doi:10.2489/jswc.67.6.495

Water table, drainage, and yield response to drainage water management in southeast Iowa

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Abstract: Subsurface drainage is an important practice for optimizing crop production, but it accelerates nitrate-nitrogen (NO_3-N) loss to downstream water bodies. As a result, there is a need for practices that can maintain crop production while decreasing subsurface drainage volume and NO_3-N export. The objectives of this work were to evaluate the impact of drainage water management through controlled drainage, shallow drainage, conventional drainage, and no drainage on subsurface drainage volumes, water table depths, crop yields, and NO_3-N export. This research was conducted at the Iowa State University Southeast Research Farm and consisted of four management schemes with two replicates for a total of eight plots. Plots consisted of a corn (*Zea mays* L.)–soybean (*Glycine max* L. Merr.) rotation with half of the plot planted in corn and half planted in soybeans each year. Findings from four years show that undrained plots had a high occurrence of elevated water tables. Controlled and shallow plots had elevated water tables in the early spring and early fall in accordance with the rainfall and management protocols for controlled drainage. Water table response was quick, with drawdown to tile depth within one to two days after significant rain events. During the period of the study, drainage water management through controlled drainage or shallow drainage reduced overall drainage volume by 37% and 46%, respectively. Average annual NO_3-N loss for the study period was reduced by 36% and 29% for controlled drainage and shallow drainage, respectively. Over the four-year period, corn yields in the controlled plots were significantly lower than conventional drainage; however, yields were not statistically different from shallow drained plots. There was no statistically significant difference between drained plots in terms of soybean yield for the study period. Undrained plots, however, had significantly lower yields for corn when compared with shallow and conventional treatments and for soybeans when compared to all treatments. This study highlighted the potential for use of drainage water management practices in reducing subsurface drainage volume and downstream NO_3-N loss. In addition, the study highlighted the overall importance of drainage on maintaining crop yields.

Key words: controlled drainage—crop yield—nitrate—water table depth

Excessive nitrate-nitrogen (NO_3-N), as it relates to water quality in the Midwest, is tied to hypoxia in the Gulf of Mexico (Turner and Rabalais 1994). Major contributing areas relative to NO_3-N loading to the Gulf of Mexico are the Ohio and Upper Mississippi River basins, which from 1997 to 2006 were estimated to contribute 5.9 and 7.2 kg N ha^{-1} y^{-1} (5.3 and 6.4 lb N ac^{-1} yr^{-1}) of riverine nitrate (NO_3), respectively (David et al. 2010). Since a significant portion of NO_3-N export originates from areas where agricultural subsurface drainage systems are utilized (David et al. 2010), there is a need to implement practices that have the potential to reduce subsurface drainage volumes and, consequently, NO_3-N export. One potential practice to reduce NO_3-N export is drainage water management.

Drainage water management, in the context of subsurface agricultural drainage, consists of managing outflow or designing with a goal of reducing drainage volume. Drainage water management can be accomplished by shallower drain placement or through managing the outlet of the subsurface drainage systems during certain portions of the year (i.e., controlled or management drainage) (Wortmann et al. 2006). Specifically, the drainage system would be managed to reduce drainage outflow during times of the year when drainage is not necessary. For shallower drain placement, the drains would be placed closer together to maintain a consistent drainage intensity or drainage design rate (Strock et al. 2011). Strock et al. (2011) reported an average subsurface drainage volume reduction of 40% from a review of 15 peer-reviewed controlled drainage studies. These studies included both observed and simulated conditions in the United States, Canada, Belgium, Sweden, Italy, and Egypt. For shallower drain placement (90 versus 120 cm [35 versus 47 in]), Sands et al. (2008) measured reductions in annual drainage of 20% over a six-year study in south-central Minnesota. Due to less water leaving the system, a corresponding NO_3-N load reduction similar to the subsurface drainage volume has been observed since the concentrations of NO_3-N tend to be similar when compared to conventional drainage. As noted by Riley et al. (2009), the differences in crop yield between conventional drainage and drainage water management have been inconsistent. Corn yield increases of 10% to 20% have been reported (Fisher et al. 1999 and Hunt et al. 1993), but corn yield decreases of about 3% have also been reported (Grigg et al. 2004). While drainage water management has been shown to reduce subsurface drainage volume, there is the potential that this reduction could lead to an increase in surface water runoff due to a wetter soil profile (Frankenberger et al. 2007; Riley et al. 2009; Singh et al. 2007).

