		Soybean	
	Planting	Harvest	Planting	Harvest
2006	4 May	7 Oct.	10 May	7 Oct.
2007	14 May	22 Oct.	17 May	24 Oct.
2008	15 May	20 Oct.	23 May	20 Oct.
2009	19 May	3 Nov.	20 May	3 Nov.
2010	6 May	14 Oct.	18 May	6 Oct.
2011	10 May	14 Oct.	11 May	6 Oct.

ed dry period definitely reduced the growth of the PF. The RC plots followed common fertilization practices for the research area. The corn yield during the treatment period averaged 9,841 kg ha^{-1} and ranged from 7,532 kg ha^{-1} (in 2009 on plot 16-2) to 11,738 kg ha^{-1} (in 2010 on plot 20-1). The soybean yield during the treatment period averaged 3,176 kg ha^{-1} and ranged from 1,211 kg ha^{-1} (in 2009 on plot 20-1) to 4,371 kg ha^{-1} (in 2010 on plot 16-2).

Proc Mixed ($p \leq 0.05$) in SAS 9.3 (SAS, 2011) was used to determine the differences in drainage season (March to November) subsurface drainage between the control and treatment plots. For the monthly data, Proc Mixed ($p \leq 0.05$) was used to determine the differences in subsurface drainage between the control and treatment plots for the months of April, May, June, and July. These four months were selected for analysis because the largest amounts of subsurface drainage and NO_3-N leave row crop fields in Iowa during this period.

RESULTS AND DISCUSSION

RESEARCH SITE PRECIPITATION

The drainage season is a period in which the ground is usually not frozen and can discharge soil water as drainage; this period was considered to be March through November. The long-term (1984-2010) normal drainage season precipitation for Pocahontas, Iowa, was 704 mm. During the 22 years of this study, the average drainage season precipitation was 680 mm, or 3% below the long-term normal for the area. Drainage season precipitation ranged from 458 mm in 1997, or 35% below normal, to 908 mm in 2010, or 29% above normal (table 3). Eight of the 22 drainage seasons were wetter than normal, ranging from 2% to 29% wetter. The other 14 drainage seasons were between 1% and 35% drier than normal. Nine of the 22 drainage seasons had precipitation totals within 10% of normal, all of which were during the pretreatment period (1990-2004). Table 3 also lists growing season (May to September) precipitation. The growing season average precipitation for the study period was 490 mm, only 2 mm wetter than normal. Overall precipitation averages for the months of May, June, and October during the study period surpassed the normal for each month by 2%, 18%, and 3%, respectively, with all other months drier than normal, ranging from 2% to 28% drier.

During the pretreatment period (1990-2004), the average drainage season precipitation was 677 mm, or 4% below the long-term normal for the area. During these years, precipitation averages for May and June surpassed the normal precipitation by 6% and 16%, respectively, while all other months were drier than normal, ranging from 6% drier in July, August, and October to 26% drier in November with a deficit of 9 mm. During the treatment period (2006-2011), the average drainage season precipitation was 705 mm, almost exactly the same as the normal of 704 mm. However, the variability among drainage seasons was great, as none of the years were within 10% of the normal, ranging from 28% drier than normal in 2011 to 29% wetter than normal in 2010. In addition, during the treatment period,

Table 3. Precipitation at the research site during the study period (mm).

Year	Month									Growing Season[a]	Drainage Season[a]
	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.		
1990	0	38	117	290	150	80	50	24	13	686	761
1991	108	131	168	131	76	65	44	38	50	483	811
1992	53	61	50	90	187	80	16	77	53	423	667
1993	51	113	125	179	143	160	28	31	12	636	843
1994	2	52	41	179	89	51	37	48	30	396	528
1995	54	54	91	93	54	127	99	54	7	464	633
1996	45	24	114	116	82	199	50	60	60	562	751
1997	35	60	55	82	86	15	78	40	6	317	458
1998	57	56	104	171	102	53	24	76	17	454	660
1999	37	212	115	83	70	57	24	15	21	348	633
2000	28	34	93	113	152	92	35	67	70	485	684
2001	22	78	171	79	117	72	42	51	54	481	686
2002	25	61	77	51	87	279	35	77	3	529	695
2003	28	36	109	222	126	42	46	12	0	545	621
2004	97	72	146	121	58	48	143	15	20	517	720
2005	21	89	129	134	63	45	39	20	43	409	582
2006	69	93	22	61	28	135	91	19	21	337	538
2007	46	83	90	44	41	336	97	107	1	609	845
2008	35	88	151	152	105	80	65	100	37	553	812
2009	36	56	66	74	128	48	37	151	23	352	619
2010	NA[b]	70	81	331	176	85	108	14	41	782	908
2011	6	86	102	185	73	22	24	4	8	406	510
Average	41	75	101	135	100	99	55	50	27	490	680
Normal[c]	49	80	99	115	112	101	61	49	37	488	704

