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# Temporal Subsurface Flow Patterns from Fifteen Years in North-Central Iowa

**Matthew J. Helmers, Assistant Professor**
Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011
**Peter Lawlor, Research Associate**
Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011
**James L. Baker, Professor Emeritus**
Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011
**Stewart Melvin, Professor Emeritus**
Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA 50011
**Dean Lemke, Chief Water Resources Bureau**
Department of Agriculture and Land Stewardship, Des Moines, IA 50319

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***Abstract.*** Subsurface drainage in the Upper Midwest is of importance to agricultural production. However, proper management of these systems through in-field management, drainage management, or edge of field practices is needed to limit negative environmental impacts particularly from nitrate-nitrogen leaching losses. One management practice being considered is drainage management where the outflow of subsurface drainage is managed to conserve water and decrease the overall outflow of subsurface drainage. To understand how and when drainage management may be utilized in the upper Midwest it is important to review long-term drainage data to understand the timing, duration, and volumes of subsurface drainage in these climates. An on-going drainage study from north-central Iowa allows for reviewing fifteen years of subsurface drainage which encompasses a range of climatic conditions. This information has been reviewed with the objective of understanding the timing, duration, and drainage volumes considering temporal drainage flow patterns. In particular, the monthly and seasonal flow patterns have been investigated using this long-term drainage record. On this site with a relatively narrow drain spacing of 7.6 m, drainage volume was approximately 40% of the precipitation. The time period from April through June had approximately 50% of the average annual precipitation and approximately 70% of the average annual drainage. In addition, the percent of annual drainage occurring after August 1 was only approximately 7%. The timing of subsurface flow in these areas specifically during the spring coincides with time of planting, crop germination, and early crop development has implications when considering drainage management practices and the effectiveness of these practices to limit flow and therefore nitrate-nitrogen leaching losses. To minimize outflow of drainage water, these drainage management systems would need to allow for adequate flexibility to ensure crop production while effectively managing subsurface drainage flow to potentially minimize the outflow of water.

**Keywords.** Subsurface drainage, hydrology, drainage water management.

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## Introduction

Subsurface drainage is a common water management strategy for agricultural productivity in areas with poorly drained soils and seasonal high water tables. The use of subsurface drainage promotes agronomic and environmental benefits including greater water infiltration, lower surface water runoff and erosion, and improved crop growth and yield (Skaggs and Van Schilgaarde, 1999). However, the use of subsurface drainage increases the losses of nitrate-nitrogen (Gilliam et al., 1999). Logan et al. (1980) reported nitrate-nitrogen concentrations ranging from 0.5 to 120 mg/L in tile drainage water under corn in Iowa, Minnesota, and Ohio. This loss of nitrate-nitrogen is a factor in nonpoint source pollution of local surface waters and has been implicated as a cause of the Hypoxic Zone in the Gulf of Mexico (Rabalais et al., 1996).

Numeric criteria being proposed in EPA Region VII (Iowa, Kansas, Nebraska, and Missouri) for total nitrogen and total phosphorus in flowing water are 1.5 and 0.075 mg/L, respectively (Lemke and Baker, 2002). To achieve these levels of nutrient concentrations in agricultural landscapes would be challenging, if not impossible, with present management practices. As a result, there is a need to investigate methods for reducing the overall export of nutrients to downstream water bodies. Subsurface drainage management is a technology that has shown potential to reduce the export of nutrients to downstream water bodies. Subsurface drainage management can include shallower drain tube installation and controlled drainage (water-table management). Shallow drainage consists of placing conventional tile drains at shallow depths (e.g., at 0.6-0.75 m, rather than at 1.2 m). Controlled drainage raises the outlet of the drainage system at certain times to raise the water table and restrict outflow. These modifications have the potential to reduce subsurface drainage volumes, thereby decreasing the export of nutrients and other pollutants from agricultural landscapes.

Evans et al. (1989) reported that drainage control reduced the annual transport of total nitrogen at the field edge by 46% and total phosphorus by 44%. Gilliam et al. (1979) reported nitrate-nitrogen loss reductions of nearly 50% using controlled drainage, compared to uncontrolled fields. Other research in North Carolina has shown that controlled drainage can reduce nitrogen and phosphorus transport by 30% and 50% when compared to conventional drainage practices but controlled drainage research has shown little net effect in total nitrogen and phosphorus concentrations in drainage outflow (in some cases there was a 10-20% reduction in nitrate-nitrogen concentrations in controlled versus conventional drainage) (Evans et al., 1995). Fausey (2004) found a reduction in subsurface drainage volume of approximately 38% when comparing controlled drainage and conventional drainage for a site in Ohio. Shallower drainage depths have been investigated in Illinois (0.6, 0.9, and 1.2 m). Data from this study indicated a direct correlation between decreased tile flow and decreased tile depth. The tiles at 0.6 m released about 44% less flow than a tile installed at 1.2 m (Cooke et al., 2002). Results from two years of analysis in southern Minnesota have shown that shallow drains reduced annual drainage by about 25% (Sands et al., 2003).

