IMPACT OF RAINFALL ON DRAINAGE AND NITRATE-N AT A LONG-TERM RESEARCH SITE NEAR GILMORE CITY, IOWA

A Historic Look

Abstract

Historic data were evaluated for a consistent management regime between 1989 and 2017. Evaluation was based on rainfall and drainage pattern and the resulting nitrate-nitrogen (NO3-N) concentration, yield, and load. Results show average drainage volume from the treatment evaluated adequately represents drainage from the entire site, NO3-N concentration is relatively constant despite the rainfall or time of year, and NO3-N yields are higher during wet years. Also, April through June consistently had the most rainfall, the most drainage, and the highest NO3-N yields. Finally, drainage can most realistically be predicted when looking at long-term trends and relationships. For the control, a 1% increase in precipitation above average results in a 2.2% increase in drainage. For the treatment with cover crops, a 1% increase in precipitation above average results in a 1.5% increase in drainage.

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Introduction

Current environmental issues of national concern include nutrient, particularly nitrate-nitrogen (NO3-N), loss (Bowles et al., 2018) from the tile-drained landscape (Christianson et al., 2018). In Iowa, a conservative estimate of 3.6 million hectares (8.8 million acres) of tile drained cropland exists (Sugg, 2007), which is some of the most productive in the world (Figure 1) (Hansen, Buis, & Wette, 2014).

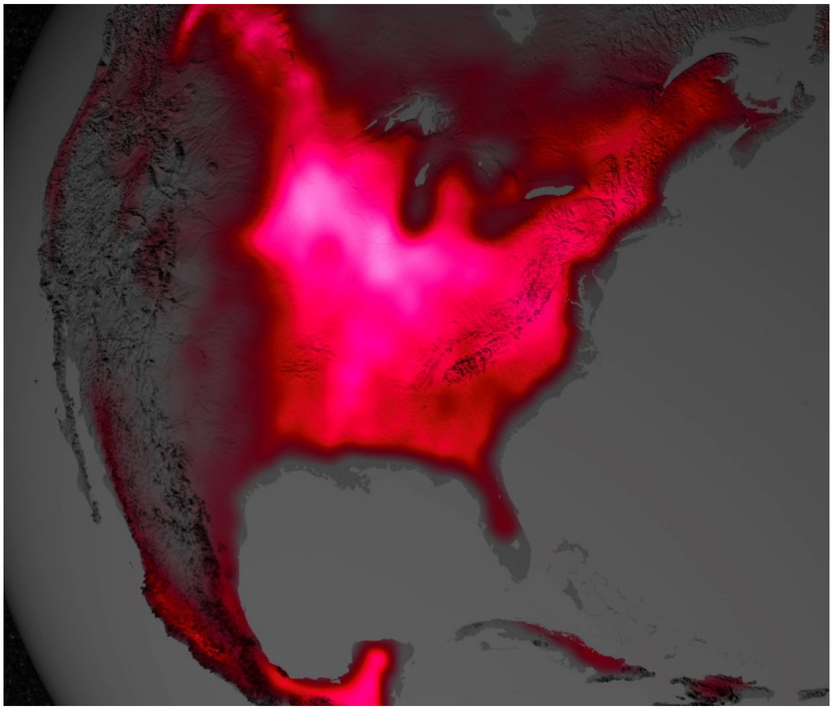


Figure 1. Image of the US Midwest/Corn Belt fluorescence. From NASA's Goddard Space Flight Center, "The glow represents fluorescence measured from land plants in early July, over a period from 2007 to 2011." Image Credit: NASA's Goddard Space Flight Center.

As understanding of our natural environment grows, looking back at historic data can inform trends and allow for the development of better decision support tools. Knowing how our agricultural systems react to weather variability will allow strategic intensification. Additionally, being able to accurately predict performance of implemented agricultural conservation practices will facilitate adoption of those practices that add resiliency as well as perform consistently, regardless of weather variability within a year, and over many years.

The work in this manuscript evaluated the importance of rainfall on tile drainage volumes as well as developed trends in nitrate-nitrogen loss. Specifically, the objectives of this work were to,

1) Evaluate drainage volumes, NO3-N concentrations, and NO3-N loads from consistently managed long-term (1990 to 2017) drainage plots in Iowa
2) Evaluate impacts of cover crops on drainage volumes, NO3-N concentrations, and NO3-N loads from consistently management drainage plots with and without cover crops (2004-2017)

3) Compare trends annually, seasonally, and monthly in dry, normal, and wet years
4) Predict drainage trends based on weather patterns

Methods

Data Collection

Rainfall, drainage, and NO3-N data were collected from historic research at a long-term research site, managed by Iowa State University, near Gilmore City, Iowa between 1990 and 2017 (28 years). Nearly all of these data have been previously published (Baker & Melvin, 1999; M. Helmers, Zhou, Qi, Christianson, & Pederson, 2011; M. J. Helmers, Lawlor, Baker, Melvin, & Lemke, 2005; Lawlor, Helmers, Baker, Melvin, & Lemke, 2008; Z Qi & Helmers, 2008; Zhiming Qi, Helmers, Christianson, & Pederson, 2011), though they have been collated in this manuscript to evaluate long-term trends and responses to precipitation patterns. Details about site layout, management, and data collection methods can be found in Lawlor et al., (2008).

Data Collation

Original data archives were revived for plots having a corn and soybean rotation, or in certain years, plots split between corn and soybeans and nitrogen application rates to corn of between 168 and 179 kg/ha (150 to 160 lbs/ac). Tillage was also consistently chisel plowing after corn in the fall and disking in the spring. A full description of field activities is included in Lawlor et al. (2008). All collected or aggregated data used for this study are briefly described in Table 1. From 2004-2017, winter cereal rye cover crops were drilled and grown in a set of corn and soybean plots during the fallow period. The management of these plots is described in greater detail by Qi et al. (2012). Drainage volumes, NO3-N concentrations and NO3-N loads from cover crop plots were compared to the non-cover crop plots.

Table 1. Historic water and site parameters compiled for analysis at a long-term drainage research site near Gilmore City, Iowa.

Parameter	Data Type (Range)	Description
Month	Numeric (1 to 12)	The month number data were collected
Season	String and numeric (winter, spring, summer, fall; 1 to 4)	Winter (1): January to March Spring (2): April to June Summer (3): July to September Fall (4): October to December
Drainage Block	Numeric (1 to 4)	A hydraulic response blocking scheme to differentiate between plots consistently having much lower than average, lower than average, higher than average, and much higher than average drainage volume
Monthly Rainfall (mm)	Numeric (0 to 313)	Amount of rainfall in each month and year
Seasonal Rainfall (mm)	Numeric (0 to 634)	Amount of rainfall in each season and year
Annual Rainfall (mm)	Numeric (490 to 1,156)	Amount of rainfall in each year
Previous Month Rainfall (mm)	Numeric (0 to 313)	Amount of rainfall in each preceding month
Previous Season Rainfall (mm)	Numeric (0 to 634)	Amount of rainfall in each preceding season
Previous Year Rainfall (mm)	Numeric (490 to 1,156)	Amount of rainfall in each preceding year
Incremental Drainage (mm)	Numeric (0 to 901)	Measured sub-monthly drainage volume for each plot in each year

Monthly Drainage (mm)	Numeric (0 to 1,205)	Aggregated monthly drainage for each month and plot in each year
Seasonal Drainage (mm)	Numeric (0 to 1,255)	Aggregated seasonal drainage for each season and plot in each year
Annual Drainage (mm)	Numeric (0 to 1,887)	Aggregated annual drainage for each plot in each year
NO3-N (mg/L)	Numeric (0 to 42.66)	Measured sub-monthly nitrate-n concentration for each plot in each year
NO3-N (kg/ha)	Numeric (0 to 220.6)	Nitrate yield from multiplying NO3-N (mg/L) with Incremental Drainage (mm) and plot area
Monthly NO3-N Yield (kg/ha)	Numeric (0 to 220.6)	Summed NO3-N (kg/ha) for each plot and month for each year
Seasonal NO3-N Yield (kg/ha)	Numeric (0 to 227.5)	Summed NO3-N (kg/ha) for each plot and season for each year
Annual NO3-N Yield (kg/ha)	Numeric (0 to 267.2)	Summed NO3-N (lg/ha) for each plot for each year

Precipitation estimates were developed largely from on-site rain gauge data and supplemented with rain gauges in surrounding towns. Precipitation from 1989 to 2009 were summarized in Qi et al. (2012). Precipitation from 2013 to 2017 were compiled in a consistent manner to that of Qi et al. (2012) to complete this analysis.

Comparison to Site Totals

To ensure the plots focused on in this manuscript were representative of the entire site, average annual treatment plot drainage was directly compared to sitewide annual drainage values reported by Lawlor et al. (2008) between 1990 and 2004. From 2005 to 2017, sitewide annual drainage values were collected using the same method as Lawlor et al. (2008) but have yet to be published. Each year represented a data point, and a linear best fit line between the two data sets was developed with the Trendline function in Microsoft Excel 2016. A t-Test assuming equal variances was run on these data to test significance.

Statistics

Many of the statistical procedures were completed with the R Core Team (2018) R version 3.4.4 functions. Additional statistics were completed with built-in (i.e., t-Test) and custom worksheets in Microsoft Excel 2016 (i.e., slope analysis).

- Slope statistic, which uses a t-Test statistic (Andrade & Estévez-Pérez, 2014)
- Two-sample t-Test assuming equal variances; reporting the two-tail probability
- Tukey's Honest Significance Difference
- Correlation significance after the Texas Education Agency (2018)
- Regression analysis to test slope and intercept significance between regression lines (Grabow, Spooner, Lombardo, Line, & Tweedy, 1998)

Results

Drainage Characteristics for Control Compared to Site as a Whole

When considering how annual drainage from the selected set of treatment data (Corn and Soybeans @ ~150 lbs/ac) represents the overall site drainage, the treatment represents the site well (Figure 2). This relationship shows the selected treatment plots are a good representation of overall site drainage. There were several years with substantial departure from the trend (1992, 1993, 1995, 1996, and 2011) (Figure 2). However, the treatment drainage is not significantly different than the overall site (alpha = 0.05; Two-Sample t-Test assuming equal variances; two-tail P = 0.70). Also, there was no statistical difference in the slopes of the regression lines (t-Test with pooled variance; P=0.38) (Andrade & Estévez-Pérez, 2014).