[a] Growing season was May through September, and drainage season was March through November.
[b] Climate data not available for the research site.
[c] Source: Climatological Data for Iowa, National Climate Data Center for Pocahontas, Iowa, 1984-2010.

precipitation averages for June, August, September, and October surpassed the normal by 23%, 17%, 15%, and 35%, respectively, while all other months were drier than normal, ranging from only 1% drier in April to 42% drier in November with a deficit of 15 mm. During the pretreatment period, the average growing season precipitation was 488 mm, the same as the normal for this period. During the treatment period, the average growing season precipitation was 506 mm, or 4% wetter than the normal.

SUBSURFACE DRAINAGE VOLUME AND TIMING

In general, only a small amount of drainage occurred in March, followed by a sharp increase in drainage in April (fig. 1). The most drainage occurred in May and June, decreasing to small amounts in September, October, and November. Precipitation increased more gradually throughout the year to the highest amount in June, from which it decreased. During the study period, average growing season drainage was 77% and 78% of drainage season drainage for the control and treatment plots, respectively. Growing season drainage was 100% of total drainage season drainage for six years in the control plots and for eight years in the treatment plots, all during the pretreatment period. The year with the smallest percentage of drainage season drainage occurring during the growing season was 2006, in which 37% and 21% of drainage occurred during the growing season for the control and treatment plots, respectively.

The average drainage season subsurface drainage for the control plots over the entire study period was 226 mm (table 4). Drainage ranged from 5 mm in 2000 to 437 mm in 2007. The average drainage season subsurface drainage was 199 mm for the pretreatment period and 294 mm for the treatment period. Drainage season drainage ranged from 5 to 398 mm during the pretreatment period and from 114 to 437 mm during the treatment period. During the entire study period, the largest amount of drainage occurred in June, with an average of 69 mm, followed by May with an average of 65 mm. March and September had the least drainage, with an average of 1 mm each. May had the largest amount of drainage during the pretreatment period, while June had the most drainage during the treatment period. On average, for the control plots, 76% of drainage season drainage occurred during April through June. During the pretreatment period, 78% of drainage season drainage occurred in April, May, and June; during the treatment period, 73% of drainage season drainage occurred during these three months. Over the study period, April, May, and June had the highest average amounts of drainage. Over the same period, these months also had the highest drainage to precipitation ratio (D:P). During both the pretreatment and treatment periods, May had the largest D:P, while March had the smallest. Drainage season D:P ranged from 0.01 in 2000 to 0.54 in 2011, with an overall average drainage season D:P of 0.32. The average drainage season D:P was 0.28 for the pretreatment period and 0.41 for the treatment period.

Even in years with nearly identical precipitation, drainage can vary widely, as seen in 2000 and 2001 (table 4). There was 684 mm of precipitation in 2000 and 686 mm in 2001, but there was only 5 mm of drainage in 2000 as compared to 189 mm in 2001. During April and May in 2001, there was nearly two times the precipitation as during the same period in 2000. There is generally no vegetative cover in row crop fields in Iowa during April and May, so a large amount of drainage would be expected if the soil moisture was adequate. Lawlor et al. (2008) found that years with equal precipitation can have statistically different drainage volumes in plots, as drainage volumes are directly tied to soil moisture, rainstorm timing and intensity, and the crop water demand during a given part of the growing season.