Despite the available information about drainage management practices there is a need for understanding the performance of these systems under the climatic and soil conditions present in much of the upper Midwest, and a first step is to understand drainage flow patterns over a range of climatic conditions. In addition, for integrating in-field management practices and downstream practices an understanding of the temporal patterns of drainage flow are useful. The objectives of this study were to review a fifteen-year drainage record to investigate the timing and quantity of subsurface drainage and to determine usual patterns of drainage over an extended period.

## Materials and Methods

### *Research Site and Monitoring Equipment*

The field experimental site was located near Gilmore City in rural Pocahontas County, IA. It was in Garfield Township at SW 1/4, Section 27, T92N, and R3IW. Predominant soils were Nicollet (fine-loamy, mixed, superactive, mesic Aquic Hapludoll) and Webster and Canisteo (fine-loamy, mixed, superactive, mesic Typic Endoaquolls) clay loams with 3-5% organic matter. These are poorly to somewhat poorly drained glacial till soils with an average slope of 0.5 to 1.5 percent.

Total research area was 4.5 ha, of which 1.5 ha were used as plots for this study and the remainder as additional plot area, border and buffer. Each of the thirty plots were 0.05 ha (15.2 x 38 m) and established in 1989. Subsurface drainage lines were installed parallel to the long dimension through the center of each plot and on the borders between plots (7.6 m apart) at a depth of 1.06 m. Subsurface drains at plot borders were installed to help prevent lateral, subsurface drainage flow from adjacent plots. The border drain lines have an outlet to the surface at a remote location. The centerline subsurface drainage line position is illustrated in Figure 1**.** Only the center drainage line is monitored for drainage volume and pollutant concentrations. Corn (Zea mays L.) and soybean (Glycine max [L.] Merr.) were grown on 0.762m centers. The first five years of the study had full plots of corn or soybeans in rotation but from 1994-2004 the plots were spilt with half corn and half soybean in a given year still in a corn soybean rotation. This resulted in ten rows of each crop in each plot. Reasoning behind combining both crops in rotation within a single, monitored experimental plot stems from previous research and bolstered by more current research. Weed and Kanwar (1996), Kanwar et al. (1997), Randall et al. (1997) and Zhu and Fox (2003) found that at close to recommended rates of N (150-200 kg N $ha^{-1}$) for corn production in a corn-soybean rotation, $NO_3$-N losses and concentrations were not significantly different between the corn or soybean years.

Ten aluminum culverts, 1.2 m in diameter were buried vertically at the terminus of three drainage lines from individual plots to accommodate a water table dewatering sump and three sampling/monitoring configurations. The configuration is illustrated in Figure 2. Drainage lines, each from individual plots, terminated in the aluminum culvert and were directed to separate sumps within the culvert and pumped by a Zoeller model M53 submersible pump (Zoeller Pump Co., Louisville, KY) through plastic plumbing fitted with a common plated sprayer orifice nozzle and a 16mm, Trident T-10 water meter (Neptune Technology Group, Inc., Tallassee, AL). Back pressure created by the meter forced a small constant fraction (0.25%) of all drainage to be diverted through plastic tubing to a 20 L glass sampling bottle. These flow-weighted drainage samples were collected and volume measurements recorded as dictated by flow patterns. Typically, after 13 mm of subsurface drainage, sample jars would contain 10 liters of water available for sub-sampling. This rather unique configuration provided the infrastructure for continuously monitored flow volume measurement and sampling of subsurface drainage emanating from below the treated area. Sub-samples were collected at this point and over each flow period and represented the quality of water that was intercepted under the treated area. Sampled and metered drainage was then surface discharged some distance away. Due to freezing conditions during the winter months and concern for maintaining the monitoring equipment, drainage was monitored from April through November during this study period. However, only on rare occasions was any observed and it is expected that there is little winter drainage in this area (Randall, 2004). For reviewing the drainage flow discussed within, a representative flow plot was chosen for investigating flow patterns and volumes.

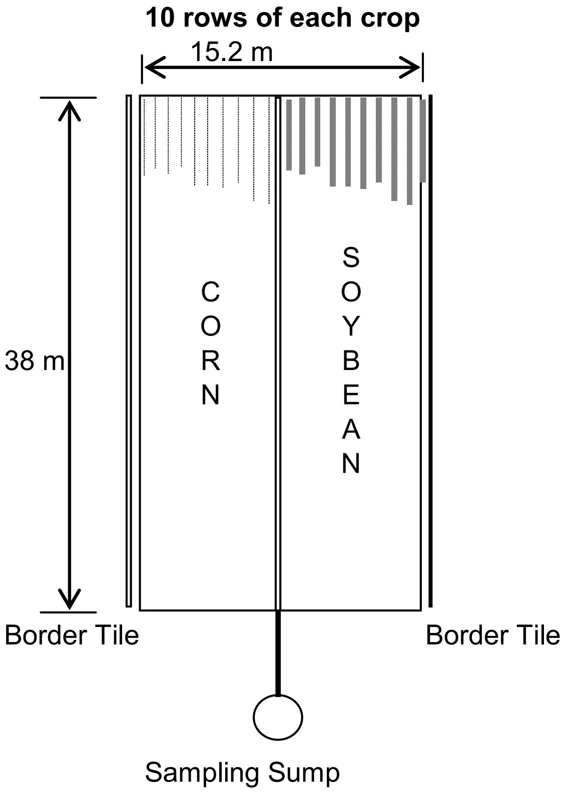

Figure 1. Subsurface drainage line configuration.