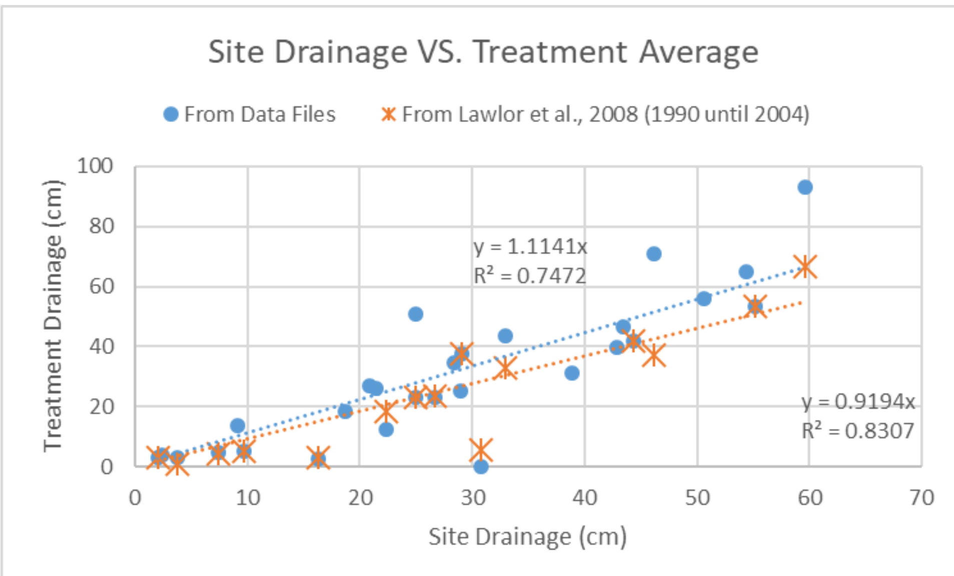
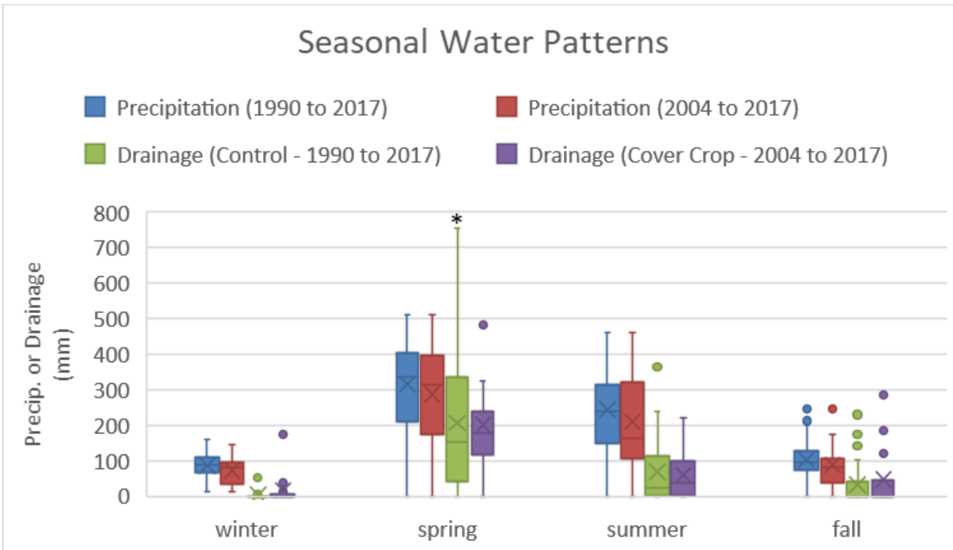


Figure 2. Annual site-wide drainage (x-axis) compared to average drainage from treatment plots (y-axis). Recorded years are 1990 to 2017. Values from the Lawlor et al., 2008 paper were also included for comparison. It is unclear if these values straddle calendar years or not.

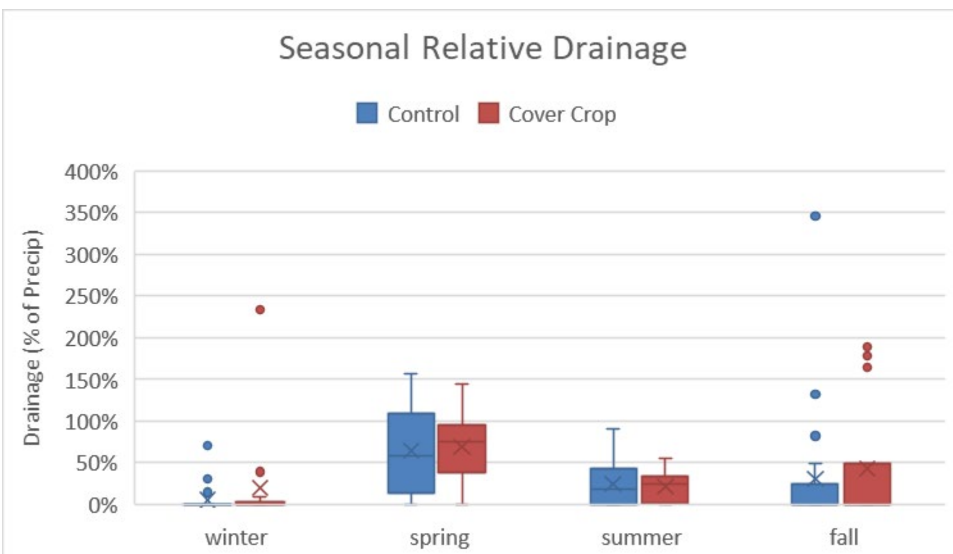
Precipitation and Drainage Patterns

The timing of precipitation and drainage over the data range of 1990 to 2017 was considered by breaking each year into four seasons, with winter being January through March, spring being April through June, summer being July through September, and fall being October through December

Figure 3). The spring season has the most precipitation and drainage, though summer drainage is limited even with substantial precipitation. The cover crop study years were 2004 to 2017 and there were no statistically significant differences in precipitation (total or seasonally) for this time period when compared to the 1990 to 2017 time period (two tailed t-Test, p values ranging from 0.20 to 0.51), though total average precipitation for 2004 to 2017 was 73 mm lower. For the control and cover crop treatments, spring drainage was significantly different than winter, summer, or fall drainage (Tukey's Honest Significance Difference; alpha = 0.05). Further, there were no significant differences in control or cover crop drainage for any of the seasons. There were a couple of seasons where drainage was above precipitation likely due to hydraulic interactions between plots and/or carryover drainage from a previous season. For example, the winter of 1991 was wet at 123 mm of precipitation while no drainage occurred; however, the spring of 1992 was dry with only 181 mm of precipitation but 236 mm of drainage. Combining these two seasons brings the percentage of drainage down to 78%, which is in the range of other observations. There were no statistical differences in drainage between the control and cover crop (two tailed t-Test, p values ranging from 0.19 to 0.91). Drainage as a percentage of precipitation between the control and cover crop are also very similar (Figure 3, panel b).



a)

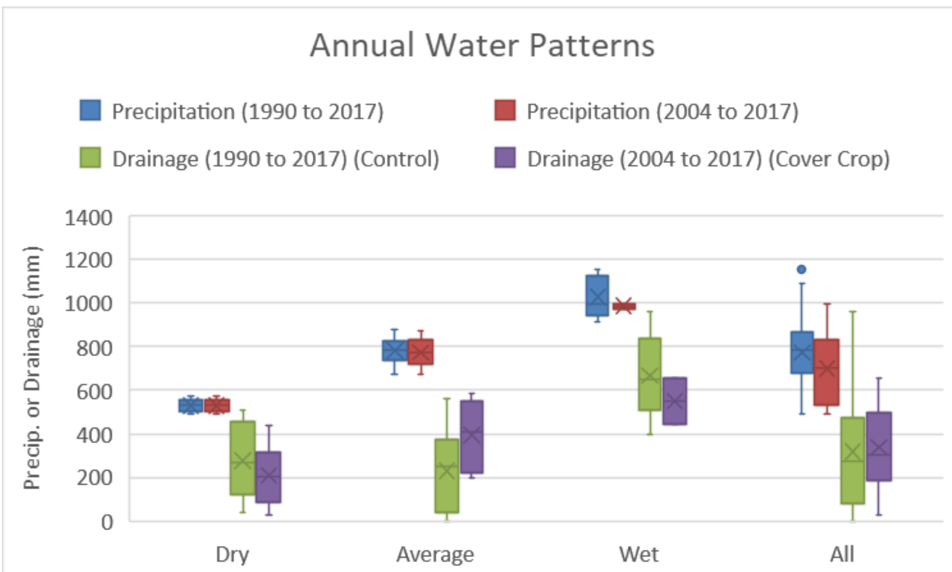


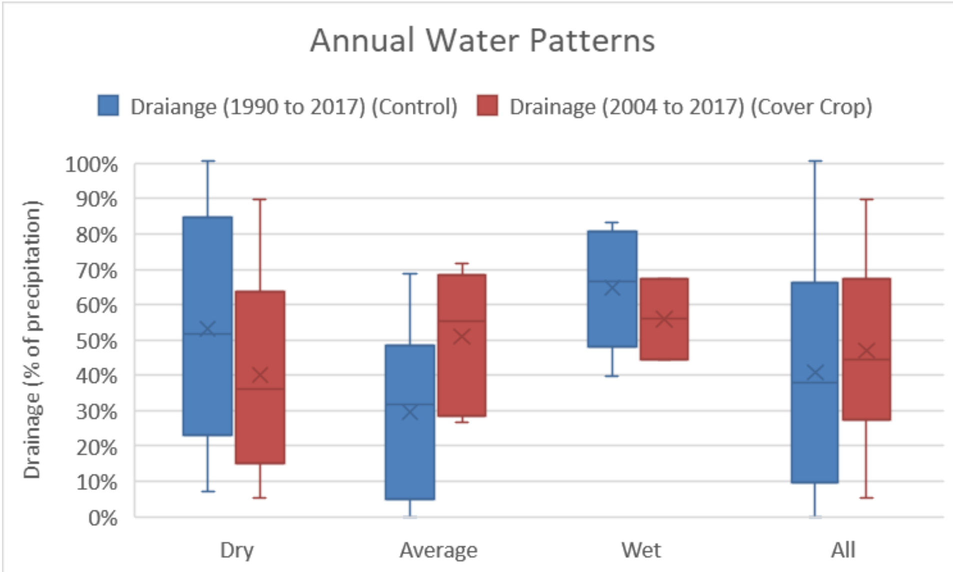
b)

* The high value was in 1993, when the site experienced extreme flooding.

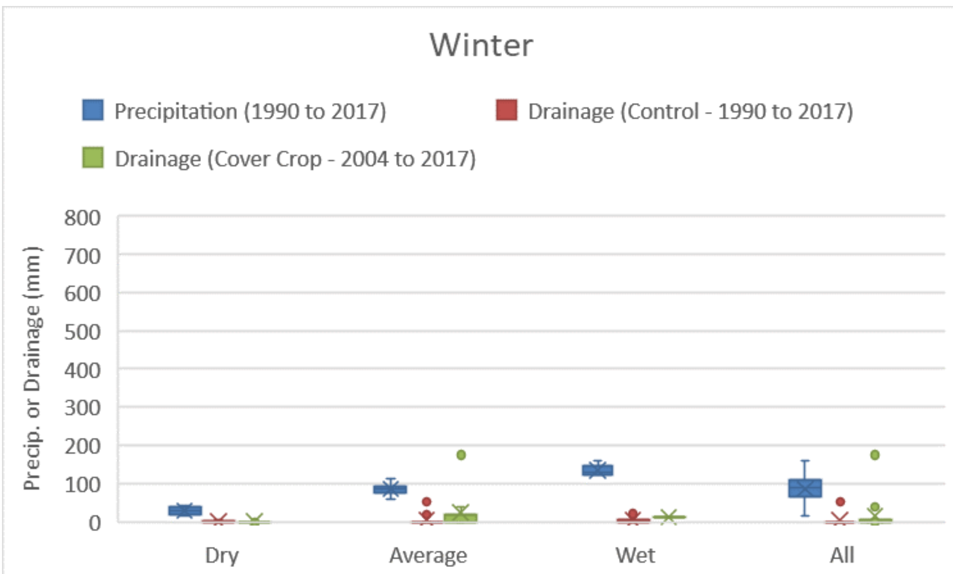
Figure 3. a) Seasonal precipitation and drainage. b) Relative drainage compared to paired precipitation. Values exceeding 100% represent carryover from a previous season or wet drainage blocks occasionally yielding excess water. The whiskers represent the upper and lower quartiles, the line represents the median, and the x represents the mean. Precipitation from 2004 to 2017 represents the time period of the cover crop treatment.

