THREE ESSAYS: SWITCHGRASS YIELD PREDICTION; BIOMASS HARVESTING COOPERATIVE; AND OKLAHOMA GRAIN INFRASTRUCTURE REPLACEMENT

By

ARJUN BASNET

Bachelor of Science in Agriculture
Tribhuvan University
Rampur, Nepal
2005

Master of Science in Agricultural Economics
Oklahoma State University
Stillwater, Oklahoma
2009

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May, 2014

THREE ESSAYS: SWITCHGRASS YIELD PREDICTION; BIOMASS HARVESTING COOPERATIVE; AND OKLAHOMA GRAIN INFRASTRUCTURE REPLACEMENT

Dissertation Approved:

Dr. Philip Kenkel

Dissertation Adviser

Dr. Wade Brorsen

Dr. Rodney Holcomb

Dr. Michael Buser

ACKNOWLEDGEMENTS

I would like to thank my advisor Dr. Phil Kenkel for accepting me as a graduate research assistant and mentoring, advising and guiding me throughout my PhD studies. I would also like to extend my sincere thanks to my committee members Dr. Wade Brorsen, Dr. Rodney Holcomb and Dr. Michael Buser whose insightful thoughts and advice have helped me successfully complete my graduate research work.

My sincere thanks go to Dr. Art Stoecker who helped me with GAMS programming and Dr. Francis Epplin for his valuable guidance. I would like to thank Dr. Al Tongo and Mark Gregory for helping me with the GIS works. I would like to thank Dr. Jon Biermacher for providing the switchgrass data; Wheeler Bros, Johnston Inc. and Triangle Insurance for providing the grain elevator data and Monica Deming (Mesonet) for helping me with the weather data. Further words of thank go to the staffs of the Dept. of Ag. Economics: Andy, Shawn and Gracie for computer supports and Anna and Joyce for administrative works. I would also like to thank Dr. Mike Woods (Former Dept. Head) and Dr. Damona Doye (Interim Dept. Head) for their valuable advice and help with the administrative works. Loads of thanks go to all my fellow graduate students at the Dept. of Ag. Economics and the Nepalese Community in Stillwater as well.

Finally, I would like to thank my parents, wife, sisters and brothers in law for their love, support and encouragement in finishing my PhD studies. Many love and thanks are to my little daughter who gave me the strength and energy to graduate on time.

Name: ARJUN BASNET

Date of Degree: MAY, 2014

Title of Study: THREE ESSAYS: SWITCHGRASS YIELD PREDICTION; BIOMASS HARVESTING COOPERATIVE; AND OKLAHOMA GRAIN INFRASTRUCTURE REPLACEMENT

Major Field: AGRICULTURAL ECONOMICS

Abstract:

The first essay estimates switchgrass yields in Oklahoma using average temperature and total rainfall during summer months. The fitted model agrees well with available yield data and the estimated yields were consistent with most previous studies. The model's results indicated lower average yields and lower year-to-year variation in yields in the Western region with higher yields and higher year-to-year variation in the Central region. The model developed in this study shows a promising result which could be used to predict switchgrass yields for any county in Oklahoma and would likely apply across the Southern Plains.

The second essay attempts to model the cost of harvesting and transporting biomass (switchgrass) in an individual producer versus a cooperative structure. The results show that small scale biomass harvesting cooperative (10-12 members) could have substantial cost savings versus individual member operations. For a five member cooperative the cost savings was not significant compared to the individual producers. With five members the cost savings was \$3.47 Mg^{-1} while cost savings was \$6.08 Mg^{-1} with eleven members. The cost savings are more if machineries are brought to enough use which could be obtained either by increasing the number of members in cooperative or by increasing the total hectares or by renting the machineries.

