Spatial Characteristics of Irrigated Cropland in the South Platte River Basin

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Contents

Chapter 1

Introduction

Farms and ranches are being challenged to provide greater amounts of food for a growing global population. As global incomes rise an increasing proportion of this food demand will be for meat (Thronton 2010). Simultaneous with this demand trend is a shift in climate towards increases in air temperature, increased variability of precipitation, changes in timing of spring snowmelt, and other factors which are leading to increased incidence of drought and aridification in several regions of the world, including the US Mountain West. This trend precludes the possibility of increasing meat production by simply intensifying grazing on fixed land base due to the propensity for desertification and loss of productivity from overgrazing in semiarid rangelands (Schlesinger et al. 1990). Concurrently, the multifunctional nature of agricultural systems in their provision of ecosystem services is increasingly important in policy contexts and it is increasingly apparent that conventional agricultural systems are unable to effectively address conservation requirements for sustainable provision of these services (Boody et al. 2005). Therefore, it is critical that new agricultural technologies be developed and incentivized in commodity scale food production.

Irrigated pasture is a relatively novel land and water resource management option that shows great potential for sustainable production of beef and dairy cattle, as well as other ruminants. A well designed and well managed irrigated pasture system would allow for the ranching sector to support a greater number of cattle on the same fixed land resource base while also mitigating price and production risks associated with increased climatic variability. Producers would also be able to access new marketing opportunities that offer price premia and decrease reliance on conventional livestock supply chains, eg. local, 100% grass-fed beef. These marketing benefits may be able to be realized while simultaneously reducing negative externalities associated with current meat production systems and market channels. (Boody et al. 2005; Capper and Bauman 2013; Pitesky et al. 2009; Place and Mitloehner 2014; Russelle et al. 2007).

However, the economic feasibility of intensification via irrigated pasture is still uncertain. Several farm and field level studies have been conducted to examine the usefulness of perennial crops to address the need for multifunctional agricultural systems (Alexander et al. 2014; Tyndall et al. 2013) and there is a well developed theoretical framework for producer decision making regarding land use change under uncertainty and costly reversibility (Dixit and Pindyck 1994; Schatzki 2003; Song et al. 2011; Williams et al. 2009). However, the full potential and criteria for optimal integration of perennial cropping into existing agricultural systems in a larger spatial context is not yet fully understood (Schulte et al. 2006).

The benefits of perennials in the context of a local agroecosystem across a given landscape or watershed will depend on the locations of perennial crops within a given landscape, as well as the proportion of perennial crops across the landscape. More research at the watershed or regional level is needed (Schulte et al. 2006). Several simulation models and case studies have been conducted in the Midwestern United States, mostly in the context of bioenergy crops (Johnson et al. 2012; Cibin et al. 2016). Very few studies have focused on crop-livestock systems, as in Burkart et al. 2005. I know of no peer-reviewed literature that has studied perennial crop-livestock systems in the US Mountain West in any significant depth. This project will examine cropping patterns in the South Platte River Basin of eastern Colorado. The spatial characteristics and distribution of alfalfa, grass pasture, and corn will be used to answer the following research questions:

How has the distribution of cropping changed between 2010 and 2015 in both areas?

How similar are cropping patterns between the two areas?

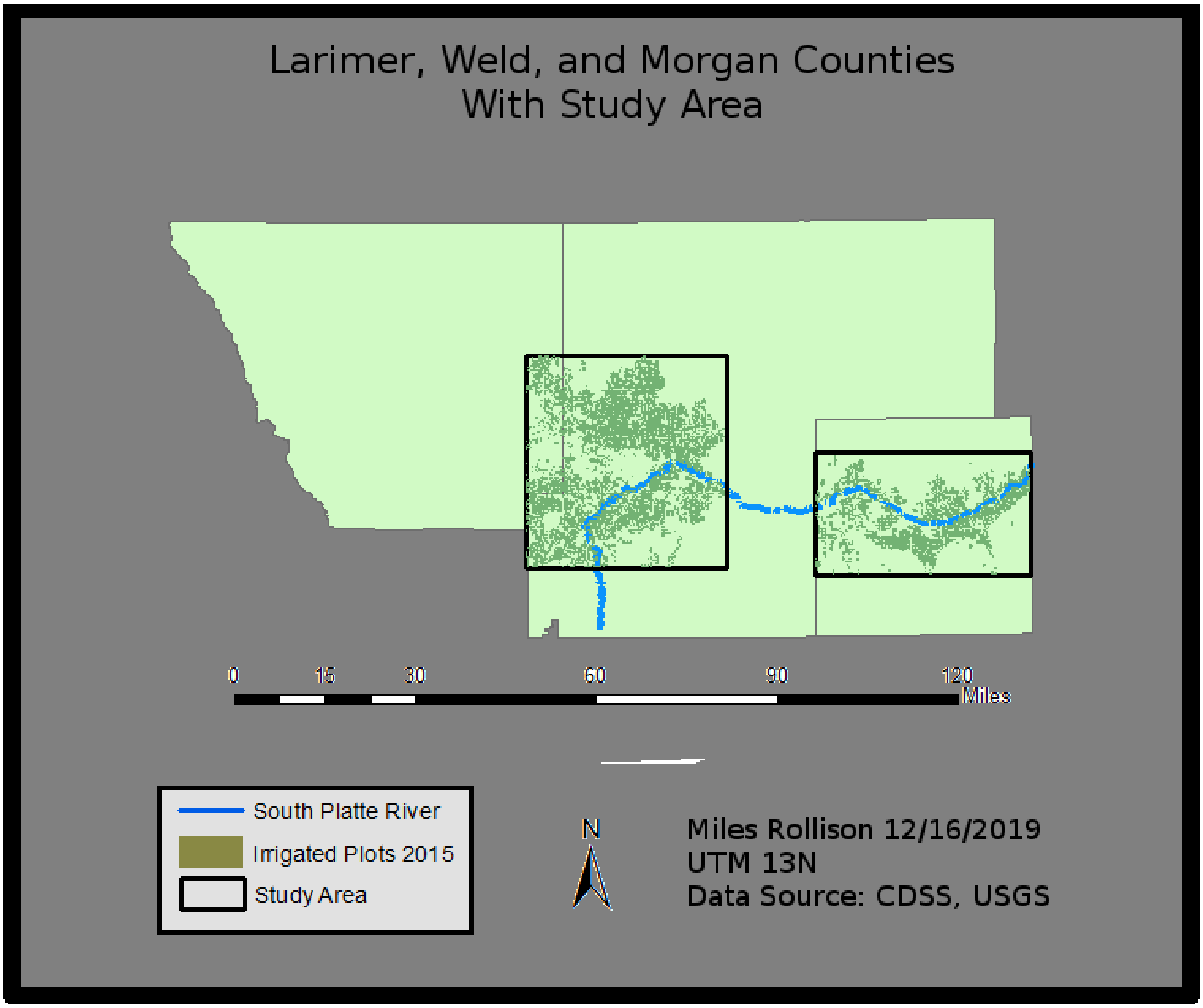
How can these conclusions inform future research efforts?

Chapter 2

Locator Map

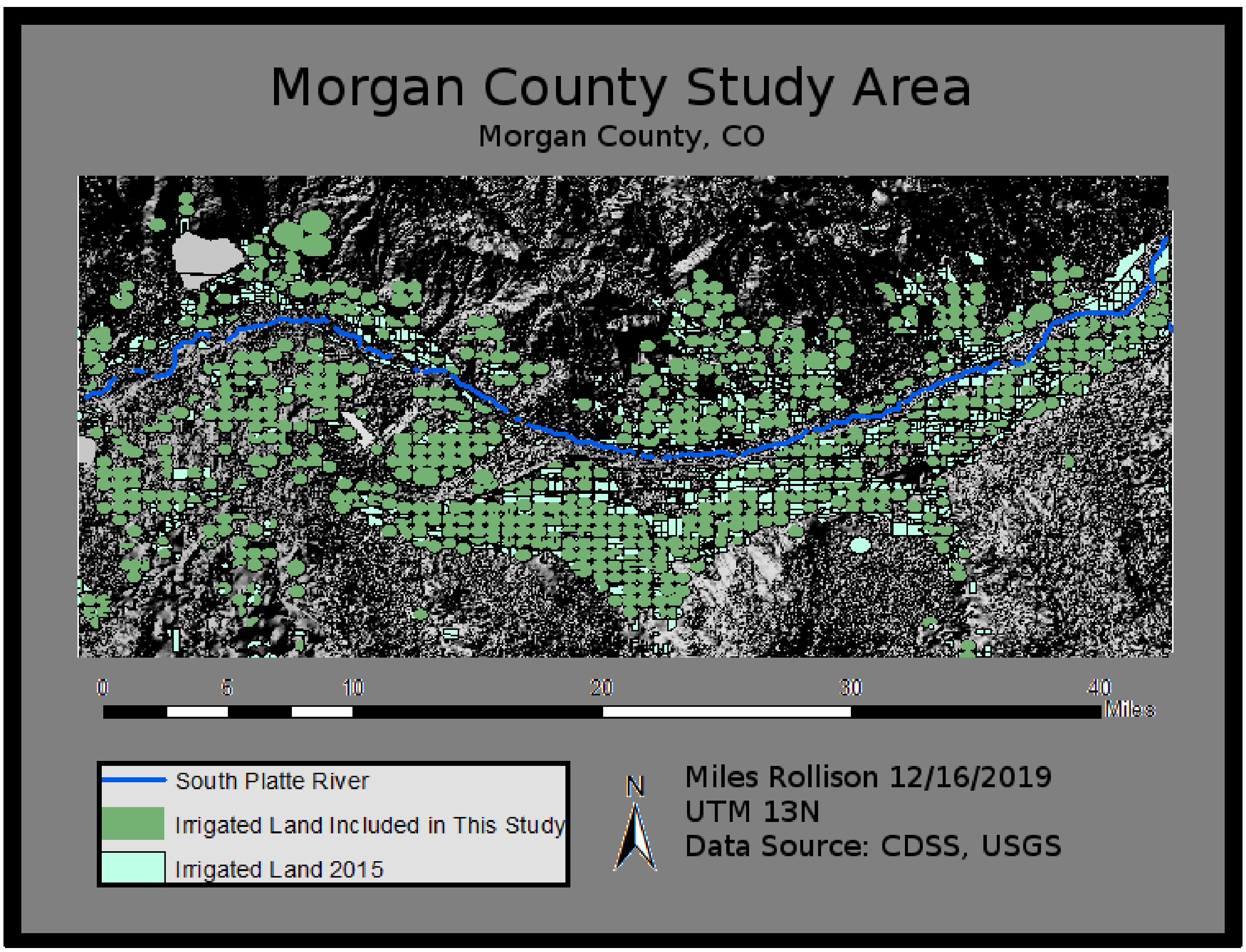
I constructed two study areas encompassing parts of the basin with high density of irrigated fields fitting the above criteria. The western study area is located in southwestern Weld County is centered on Greeley, CO and is approximately 900 square miles. The eastern study area is located in central Morgan County is centered on Ft. Morgan, CO and is approximately 735 square miles.