Installation of a drainage water management system (controlled drainage) is typically done on slopes less than 1% as control structures are required for every 30 to 60 cm (12 to 24 in) of elevation drop (Frankenberger et al. 2007; Strock et al. 2011). This allows for even water table management and serves to limit ponding on the soil surface. In addition, installation cost and control structure management time increases substantially

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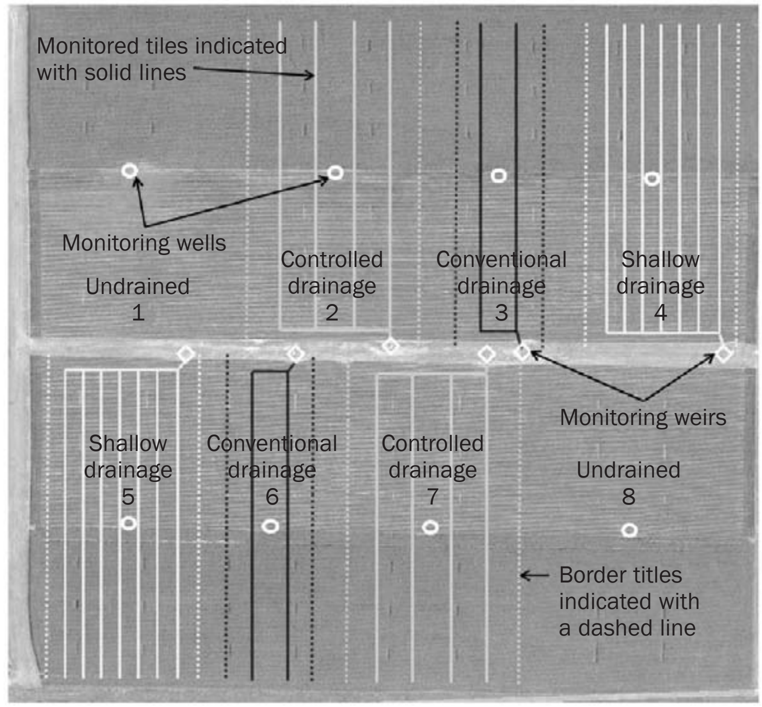
on steeper slopes. Generally, in Iowa drains are placed at a 1.2 m (3.9 ft) depth. Shallow drainage (0.75 to 0.9 m [2.46 to 2.95 ft]) can be installed as an alternative to conventional drainage while still resulting in some of the benefits of controlled drainage (Strock et al. 2011). To maintain a consistent drainage design rate and drainage intensity in a shallow drainage system, the drain tiles are installed closer together (Strock et al. 2011). For example, from Sands et al. (2008) at a drainage intensity of 13 mm d^{-1} (0.5 in day^{-1}), the drainage spacing was 24 m (79 ft) for a depth of 120 cm (47 in) and 18 m (59 ft) for a depth of 90 cm (35 in). The specific drainage design rate for an individual field is a function of climate, site, and soil characteristics, along with characteristics of the crops to be planted in the field (Strock et al. 2011)

A consideration relative to drainage water management is the cost compared to a conventional drainage system. While actual costs would vary by location, there would be an increased cost of implementing shallow drainage or controlled drainage. Since the shallower drain placement would have the drains spaced closer together, the linear meters of drain tile per hectare would increase, and the cost would increase proportionally. For controlled drainage, there would be systems that would be retrofit with existing drainage systems or new systems. For the retrofit systems, the primary costs would be for the control structure and any costs associated with increased management of the system. For a new system, there would be costs associated with the control structures and management, but there may also be increased design costs to incorporate the concept of controlled drainage. In addition, at some point during the design life of the drainage system, there could be a need to replace the control structure. Based on a review of several fields in Illinois, the average difference in cost between conventional and controlled drainage was US$120 ha^{-1} (US$49 ac^{-1}), with a range in cost of implementing controlled drainage from US$100 to US$220 ha^{-1} (US$40 to US$89 ac^{-1}) (Cooke et al. 2008).

Since performance of drainage water management can be region specific due to the timing of subsurface drainage, there is a need to investigate the performance of drainage water management under Iowa conditions. The objectives of this work were to evaluate the impact of drainage management through controlled drainage, shallow drainage, conventional drainage, and no drainage on subsurface drainage volumes, water table depths, NO_3-N loss, and crop yields.