The third essay uses a mixed integer programming model to forecasts grain facility replacement in Oklahoma. The results indicated regionalization in grain storage with fewer but larger capacity structures. The results of sequential replacement overtime indicated that there would be some abandonment of facilities and some shift to larger capacity structures. Producer's transportation cost did not increase with sequential replacement as expected because storage were added in places to the current deficits. The results were not sensitive to crop production, fuel and construction cost and amortization factors. Cost comparison per bushel between configuration after sequential replacement and unrestricted replacement show that transportation cost was \$0.04 lower in sequential replacement but total cost was \$0.02 higher than unrestricted replacement.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

LIST OF FIGURES

PAPER I

ESTIMATING COUNTY SWITCHGRASS YIELD CONDITIONAL ON WEATHER

Introduction

Interest in feedstock suitable for biomass production has increased dramatically due to the mandates of the renewable fuel standard provisions (Energy Policy Act (EPA), 2005 and Energy Information and Security Act (EISA), 2007). The EPA 2005 required 7.5 billion gallons of renewable fuel to be blended into gasoline by 2012. The EISA 2007 mandate required 36 billion gallons of ethanol to be produced by 2022 of which 16 billion gallons has to be produced from cellulosic feedstock. If cellulosic ethanol and other advanced biofuels are to be commercialized, a feedstock supply chain must be developed. Dedicated bioenergy crops are anticipated to be key feedstock for cellulosic ethanol and advanced biofuels. The most promising dedicated bioenergy crop is switchgrass (*Panicum virgatum*). It was identified as the best source to produce cellulosic feedstock after years of evaluations throughout the U.S. (Caddel et al. 2009). Graham and Walsh, 1999 show that the southern plains (Oklahoma and Texas) is a very promising region for large scale production of switchgrass if consistent yields of 4 to 5 dry tons or more per acre can be achieved. USEPA 2010 estimates that by 2022 eleven cellulosic ethanol bio-refineries that use switchgrass as the feedstock will be operating in Oklahoma. If this prediction is to be realized, a switchgrass supply chain must be developed since there is currently no commercial production of switchgrass in the region. One challenge in developing a switchgrass supply chain and a viable cellulosic ethanol industry is accurately forecasting the yield potential across a geographically diverse region. Because switchgrass yield trials are limited to a few locations, we do not have a clear understanding of either the spatial variation or the year-to-year variation in switchgrass yields in the Southern Plains region. This information would be vital to potential investors considering switchgrass-based bio-refineries. The investors want to reduce the risk of any short supply of feedstock and want to have ample supply of feedstock to run the bio-refineries in their fullest capacity even in bad weather years. Information on the spatial distribution and year to year variability of switchgrass yield would assist in plant location, land leasing decisions, long term contracts and storage strategies. This information would also help producers in decisions to diversify into switchgrass and in their marketing and storage decisions.

Studies are underway to determine factors like cultivar type, fertilizer inputs, location, stand age and harvest frequency that could improve switchgrass yields (Christensen and Koppenjan 2010). Several studies (Boyer et al. 2012; Thomason et al. 2005; Mooney et al. 2009; Muir et al. 2001) focused on identifying the optimal nitrogen for switchgrass on different soil conditions and landscapes. Some studies (Aravindakshan et al. 2011; Lee and Boe 2005; Lee, Owens and Dolittle 2007; Sanderson et al. 2006) focused on determining the best cultivar type while others (Aravindakshan et al. 2011; Thomason et al. 2005) worked to determine the optimal harvest frequency. There are however limited studies that have focused on predicting switchgrass yields. This is in part due to the limitation of switchgrass yield data outside of the experiment station plots.

Weather based crop yield forecast models have been very popular and have been used to forecast yields of several crops. Lee, Kenkel, and Brorsen (2013) and Lobell and Burke (2010) describe statistical models and biological simulation models as two common approaches to forecasting crop yields using weather data. In comparing these two approaches they describe how statistical models can be easier to use and potentially provide better predictions of crop yields relative to the simulation type approach. The major disadvantage of the simulation approach is extensive data requirement (soil type, plant parameters and weather data related to the crop development stage) which may not be readily available (Walker, 1989). Both approaches have been applied to switchgrass yield projections with Gunderson et al. 2008, Jager et al. 2010, Wullschleger et al. 2010 and Wang, Lebauer, and Dietze 2010 using multiple regression approaches and Thomson et al. 2009, Kiniry et al. 2008, White and Storm 2008 and Debnath, Stoecker, and Epplin 2012 using simulation models.