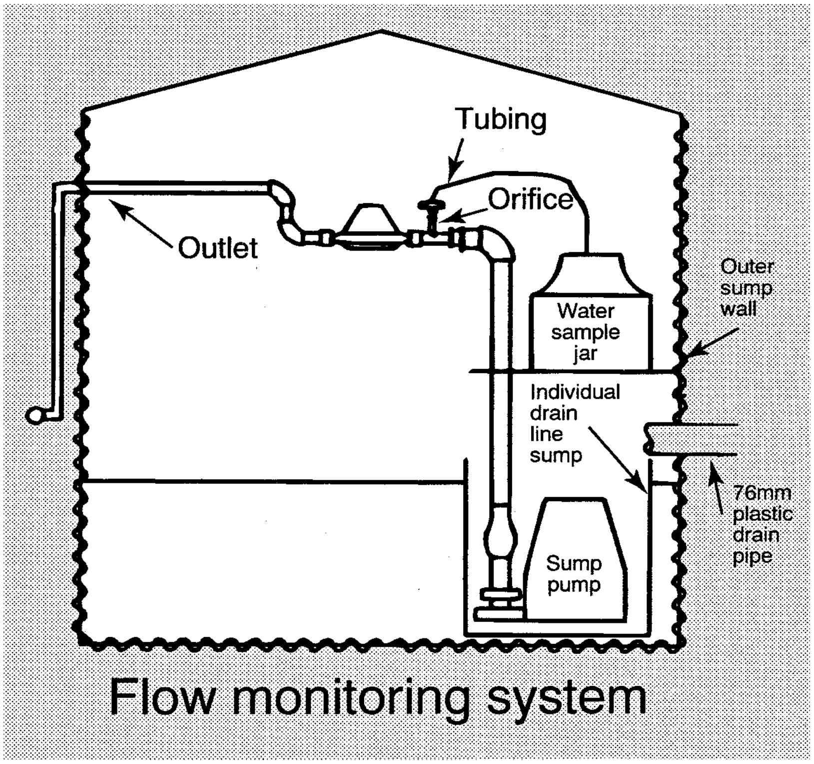

Figure 2. Flow monitoring system configuration.

## Results and Discussion

From nearby weather records, the 30-yr (1975-2004) average annual precipitation is 820 mm (Table 1) and the 30-yr average for the primary drainage season months of April through November is 700 mm. During the fifteen years of this study both the average annual and average drainage season precipitation were below the 30-year normal. The wettest year at the site was 1991 (918 mm) and the driest year was 1997 (471 mm). The amount of drainage varied significantly from a low of 11 mm in 1997 to high of 587 mm in 1993. Overall from the fifteen years the ratio of drainage to precipitation for the April to November time period was 41% (Table 1). From the fifteen year project site precipitation record the greatest precipitation months are April through August (Figure 3). June had the greatest monthly mean precipitation during this period with a mean precipitation of approximately 125 mm.

Table 1. Summary of yearly precipitation, drainage, and ratio of drainage to precipitation

| | Precipitation (mm) | | Drainage (mm) | Drainage Ratio | |
|---|---|---|---|---|---|
| Year | Annual | Drainage Season (April-November) | Drainage Season (April-November) | Drainage to Annual Precipitation | Drainage to Drainage Season Precipitation |
| 1990 | 839 | 715 | 353 | 0.42 | 0.49 |
| 1991 | 944 | 776 | 362 | 0.38 | 0.47 |
| 1992 | 815 | 656 | 386 | 0.47 | 0.59 |
| 1993 | 942 | 787 | 587 | 0.62 | 0.75 |
| 1994 | 656 | 528 | 21 | 0.03 | 0.04 |
| 1995 | 721 | 600 | 268 | 0.37 | 0.45 |
| 1996 | 763 | 651 | 465 | 0.61 | 0.71 |
| 1997 | 525 | 421 | 11 | 0.02 | 0.03 |
| 1998 | 708 | 592 | 243 | 0.34 | 0.41 |
| 1999 | 675 | 560 | 133 | 0.20 | 0.24 |
| 2000 | 687 | 555 | 15 | 0.02 | 0.03 |
| 2001 | 702 | 600 | 278 | 0.40 | 0.46 |
| 2002 | 680 | 651 | 237 | 0.35 | 0.36 |
| 2003 | 684 | 599 | 439 | 0.64 | 0.73 |
| 2004 | 767 | 610 | 235 | 0.31 | 0.39 |
| Avg. | 741 | 620 | 269 | 0.35 | 0.41 |
| 30-yr Normal | 820 | 700 | | | |