Precipitation ranged from 490 mm in 2009 to 1,156 mm in 1993 with an average of 765 mm. There were obvious breaks for wet and dry, which occurred at 900 mm and wetter and 600 mm and dryer (Figure 4). Data subsets were developed for drainage volumes, where each year was binned based on the precipitation classification. In other words, a wet precipitation year would also be a wet drainage year. Drain volumes range from 0.3 mm in 1996 to 962 mm in 1993 with an average of 307 mm. There were no significant differences in drainage between the dry and normal years for the 1990 to 2017 control plots; however, drainage was significantly higher during wet years when compared to the dry, normal and overall data subsets (Tukey's Honest Significance Difference; alpha = 0.05). While the mean precipitation for wet years was approximately 30% greater than the mean for average years, mean drainage increase by 190% when comparing wet and average years. For the cover crop plots, there were no significant differences in drainage between wet or dry years (Tukey's Honest Significance Difference; alpha = 0.05). Finally, there were no significant differences between corn and soybeans for the control or cover crop for annual drainage (Tukey's Honest Significance Difference; alpha = 0.05).

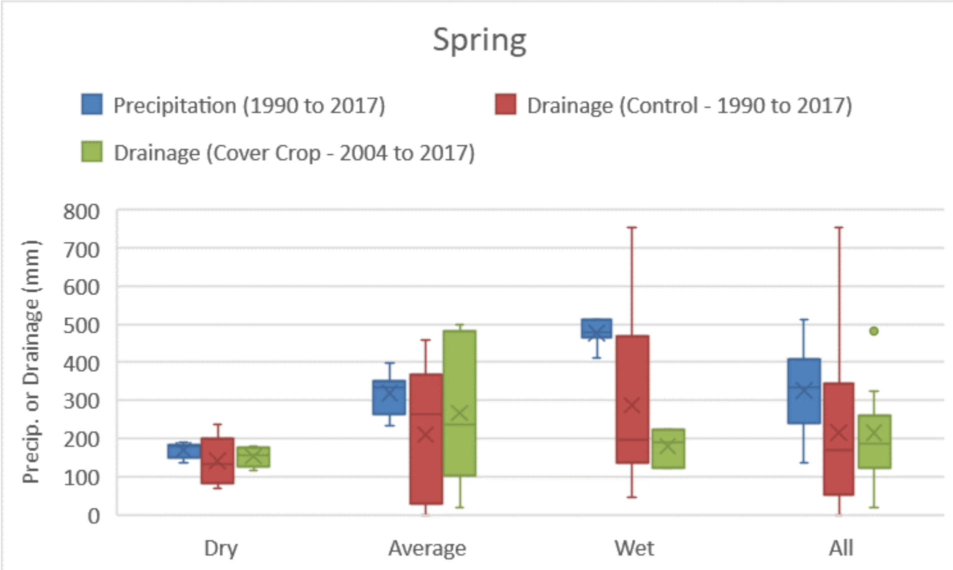
a) 

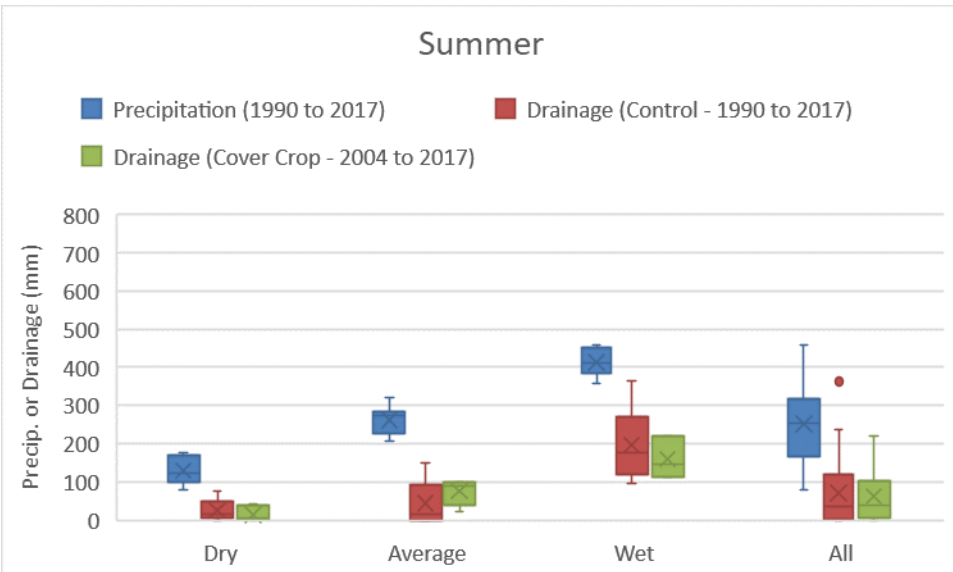

Annual Water Patterns
Draiange (1990 to 2017) (Control)
Drainage (2004 to 2017) (Cover Crop)
Drainage (% of precipitation)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Dry
Average
Wet
All

b)


Winter
Precipitation (1990 to 2017)
Drainage (Control - 1990 to 2017)
Drainage (Cover Crop - 2004 to 2017)
Precip. or Drainage (mm)
800
700
600
500
400
300
200
100
0
Dry
Average
Wet
All

c)

d) 
Spring
Precipitation (1990 to 2017)
Drainage (Control - 1990 to 2017)
Drainage (Cover Crop - 2004 to 2017)
Precip. or Drainage (mm)
800
700
600
500
400
300
200
100
0
Dry
Average
Wet
All

e) 
Summer
Precipitation (1990 to 2017)
Drainage (Control - 1990 to 2017)
Drainage (Cover Crop - 2004 to 2017)
Precip. or Drainage (mm)
800
700
600
500
400
300
200
100
0
Dry
Average
Wet
All

f)

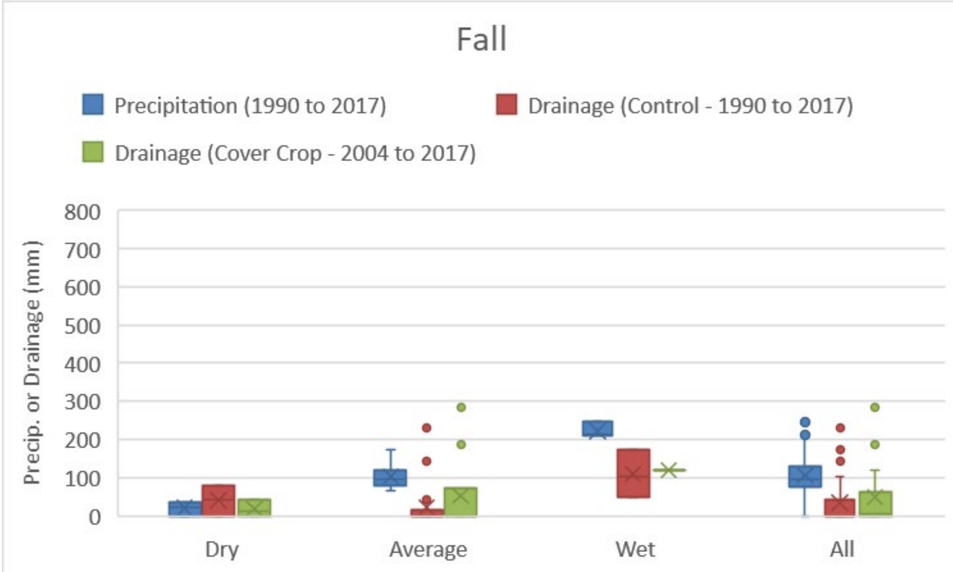


Figure 4. Precipitation and drainage patterns from 1990 to 2017 at the long-term drainage research site near Gilmore City, Iowa. Where panel a is the annual distribution (wet years vs dry years), panel b is drainage represented as a percent of precipitation, panel c is the distribution of winter precipitation and drainage, panel d is the distribution of spring precipitation and drainage, panel e is the distribution of summer precipitation and drainage, panel f is the distribution of fall precipitation and drainage. The whiskers represent the upper and lower quartiles, the line represents the median, and the x represents the mean.

Seasonality was refined into dry normal and wet conditions (Figure 4). There are no significant differences in drainage between dry, normal, or wet conditions for any of the seasons (Tukey's Honest Significance Difference; alpha = 0.05), though the P-value comparing the control summer dry to the wet conditions is 0.089 (Tukey's Honest Significance Difference).

When we look at seasonal trends over the entire time period, the annual variability adds complexity; however, a few additional patterns may emerge as shown in Figure 5 and Figure 6. For example, the dry time between 1994 and 2000 had relatively little drainage with a couple years (1996, 1998, and 2000) where there was nearly average precipitation with little to no drainage response. This may indicate initial soil conditions are important to observed drainage volumes.

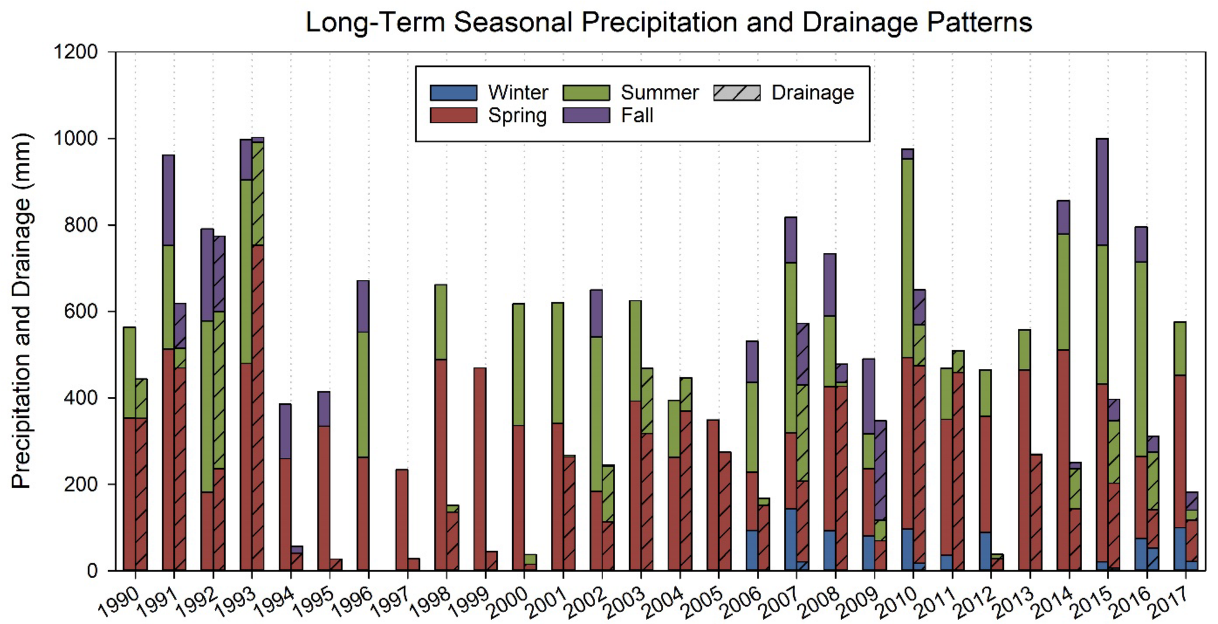


Figure 5. Seasonal precipitation and drainage over the monitoring period at the long-term drainage research site near Gilmore City, Iowa. These values represent the control treatment.