All previous studies to predict switchgrass yields have relied on data from test plots and demonstration plots. The major difference in previous efforts to predict switchgrass yields are the independent variables and the predictive models. Gunderson et al. 2008 used precipitation and temperature to predict switchgrass yield using quantile regression. Jager et al. 2010 used logistic regression to estimate average yield of switchgrass using environmental covariates such as climate, soils and management. Wullschleger et al. 2010 used a multiplicative parametric model to predict switchgrass yield using temperature, precipitation, nitrogen and ecotype. Wang, Lebauer, and Dietze (2010) evaluated yield of switchgrass in monocultures and mixtures in response to growing degree days, precipitation and nitrogen. Gunderson et al. 2008, Jager et al. 2010 and Wullschleger et al. 2010 used their prediction models to predict switchgrass yields throughout the U.S. while Wang, Lebauer, and Dietze (2010) used their model to examine the effects of climate and management factors on yields of switchgrass rather than predicting switchgrass yields.

Crop simulation models have also been used to predict switchgrass yields. Kiniry et al. 2008 used the Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) model to predict switchgrass yields in the Northern Great Plains of the U.S. Thomson et al. 2009 and Debnath, Stoecker, and Epplin (2012) used Environmental Policy Integrated Climate (EPIC) model to predict switchgrass yields. Thomson et al. 2009 projected switchgrass yields throughout the U.S. while Debnath, Stoecker, and Epplin (2012) predicted switchgrass yields for 30 counties in Oklahoma. White and Storm 2006 used the Soil and Water Assessment Tool (SWAT) model to predict switchgrass yield on 468 soils under five levels of fertilization and nine climate zones in Oklahoma.

While most of the previous studies attempted to predict switchgrass yields throughout the U.S., regional models have also been developed. White and Storm 2006 and Debnath, Stoecker, and Epplin 2012 simulated SWAT and EPIC models to predict switchgrass yields only in Oklahoma. These studies however have their limitations because they relied on experiment data collected only from few (2-3) locations which may not have well captured the spatial variability of yields due to weather. The goal of the current study is to improve on these efforts by considering the spatial variability in yields due to weather variables. The Oklahoma Mesonet maintains a good database of weather information. The Mesonet is a network of 120 automated weather stations covering Oklahoma and there is at least one

Mesonet station in each county. Oklahoma State University's Department of Plant and Soil Sciences and The Samuel Roberts Noble Foundation at Ardmore have been conducting switchgrass field trials in several places in Oklahoma. The data sets from these two unique resources can be used to develop weather based county level switchgrass yield forecast models. The weather based forecast models could better predict the year to year yield variability along with the spatial distribution of switchgrass yields across Oklahoma. The method could be extended to other areas across the Southern Plains as well.

The main objective of the study is to develop a switchgrass yield forecast model based on weather information and to predict switchgrass yields accurately.

Specific objectives include:

- To predict switchgrass yields by county in Oklahoma from meso-scale weather information.
- To determine spatial distribution and the year to year variation of switchgrass yields in Oklahoma.
- To determine differences in the predicted yields with predictions from other studies and more complex prediction models such as EPIC.