The average drainage season subsurface drainage for the treatment plots over the study period was 237 mm (table 5). Drainage ranged from 15 mm in 2000 to 472 mm in 1993. Average drainage season subsurface drainage was 217 mm for the pretreatment period and 288 mm for the treatment period. Drainage season drainage ranged from 15 to 472 mm during the pretreatment period and from 82 to 435 mm during the treatment period. During the study period, the largest amount of drainage occurred during June, with an average of 84 mm, followed by May with an average of 66 mm. March and September had the least drainage, with an average of 1 mm each. May had the highest average drainage during the pretreatment period, while June had the most drainage during the treatment period. For treatment plots, on average, 79% of drainage season drainage occurred during April through June. During the pretreatment period, 83% of drainage season drainage occurred in April, May, and June; during the treatment period, 71% occurred during these three months. For treatment plots, April, June, and May had the largest D:P. During the pretreatment period, May had the largest D:P, while March

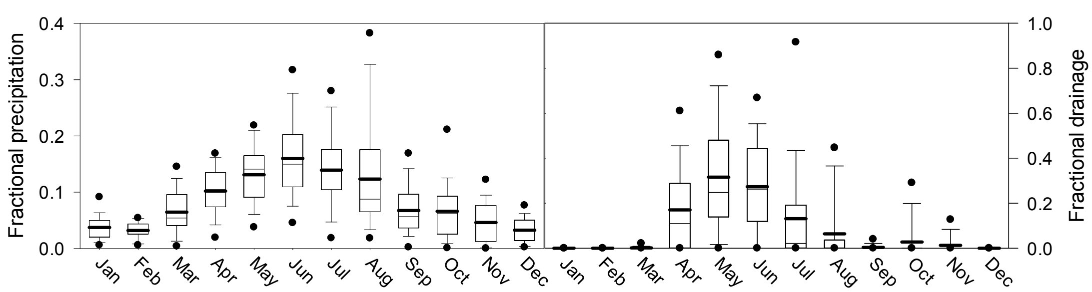

Figure 1. Box plots of precipitation and subsurface drainage volumes. Fractional precipitation is the average for 1990-2011 based on NCDC weather data at Pocahontas, Iowa. Fractional drainage is the average for 1990-2011 in the control plots. Each box indicates the following: bottom point = 5th percentile, error bar below box = 10th percentile, lower boundary of box = 25th percentile, upper boundary of box = 75th percentile, error bar above box = 90th percentile, top point = 95th percentile, thin line within box = median, and thick line within box = mean.

Table 4. Subsurface drainage (mm) at the research site for control plots.

Year	Month: March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Growing Season	Growing Season D:P[a]	Drainage Season	Drainage Season D:P[a]
Pretreatment (before PF establishment)													
1990	0	16	53	141	58	0	0	0	0	253	0.37	268	0.35
1991	0	104	138	103	0	0	0	0	53	241	0.50	398	0.49
1992	0	55	11	38	84	0	0	7	0	133	0.31	194	0.29
1993	0	123	53	71	49	54	0	0	0	227	0.36	350	0.42
1994	0	0	0	8	6	0	0	0	0	14	0.03	14	0.03
1995	0	0	159	61	0	0	0	0	0	220	0.47	220	0.35
1996	0	0	75	94	11	161	10	0	0	352	0.63	352	0.47
1997	0	35	35	0	1	0	0	0	0	35	0.11	70	0.15
1998	0	0	75	47	10	0	0	0	0	132	0.29	132	0.20
1999	0	0	122	14	2	0	0	0	0	138	0.40	138	0.22
2000	0	0	0	0	5	0	0	0	0	5	0.01	5	0.01
2001	0	18	136	30	0	5	0	0	0	170	0.35	189	0.27
2002	0	8	62	20	0	62	7	2	0	151	0.29	162	0.23
2003	0	39	77	140	63	0	0	0	0	280	0.51	318	0.51
2004	0	15	82	74	0	1	0	0	0	157	0.30	171	0.24
Average	0	28	72	56	19	19	1	1	4	167	-	199	-
Average D:P	0.00	0.36	0.64	0.40	0.14	0.10	0.03	0.01	0.07	-	0.33	-	0.28
Treatment (after PF establishment)													
2006	0	72	41	0	1	0	0	0	0	42	0.13	114	0.21
2007	5	106	47	6	0	142	2	128	0	197	0.32	437	0.52
2008	0	99	95	173	7	0	0	0	0	275	0.50	374	0.46
2009	0	24	26	27	33	0	0	47	16	86	0.24	173	0.28
2010	9	11	22	271	32	26	1	0	24	351	0.45	395	0.44
2011	0	83	50	134	7	0	0	0	0	191	0.47	274	0.54
Average	2	66	47	102	13	28	0	29	7	190	-	294	-
Average D:P	0.02	0.79	0.69	0.53	0.11	0.12	0.00	0.25	0.21	-	0.35	-	0.41
Total average	1	39	65	69	18	21	1	9	4	174	-	226	-
Total average D:P	0.01	0.48	0.66	0.44	0.13	0.10	0.02	0.08	0.11	-	0.34	-	0.32

[a] D:P = ratio of drainage to precipitation, using precipitation data from an on-site meteorological station.