Figure 1

Aerial view of plots and layout of drainage treatments at the Crawfordsville, Iowa, research site.



Materials and Methods

Site Location and Background. Research was conducted on drainage management systems at the Southeast Research Farm in Crawfordsville, Iowa (41°11'38" N, 91°28'58" W), from 2007 to 2010. The site consists of Taintor (silty clay loam, fine, smectitic, mesic Vertic Argiaquolls) and Kalona (silty clay loam, fine, smectitic, mesic Vertic Endoaquolls) soils. The research site has eight plots with two replications for each treatment (figure 1). Individual plots ranged in size from approximately 1.2 to 2.4 ha (3 to 6 ac) for a total project area of 17 ha (42 ac). Plots were split down the middle and cropped east to west with both corn (*Zea mays* L.) and soybeans (*Glycine max* L.

Table 1

Field activities including control dates for drainage water management. An open control structure indicates the drainage depth is 1.2 m. In the spring, a closed control structure indicates the drainage depth is 0.76 m. In the fall, a closed control structure indicates the drainage depth is 0.30 m.

Year	Corn planting	Harvest	Soybean planting	Harvest	Spring control		Fall control
					Open	Close	Close
2007	May 8	Oct. 16	late May	Oct. 25	Apr. 30	June 2	Jan. 7, 2008
2008	May 9	Nov. 4	June 2	Oct. 11	Apr. 14	June 5	Nov. 19
2009	Apr. 17 to 18	Oct. 7, Oct. 12 to 13	May 22	Oct. 20	Apr. 15	May 29	Nov. 5
2010	Apr. 15	Sept. 30, Oct. 12	May 28	Oct. 1 to 2	Apr. 15	June 24	Oct. 18

Merr.) each year, which were alternated each consecutive year to replicate a typical corn–soybean rotation in Iowa. The eight plots included two undrained plots, two plots with conventional drainage, two plots with shallow drainage, and two plots with controlled drainage. The conventional and controlled drainage plots had tiles installed to a 1.2 m (4 ft) depth with a drain spacing of 18 m (60 ft). Shallow drainage plots had tiles installed to a 0.76 m (2.5 ft) depth with a 12.2 m (40 ft) spacing. All drained plots were designed to have a maximum drainage coefficient of 1.9 cm d^{-1} (0.75 in day^{-1}).

Generally, the gates in the water table control structures are removed to allow free drainage approximately two weeks before planting and harvest. At this site, controlled plots were drained only when needed for field activities. The gates were opened in mid to late April prior to planting and generally closed in late May to early June after planting was completed; however, a wet spring in 2010 delayed control structure closure until near the end of June. Specific management dates can be found in table 1. Management in the fall was typically not required at this site due to low water table conditions.

Precipitation at the site was collected with three different instruments: a tipping bucket and a catch gauge approximately 1 km (0.6 mi) from the plots and a tipping bucket at the site. Data from the three sites were consistently similar and were averaged to determine rainfall. Onsite data were collected from March through November of each year to avoid freezing. This timeline also corresponds to the primary drainage season in Iowa (April to November) (Helmers et al. 2005).

Tile lines for all plots were laid out in a north-south orientation with interior tiles continuously monitored for flow rate with a 13 cm (18 in) tall 45° V-notch weir and a Global Water pressure transducer (Global Water, Sacramento, California) logging in 5- to 30-minute intervals. Border tiles on each plot were installed to hydraulically isolate the treatments. The border tiles were routed through the same discharge pipe (drainage main); however, they were not monitored. On controlled drainage plots, the border tiles also had control structures. Plot water samples were taken by grab sampling outflow on a weekly basis, when water was available, for assessment of NO_3-N concentrations. Samples were analyzed for NO_3-N concentration by the Wetland Research Laboratory at Iowa State University. Their method for analysis was the second-derivative spectroscopy technique (Crumpton et al. 1992). A linear interpolation was done between the weekly NO_3-N concentration sample data to estimate daily concentrations. The resulting daily concentrations were multiplied by daily flow volume to estimate total NO_3-N loss from each drained plot. This loss was divided by annual flow to determine flow-weighted NO_3 concentrations.