The monthly distribution of mean drainage and precipitation from the on-site record (fifteen years) is shown in Figure 4. Also included is the approximate evapotranspiration (ET) based on drainage modeling simulations at the site using DRAINMOD (Skaggs, 1978) assuming corn as vegetation. It is evident that during the months of April and May we have relatively low ET compared to other drainage season months. During these months significant precipitation may occur and result in drainage. This likely extends into much of June until the crop water usage increases significantly. While, drainage occurs in both April and May, in general, there was greater drainage in May as a result of greater precipitation and likely greater soil moisture in the soil profile. During April, some of the precipitation likely goes toward replenishing the soil profile. In July and August, the ET exceeds precipitation which will deplete soil moisture within the soil profile. This will then need to be recharged by precipitation in the fall and early spring. As a result there is little drainage in the late fall.

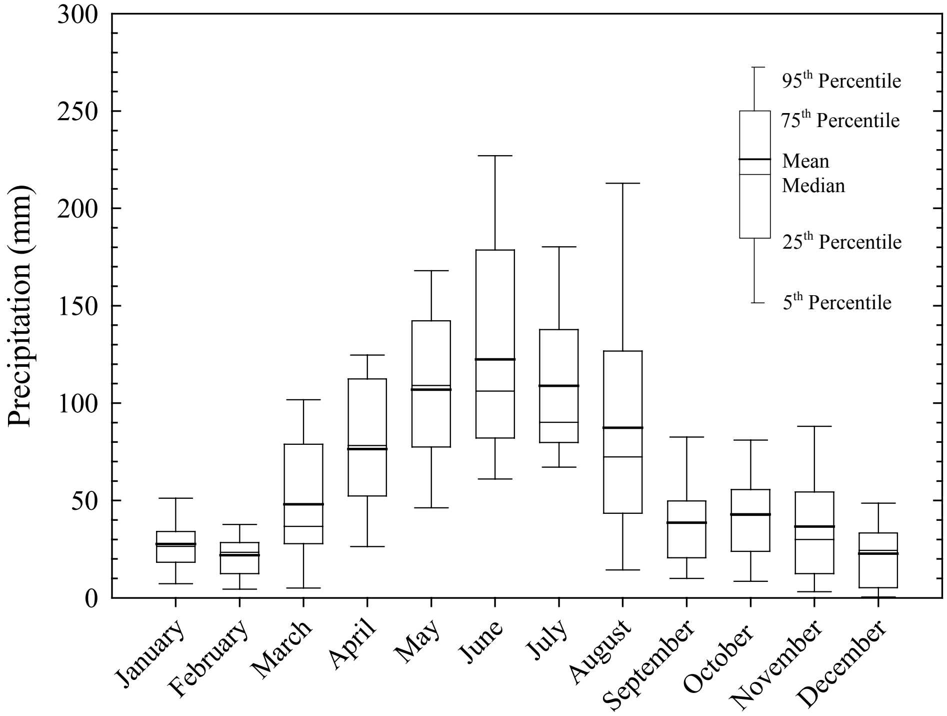

Figure 3. Distribution of monthly precipitation for the fifteen years at the project site

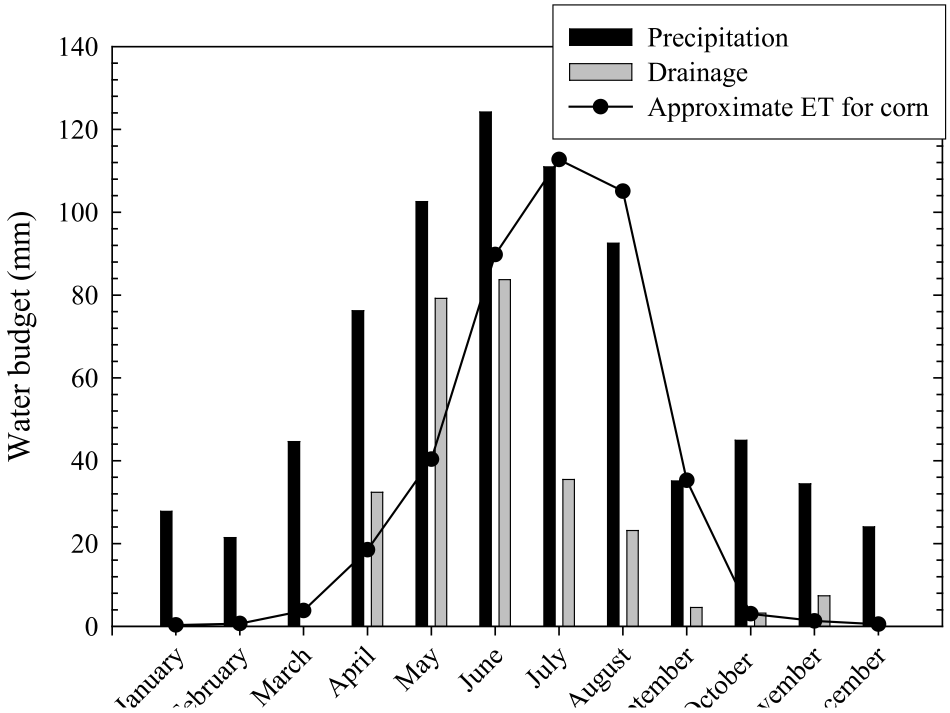

Figure 4. Monthly distribution of precipitation, drainage, and approximate evapotranspiration for the fifteen years at the project site