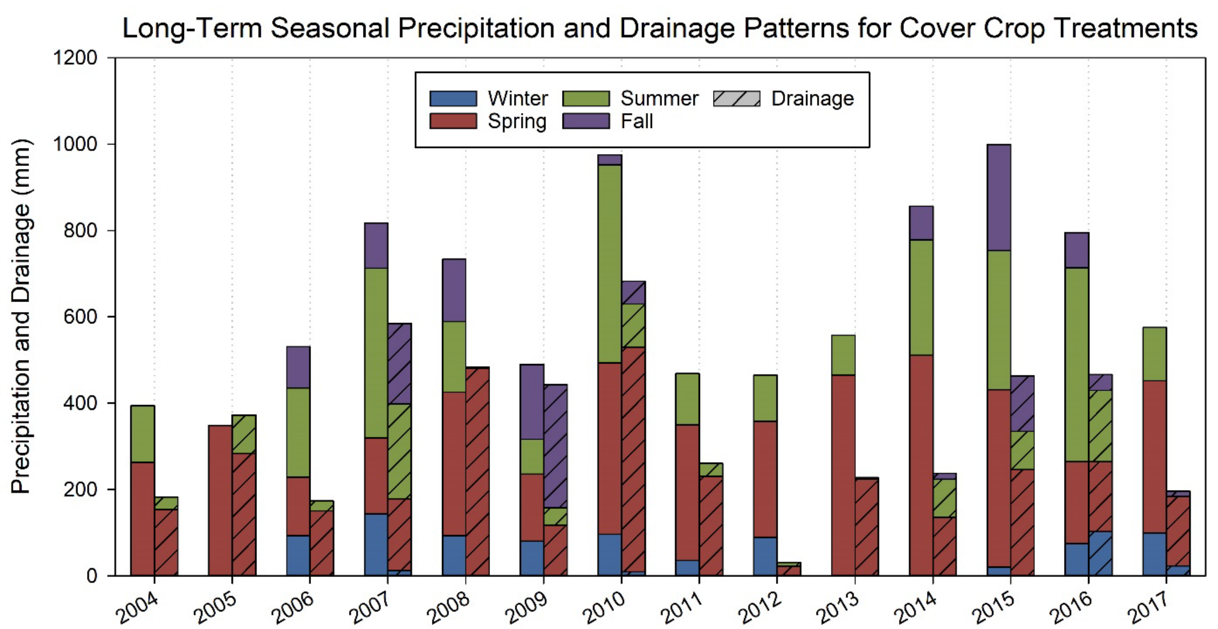


Figure 6. Seasonal precipitation and drainage over the monitoring period at the long-term drainage research site near Gilmore City, Iowa. These values represent the cover crop treatment.

When comparing drainage for control and cover crop plots for the same time period, similar volumes were seen (Figure 7). Though average drainage from cover crop plots was slightly higher, no significant differences were found (Two-sample t-Test assuming equal variances; P=0.65). When evaluating drainage by month (Figure 8), both control and cover crop plots had the majority of rainfall and drainage in the spring months (April through June) with between 60% and 65% of annual volumes occurring.

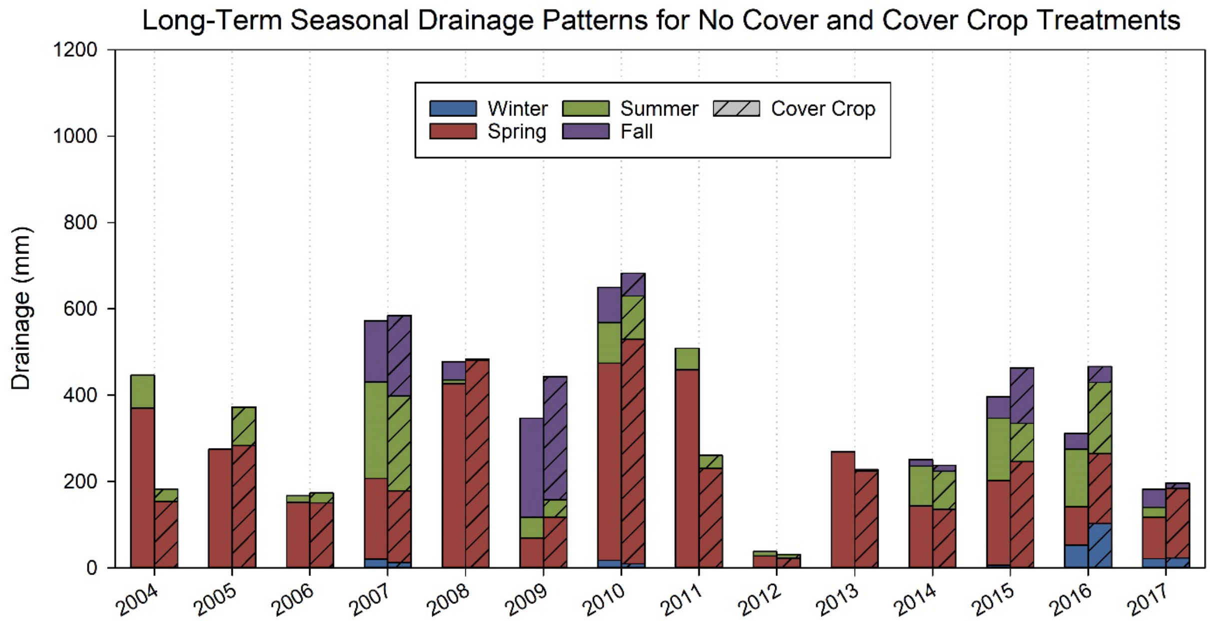


Figure 7. Drainage differences for cover crop and non-cover crop plots.

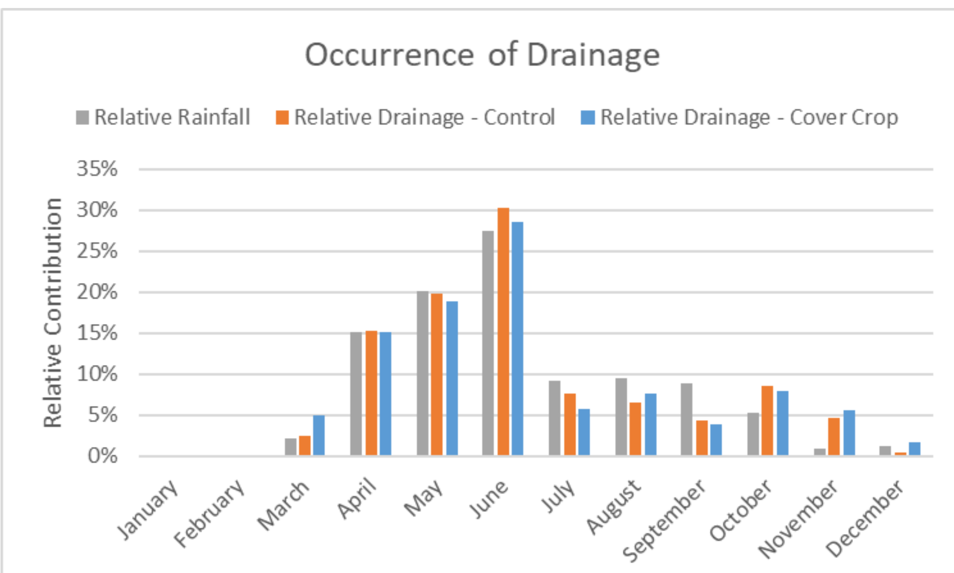
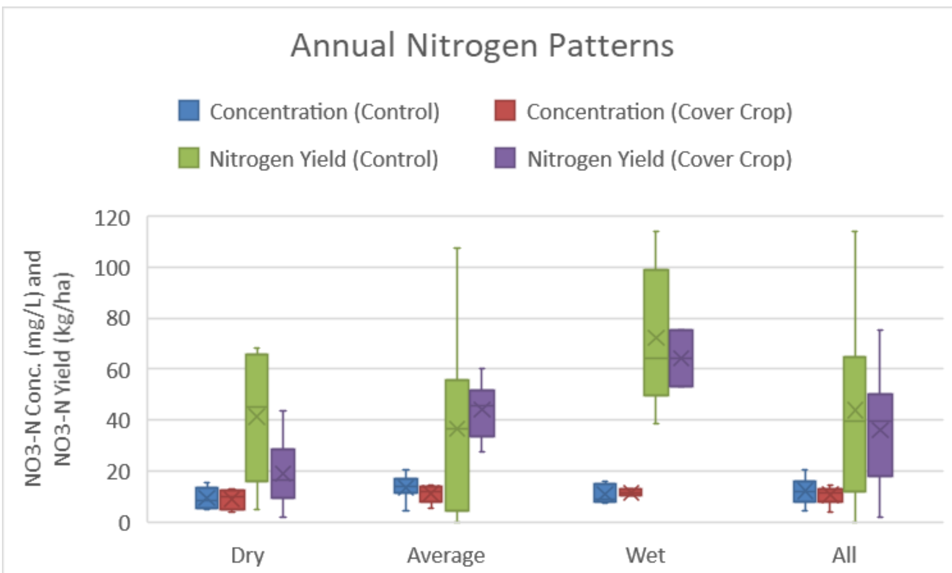


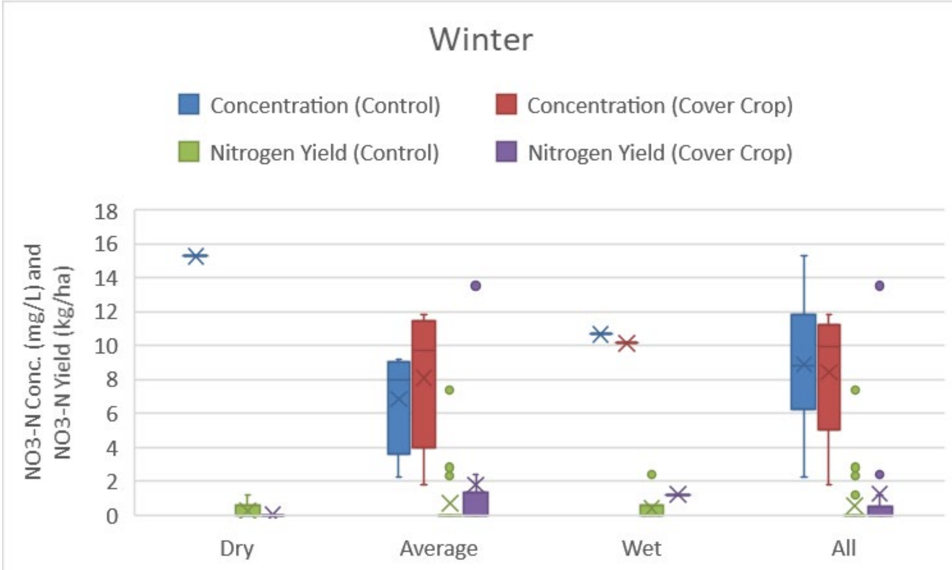
Figure 8. Monthly drainage relationships for control and cover crop plots between 2010 and 2017.