In 2007, water table monitoring wells for determining the depth to water table were installed to a depth of 1.5 to 1.75 m (5 to 5.7 ft) midway between an interior set of tile lines in each drained plot (plots 2, 3, and 4) (figure 1). In the undrained plot (plot 1), the monitoring well was located in the middle of the plot. These wells were subsequently replaced in 2009 to move the wells to the border between the corn and soybeans of each treatment at the center of the plot to minimize the impact on farming operations (figure 1). Additional wells were also installed in plots 5, 6, 7, and 8 in 2009 following the same protocols. Depth to water table was monitored hourly using Global Water pressure transducers.

Yield data were collected with a combine yield monitor, and readings were constrained to the center 12 to 18 rows of corn and soybeans for each plot depending on the equipment used. The length monitored was 36.6 m (120.1 ft) for each plot. The start and end locations were midway between tile lines in the center of the plots.

Statistical analyses were conducted using Statistical Analysis System software (SAS 2003). The general linear model procedure was used with two replicates per treatment to determine the statistical significance of treatment effects on subsurface drainage, crop yield, flow-weighted NO_3-N concentration, and NO_3-N loss. The mean values for the subsurface drainage, crop yield, flow-weighted NO_3-N concentration, and NO_3-N loss were separated using a least significance difference (LSD) test at $p = 0.05$ ($LSD_{0.05}$).

Results and Discussion

Precipitation. Precipitation data show that 2008 was the driest year in the study with an annual precipitation of nearly 92 cm (36 in) (table 2). Although 2008 had approximately 5.4 cm (2.1 in) less in total annual precipitation than the 30-year average (1981 to 2010), the precipitation over the potential growing season (April to October) was 14.9 cm (5.9 in) more than the historic average of 73.1 cm (28.8 in). Precipitation in 2007 was 102.4 cm (40.3 in), which was the next driest year in the study, while 2009 and 2010 had nearly the same amount of annual precipitation, just over 123 cm (48.4 in). Precipitation in the growing seasons of 2009 and 2010 was also similar, with 101.5 and 105.2 cm (40.0 and 41.4 in), respectively. Precipitation in June of every year was substantially higher than the 30-year average. Overall, the study period was characterized by above average precipitation, especially during the growing season.

Table 2
Thirty-year average monthly precipitation and monthly precipitation in 2007, 2008, 2009, and 2010. Dashes indicate unavailable data.

Month	30-year average (mm)	2007 (mm)	2008 (mm)	2009 (mm)	2010 (mm)
Jan.	31	22	8	—	41
Feb.	41	45	3	—	7
Mar.	62	92	23	108	74
Apr.	85	127	136	57	113
May	123	85	136	151	151
June	120	191	159	219	321
July	118	107	85	123	129
Aug.	100	191	97	248	119
Sept.	109	51	207	35	189
Oct.	76	98	60	182	30
Nov.	63	15	5	68	34
Dec.	46	—	—	41	27
Year	972	1,024	918	1,232	1,234

Table 3
Average monthly drainage (cm) from the three drainage treatments: conventional drainage (Conv), controlled drainage (CD), and shallow drainage (SH). Dashes indicate unavailable data.

	Monthly subsurface drainage (cm)											
	2007			2008			2009			2010		
Month	Conv	CD	SH	Conv	CD	SH	Conv	CD	SH	Conv	CD	SH
Jan.	0.0	0.0	0.0	—	0.0b	1.1a	0.0	0.0	0.4	0.1	0.0	1.5
Feb.	0.0	0.0	0.0	—	0.0	0.0	0.2a	0.0b	0.0b	0.0	0.0	0.0
Mar.	0.0	0.0	0.0	—	1.3	0.2	—	0.5b	2.2a	7.3	4.1	3.7
Apr.	—	—	—	5.5	7.6	4.2	4.5	2.0	0.8	5.8a	4.2b	3.3c
May	3.0	5.6	2.8	5.5	5.6	3.2	8.4a	5.8a	2.9b	8.9a	6.1ab	4.0b
June	9.8	6.4	8.0	7.4a	3.2b	3.3b	13.9a	4.3b	5.0b	19.2a	13.4b	10.3b
July	0.2	0.2	0.1	1.1a	0.0b	0.0b	6.8 a	1.3b	1.6 b	0.3a	0.0b	0.0b
Aug.	4.1	2.0	2.8	0.0	0.0	0.0	4.0	3.0	2.3	0.4a	0.0b	0.0b
Sept.	0.0	0.1	0.0	5.5a	4.6b	4.7ab	0.0	0.0	0.0	7.8	4.7	4.1
Oct.	4.1a	2.8b	3.0b	0.4	0.0	0.1	7.5a	4.9b	4.2b	1.0a	0.0b	0.0b
Nov.	0.0	0.0	0.0	0.3	0.0	0.0	2.8a	0.1b	0.8ab	0.0	0.0	0.0
Dec.	3.9	0.0	0.0	0.2	0.0	0.1	1.0a	0.0b	0.2ab	0.0	0.0	0.0