Conceptual Framework

Switchgrass is a native prairie grass of the Great Plains and is well adapted to the weather conditions of the region. It has been identified as a model crop to produce cellulosic ethanol. The major concern however is to have higher yields once it goes into commercial production. Beside fertilizer, soil types and variety, weather is regarded as an important variable affecting switchgrass yields. Previous studies have predicted switchgrass using weather variables (rainfall and temperature). Some study have used only weather as the exogenous variables while others have used fertilizers, soil types and management factors in addition to the weather variables. Wullschleger et al. 2010 used ecotype, annual temperature, growing season precipitation and nitrogen as the predictors of switchgrass yield and found an equal contribution of these variables in switchgrass yields. Wang, Lebauer, and Dietze (2010) used precipitation, growing degree days (GDD), nitrogen application, stand age, ecotype and cultivars as the covariates to examine the effect of these covariates on the yields of switchgrass. They show significant positive response to nitrogen and precipitation on the yield of switchgrass but not to GDD. Gunderson et al. 2008 used mean annual temperature and growing season rainfall to predict switchgrass yields. In a preliminary analysis they found that temperature and precipitation had more influence than nitrogen application or stand age. Heaton, Voigt, and Long (2004) did not find GDD significantly affecting yield but stress that if GDD is limiting could affect yield. Lee and Boe (2005) found April and May precipitation to effect switchgrass yield in S. Dakota.

Switchgrass yields are closely related to growing conditions but the growing season used in the previous studies vary. According to "The Switchgrass Production Guide in Oklahoma" (Caddel et al. 2010), switchgrass grows rapidly after breaking dormancy (March in Oklahoma) and slows when it begins to produce seed heads (July in Oklahoma). We therefore use March to September as the growing season in our study. The "Switchgrass Production Guide" mentions that switchgrass requires relatively warm temperature and long growing season for the plants to fully develop and suggest that the optimal switchgrass growing temperature is between 60 and 95°F. This supports the broad temperature range found by Gunderson et al. 2008 outside which are detrimental to switchgrass yields. Beside temperature, rainfall has been regarded as the most important factor to affect switchgrass yields. Jagger et al. 2010 found strong correlation between switchgrass yields and total precipitation from April to September. Caddel et al. 2010 mentions that precipitation is the most important limiting factor determining switchgrass biomass yield. Makaju et al. 2013 did not find consistent correlation between accumulated monthly rainfall in winter with monthly yield for three test winters. They however emphasize that May, June, July and August are critical growth period of switchgrass and any deviations from normal rainfall could affect switchgrass growth. The previous studies show that there is relationship between switchgrass yield and weather variables but the patterns of relationship shown in each study vary.

The data used in the study are separated by location and it is likely that we have spatial autocorrelation. Anselin and Bera 1998 suggest spatial lag and spatial error are the two main alternative models of spatial autocorrelation. Spatial lag occurs if the weather observations of the adjoining weather station, as well as the observations at the nearest weather station, might be expected to be related to the observed yields. Spatial error occurs when residuals at each location are correlated with the residuals of another nearest location. Presence of spatial autocorrelation in the model causes the violation of independence assumptions of the errors terms. We examine spatial error in the empirical model estimations rather than the spatial lag because our data set does not have locations that are extremely close to one another and it is less likely that the yields at one location will be affected by the weather at other locations.

The general form of the spatial error model can be expressed as

$$\boldsymbol{y} = \boldsymbol{\beta X} + \rho \boldsymbol{W}_{\boldsymbol{\varepsilon}} + \boldsymbol{\varepsilon} \tag{1.1}$$

where $\boldsymbol{y}$ is a vector of dependent variables, $\boldsymbol{X}$ is the vector of independent variables, ρ is a parameter that determines spatial autocorrelation, $\boldsymbol{W}$ is a $N \times N$ spatial weight matrix based on distance and ε is the random error term where $\varepsilon \sim iid(0, \sigma_{\varepsilon}^{2})$. The spatial autocorrelation is determined using Moran's I which varies on a scale from -1 to +1. If the value of Moran's I is +1 then we have large positive spatial autocorrelation, if it is -1 we have large negative spatial autocorrelation and if it is 0 then there is no spatial autocorrelation.