From Table 1, there were large differences in the amount of drainage season precipitation and drainage, and drainage volume also varied with similar precipitation amounts. Years 1999 and 2000 had nearly equal precipitation amounts (560 and 555 mm) but the drainage amounts were dissimilar with 133 mm in 1999 and 15 mm in 2000. The climatic conditions that affect drainage volume include not only precipitation amount but also previous precipitation history since the previous rainfall would influence soil water storage. Also important are the intensity and duration of the event. Despite this, we found a strong correlation in precipitation and drainage for the months of April through November for the study period (Figure 5).

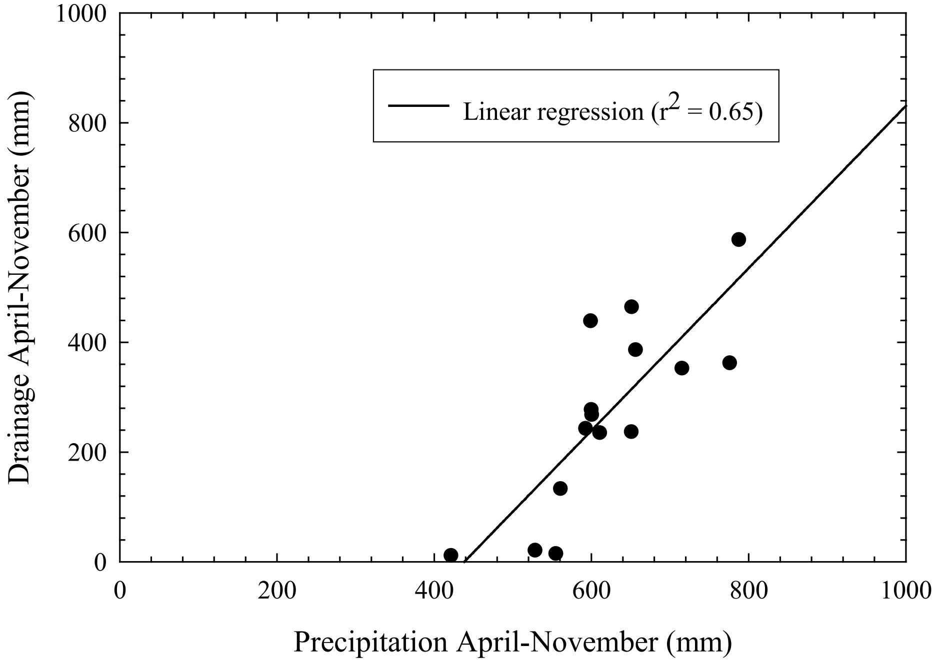

Figure 5. Correlation of precipitation and drainage (April-November)

From the monthly precipitation is it evident that the rainfall is not uniformly distributed throughout the year; spring and summer months have greater precipitation than late fall and winter. A review of the precipitation and drainage data during the predominant drainage season (April-November) indicated that October was the driest drainage month with 6% of the drainage season rainfall and only 1% of the total season drainage (Figures 6a and 6b). Approximately 50% of the drainage season precipitation occurs in April, May, and June resulting in 70% of the total drainage observed. The wettest of these three was June with 20% of the rainfall and 31% of the drainage. On average, there is significant rainfall in September, October, and November but little drainage. As discussed above, this is likely a result of the rainfall recharging the soil profile after the soil moisture was depleted during the growing season. A comparison of cumulative percent precipitation and drainage for the time period from April through November is shown in Figure 7. As discussed above, on average there is little drainage in the months of August, September, October, and November. While the significant drainage periods from April through June correspond with periods of significant rain, most of this time also coincides with periods without much vegetative growth. The ratio of drainage to precipitation is greater in April, May, and June than any of the other months (Figure 8).