Notes: Monthly means within years with a different letter are significantly different ($p = 0.05$). Only months where there were significance differences have letters included.

Table 4
Average annual drainage from the three drainage treatments.

	Drainage (cm)				
Treatment	2007	2008	2009	2010	4-year average
Conventional	25a	23a	49a	51a	37a
Controlled	17a	22a	22b	32b	23b
Shallow	17a	16a	20b	27b	20b

Note: Means within years or for the four-year average with a different letter are significantly different ($p = 0.05$).

Drainage. Overall, 2008 was the driest year in the study, which is reflected in the drainage volume from the conventional and shallow drainage treatments (tables 3 and 4). Heavy precipitation in April, along with the opening of the control structures in the controlled drainage plots caused relatively high annual drainage for this treatment. The closure of controlled drainage structures in early June reduced drainage from this treatment for the remainder of the year. The lowest drainage year for the controlled plots was 2007, when the majority of rainfall occurred in June through August, at which time the control structures were closed and crop transpiration was the greatest. Large rainfall in June and October of 2009 contributed to the high annual drainage volume from the conventional treatment. The control structures in the controlled drainage plots were closed during this time, which reduced drainage from these plots. A wet spring in 2010 delayed the control structure closure until late June. As a result, there was dramatically greater drainage in June 2010 from the controlled drainage treatment than in June 2009 even though both months had over 200 mm (7.9 in) of precipitation (30-year average was 120 mm [4.7 in] of precipitation for June). Although not always significantly different, for all months with available data there was lower subsurface drainage volume from the shallow drainage treatment than the conventional drainage treatment. This was the case even in the high drainage month of June each year where the shallow drainage had significantly lower subsurface drainage than the conventional drainage in 2008, 2009, and 2010. Drainage in 2010 was the highest during the period of record for all drainage treatments.

Statistically significant differences in average annual drainage between the conventional drainage treatment and the controlled drainage treatments were observed in 2009 and 2010 (table 4). This trend was also apparent when comparing the conventional treatment to the shallow drainage treatment for 2009 and 2010. No significant differences were observed between the controlled drainage and shallow drainage treatments in any year. In 2009 and 2010, a sensor used on one of the two conventional drainage treatment plots malfunctioned, which may have had an impact on statistical significance; however, drainage from the plots in this treatment were generally very similar. When reviewing the four-year average subsurface drainage, volume was reduced by 37% and 46% when comparing controlled drainage and shallow drainage to conventional drainage.

Water Table. Groundwater monitoring showed shallow and controlled drainage plots trace similarly throughout the year with nearly a 20 cm (8 in) difference in average groundwater depth between conventional drainage and both the controlled and shallow plots (table 5). In the undrained plots, there were a greater number of days when the water table was within 30 cm (12 in) of the ground surface than the drainage treatments (table 6), which would be expected to impact crop production and trafficability.

Although tile depths in the shallow plots were installed at 76 cm (2.5 ft) and in the controlled plots the control depth varied between 30 cm and 120 cm (1 ft and 4 ft),

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Table 5
Average monthly depth to water table for all treatments: undrained (UD), conventional drainage (Conv), controlled drainage (CD), and shallow drainage (SH). Data presented for 2009 and 2010 are the average of two replicates. Dashes indicate unavailable data.