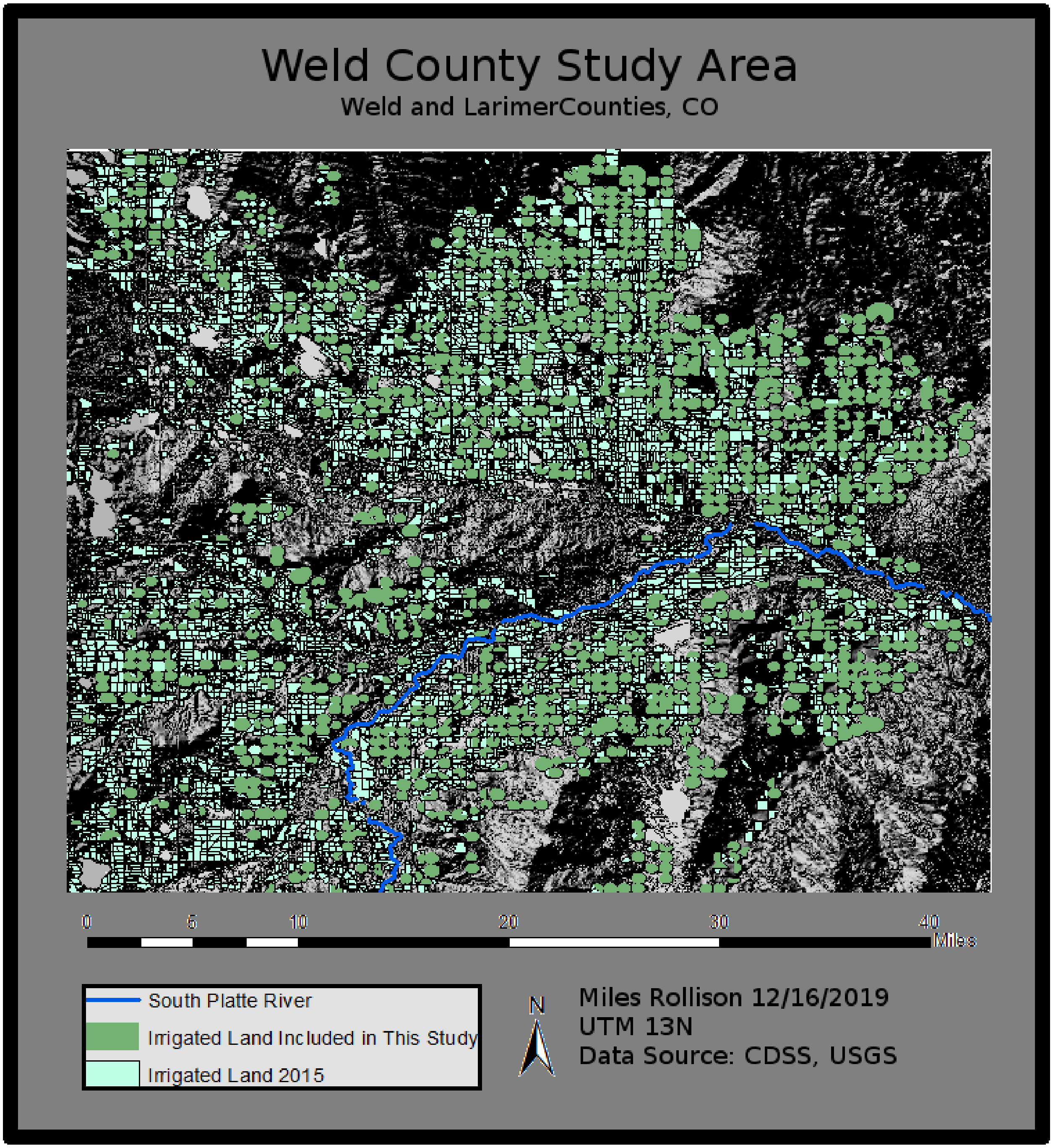

State of Colorado
0
45
90
180
270
360
Miles
South Platte River
Irrigated Plots 2015
Counties in South Platte River Basin
N
Miles Rollison 12/16/2019
UTM 13N
Data Source: CDSS, USGS


Larimer, Weld, and Morgan Counties
With Study Area
0
15
30
60
90
120
Miles
South Platte River
Irrigated Plots 2015
Study Area
N
Miles Rollison 12/16/2019
UTM 13N
Data Source: CDSS, USGS

Chapter 3

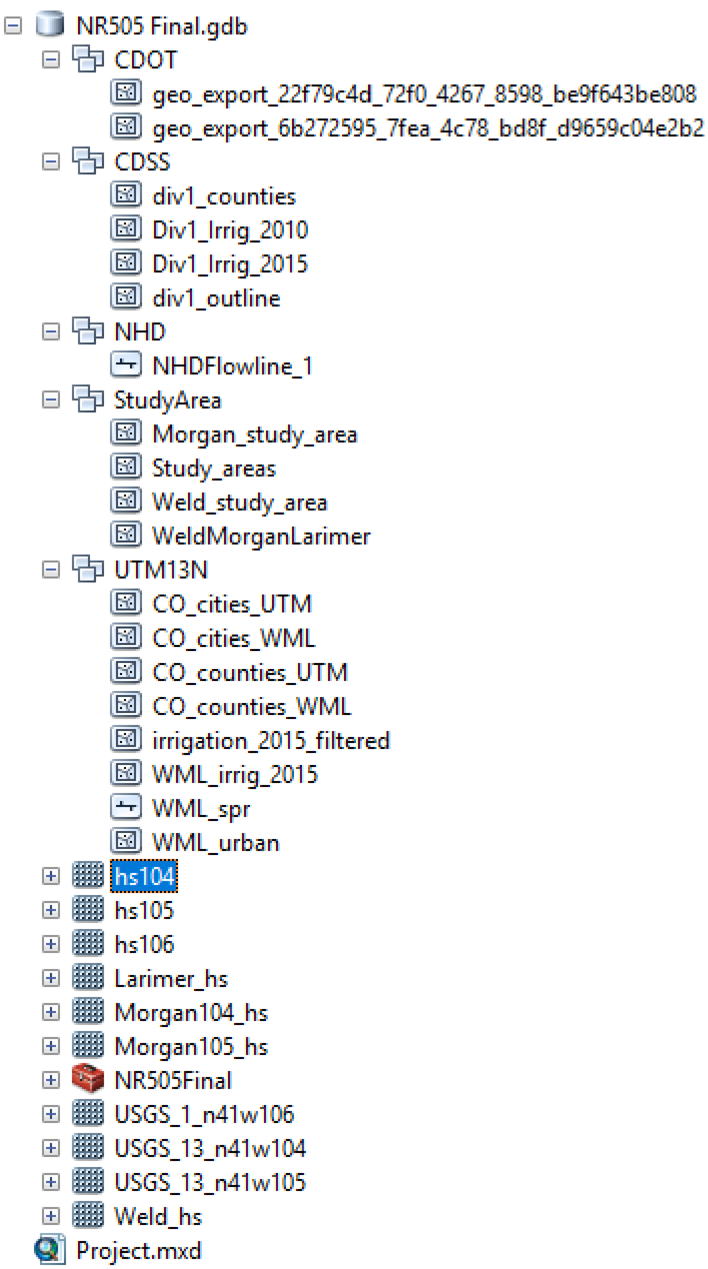
Base Maps




Weld County Study Area
Weld and LarimerCounties, CO
0
5
10
20
30
40
Miles
South Platte River
Irrigated Land Included in This Study
Irrigated Land 2015
N
Miles Rollison 12/16/2019
UTM 13N
Data Source: CDSS, USGS

Chapter 4

Database Schema



Chapter 5

Conventions

5.1 Projection

All GIS data is projected into the UTM 13N coordinate system.

5.2 Filenames

All filenames are written in Upper_snake_case

Files that are the output of a tool are appended with an underscore followed by the name of the tool
e.g. irrig_2015_clip.shp

Files with a temporal component are labeled with an underscore followed by the year the data is from
e.g. irrig_2010.shp

Files that are clipped to the Weld, Morgan, and Larimer counties area are designated with WML
e.g. CO_counties_WML.shp

Chapter 6

GIS Analyses

I studied the spatial distribution of crops across irrigated farmland in the South Platte River basin of northeastern Colorado in two different years 2010, and 2015. There were 14 different crops grown in 2010 and 12 different crops grown in 2015. Table 6.1 and Figure 6.1 below summarize the distribution of crops in both years. For the purpose of this analysis I focused on the most common annual row crop, corn, and the most common perennial forage crops, alfalfa and grass pasture.

Figure 6.1: Distribution of Crops by Acreage Across the South Platte River Basin

Table 6.1 Crops Grown in the South Platte River Basin Under Irrigation

CROP	2010	2015
ALFALFA	•	•
BARLEY	•	•
CORN	•	•
DRY BEANS	•	•
GRASS PASTURE	•	•
POTATOES	•	•
SMALL GRAINS	•	•
SNAP BEANS	•	
SORGHUM GRAIN	•	•
SUGAR BEETS	•	•
SUNFLOWER	•	•
VEGETABLES	•	•
WHEAT, FALL	•	
WHEAT, SPRING	•	•

Historically, corn has been the main crop cultivated under irrigation in this region, with relatively small acreage of irrigated alfalfa (Figure 6.2). In recent years the amount of corn has decreased notably.

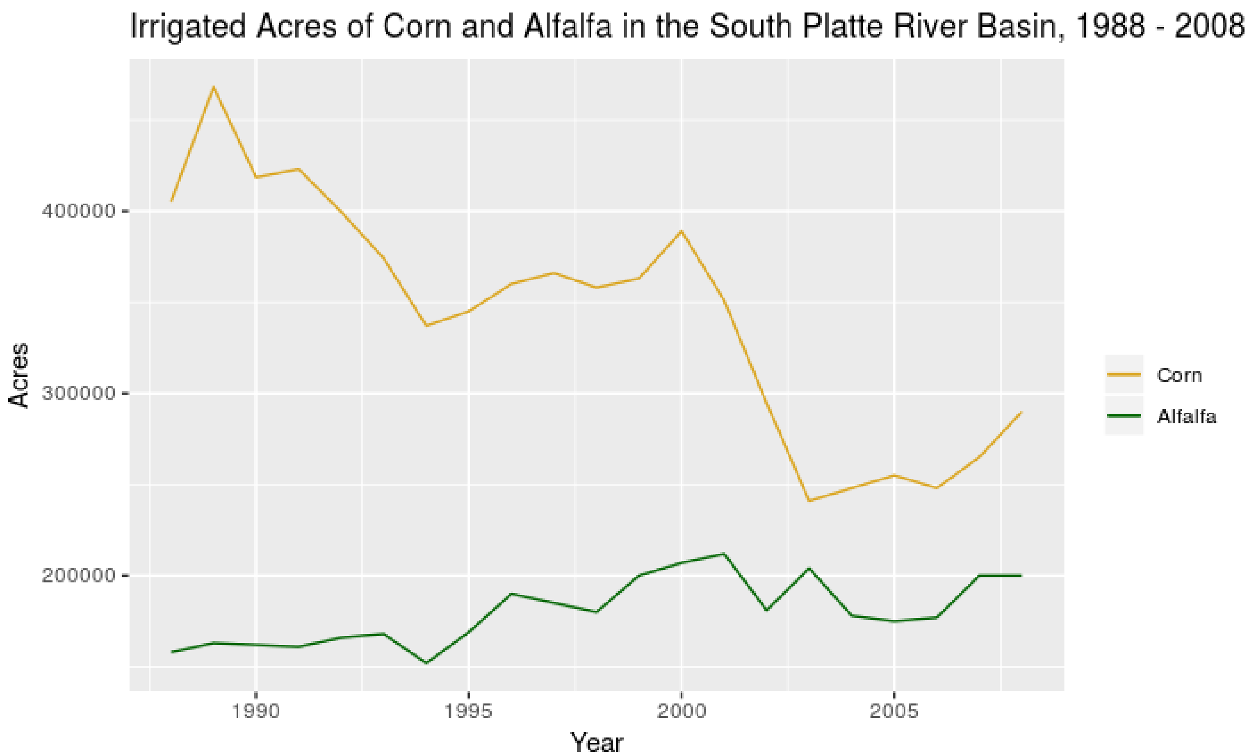


Figure 6.2: Historical Series of Corn and Alfalfa Acreage in the South Platte River Basin

6.1 Data Acquisition

Data for irrigated cropland were collected from the Colorado Decision Support System Division 1 irrigated land GIS data for 2010 and 2015 (CDWR 2019). Table 6.2 provides summary statistics for relevant variables.