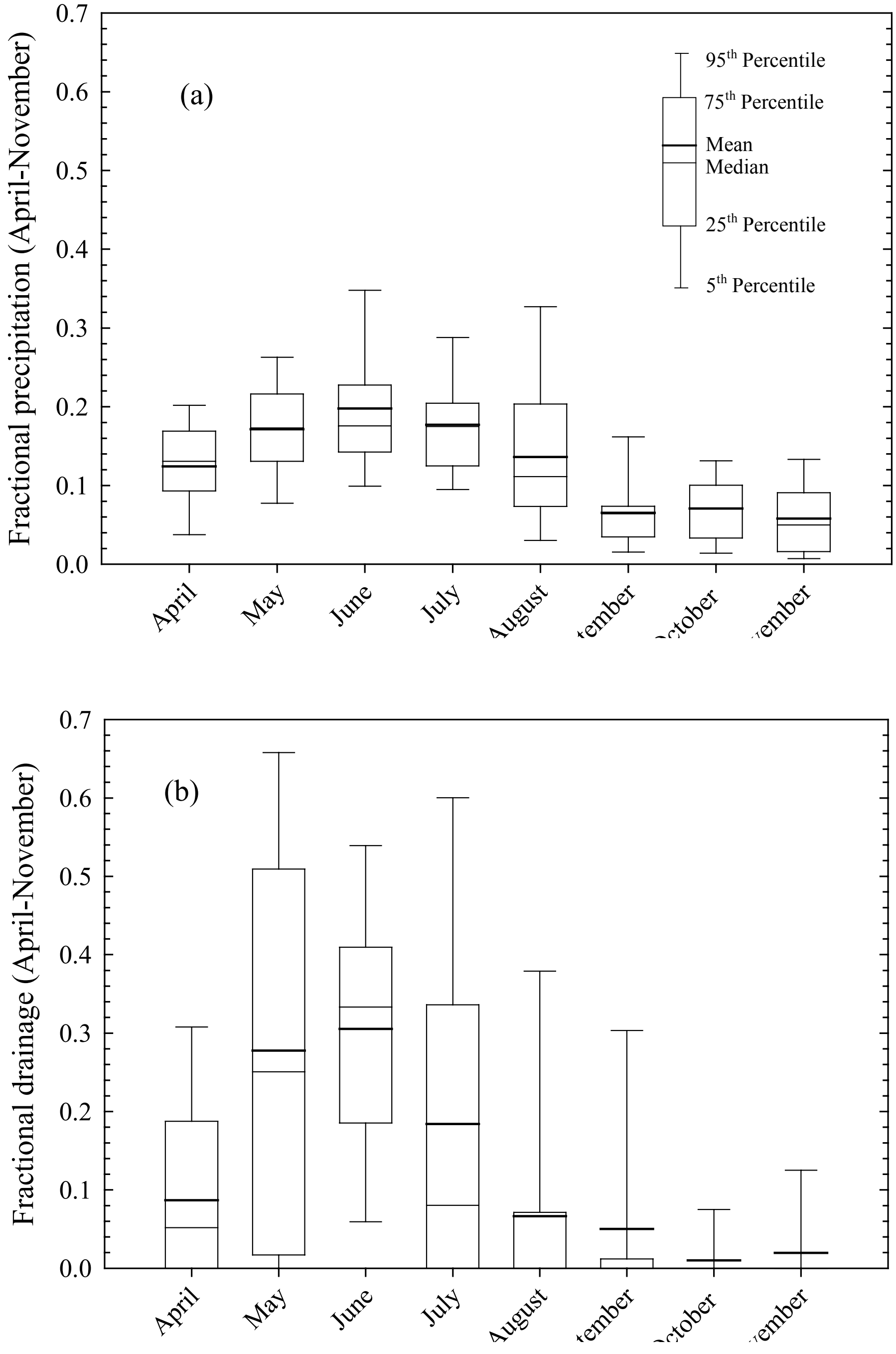

Figure 6. Box plot diagrams of monthly fraction of drainage season (a) precipitation and (b) drainage

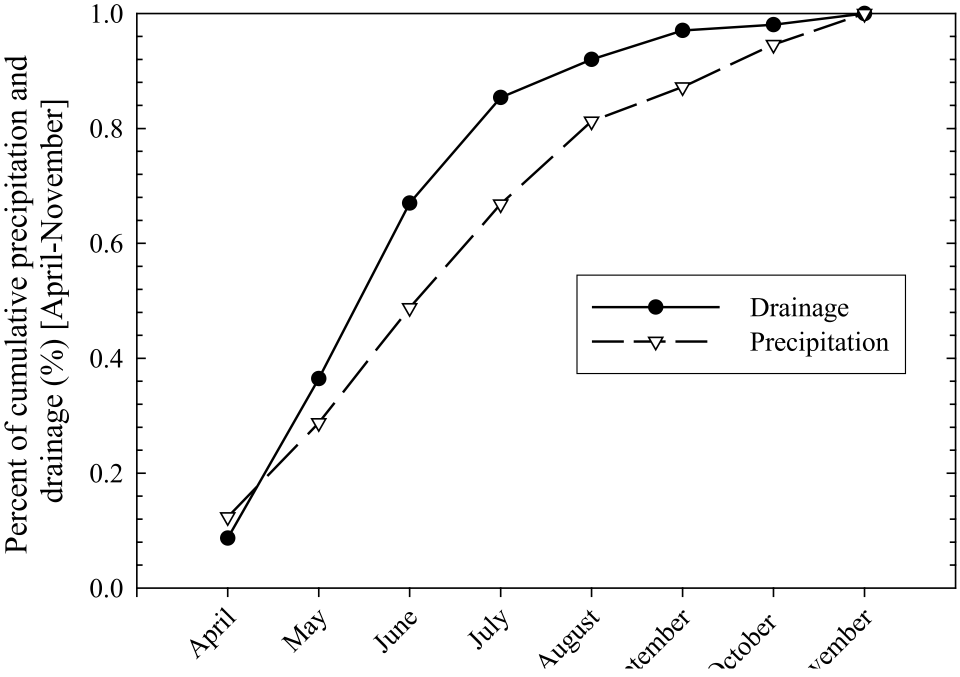

Figure 7. Percent cumulative precipitation and drainage from April through November