	Groundwater depth (cm)															
	2007				2008				2009				2010			
Month	UD	Conv	CD	SH	UD	Conv	CD	SH	UD	Conv	CD	SH	UD	Conv	CD	SH
Jan.	—	—	—	—	86	131	101	114	113	140	132	128	67	130	126	131
Feb.	—	—	—	—	120	145	141	131	112	143	134	127	76	141	148	144
Mar.	—	—	—	—	96	138	118	123	73	127	94	111	44	119	112	117
Apr.	—	—	—	—	71	127	100	110	94	127	114	115	52	129	122	116
May	—	—	—	—	90	129	116	112	68	124	114	103	37	127	120	104
June	—	—	—	—	70	124	100	103	16	115	88	82	27	116	107	93
July	123	175	160	163	—	—	—	—	37	125	110	103	57	138	133	133
Aug.	115	174	149	110	123	173	160	159	55	131	127	126	78	139	142	146
Sept.	105	142	125	135	94	143	121	127	54	137	134	132	67	131	127	126
Oct.	85	126	102	116	106	139	126	126	43	118	107	101	64	138	138	142
Nov.	114	140	133	129	105	135	122	120	5	126	108	106	91	142	149	158
Dec.	104	136	123	120	104	136	125	118	54	129	122	127	104	141	148	158
Average	108	149	132	129	97	138	121	122	61	129	115	112	64	133	131	131

Table 6
Number of days during the growing season (April 1 to October 31) that the water table was within 30 cm of the ground surface.

Year	No drainage	Shallow drainage	Controlled drainage	Conventional drainage
2007	2	1	1	0
2008	7	1	4	0
2009	46	0	0	0
2010	38	0	0	0

Table 7
Average annual flow weighted nitrate-nitrogen (NO_3-N) concentration from the three drainage treatments.

	Flow-weighted NO_3-N concentration (mg L^{-1})				
Treatment	2007	2008	2009	2010	Four-year average
Conventional	14ab	11a	9a	7a	10b
Controlled	13b	10a	8a	6a	9b
Shallow	15a	13a	12a	9a	12a

Note: Means within years or for the four-year average with a different letter are significantly different (p = 0.05).

the water table drained below this level, which was likely a combination of lateral water movement, deep percolation, and crop water use. The water table in the undrained plots had the same trend but tended to stay perched, particularly in 2009 and 2010 when precipitation was greater. The response to rainfall was similar in all treatments (figure 2) with drawdown to tile depth (or controlled depth) occurring within one to two days.

Nitrate Loss. Flow-weighted NO_3-N concentration (table 7) indicates that the four-year average concentration for shallow drainage is significantly higher than controlled or conventional treatments. This result is in contrast to that of Sands et al. (2008) where there was no difference in flow-weighted NO_3-N concentrations between shallow and conventional drainage. Annual concentrations show that in 2007, shallow drainage concentrations were statistically higher than controlled drainage with no difference when compared to the conventional drainage treatment. There were also no statistically significant differences between the conventional and controlled drainage treatments. No statistically significant differences were seen in 2008, 2009, or 2010 NO_3-N concentrations between treatments.

The four-year average load for each treatment was 35 kg ha^{-1} (31 lb ac^{-1}), 21 kg ha^{-1} (19 lb ac^{-1}), and 24 kg ha^{-1} (21 lb ac^{-1}) for the conventional, controlled, and shallow drainage treatments, respectively, with the conventional treatment being statistically higher than the other two over the four-year period although there were no significant differences between treatments in any of the years (table 8). Of note is that despite greater flow-weighted NO_3-N concentrations from the shallow drainage treatment, the NO_3-N load from the shallow drainage treatment was significantly less than the conventional drainage treatment. The similar flow-weighted NO_3-N concentrations between the controlled and conventional drainage treatment but reductions in NO_3-N load with drainage water management are consistent with previous drainage water management research where the reduction in NO_3-N load is attributed to a reduction in subsurface drainage volume rather than a reduction in NO_3-N concentrations (Strock et al. 2011).

Crop Yields. Average treatment yields varied widely over the years and treatments (figures 3 and 4). However, 2008 showed

Figure 2

Water table response to a rain event in 2009. Rainfall is summed on an hourly basis.