Table 6.2 Summary Statistics

	Site	Year	Min	Mean	Median	Max	N
Acres	Weld	2010	50.21	85.45	95.67	547.27	856
Acres	Weld	2015	50.21	84.86	93.83	457.62	1008
Acres	Morgan	2010	50.21	104.73	103.64	530.89	600
Acres	Morgan	2015	50.24	109.61	105.36	536.14	606
Field Diameter (M)	Weld	2010	508.6	663.5	690.2	1679.2	856
Field Diameter (M)	Weld	2015	508.6	661.2	684.2	1535.6	1008
Field Diameter (M)	Morgan	2010	508.6	734.6	717.7	1653.9	600
Field Diameter (M)	Morgan	2015	508.8	751.5	724	1662.1	606

6.2 Data Preparation

All data were processed in ArcGIS 10 and exported to R for further statistical analysis.

All GIS data was projected into the same UTM 13N coordinate system. Irrigation data were clipped to the selected study areas. A spatial join was used with the study area polygon to join a field to indicate which study area contained each record for the clipped irrigation data. The resultihng attribute table was exported into Excel using the Table to Excel tool in ArcGIS.

The attribute table data were then imported into R and filtered for observations of sprinkler irrigated fields of 150 acres or larger growing either corn, alfalfa, or grass pasture.

6.3 Data Analysis

The R package spatstat (Baddeley and Turner 2005) was used to calculate pair correlation functions, kernel densities, and K-functions as presented in the results section. Base R (R Core Team 2019) was used to construct Quantile-Quantile plots of the K-functions and to calculate summary statistics.

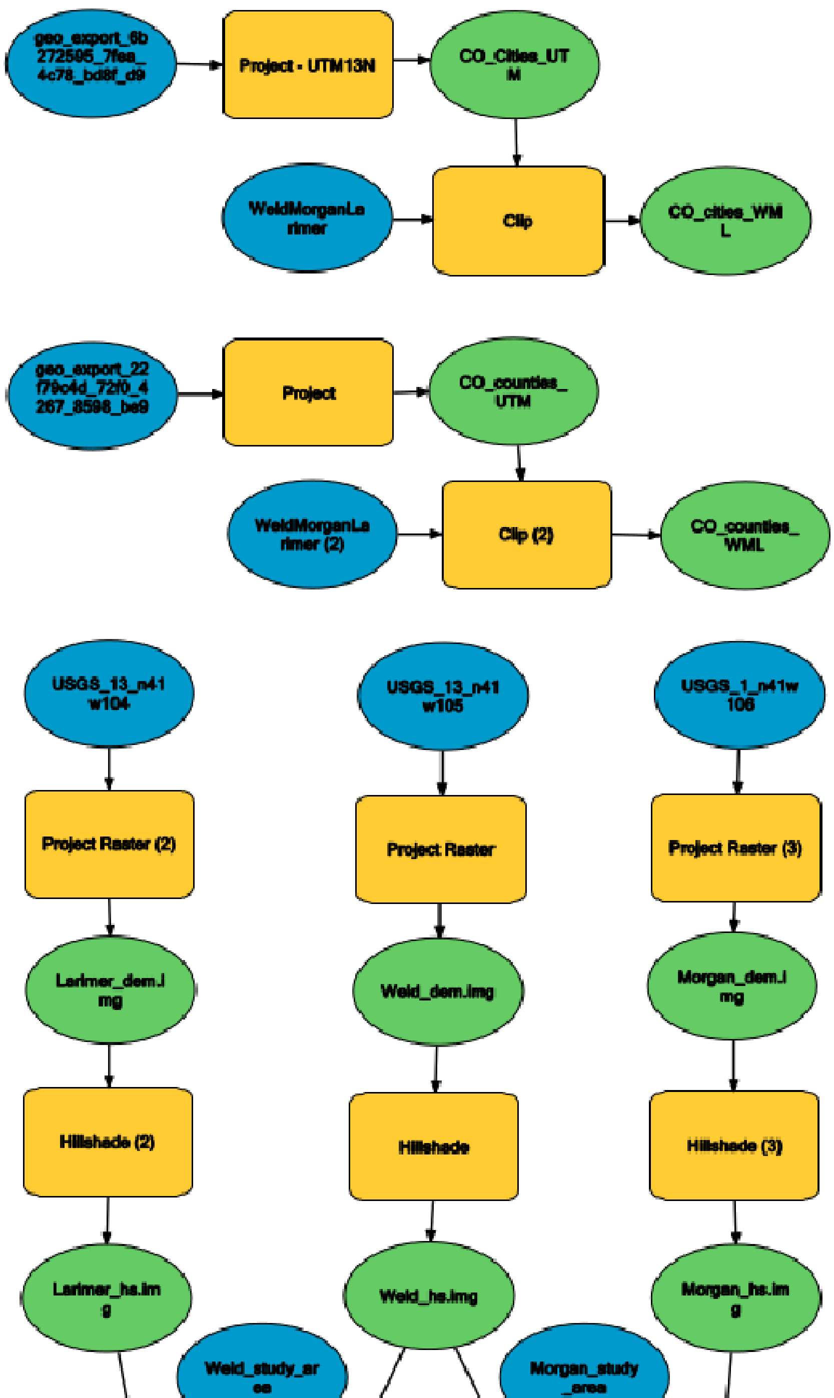
6.4 Map Preparation

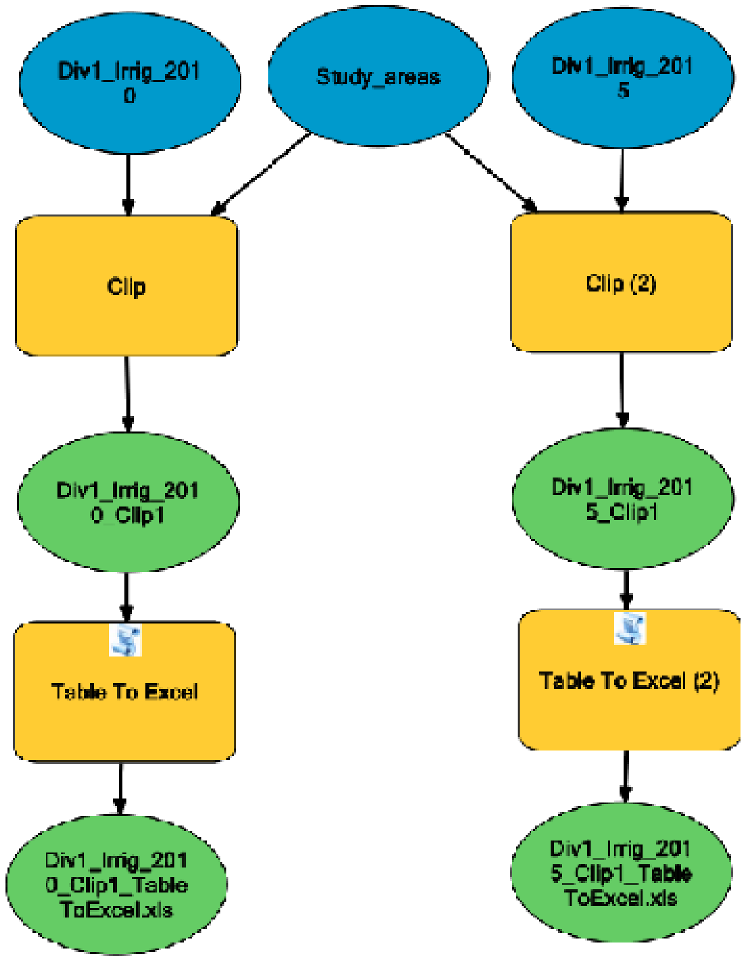
The locator map was prepared by overlaying the Division 1 Boundaries Data on top of CO county boundaries. The South Platte River layer was made using select by attribute from HUC 1019 stream data. The Larimer, Weld, and Morgan boundaries were made using select by attribute from the Division 1 boundaries data. DEM data were used to create a hillshade for the region. Urban area, river, and irrigation layers were then clipped to this tri-county polygon.

Base maps were prepared by clipping hillshade, river, and irrigation data to the individual study areas.

Chapter 7

Flow Chart




Div1_Irrig_201
0
Study_areas
Div1_Irrig_201
5
Clip
Clip (2)
Div1_Irrig_201
0_Clip1
Div1_Irrig_201
5_Clip1
Table To Excel
Table To Excel (2)
Div1_Irrig_201
0_Clip1_Table
ToExcel.xls
Div1_Irrig_201
5_Clip1_Table
ToExcel.xls

Chapter 8

GIS and Statistical Concepts

8.1 Project

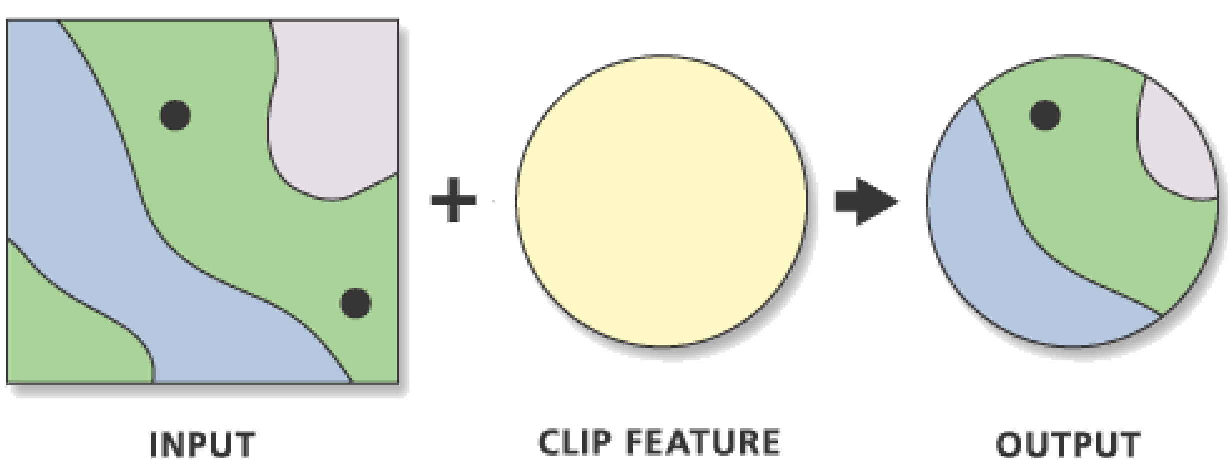
All GIS data needs a coordinate system to be useful. The project tool is used to translate data from one coordinate system to another. All data in this analysis were projected into UTM 13N coordinate system.