NO3-N Concentration and Yield

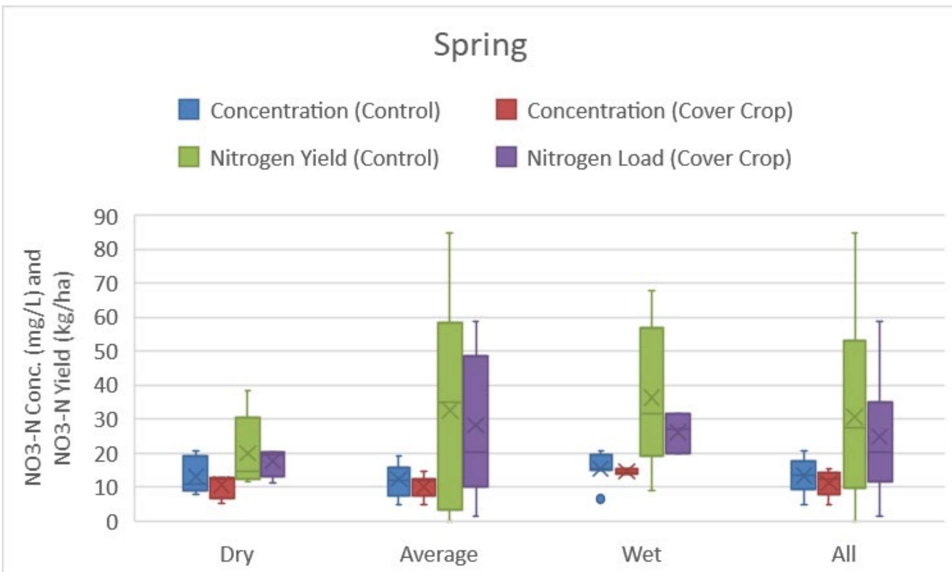
Nitrate-N concentration and yield were divided using the same criteria as precipitation and drainage (Figure 9). It is apparent, NO3-N concentrations do not change substantially with changes in precipitation and no significant differences are apparent between precipitation conditions (Tukey's Honest Significance Test; alpha = 0.05). When considering annual values for each plot, NO3-N concentrations from cover crop plots are significantly lower (12.13 mg/L for the control and 10.76 mg/L for cover crops; Two-sample t-Test assuming equal variances; P=0.036). Since NO3-N yields are directly impacted by drainage volume, the NO3-N yield for wet years was elevated, though when analyzed with Tukey's Honest Significant Difference test (alpha = 0.05) no significant differences were found between average and wet years. When considering annual values for each plot, NO3-N yield from cover crop plots are significantly lower (43.2 lbs N/ac [48.4 kg N/ha] for the control and 34.6 lbs N/ac [38.7 kg N/ha] for cover crops; Two-sample t-Test assuming equal variances; P=0.029). Finally, no statistically significant differences existed between NO3-N concentrations for any individual seasons for the control or cover crop (Tukey's Honest Significance Test; alpha = 0.05; Figure 10).



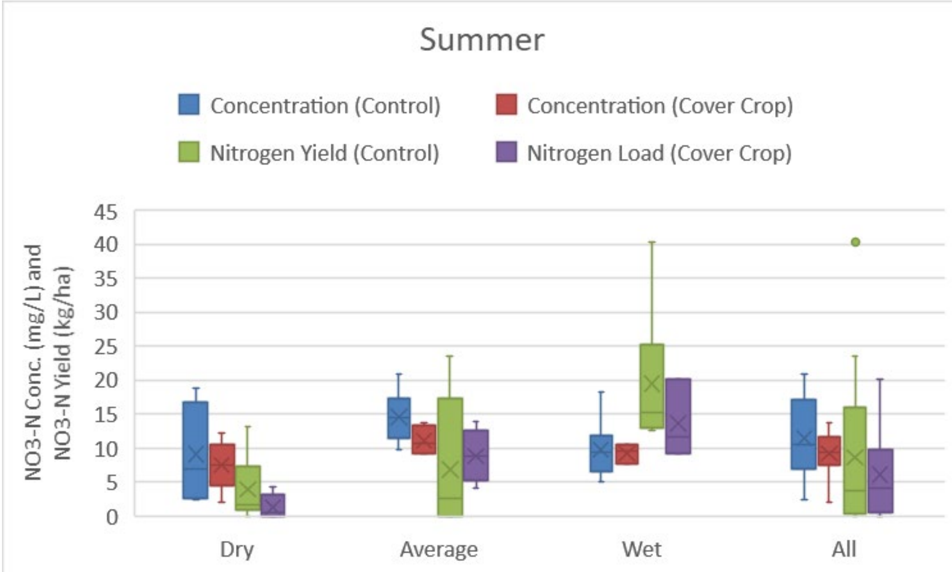
a)


Winter
Concentration (Control)
Concentration (Cover Crop)
Nitrogen Yield (Control)
Nitrogen Yield (Cover Crop)
NO3-N Conc. (mg/L) and NO3-N Yield (kg/ha)
0
2
4
6
8
10
12
14
16
18
Dry
Average
Wet
All

b)


Spring
Concentration (Control)
Concentration (Cover Crop)
Nitrogen Yield (Control)
Nitrogen Load (Cover Crop)
NO3-N Conc. (mg/L) and NO3-N Yield (kg/ha)
0
10
20
30
40
50
60
70
80
90
Dry
Average
Wet
All

c)

d) 

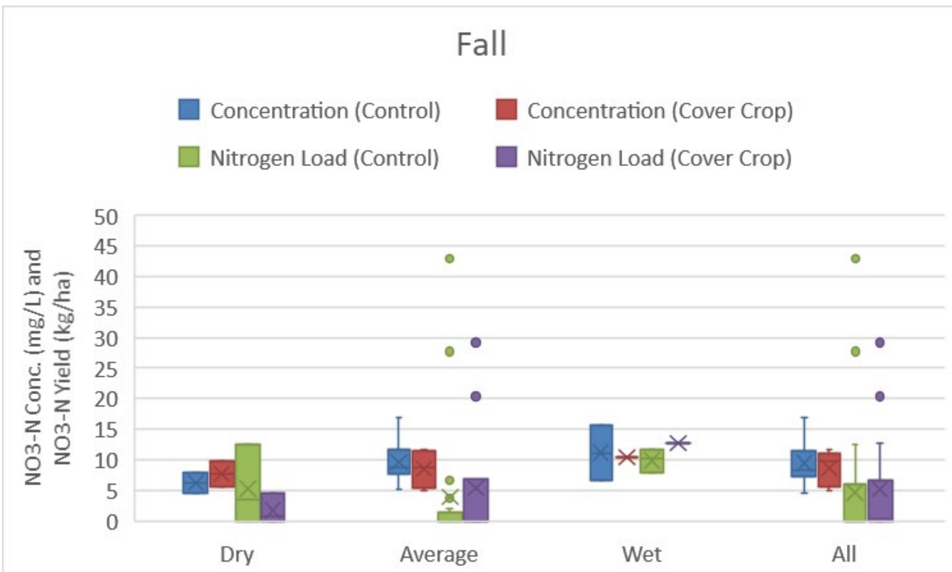
e) 

Figure 9. Nitrate-nitrogen concentration and yield patterns from 1990 to 2017 for the control and 2004 to 2017 for cover crops at a long-term drainage research site near Gilmore City, Iowa. Where panel a is the annual distribution (wet years vs dry years), panel b is the distribution of winter nitrogen, panel c is the distribution of spring nitrogen, panel d is the distribution of summer nitrogen, and panel e is the distribution of fall nitrogen. The whiskers represent the upper and lower quartiles, the line represents the median, and the x represents the mean.

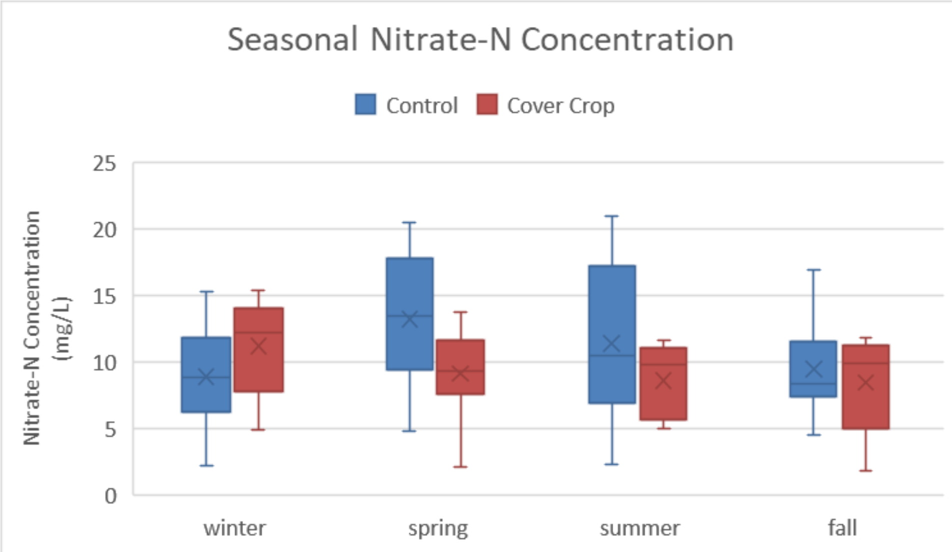


Figure 10. Seasonal variation in nitrate-nitrogen concentration for the control plots and the cover crop plots. No-flow data points have been removed as concentrations were not available for these times.

The majority (>60%) of drainage and nitrate loss occurs during the spring period (April through June) (Figure 11). All three months of spring are higher than any other months (Figure 12).

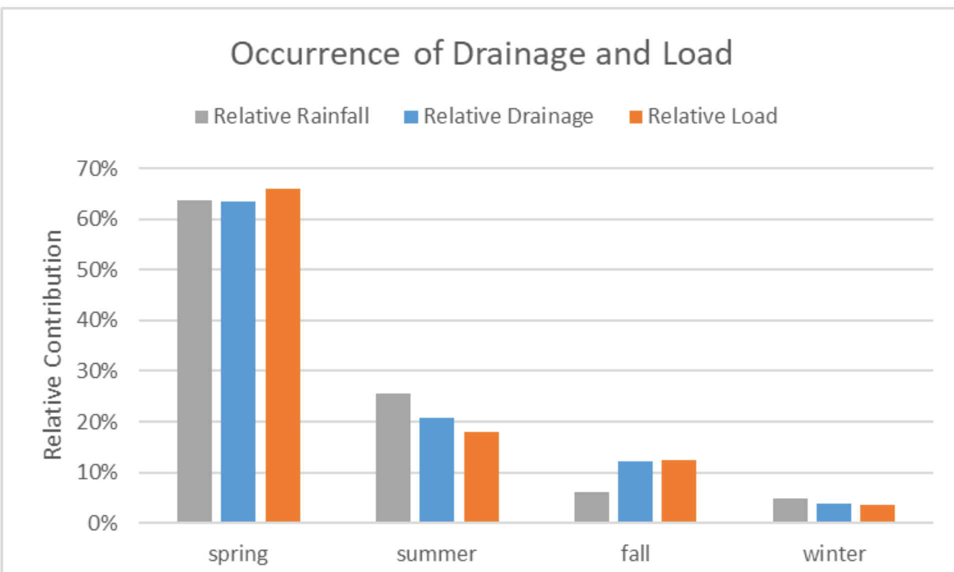


Figure 11. Relative contribution of flow and nitrate loss across seasons. Data include the years 1990 through 2017.