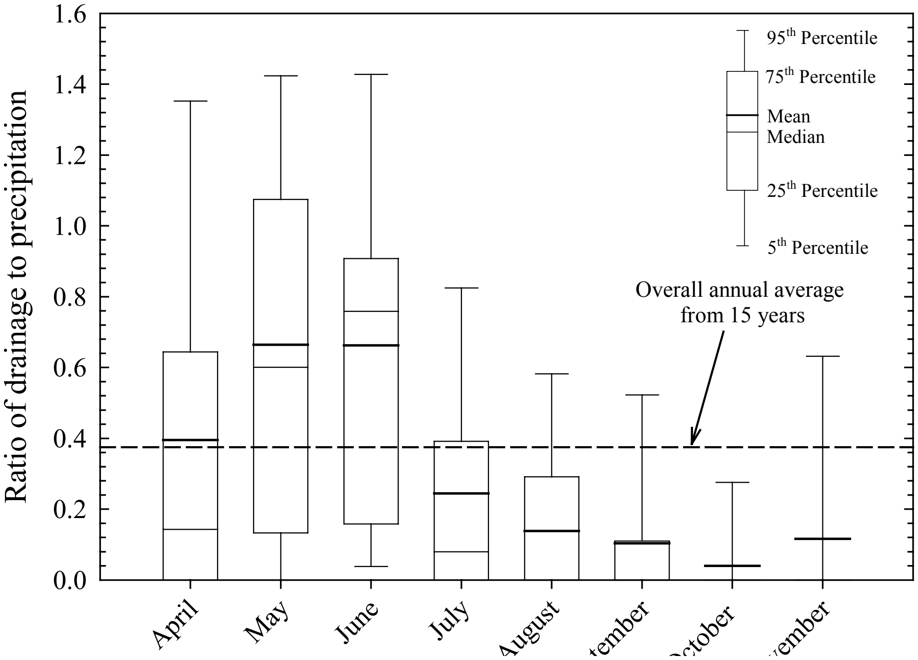

Figure 8. Ratio of monthly drainage to monthly precipitation

Based on the discussion above, seasonally the greatest amount of drainage occurs in the months of April, May, and June. The amount of drainage occurring in shorter time increments can also be reviewed. The percent of overall drainage occurring during weekly increments is shown in Figure 9a for 1990 and Figure 9b for 2001. In 1990 nearly 40% of the overall drainage occurred in a one week period in late June and in 2001 about 25% occurred in a one week period in early May. In 2001, greater than 90% of the overall drainage occurred prior to the middle of June.