8.1.1 UTM 13N

Universal Transverse Mercator is a cylindrical projection in which the globe is segmented into 60 North and South zones measuring 6° of longitude. Each segment has a central meridian. The central meridian of 13N is 105° W. This projection is a conformal projection, and as such shapes will become increasingly distorted as they are distance increases away from the central meridian.

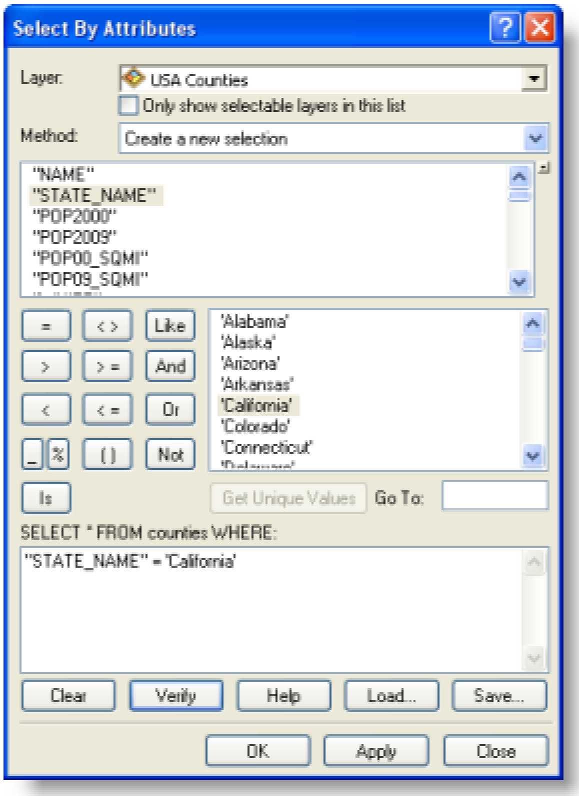
8.2 Clip

The clip tool extracts elements from an input that overlay with a clip feature.



Visual Illustration of Clip Tool. Image Source: ESRI

##Select By Attribute Select by attribute uses a SQL query to select records in an attribute table that match certain criteria.



ArcGIS 10 GUI for Select by Attribute. Image Source: ESRI

##Export - Table to Excel The Table to Excel tool exports a layer's attribute table to Excel for for further processing or for import into other software such as R.

8.3 Kernel Density

This tool uses input points or lines to fit a smoothed surface over the input feature by calculating a per-unit density across the area of the input features. The calculations are performed using a kernel function to weight neighboring features.

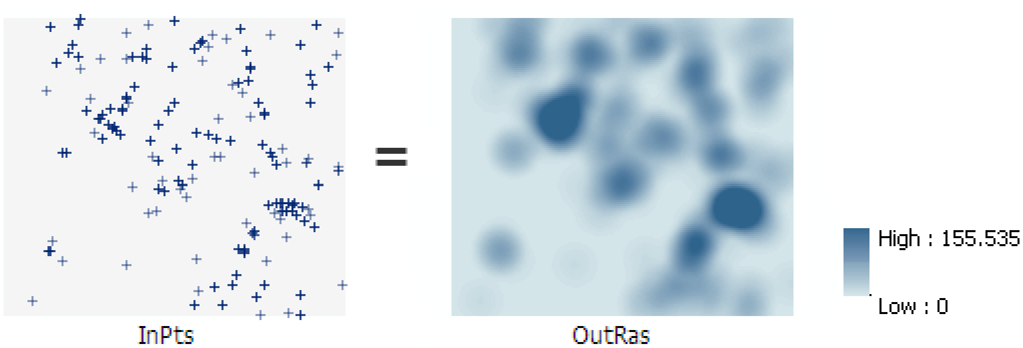


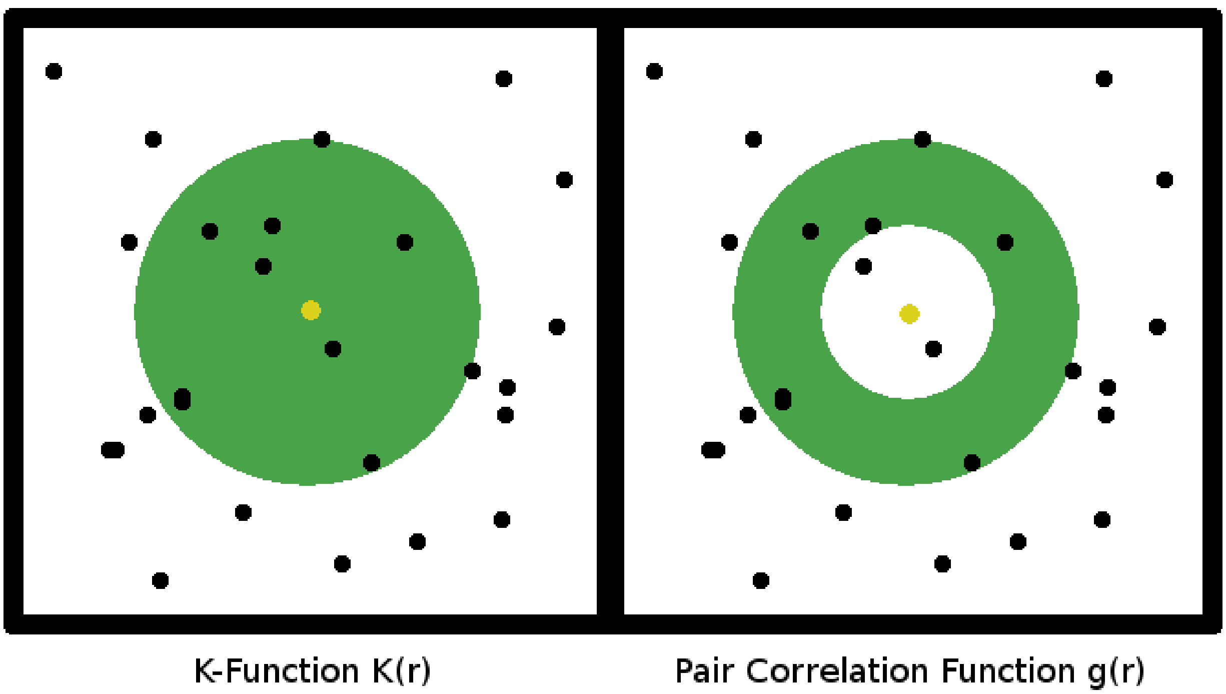
Illustration of Kernel Density. Image Source: ESRI

8.4 K function

Ripley's K function, K(r), describes the clustering or dispersion of a point pattern compared with complete spatial randomenss by counting the number of other points within a given distance, r, of each individual point.

8.5 Pair Correlation

The pair correlation function g(r) describes clustering or uniformity of points in relation to complete spatial randomness as distance, r, increases. A value of $g(r) = 1$ indicates complete spatial randomness. A value greater than 1 indicates clustering. A value less than 1 indicates uniformity. This function is similar to the K-function, with the main difference being that the K function uses a circle, whereas this function uses a donut shape to count neigbors.



The univariate pair correlation function describes this relationship for points with the same mark. The bivariate pair correlation function describes this relationship for points of two different marks.

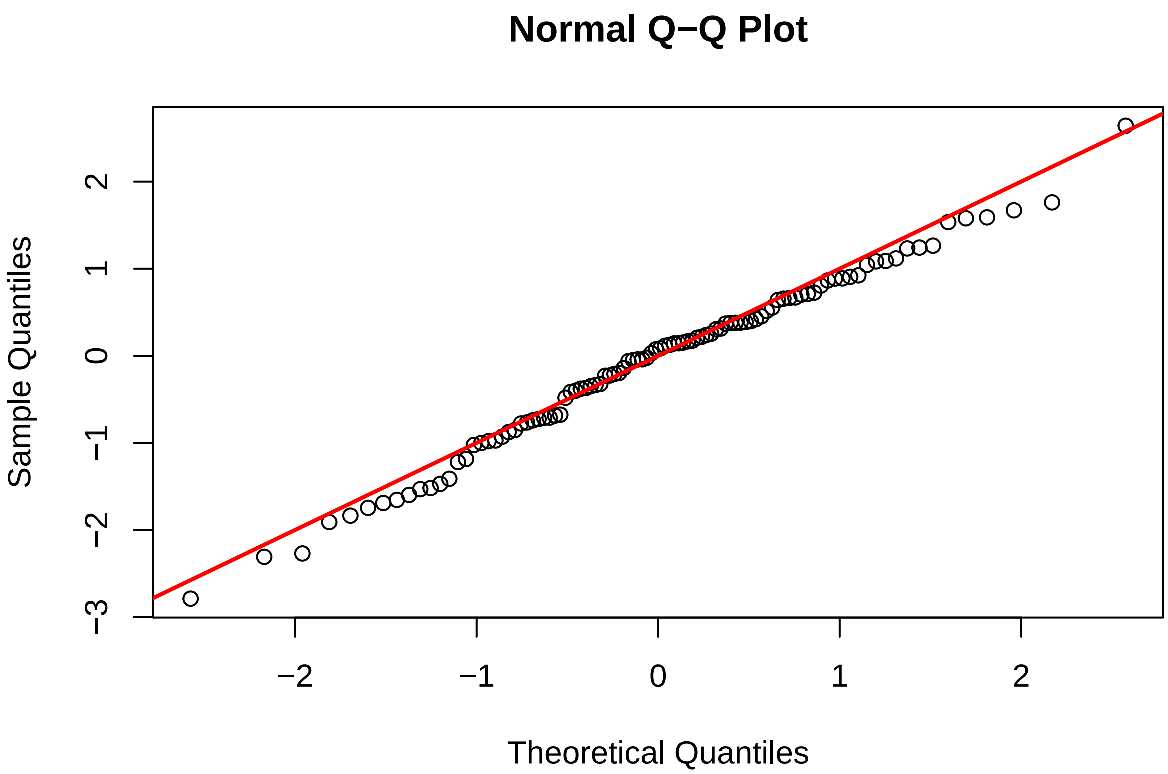
8.6 Quantile-Quantile Plot

A quantile-quantile (Q-Q) plot is a graphical technique for comparing two datasets. Most often it is used to compare two probability distributions. Data in each set are ordered and then the quantiles from one set is plotted against the same quantiles for the other set.

If the two datasets being compared are the same, the plotted points will lie on the line $y = x$. Any deviation from this line indicates a difference in the two datasets.