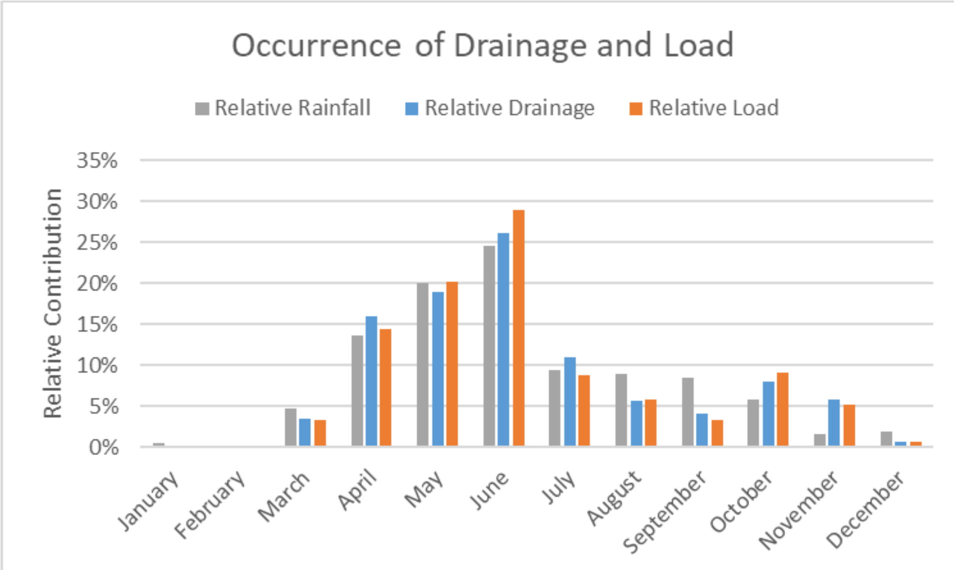


Figure 12. Relative contribution of precipitation, flow, and nitrate loss across months. Data include the years 1990 through 2017.

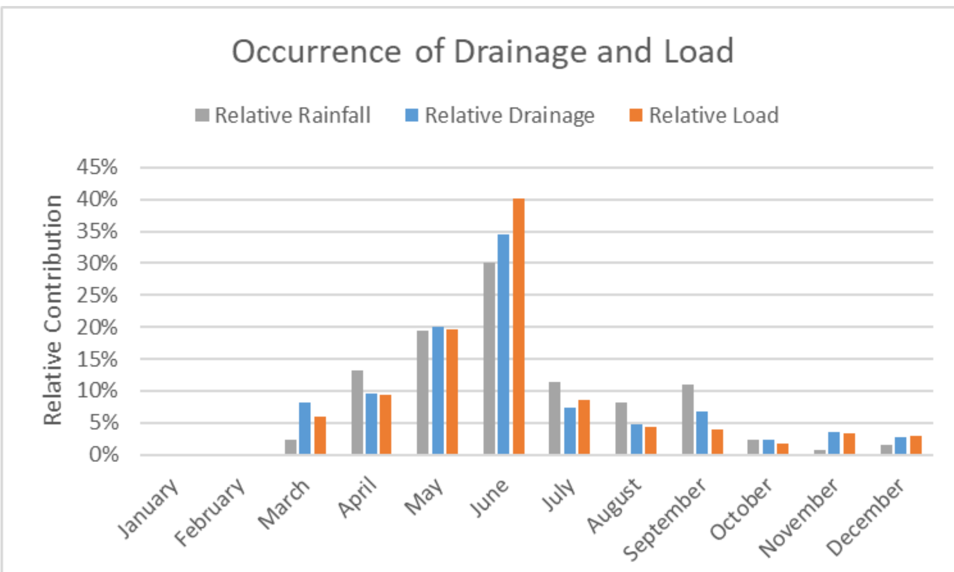


Figure 13. Monthly drainage and load relationships for cover crop plots between 2010 and 2017.

As found with previous publications based on data from this site, as well as large portions of the cover crop literature body (IDALS, IDNR, & ISU, 2016), long-term average nitrate-nitrogen load reduction for cover crops was found to be approximately 30% with this study. Interestingly, the relative nitrate-nitrogen reduction is stable across the range of event-based drainage volumes observed over the study period (Figure 14). The shift seen between control and treatment measurements was evaluated for significance using a regression analysis method proposed by Grabow et al. (1998) and is significant at alpha = 0.05.

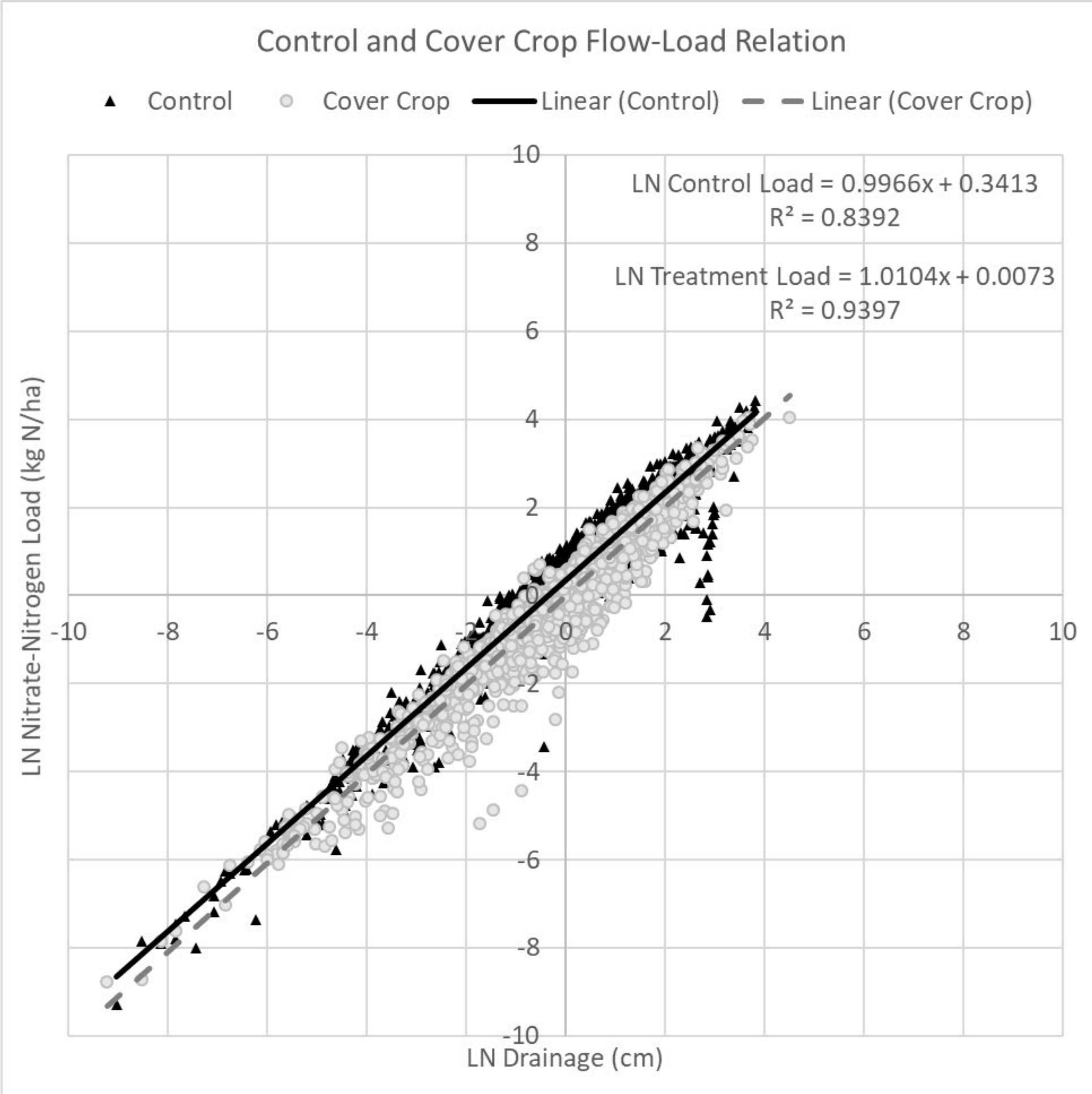


Figure 14. Incremental drainage and nitrate-nitrogen load relationship at the Gilmore City long-term research site. Data have been transformed using a natural log function for both parameters. The regression line for the cover crop treatment is shifted down, indicating lower loads.

When aggregating control and cover crop data to annual values, drainage and load correlations are still significantly positive. Further, when evaluating these data for the same time period using regression analysis (Grabow et al., 1998), resulting trendline slopes are significantly different (alpha = .05) between control loads and cover crop loads with respect to drainage (Figure 15). Trends show increases in load with increasing drainage, though the increase in the resulting slope for the cover crop treatment is lower, indicating a slight relative increase in performance with increasing annual drainage (~0.1% per 1 cm increase in drainage volume).