Table 5. Subsurface drainage (mm) at the research site for treatment plots.

Year	Month: March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Growing Season	Growing Season D:P[a]	Drainage Season	Drainage Season D:P[a]
Pretreatment (before PF establishment)													
1990	0	13	75	214	72	0	0	0	0	361	0.53	374	0.49
1991	0	82	99	117	0	0	0	8	29	216	0.45	335	0.41
1992	0	55	3	69	82	0	0	6	36	155	0.37	253	0.38
1993	0	216	105	62	22	64	0	0	3	252	0.40	472	0.56
1994	0	0	0	49	0	0	0	0	0	49	0.12	49	0.09
1995	0	0	248	42	0	0	0	0	0	290	0.63	290	0.46
1996	0	0	96	181	12	45	7	1	0	340	0.61	341	0.45
1997	0	0	49	2	0	0	0	0	0	52	0.16	52	0.11
1998	0	0	84	63	18	0	0	0	0	166	0.37	166	0.25
1999	0	0	112	6	3	0	0	0	0	121	0.35	121	0.19
2000	0	0	0	1	14	0	0	0	0	15	0.03	15	0.02
2001	0	29	129	29	0	0	0	0	0	158	0.33	187	0.27
2002	0	0	43	11	0	60	7	0	0	120	0.23	120	0.17
2003	0	23	77	184	63	0	0	0	0	324	0.59	347	0.56
2004	0	0	70	63	0	0	0	0	0	133	0.26	133	0.19
Average	0	28	79	73	19	11	1	1	5	183	-	217	-
Average D:P	0.00	0.32	0.72	0.50	0.13	0.06	0.02	0.02	0.10	-	0.36	-	0.31
Treatment (after PF establishment)													
2006	0	64	15	0	2	0	0	0	0	17	0.05	82	0.15
2007	5	99	20	0	0	151	0	62	0	171	0.28	337	0.40
2008	0	88	92	184	0	0	0	9	12	276	0.50	385	0.47
2009	0	32	18	11	39	0	0	62	29	68	0.19	192	0.31
2010	12	7	6	309	47	34	5	0	15	401	0.51	435	0.48
2011	0	86	40	156	16	0	0	0	0	212	0.52	298	0.58
Average	3	63	32	110	17	31	1	22	9	191	-	288	-
Average D:P	0.02	0.76	0.37	0.52	0.15	0.14	0.01	0.18	0.32	-	0.34	-	0.40
Total average	1	38	66	84	19	17	1	7	6	186	-	237	-
Total average D:P	0.01	0.40	0.62	0.50	0.14	0.08	0.02	0.07	0.17	-	0.36	-	0.33

[a] D:P = ratio of drainage to precipitation, using precipitation data from an on-site meteorological station.

had the smallest. During the treatment period, April had the largest D:P, and September had the smallest. Drainage season D:P ranged from 0.02 in 2000 to 0.56 in both 1993 and 2003, with an overall average drainage season D:P of 0.33. The average drainage season D:P was 0.31 for the pretreatment period and 0.40 for the treatment period.