This technique is used in this project to compare the calculated values of K-functions.

```
qqnorm(rnorm(100))
abline(0,1, col='red', lwd=2)
```

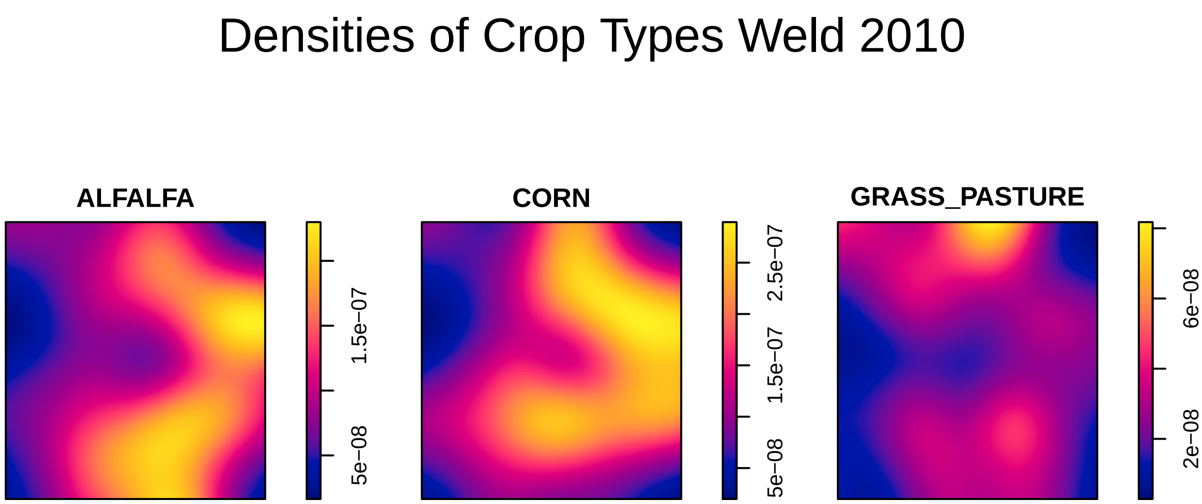


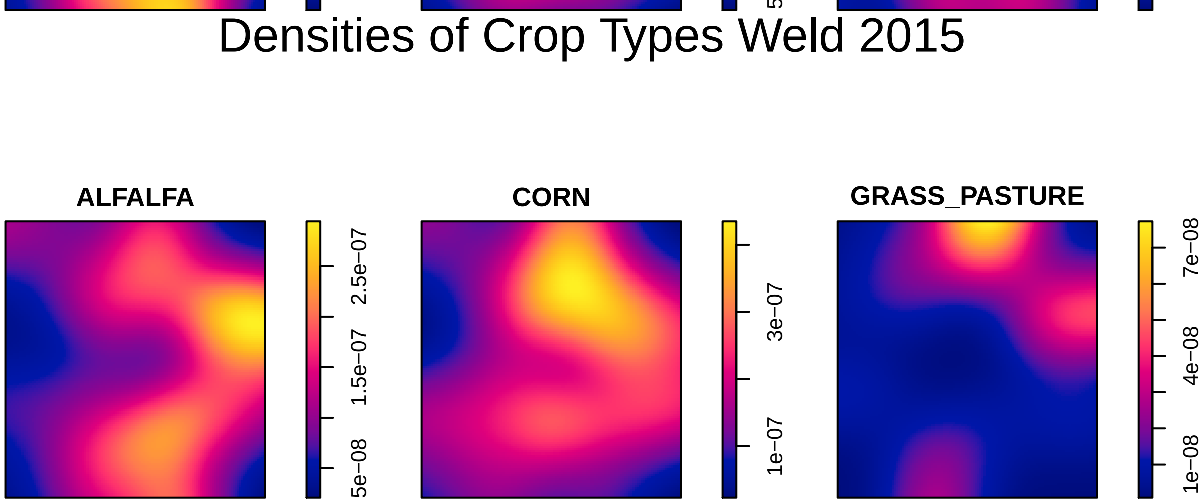
Example Quantile-Quantile Plot

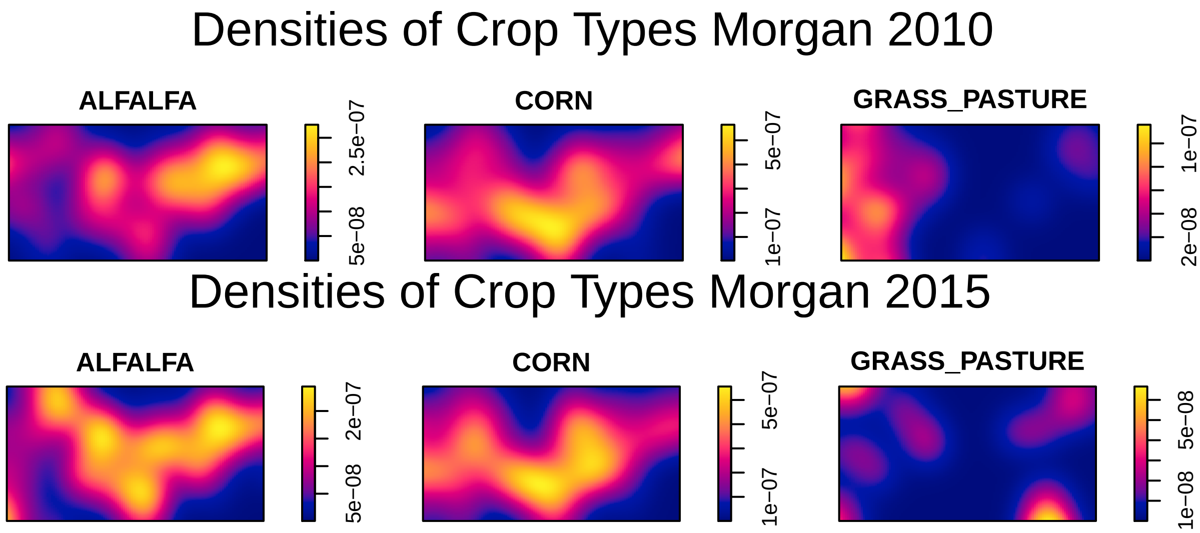
Chapter 9

Results

9.1 Kernel Densities

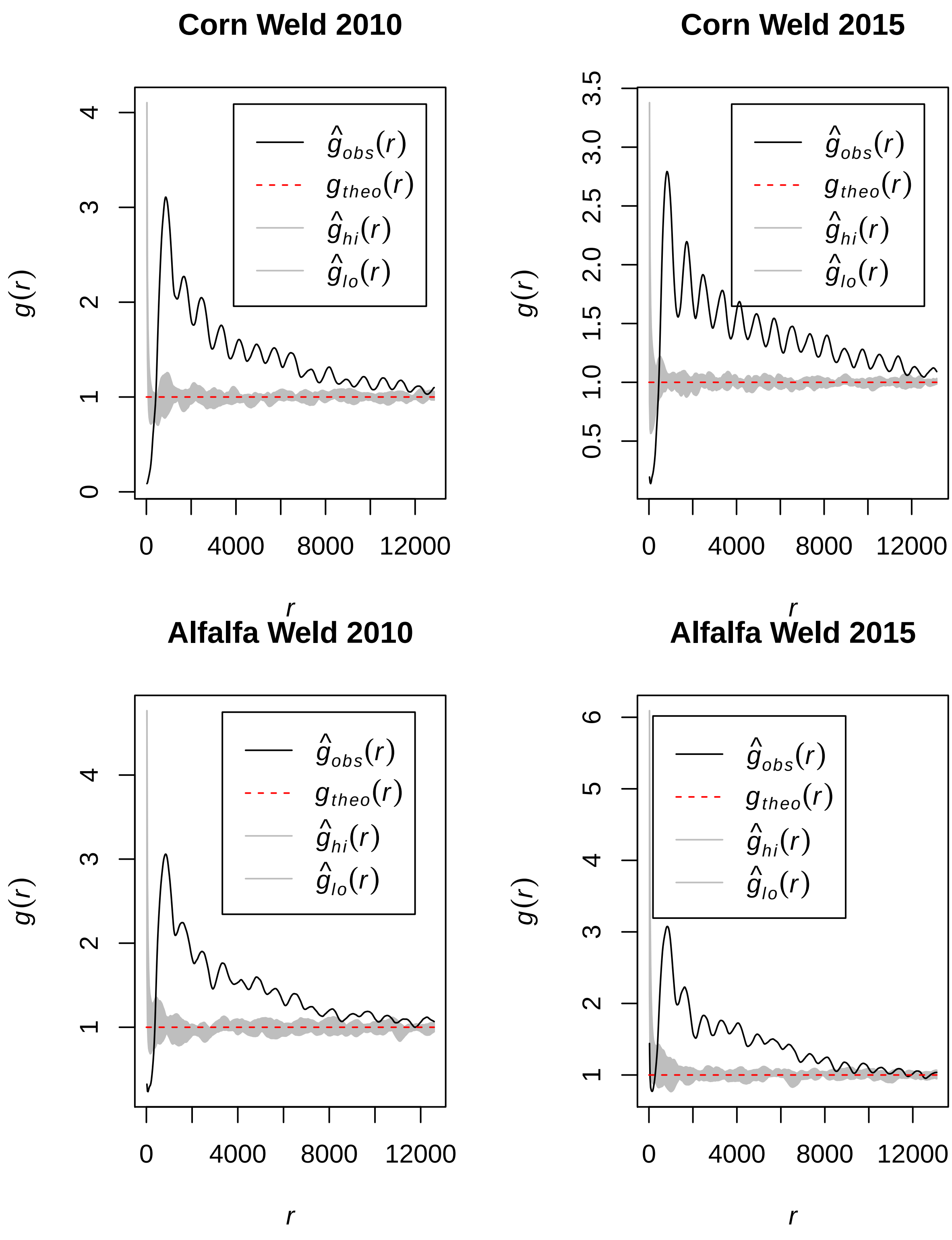


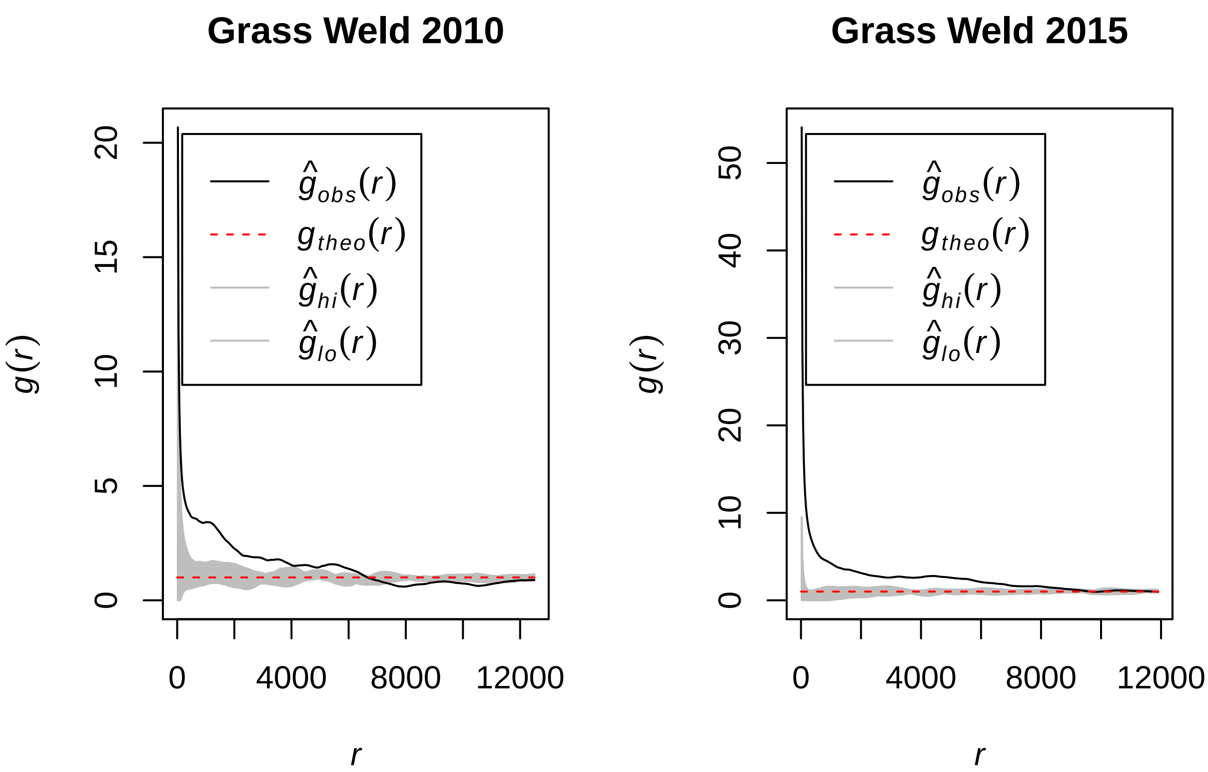


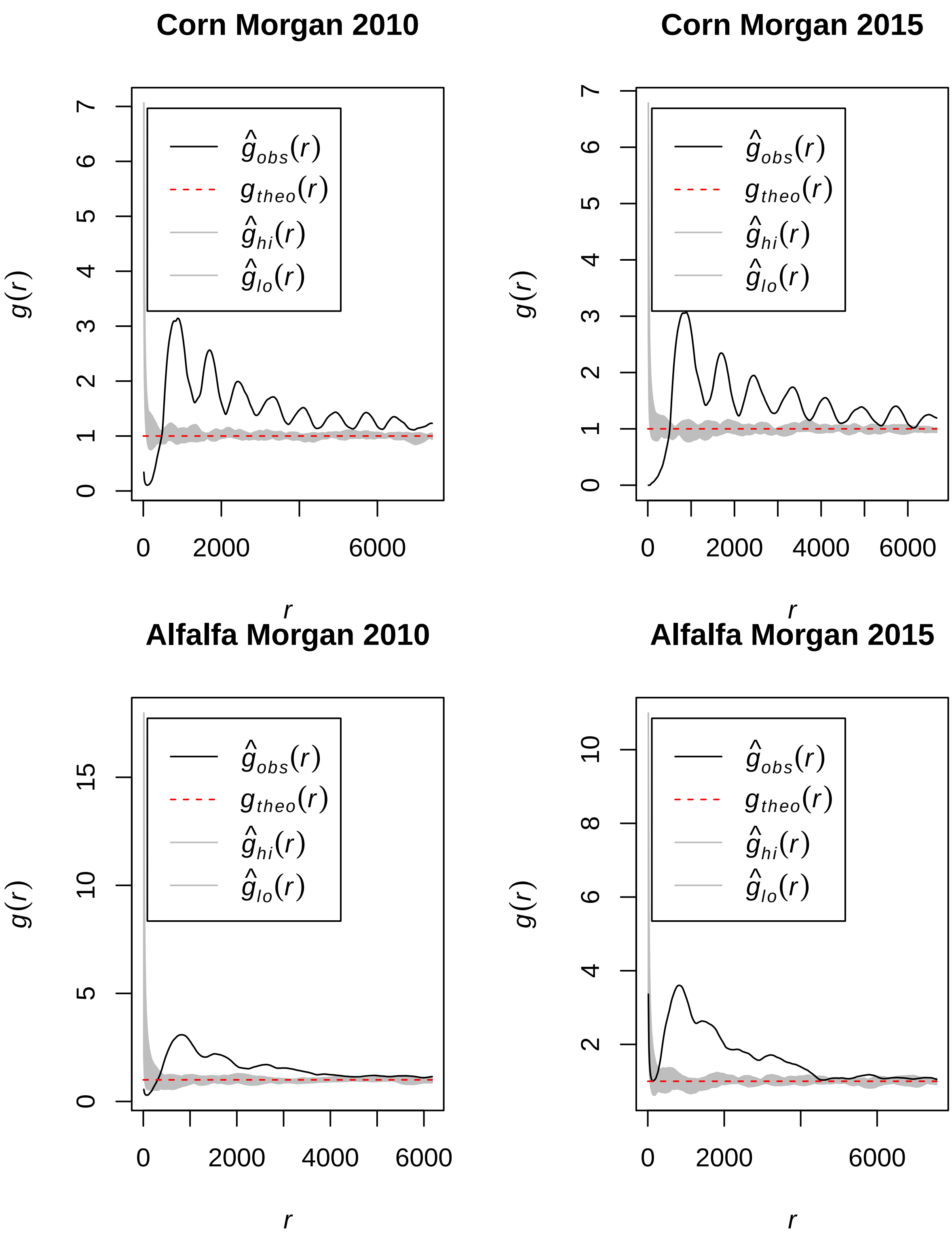


9.2 Univariate Pair Correlation Functions

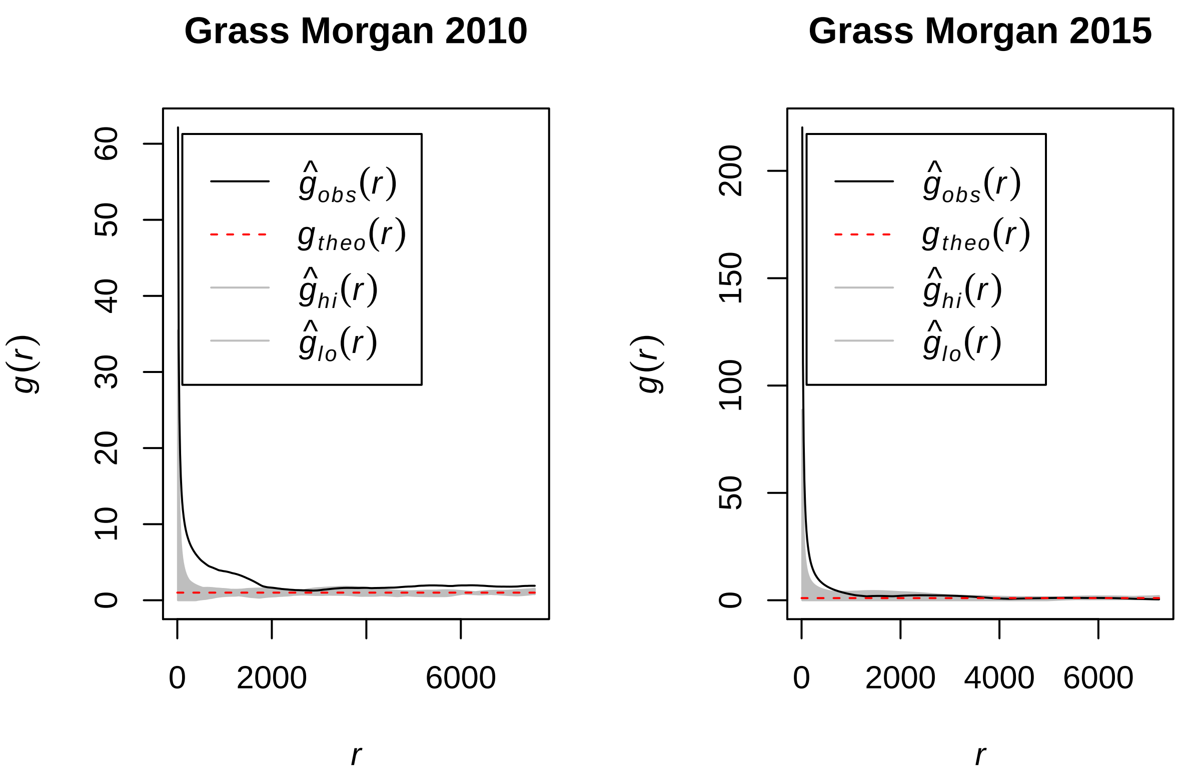
All crops exhibited similar patterns of aggregation across both study areas and both years. Grass pasture in Morgan County had noticeably shorter distances over which aggregation was present. This may be due to the fact that in this study area most of the grass pasture is on the edges of the site, whereas in Weld the distribution of grass pasture was more even as can be seen in the kernel densities above.


Corn Weld 2010
Corn Weld 2015
Alfalfa Weld 2010
Alfalfa Weld 2015
$\hat{g}_{obs}(r)$
$g_{theo}(r)$
$\hat{g}_{hi}(r)$
$\hat{g}_{lo}(r)$
$g(r)$
r
0
4000
8000
12000


Grass Weld 2010
Grass Weld 2015
$\hat{g}_{obs}(r)$
$g_{theo}(r)$
$\hat{g}_{hi}(r)$
$\hat{g}_{lo}(r)$
$g(r)$
r
0
5
10
15
20
30
40
50
4000
8000
12000