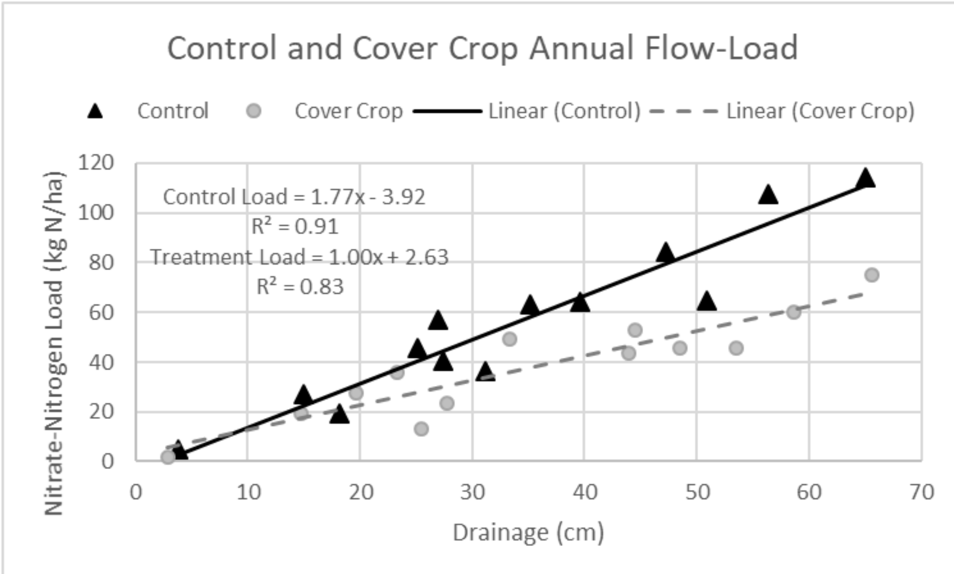
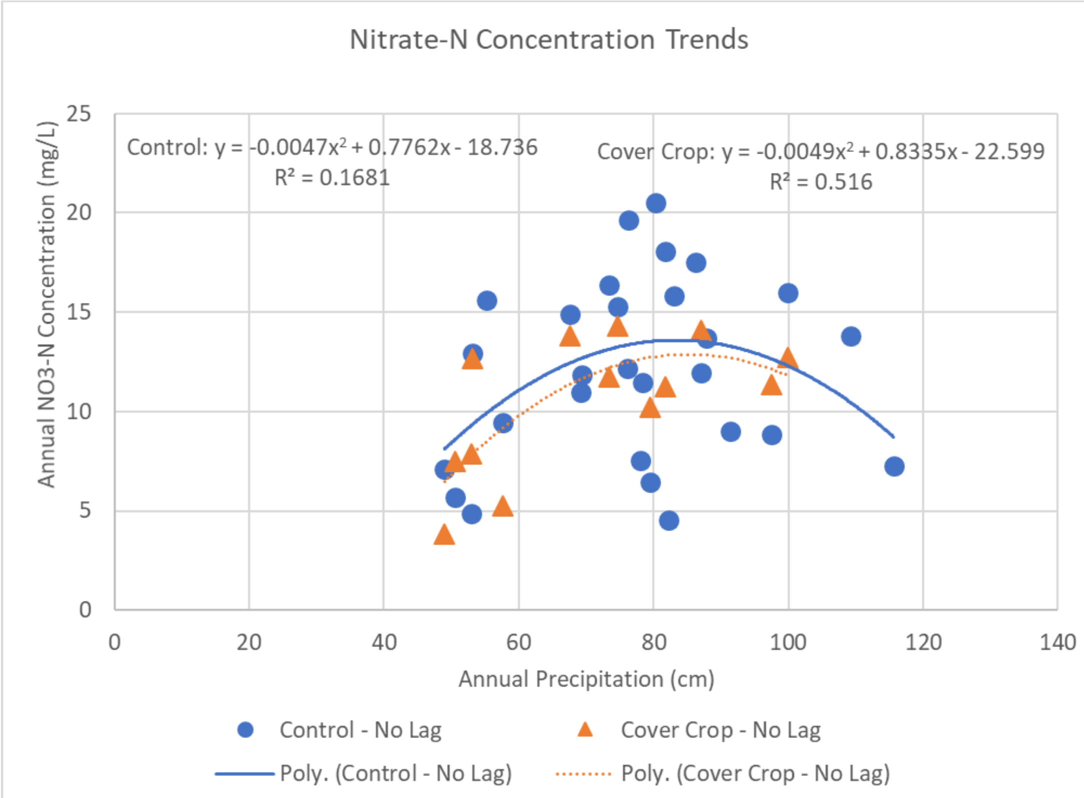
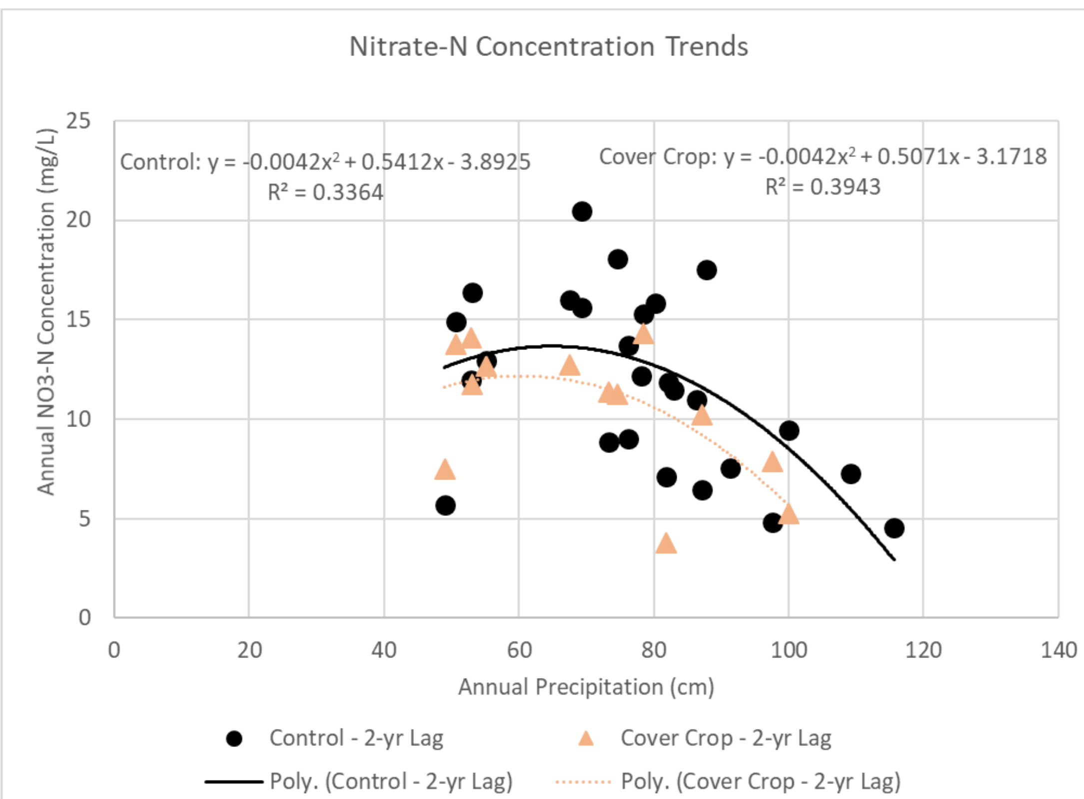


Figure 15. Annual drainage and load for control and treatment at the Gilmore City long-term research site. Trendline slopes are significantly different (alpha = 0.05) (Grabow et al., 1998).

Examining precipitation and concentration patterns, there seems to be a general relationship between annual precipitation and nitrate-N concentration (Figure 16). The results from the control plot encompass more years including the low drainage years between 1994 and 2000, which tends to shift the precipitation-concentration relationship towards a 2-year lag (high precipitation in a year leads to a low NO3-N concentration two years later; Figure 16). The lagging trend was not as strong for cover crops, which may have been due to the more consistent drainage patterns for the dataset (2004 to 2017). Though correlations are weak, they are significant (Table 2; Figure 16) (Texas-Education-Agency, 2018). Multiple linear regression suggests the two-year lag is the single best predictor, though adding same year precipitation data enhances predictions with a trend of increasing nitrate-nitrogen concentrations with increasing precipitation. With this trend in mind, persistently wet (wetter than historic average) years may lead to a reduction in nitrate-nitrogen concentrations over time.



a)



b)

Figure 16. Trends between precipitation and nitrate-nitrogen concentration for the control and cover crop. Trend lines denoted Panel a represents the direct annual relationship, while panel b represents a 2-year lag in concentration response.

Table 2. Correlation coefficients and significance results for precipitation and nitrate-nitrogen concentration based on Texas Education Agency (2018).

Comparison	Concentration Lags Precipitation (years)	Correlation Coefficient	Critical Correlation Coefficient (number of samples)	Resulting Significance @ alpha = 0.05
Precipitation (cm) – Control Nitrate Concentration (mg/l)	0	0.410	0.374 (28)	Significant
Precipitation (cm) – Control Nitrate Concentration (mg/l)	2	0.580	0.388 (26)	Significant
Precipitation (cm) – Cover Crop Nitrate Concentration (mg/l)	0	0.718	0.555 (13)	Significant
Precipitation (cm) – Cover Crop Nitrate Concentration (mg/l)	2	0.628	0.555 (13)	Significant

Water Yield with Changing Precipitation

To evaluate the impact of changes in precipitation, water yield (drainage) data and precipitation data were normalized as a percent change from mean. Annual data were considered as well as seasonal and results are presented in Figure 17 through Figure 21. Though the regression lines had poor goodness of fit measures, the annual (Figure 17), spring (Figure 19), and summer (Figure 20) periods show strong positive correlations between precipitation and drainage. The correlations between normalized annual precipitation and drainage were significant (correlation coefficient of 0.572 with a critical value of 0.367 for the control and correlation coefficient of 0.640 with a critical value of 0.532 for cover crops between 2005 and 2017; Figure 17) (Texas-Education-Agency, 2018). Though, when comparing regression line slopes between control and cover crop plots, there were no statistical differences annually or seasonally (t-Test with pooled variance; P=0.38) (Andrade & Estévez-Pérez, 2014).

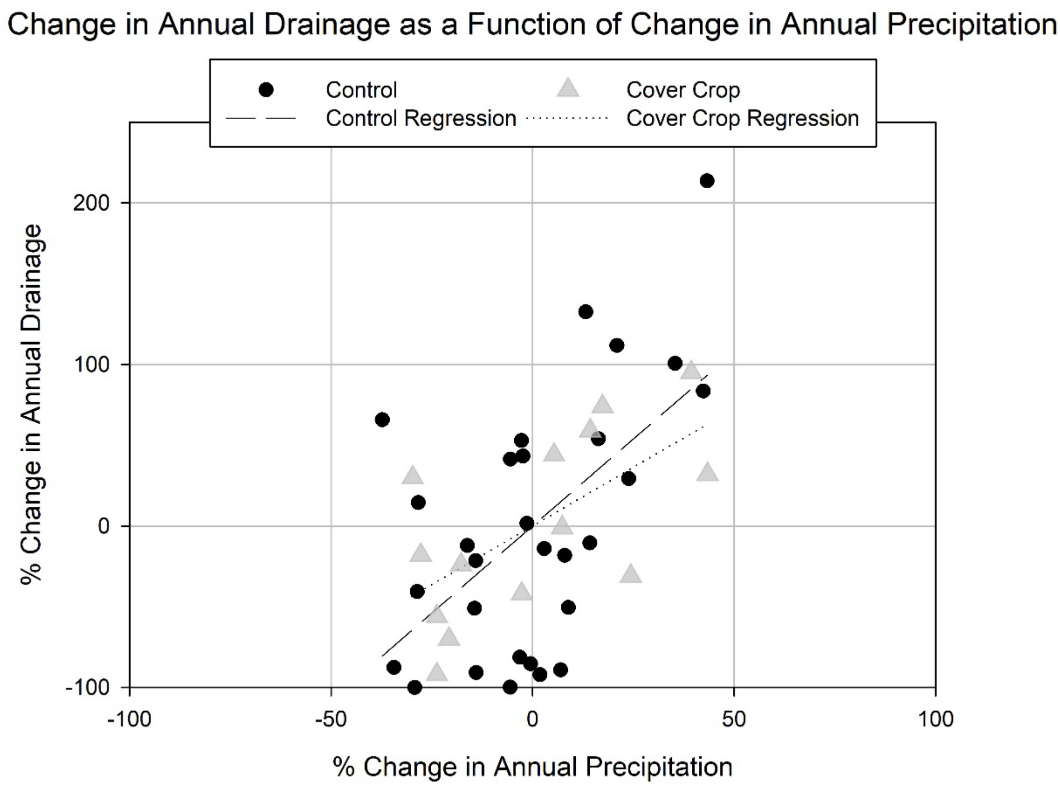


Figure 17. Change in annual drainage from a resulting change in annual precipitation. The origin (x=0, y=0) indicates average precipitation and average drainage, respectively.

Using the correlation significance test (Texas-Education-Agency, 2018), relations between precipitation and drainage for all seasons was considered. Correlations for the winter season (Figure 18) were not significant for either the control or the cover crops. Correlations for the spring season (Figure 19) were significant for the control but not for the cover crop. Correlations for summer and fall (Figure 20, Figure 21) for control and cover crops were significant. Table 3 has all these data summarized.

Table 3. Correlation coefficients and significance results for relative precipitation and drainage based on Texas Education Agency (2018).