Table 6 shows the differences in monthly drainage between the control and treatment plots for the months of April to July. These months were chosen for analysis because a large majority of the drainage occurs during this period (85% and 87% of yearly flow for the control and treatment plots, respectively). In addition, because of large amounts of precipitation and limited vegetative cover in row crop fields, most NO_3-N is leached during this period. In all four months, on average, there were no significant differences during the pretreatment period, although there was a significant difference in drainage between the control and treatment plots in June 1991. In contrast, during May in the treatment period, the PF plots showed a significant decrease (32%) in subsurface drainage as compared to the row crop (control) plots. May 2007 and May 2010 both showed a significant decrease in drainage from the PF plots compared to the row crop plots. In addition, June 2009 showed a significant decrease in drainage in the PF plots compared to the row crop plots. While not at the $p \leq 0.05$ level, the subsurface drainage for the PF treatment in July 2010 was greater than for the row crop treatment at the $p = 0.06$ level. Overall, the data show a trend of PF reducing drainage early in the growing season, which makes sense because this treatment greened up in early April and would have been transpiring when there was little or no growth of the row crops. However, during summer, it is likely that evapotranspiration may have been greater for the row crops. While not significantly greater in any month at the $p \leq 0.05$ level, there was some trend for greater drainage from the PF treatments in June and July. Since orchardgrass is a cool-season grass (C3) with greater productivity in spring and early summer and then in fall, it is understandable that the only effect we consistently observed was a reduction in drainage in May, when orchardgrass probably had maximum productivity and there was little growth of row crops.

For the complete drainage season (March to November), the pretreatment period showed no significant difference in drainage between treatments in any individual year or on average (table 6). During the treatment period, drainage season drainage was reduced significantly in the PF plots in 2006 and 2007 but not in other years nor on average. Because 2006 and 2007 had very little drainage during the summer, while 2006 had mainly early spring drainage and 2007 had early spring, late summer, and fall drainage, it is understandable that these might be years in which PF had the greatest impact on drainage season drainage, as much of the drainage would have occurred when the PF treatment was actively growing. The results of this study are slightly different from the results of Daigh et al. (2014), who found that a diverse prairie reduced cumulative drainage when compared to a corn-soybean rotation in the same region. This difference likely highlights that different perennials may affect the water balance differently depending on their growth patterns. The diverse prairie studied by Daigh et al. (2014) had a mixture of cool and warm season native vegetation, so productivity would likely have been spread throughout the growing season, rather than primarily in the early and late part of the growing season. To reduce subsurface drainage with perennials, the growth patterns and water use of the various cover types need to be studied, under-

Table 6. Comparison of subsurface drainage (mm) from control (Ctrl) and treatment (Trt) plots over the study period for the critical months of April to July and over the drainage season. Values in bold indicate a statistically significant difference ($p \leq 0.05$).

	Month														
	April			May			June			July			Drainage Season		
Year	Ctrl	Trt	p-value	Ctrl	Trt	p-value	Ctrl	Trt	p-value	Ctrl	Trt	p-value	Ctrl	Trt	p-value
Pretreatment (before PF establishment)															
1990	16	13	0.82	53	75	0.49	141	214	0.42	58	72	0.62	268	374	0.50
1991	104	82	0.56	138	99	0.44	**103**	**117**	**0.04**	0	0	-	398	335	0.58
1992	55	55	0.87	11	3	0.29	38	69	0.30	84	82	0.98	194	253	0.23
1993	123	216	0.48	53	105	0.23	71	62	0.87	49	22	0.21	350	472	0.62
1994	0	0	-	0	0	-	8	49	0.37	6	0	0.42	14	49	0.44
1995	0	0	-	159	248	0.12	61	42	0.59	0	0	-	220	290	0.36
1996	0	0	-	75	96	0.48	94	181	0.28	11	12	0.99	352	341	0.76
1997	35	0	0.42	35	49	0.72	0	2	0.42	1	0	0.42	70	52	0.79
1998	0	0	-	75	84	0.76	47	63	0.20	10	18	0.18	132	166	0.30
1999	0	0	-	122	112	0.87	14	6	0.17	2	3	0.42	138	121	0.78
2000	0	0	-	0	0	-	0	1	0.42	5	14	0.62	5	15	0.61
2001	18	29	0.65	136	129	0.72	30	29	0.93	0	0	-	189	187	0.96
2002	8	0	0.19	62	43	0.23	20	11	0.46	0	0	-	162	120	0.22
2003	39	23	0.44	77	77	0.95	140	184	0.18	63	63	0.99	318	347	0.54
2004	15	0	0.11	82	70	0.78	74	63	0.56	0	0	-	171	133	0.49
Average	28	28	0.96	72	79	0.42	56	73	0.06	19	19	0.94	199	217	0.36
Treatment (after PF establishment)															
2006	72	64	0.63	41	15	0.08	0	0	-	1	2	0.70	**114**	**82**	**0.03**
2007	106	99	0.57	**47**	**20**	**0.01**	6	0	0.19	0	0	-	**437**	**337**	**0.04**
2008	99	88	0.37	95	92	0.93	173	184	0.28	7	0	0.13	374	385	0.81
2009	24	32	0.63	26	18	0.59	**27**	**11**	**0.05**	33	39	0.69	173	192	0.84
2010	11	7	0.62	**22**	**6**	**0.03**	271	309	0.60	32	47	0.06	395	435	0.39
2011	83	86	0.87	50	40	0.90	134	156	0.61	7	16	0.62	274	298	0.57
Average	66	63	0.57	**47**	**32**	**0.03**	102	110	0.59	13	17	0.32	294	288	0.73