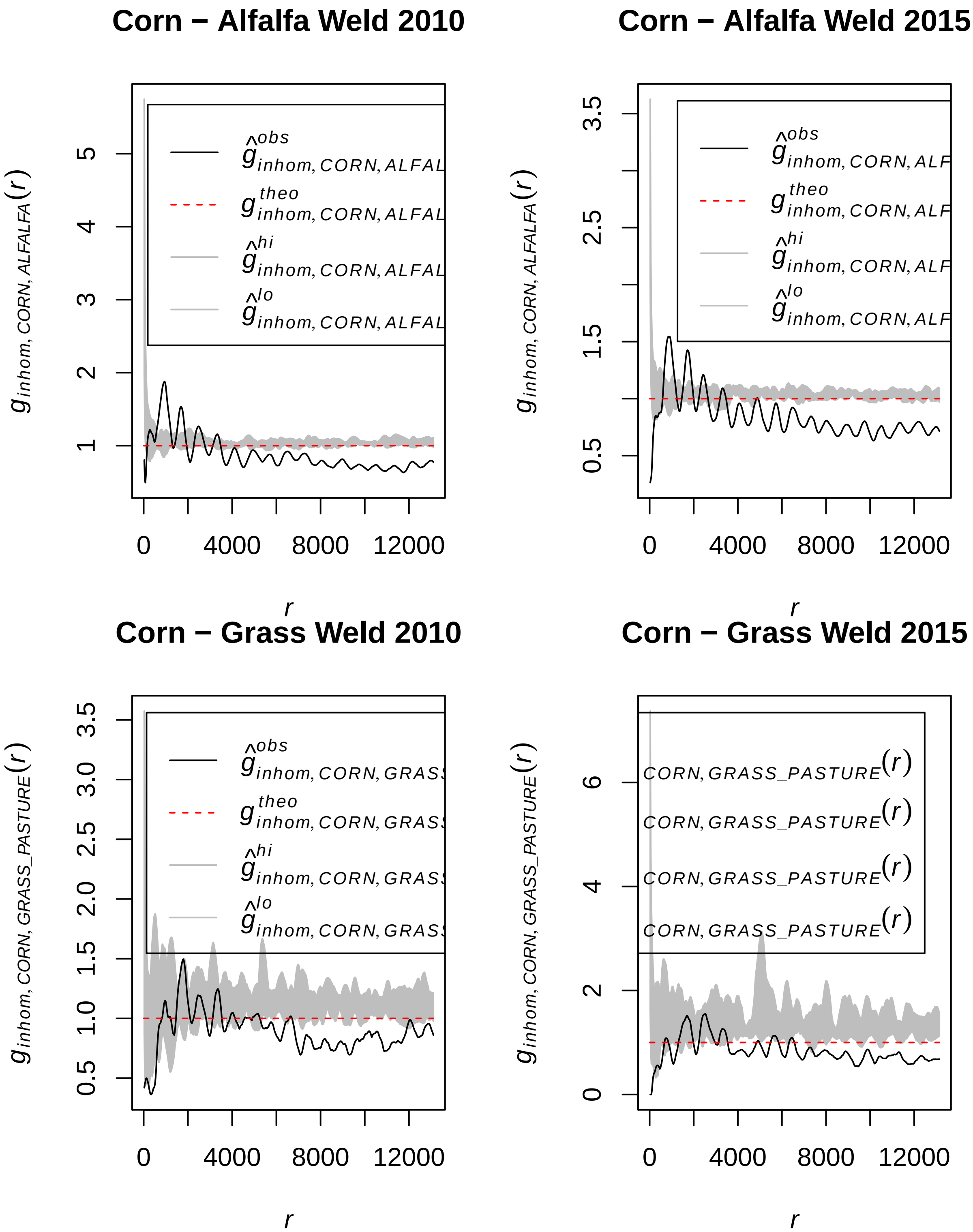


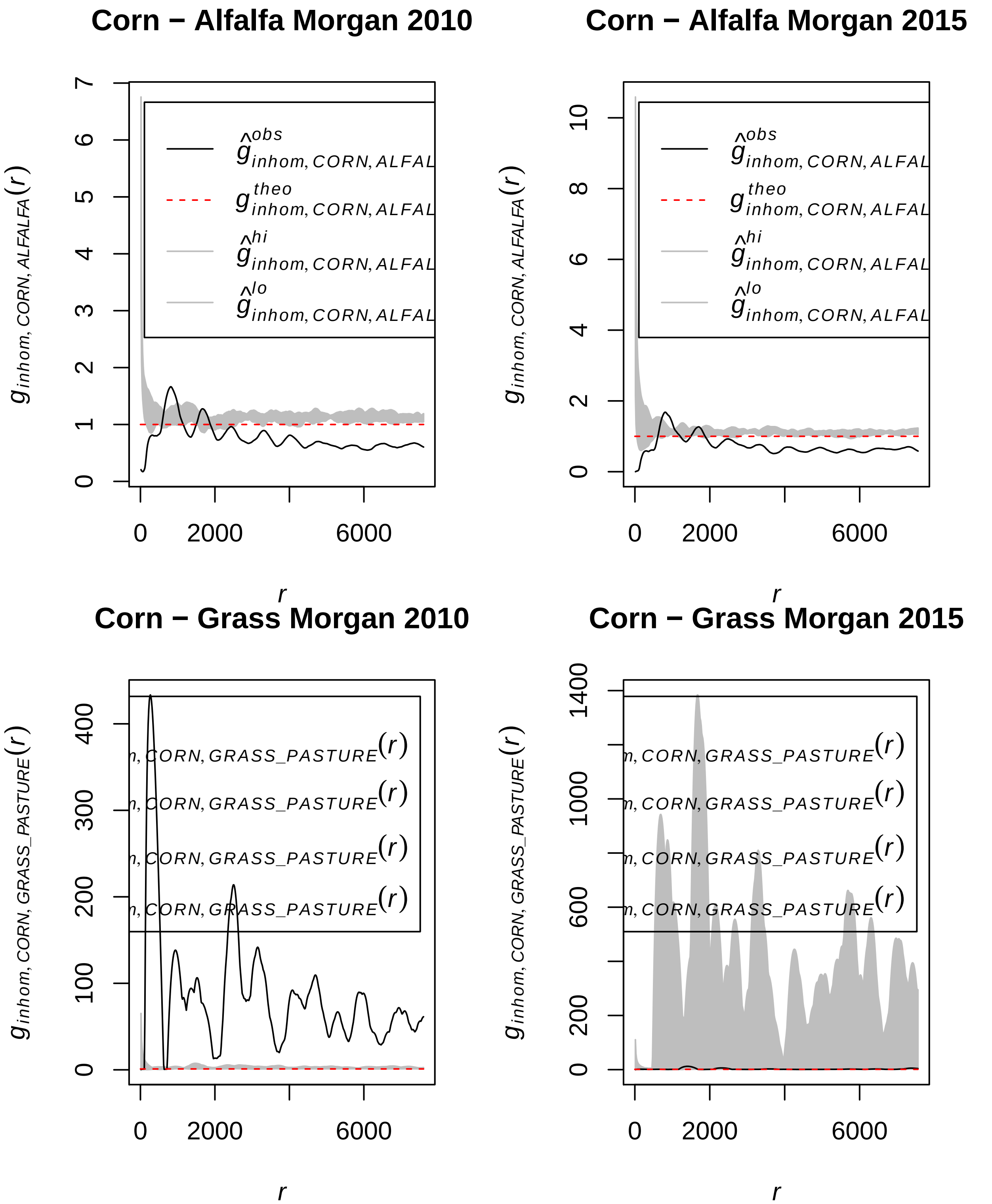
Corn Morgan 2010
Corn Morgan 2015
Alfalfa Morgan 2010
Alfalfa Morgan 2015
$\hat{g}_{obs}(r)$
$g_{theo}(r)$
$\hat{g}_{hi}(r)$
$\hat{g}_{lo}(r)$
$g(r)$
r
0 1 2 3 4 5 6 7
0 5 10 15
2 4 6 8 10
0 2000 4000 6000



9.3 Bivariate Pair Correlation Functions

Intercrop relationships were also examined using bivariate pair correlation functions to determine if certain crop types tended to cluster together or disperse away from each other. Corn and alfalfa exhibited a pattern of being grown together at a distance of about 1-2 average field lengths away from each other in both areas. Corn and grass pasture exhibited very little pattern of being grown near each other in Weld county. In Morgan County, however, there was a strong pattern of corn and grass pasture being grown near one another in 2010 that disappears in 2015.

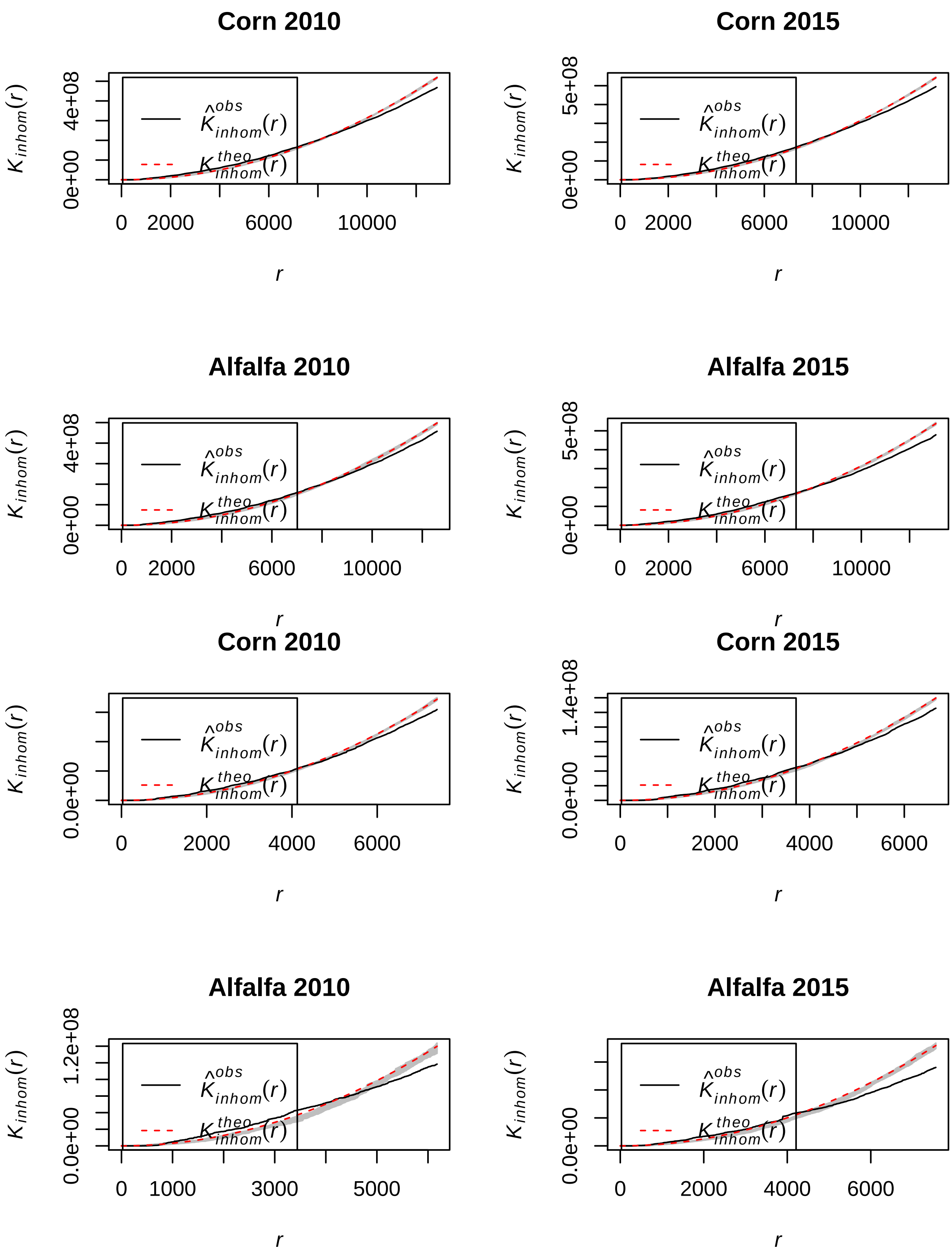

Corn − Alfalfa Weld 2010
Corn − Alfalfa Weld 2015
Corn − Grass Weld 2010
Corn − Grass Weld 2015
$g_{inhom,CORN,ALFALFA}(r)$
$g_{inhom,CORN,GRASS\_PASTURE}(r)$
$\hat{g}^{obs}_{inhom,CORN,ALFAL}$
$g^{theo}_{inhom,CORN,ALFAL}$
$\hat{g}^{hi}_{inhom,CORN,ALFAL}$
$\hat{g}^{lo}_{inhom,CORN,ALFAL}$
$\hat{g}^{obs}_{inhom,CORN,ALF}$
$g^{theo}_{inhom,CORN,ALF}$
$\hat{g}^{hi}_{inhom,CORN,ALF}$
$\hat{g}^{lo}_{inhom,CORN,ALF}$
$\hat{g}^{obs}_{inhom,CORN,GRASS}$
$g^{theo}_{inhom,CORN,GRASS}$
$\hat{g}^{hi}_{inhom,CORN,GRASS}$
$\hat{g}^{lo}_{inhom,CORN,GRASS}$
$CORN,GRASS\_PASTURE(r)$
$CORN,GRASS\_PASTURE(r)$
$CORN,GRASS\_PASTURE(r)$
$CORN,GRASS\_PASTURE(r)$
0 4000 8000 12000
r