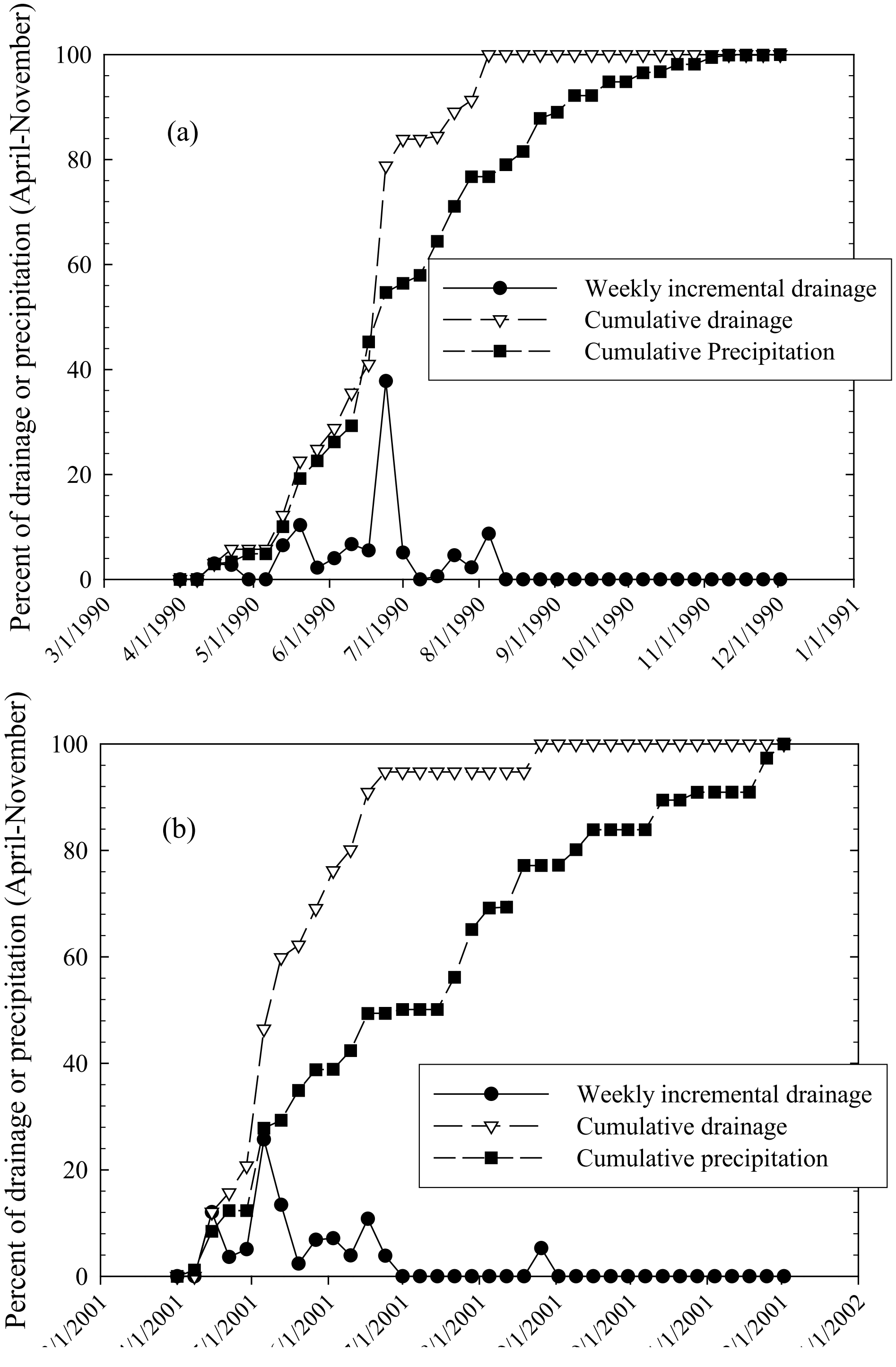

Figure 9. Percent of drainage or precipitation (April-November) using weekly incremental drainage, cumulative drainage, and cumulative precipitation for (a) 1990 and (b) 2001

In considering how to best manage drainage water volume and decrease the export of water and pollutants from drainage systems, the timing and duration of subsurface drainage is important. It is evident that for the north-central Iowa conditions observed during this study, on average the months of April, May, and June account for nearly 70% of the drainage that occurs from April through November. Due to freezing conditions and recharge of the soil profile there is likely little potential for drainage from December through March. These time periods of greatest drainage also correspond to a time of the year when removal of excess precipitation using drainage is essential to maintain trafficability, crop germination, and early crop development. So, if controlled drainage were included within the system, one would need to ensure adequate drainage capacity to reduce any potential negative effects of controlled drainage on crop production. Likewise, a wetland downstream from a drainage system would need to be sized and designed to accommodate most of the drainage water entering the system in a three-month time span on average and in some years the drainage from one or two weeks could account for a significant portion of the total annual drainage. To minimize the volume of drainage and subsequent loss of pollutants through the tile lines, crop production practices that maximize use of excess precipitation during the spring months may be beneficial. A crop system that includes vegetation which could remove excess precipitation via transpiration in April and May could significantly reduce drainage volumes while likely not adversely affecting soil moisture in most years since much of the precipitation is lost to drainage in these months.

## Conclusion and Summary

The objectives of this study were to review a fifteen-year drainage record to investigate the timing and quantity of subsurface drainage and determine usual patterns of drainage over an extended period. From this review, on average about 40% of the precipitation from April through November leaves the soil profile through the subsurface drainage system with an average drainage of approximately 269 mm of drainage. However, this value varied considerably from a high of 587 mm in 1993 to 11 mm in 1997. This percentage of drainage may be higher than in some other field conditions since the drain spacing in this study is 7.6 m.

On average, nearly 70% of the drainage occurred in the months of April, May, and June with June having the highest volume. Despite some instances of heavy precipitation later in the growing season, at these times drainage was minimal if it occurred at all. Much of the late season rainfall and even some early season rainfall probably recharged the soil profile that was depleted by previous crop use. Since there is little water use during the time period of April through mid-June any excess rainfall and soluble pollutants within the soil profile are susceptible to leaching. Methods to promote more water use during this time may have positive impacts on reducing drainage volume and subsequent loss of pollutants.

The time periods of greatest drainage also correspond to a time of the year when drainage is essential to maintain trafficability, crop germination, and early crop development. So, including drainage management practices that may manage outflow during certain times of year would need to be considered carefully so they are effective in reducing drainage volume while also ensuring adequate drainage capacity to reduce any potential negative effects of drainage management on crop production. Likewise, a wetland downstream from a drainage system would need to be sized and designed to accommodate most of the drainage water entering the system in a three-month time span on average.

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