stood, and taken into account in adopting perennial vegetation practices.

Conclusions

Although on average the perennial forage (PF) planted to perennial orchardgrass did not significantly reduce subsurface drainage over the drainage season, there were two years (2006 and 2007) in which the drainage season drainage from the orchardgrass treatment was significantly less. On average and in 2007 and 2010, the orchardgrass significantly reduced subsurface drainage during May as compared to row crops. The spring months, including May, are a critical time for subsurface drainage of row crop fields in Iowa, as this is when the most drainage occurs and when the most NO_3-N is lost due to leaching. During the 21-year monitoring period of the row crop (control) plots, 76% of the drainage season drainage occurred from April to June. The results presented in this study suggest that perennial cropping systems can reduce the deleterious effects of subsurface drainage in Iowa; however, more research is needed. Many types of perennial cover can be integrated into Iowa's agricultural landscape, and each of these types of perennial cover can be used for different purposes and in different cropping systems. For example, some perennial crops, such as warm and cool season grasses and different legumes, are used in long-term pastures, while other perennials, such as alfalfa, can be integrated into extended rotations and allowed to grow for only a year or two at a time. Differences in the physiological traits, interactions among plant species, and management strategies used with perennial crops will likely cause different responses in subsurface drainage. In fact, orchardgrass itself comes in many different varieties, each yielding differently, and the crop's forage yield also varies widely in the Midwestern U.S. (Henning and Risner, 1993). These different patterns in growth will likely cause a different response in subsurface drainage. The variance in how perennial crops grow in different geographic regions, coupled with differences in soil moisture conditions, precipitation, and weather patterns, will also affect how subsurface drainage responds to perennial cropping systems. Therefore, further research on the integration of perennial crops into agricultural systems should include diverse types and mixtures of species, and these studies should be spread over different geographic areas. Furthermore, in order to re-integrate perennial crops into our agricultural systems, there must be economic as well as environmental incentives. Current programs heavily favor row crops in the Midwest, so it is more difficult to integrate perennial crops into existing agricultural systems. Therefore, to reap the benefits from perennial crops, research must be directed at not only the production aspects of the agricultural system but the political, social, and economic factors as well.

Acknowledgements

This research is part of a regional collaborative project supported by the USDA-NIFA (Award No. 2011-68002-30190) titled "Cropping systems coordinated agricultural project: Climate change, mitigation, and adaptation in corn-based cropping systems" (sustainablecorn.org). Funding for this project was also provided by the Iowa Department of Agriculture and Land Stewardship.

References

Asbjornsen, H., Mora, G., & Helmers, M. J. (2007). Variation in water uptake dynamics among contrasting agricultural and native plant communities in the Midwestern U.S. *Agric. Ecosyst. Environ., 121*(4), 343-356. http://dx.doi.org/10.1016/j.agee.2006.11.009.

Baker, J. L., Melvin, S. W., Lemke, D. W., Lawlor, P. A., & Crumpton, W. G., & Helmers, M. J. (2004). Subsurface drainage in Iowa and the water quality benefits and problem. In *Proc. 8th Intl. Drainage Symp.* (pp. 39-50). St. Joseph, Mich.: ASAE.

Daigh, A. L., Zhou, X., Helmers, M. J., Pederson, C. H., Horton, R., & Ewing, R. (2014). Subsurface drainage flow and soil water dynamics of reconstructed prairies and corn rotations for biofuel production. *Vadose Zone J. 13*(4). http://dx.doi.org/10.2136/vzj2013.10.0177.