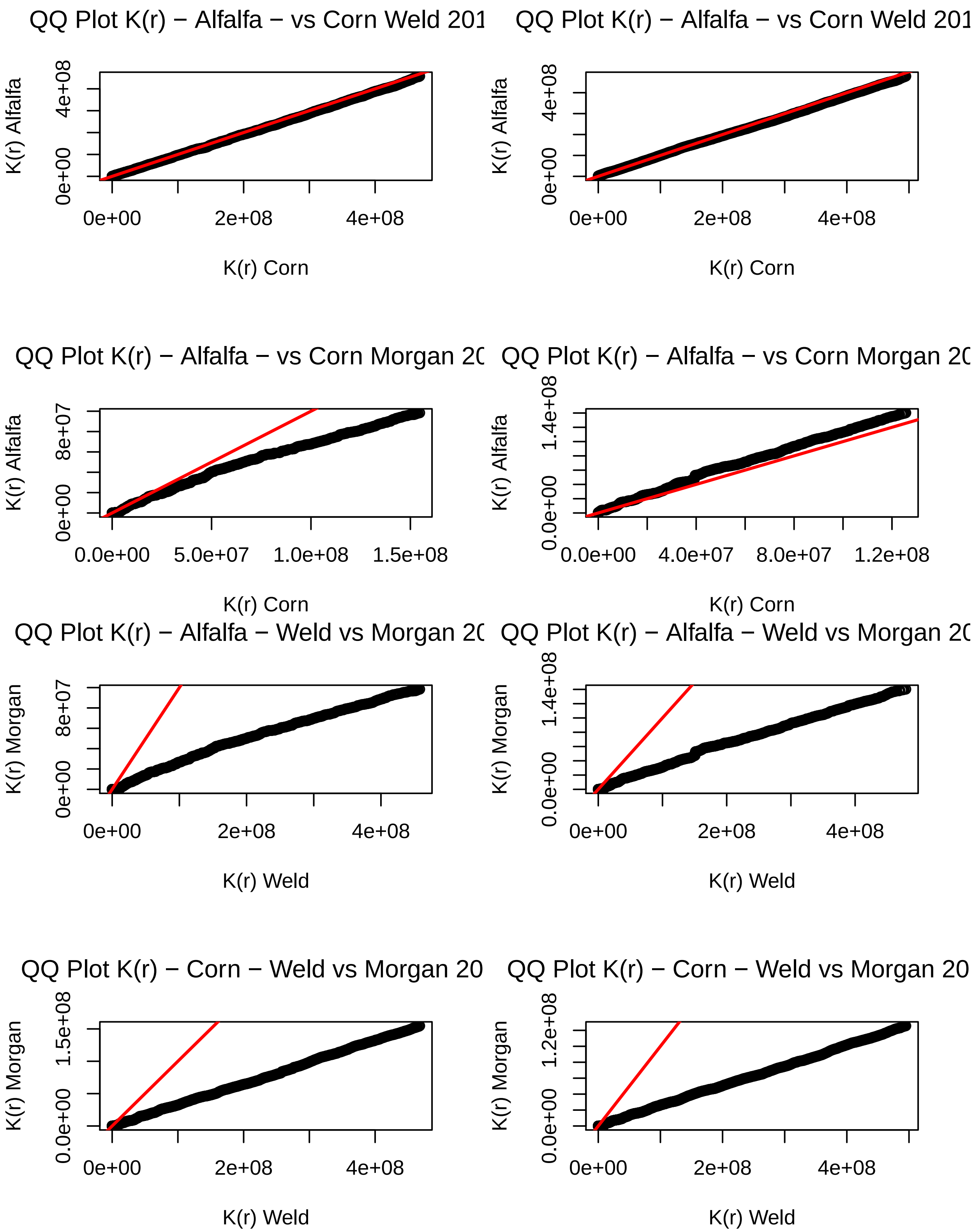


9.4 Comparison of K-Functions

The K-functions for each crop show the same relationship of aggregation at closer distances and dispersion at farther distance that was present in the univariate pair correlation functions.

The comparison of the K-functions indicates that the relative intensities of corn and alfalfa were proportional in Weld county in both years. In Morgan county they were not proportional, and that the relative intensity of alfalfa increased between the two years. Comparison of K-functions across the two sites indicates that the intensity of both crops was higher in both years in Weld County.




QQ Plot K(r) − Alfalfa − vs Corn Weld 201
K(r) Alfalfa
K(r) Corn
0e+00
4e+08
2e+08
QQ Plot K(r) − Alfalfa − vs Corn Weld 201
K(r) Alfalfa
K(r) Corn
QQ Plot K(r) − Alfalfa − vs Corn Morgan 20
K(r) Alfalfa
0e+00
8e+07
0.0e+00
5.0e+07
1.0e+08
1.5e+08
K(r) Corn
QQ Plot K(r) − Alfalfa − vs Corn Morgan 20
K(r) Alfalfa
0.0e+00
1.4e+08
4.0e+07
8.0e+07
1.2e+08
K(r) Corn
QQ Plot K(r) − Alfalfa − Weld vs Morgan 20
K(r) Morgan
K(r) Weld
QQ Plot K(r) − Alfalfa − Weld vs Morgan 20
K(r) Morgan
K(r) Weld
QQ Plot K(r) − Corn − Weld vs Morgan 20
K(r) Morgan
1.5e+08
K(r) Weld
QQ Plot K(r) − Corn − Weld vs Morgan 20
K(r) Morgan
1.2e+08
K(r) Weld

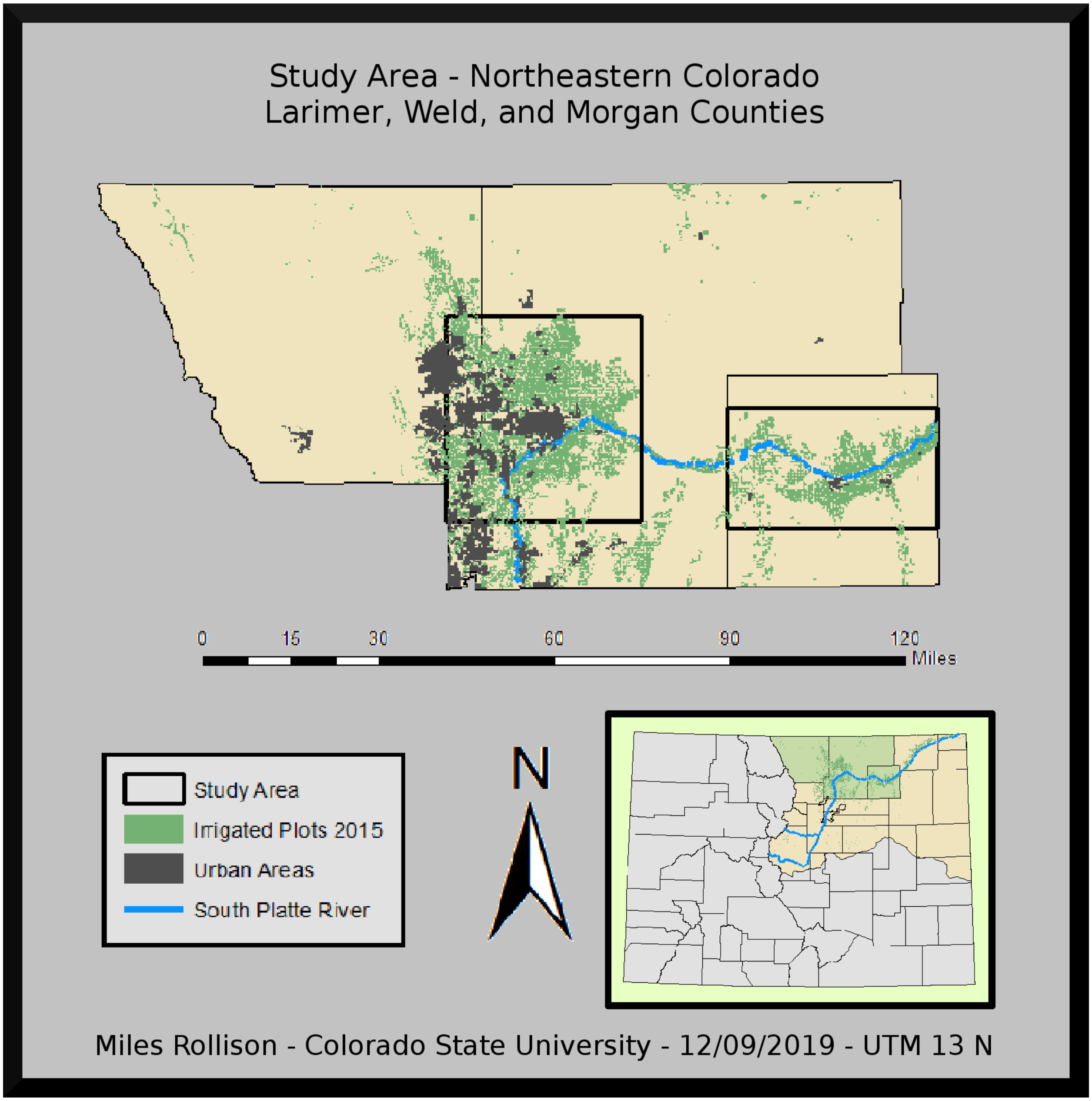
Chapter 10

Conclusion

10.1 Discussion

Both sites exhibited some cursory similarities in intracrop patterns and an indication of some intercrop aggregation at distances of around 1-2 field lengths. This may be due to farmers growing a diversified mix of crops as a risk management strategy, but more analysis incorporating ownership data is necessary to draw any reliable conclusions.

It appears that cropping patterns in Weld County have been mostly stable between 2010 and 2015, whereas there has been a noticeable change in cropping patterns in Morgan County. The most dramatic change has been the pattern of grass pasture. In 2010 there was a noticeably higher density of grass pasture on the eastern side of the county that had disappeared in favor of alfalfa and corn. One possible explanation for these differences between the two sites may be the encroachment of urban areas into agricultural areas in Weld County (Map 10.1). Census figures indicate that there has been a 24.3% increase in the population of Weld County versus a 1.4% increase in Morgan County (USDC 2019). High population growth tends to increase land values in the urban-rural transition zone, which acts like a natural insurance for agricultural producers. This may make producers in Weld County less sensitive to marginal changes in economic variables, which may lead them to change their cropping behavior less in response to market trends than their counterparts in Morgan County. There was also an extreme drought in this area from 2012 to 2014 (US Drought Monitor 2019) which may have increased price and production risk substantially, leading to a change in cropping patterns.



Map 10.1

10.2 Conclusion

In this project I examined the spatial characteristics of two types of irrigated cropland in the South Platte River Basin in the years 2010 and 2015 in two different counties. I found that cropping patterns changed very little across the two years in Weld County, but were qualitatively different in Morgan County. Furthermore, cropping intensities were different between both study sites in both years. All crops exhibited a pattern of spatial aggregation at shorter distances. Intercrop interactions were similar for corn-alfalfa interactions in both areas, exhibiting some aggregation at shorter distances. The corn-grass relationships was not prominent in Weld county and remain stable across years, whereas this relationship changed dramatically in Morgan county. These findings indicate that there are important structural differences between the two areas, even though they are in the same region of the state and part of the same watershed. This suggests that further analysis into diffusion of agricultural technology with regards to perennialization and irrigated pasture should be conducted at a more granular level.

Alexander, Peter, Dominic Moran, Pete Smith, Astley Hastings, Shifeng Wang, Gilla Sünnenberg, Andrew Lovett et al. "Estimating UK perennial energy crop supply using farm-scale models with spatially disaggregated data." Gcb Bioenergy 6, no. 2 (2014): 142-155.

Baddeley, Adrian, Ege Rubak, Rolf Turner (2015). Spatial Point Patterns: Methodology and Applications with R. London: Chapman and Hall/CRC Press, 2015. http://www.crcpress.com/Spatial-Point-Patterns-Methodology-and-Applications-with-R/Baddeley-Rubak-Turner/9781482210200/

Adrian Baddeley, Rolf Turner (2005). spatstat: An R Package for Analyzing Spatial Point Patterns. Journal of Statistical Software 12(6), 1-42. URL http://www.jstatsoft.org/v12/i06/.

Boody, George, Bruce Vondracek, David A. Andow, Mara Krinke, John Westra, Julie Zimmerman, and Patrick Welle. "Multifunctional agriculture in the United States." BioScience 55, no. 1 (2005): 27-38.

Burkart, Michael, David James, Matt Liebman, and Carl Herndl. "Impacts of integrated crop-livestock systems on nitrogen dynamics and soil erosion in western Iowa watersheds." Journal of Geophysical Research: Biogeosciences 110, no. G1 (2005).

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