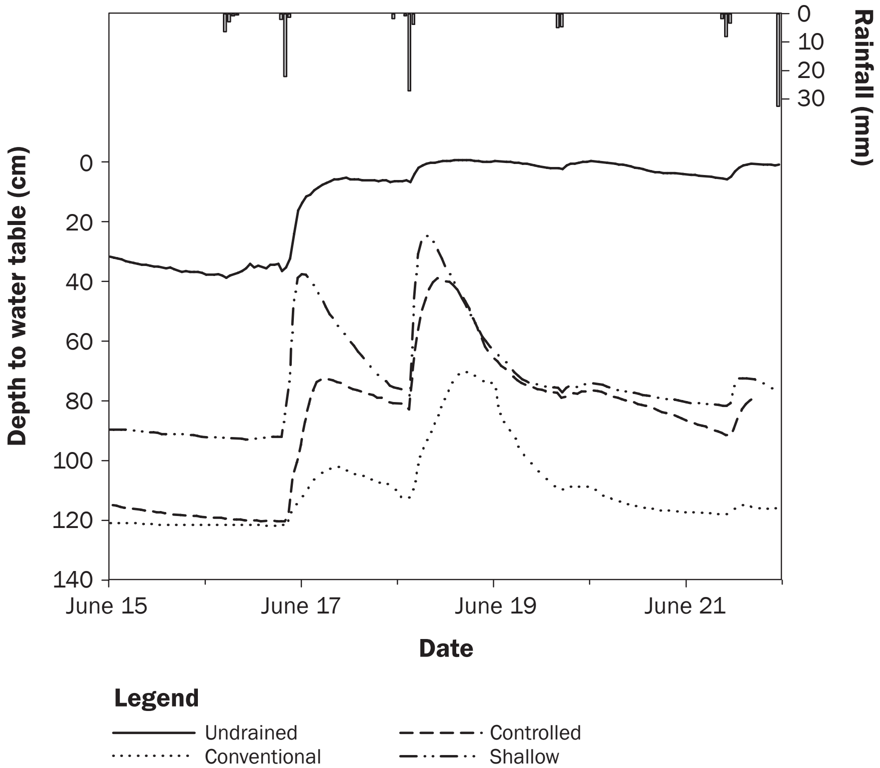


Table 8

Average annual nitrate-nitrogen (NO_3-N) load from the three drainage treatments.

	NO_3-N load (kg ha^{-1})				
Treatment	**2007**	**2008**	**2009**	**2010**	**Four-year average**
Conventional	34a	24a	43a	36a	35a
Controlled	22a	22a	19a	21a	21b
Shallow	26a	21a	24a	25a	24b

Note: Means within years or for the four-year average with a different letter are significantly different (p = 0.05).

less variability in yields than other years for both corn and soybean yields perhaps due to lower than average precipitation in July and August. Corn yields in 2009 were the lowest of the four years, while soybean yields were lowest in 2008. The undrained plots generally showed the lowest yields for both corn and soybeans, with the exception of 2008, where both corn and soybean yields were the highest in the undrained plots, although not statistically different. This was likely due to lower than average precipitation in July and August of 2008. Overall, the four-year average corn yield for conventional drainage was statistically higher than both controlled drainage and undrained plots. It is likely that the undrained plots with high water tables exhibited greater excess water stress. Corn yields in 2009 were lower than in 2007, 2008, and 2010, which was likely due to high rainfall in August of 2009. Flooding likely had a negative impact on soybeans in the undrained plots in 2009, and heavy rain in June of 2010 may have hampered soybean establishment. As noted from the groundwater depth information (table 5), the highest average water table was recorded in the undrained plots in 2009.

Summary and Conclusions

From the four-year monitoring period, drainage water management through controlled and shallow drainage significantly reduced overall drainage by 37% and 46%, respectively. In addition, annual average NO_3-N loss for controlled and shallow drainage was reduced 36% and 29%, respectively, when compared to conventional drainage. For the controlled drainage compared to the conventional drainage treatments, the primary periods for reduction in drainage volumes were from June through August, whereas volume reductions were observed during most months when comparing the conventional and shallow drainage treatments. The undrained plots consistently had shallower water tables, especially in a wet year (2009). In this year, the undrained plots had significantly lower crop yield than the drained plots. Over the four-year study period, the shallow drainage treatment did not have significantly different crop yields than the conventional drainage treatment, but the controlled drainage treatment had a significant yield reduction when compared to conventional treatments. This yield reduction with controlled drainage could likely be mitigated with greater management of the controlled drainage system.

Overall, the results of this study in southeast Iowa are consistent with other results from other locations in that subsurface drainage volume was reduced on the order of 40%, which is consistent with the review by Strock et al. (2011). In addition, the primary mechanism for reduction in NO_3-N load can be attributed to a reduction in subsurface drainage volume. Since the applicability of controlled drainage may be limited due to slope constraints, the comparison of shallow and controlled drainage and similar performance relative to subsurface drainage and NO_3-N load reduction is important as future implementation of drainage practices are considered for water quality benefits.