Dong, X., Patton, B. D., Nyren, A. C., Nyren, P. E., & Prunty, L. D. (2010). Quantifying root water extraction by rangeland plants through soil water modeling. *Plant Soil, 335*(1-2), 181-198. http://dx.doi.org/10.1007/s11104-010-0401-7.

Hatfield, J. L., McMullen, L. D., & Jones, C. S. (2009). Nitrate-nitrogen patterns in the Raccoon River basin related to agricultural practices. *J. Soil Water Cons., 64*(3), 190-199. http://dx.doi.org/10.2489/jswc.64.3.190.

Helmers, M. J., Zhou, X., Baker, J. L., Melvin, S. W., & Lemke, D. W. (2012). Nitrogen loss on tile-drained Mollisols as affected by nitrogen application rate under continuous corn and corn-soybean rotation systems. *Canadian J. Soil Sci., 92*(3), 493-499. http://dx.doi.org/10.4141/cjss2010-043.

Henning, J., & Risner, N. (1993). Orchardgrass. Document G4511. Columbia, Mo.: University of Missouri Extension. Retrieved from http://extension.missouri.edu/p/G4511.

Huggins, D. R., Randall, G. W., & Russelle, M. P. (2001). Subsurface drain losses of water and nitrate following conversion of perennials to row crops. *Agron. J., 93*(3), 477-486. http://dx.doi.org/10.2134/agronj2001.933477x.

Kranz, W. L., Irmak, S., van Donk, S. J., Yonts, C. D., & Martin, D. L. (2008). Irrigation management for corn. Document G1850. Lincoln, Neb.: University of Nebraska-Lincoln Extension. Retrieved from http://ianrpubs.unl.edu/epublic/live/g1850/build/g1850.pdf.

Lawlor, P. A., Helmers, M. J., Baker, J. L., Melvin, S. W., & Lemke, D. W. (2008). Nitrogen application rate effect on nitrate-nitrogen concentration and loss in subsurface drainage for a corn-soybean rotation. *Trans. ASABE, 51*(1), 83-94. http://dx.doi.org/10.13031/2013.24229.

Mitsch, W. J., Day, J. W., Gilliam, J. W., Groffman, P. M., Hey, D. L., Randall, G. W., & Wang, N. (2001). Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River basin: Strategies to counter a persistent ecological problem. *BioScience, 51*(5), 373-388. http://dx.doi.org/10.1641/0006-3568(2001)051[0373:RNLTTG]2.0.CO;2.

Nippert, J. B., & Knapp, A. K. (2007). Linking water uptake with rooting patterns in grassland species. *Oecologia, 153*(2), 261-272. http://dx.doi.org/10.1007/s00442-007-0745-8.

Oquist, K. A., Strock, J. S., & Mulla, D. J. (2007). Influence of alternative and conventional farming practices on subsurface drainage and water quality. *J. Environ. Qual., 36*(4), 1194-1204.

http://dx.doi.org/10.2134/jeq2006.0274.
Qi, Z., Helmers, M. J., Christianson, R. D., & Pederson, C. H. (2011). Nitrate-nitrogen losses through subsurface drainage under various agricultural land covers. *J. Environ. Qual., 40*(5), 1578-1585. http://dx.doi.org/10.2134/jeq2011.0151.
Randall, G. W., & Vetsch, J. A. (2005). Corn production on a subsurface-drained Mollisol as affected by fall versus spring application of nitrogen and nitrapyrin. *Agron. J., 97*(2), 472-478. http://dx.doi.org/10.2134/agronj2005.0472.
Randall, G. W., Huggins, D. R., Russelle, M. P., Fuchs, D. J., Nelson, W. W., & Anderson, J. L. (1997). Nitrate losses through subsurface tile drainage in Conservation Reserve Program, alfalfa, and row crop systems. *J. Environ. Qual., 26*(5), 1240-1247. http://dx.doi.org/10.2134/jeq1997.00472425002600050007x.
SAS. (2011). SAS for Windows. Ver. 9.3. Cary, N.C: SAS Institute, Inc.
Schilling, K. E. (2005). Relation of baseflow to row crop intensity in Iowa. *Agric. Ecosyst. Environ., 105*(1-2), 433-438. http://dx.doi.org/10.1016/j.agee.2004.02.008.