Comparison % Precipitation to % Drainage	**Correlation Coefficient**	**Critical Correlation Coefficient (number of samples)**	**Resulting Significance @ alpha = 0.05**
		Control	
Annual	0.572	0.367 (29)	Significant
Winter	0.057	0.367 (29)	Not Significant
Spring	0.391	0.374 (28)	Significant
Summer	0.597	0.374 (28)	Significant
Fall	0.451	0.374 (28)	Significant
		Cover Crop	
Annual	0.640	0.532 (14)	Significant
Winter	0.109	0.532 (14)	Not Significant
Spring	0.457	0.514 (15)	Not Significant
Summer	0.852	0.514 (15)	Significant
Fall	0.543	0.514 (15)	Significant

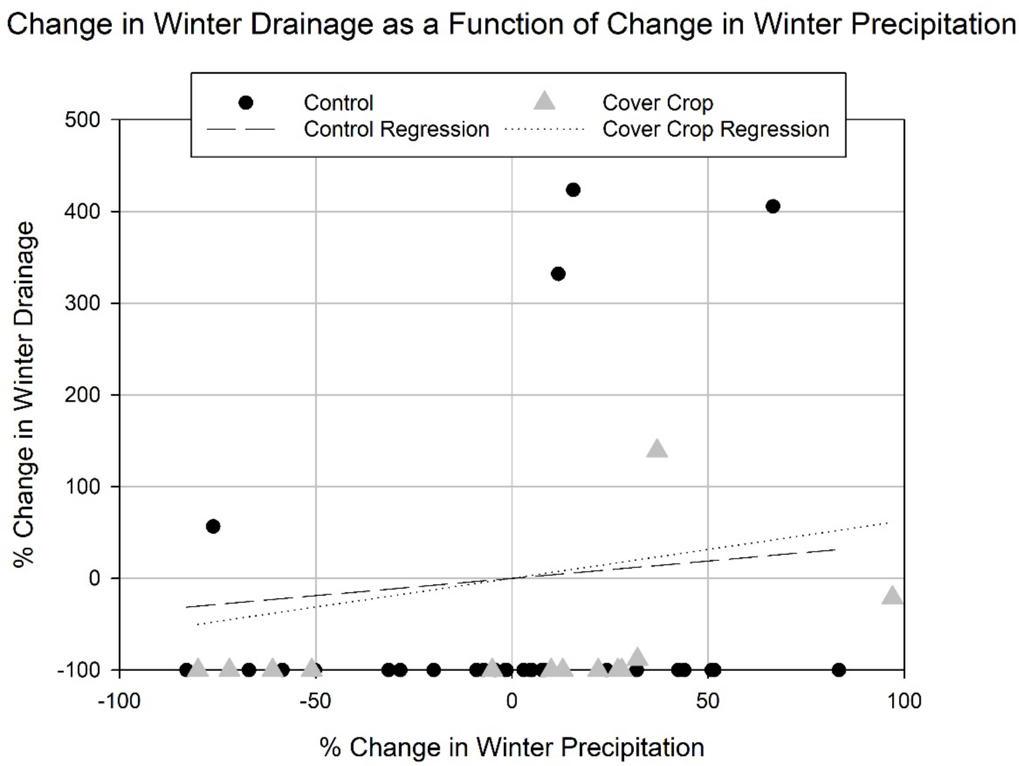


Figure 18. Change in winter drainage from a resulting change in winter precipitation. The origin (x=0, y=0) indicates average precipitation and average drainage, respectively. Neither correlations were significant.

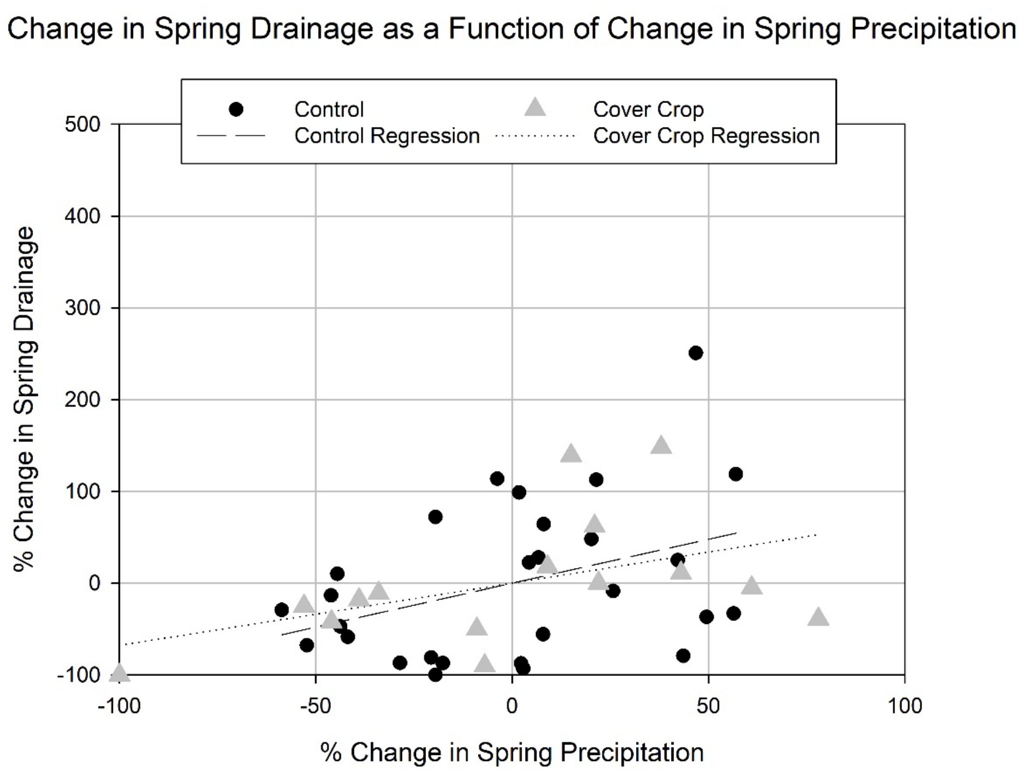


Figure 19. Change in spring drainage from a resulting change in spring precipitation. The origin (x=0, y=0) indicates average precipitation and average drainage, respectively. The cover crop correlation was not significant.

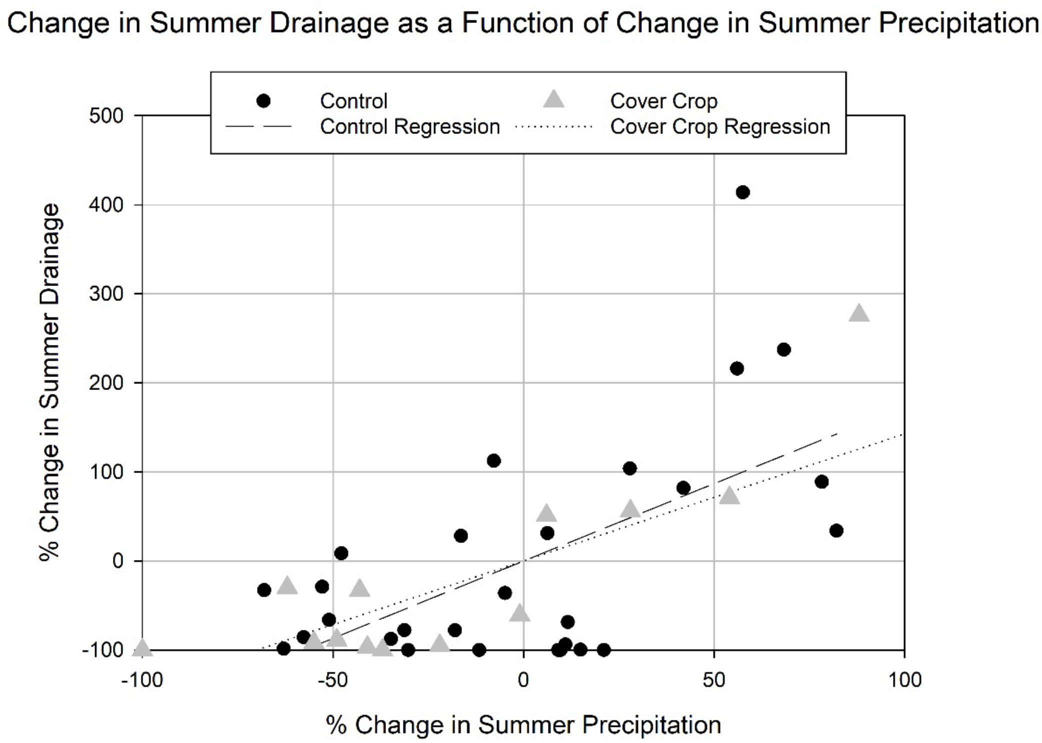


Figure 20. Change in summer drainage from a resulting change in summer precipitation. The origin (x=0, y=0) indicates average precipitation and average drainage, respectively. Both correlations were significant.

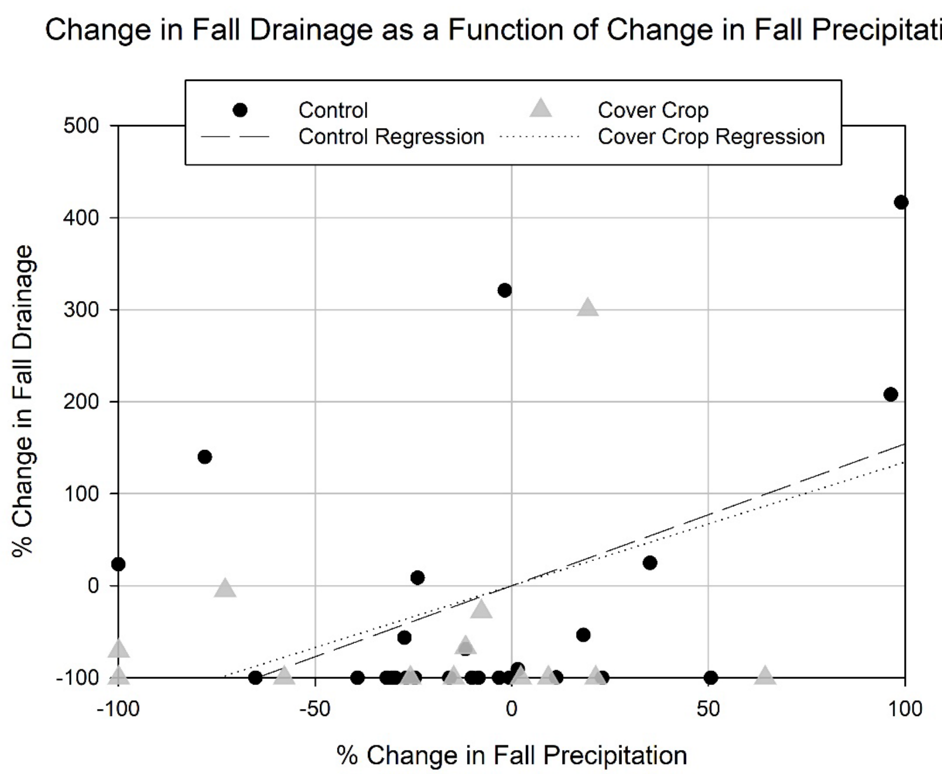


Figure 21. Change in fall drainage from a resulting change in fall precipitation. The origin (x=0, y=0) indicates average precipitation and average drainage, respectively. Both correlations were significant.

Conclusions

- Between 25% and 30% of annual precipitation and drainage occur in June, and approximately 65% occurs between April and June.
- Flow weighted nitrate-nitrogen concentrations are stable over seasons with no statistically significant differences observed.
  - Nitrate-nitrogen concentrations are more stable with cover crops, where concentration variation is lower.
- Flow weighted nitrate-nitrogen concentration is weakly correlated to precipitation and drainage, with an observed lag for the control (potentially due to low drainage volumes from 1994 to 2000).
  - The lag trend was not as strong for the cover crop treatment
  - Finding these lags at a plot scale implies they are likely amplified at the watershed scale, with a combination of tile drainage water and groundwater impacting nitrate-nitrogen concentrations.
  - Further, at larger scales, observed variability will likely be higher than shown here, which highlights the challenges faced when monitoring larger watershed water quality response to conservation practice adoption.
- Relative drainage and precipitation are positively correlated (when more precipitation occurs, there tends to be more drainage).
  - For the control, a 1% increase in precipitation above average results in a 2.2% increase in drainage.
  - For the treatment with cover crops, a 1% increase in precipitation above average results in a 1.5% increase in drainage.
  - If drainage is increasing proportionally more, exported loads will be higher, regardless of static concentrations or stable relative reductions associated with cover crops.
- Reductions due to cover crops are in the form of nitrate-nitrogen concentration reduction (~30%).
  - Since the trends shown in Figure 16 are close to parallel for the control and cover crop, the relative benefit with increasing event precipitation will likely stay around 30%. This trend is significant.
- Cover crops significantly reduce nitrate-nitrogen concentration, which lowers nitrate-nitrogen yield.
- Differences in drainage volumes associated with precipitation in control and treatment (cover crops) plots was not significantly different.

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