This study, similar to others, highlights that controlled and shallow drainage practices are methods to reduce NO_3-N movement to the Mississippi River. Further considerations, including cost of installation, overall management required by producers, and acreage of applicability of the practice, should be considered before broad implementation of these systems.

Figure 3
Annual and four-year average corn yields. Means within years or for the four-year average with a different letter are significantly different (p = 0.05). Error bars show standard deviation.

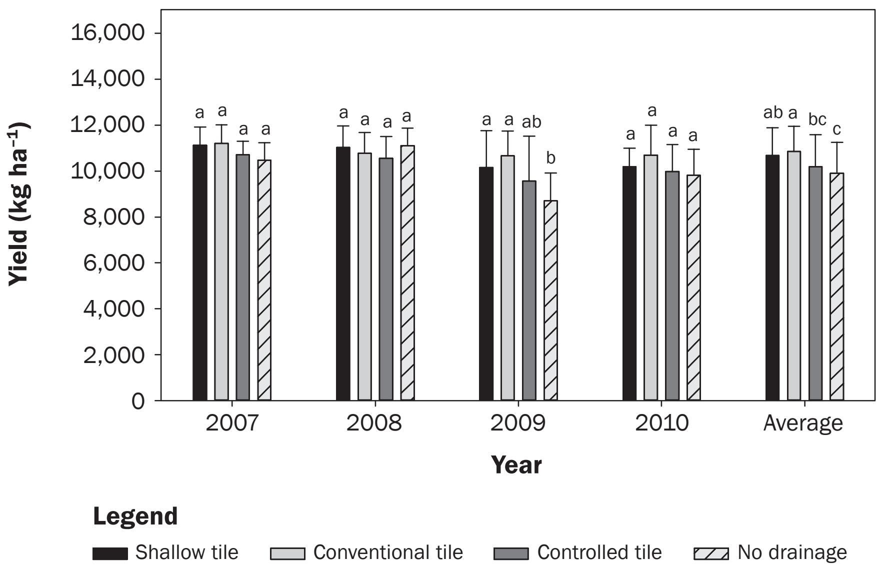
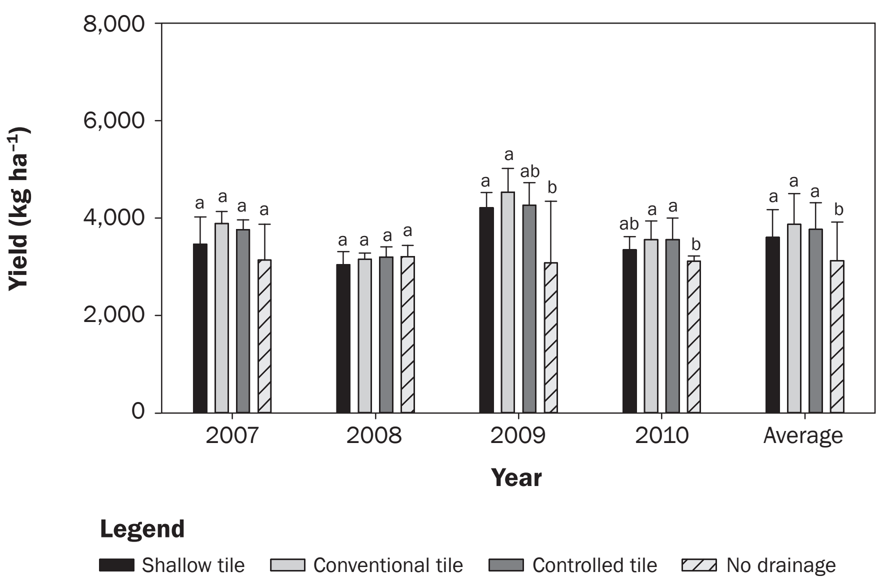


Figure 4
Annual and four-year average soybean yields. Means within years or for the four-year average with a different letter are significantly different (p = 0.05). Error bars show standard deviation.



Acknowledgements

This project has been supported by a USDA Natural Resources Conservation Service Conservation Innovation Grant and the Agricultural Drainage Management Coalition.

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