Material and Methods

Data

The yield data along with the associated agronomic practices were collected using literature reviews (journals, dissertation and thesis) and personal contacts (Table I – 8). The data were collected from the experiments conducted by Oklahoma State University (OSU) and The Samuel Roberts Noble Foundation at various locations in Oklahoma (Figure I – 1). A total of 8 journal articles, 1 dissertation, 2 thesis and 2 personal contacts (OSU and Noble Foundation) were used. The compiled data includes 1,400 observations from 14 locations or 11 counties with dates ranging from 1994 – 2012 (Table I – 9, 11, 14). The collected data vary in agronomic practices (applied fertilizers, harvest dates, number of cuts), cultivars and ecotype as they come from different experiments conducted with different objectives. All experimental plots in all studies were non-irrigated except for few plots in some studies where they were irrigated in first year to maintain growth. Other details about the experimental plots and agronomic practices are available in the relevant literatures (Table I – 8). There were in total 62 different cultivars including experimental genotypes. The cultivars and experimental genotypes were grouped into two broad categories by their ecotypes as upland and lowland and yield data from plots planted as a mixture of two varieties were not used (Table I – 10). We did not use yield data in the first year of planting because switchgrass produces one-quarter to one-third of full yield in the first year, about two-thirds in the second year and full yield in the third year after planting (Caddel et al. 2010). Other data not used in the study are yields which have multiple harvests per year. Data with details on treatment and replications were averaged to obtain one yield data for each treatment. Switchgrass yields in some locations are higher than average even in drought years such as 2011 in Payne County. Higher precipitation in the early periods of the growing seasons have been suggested as an explanation for these higher yields in the relevant literature (Sripathi, 2011). Similarly, the even distribution of precipitation over the growing season has been suggested as an explanation for the higher than average yields in Grady County in the relevant literature (Fuentes and Taliaferro, 2002). Partial data set used in the analysis are presented in the Appendix Table I – 14.

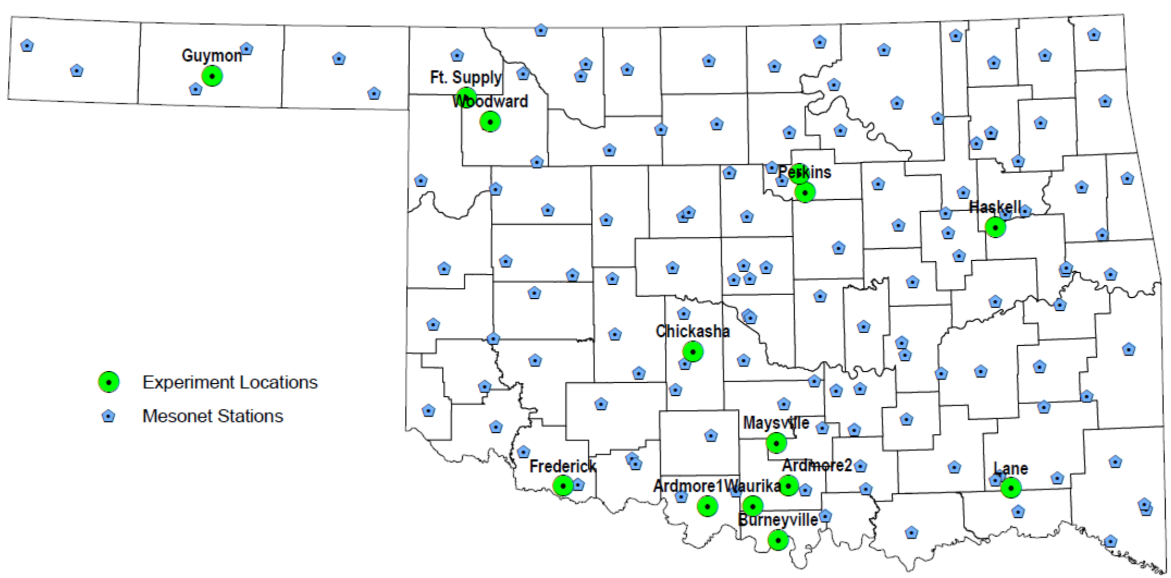

Figure I – 1. Switchgrass Experiment Locations and Mesonet Stations.

The weather data are collected from Oklahoma Mesonet which is a network of 120 automated weather stations covering every county in Oklahoma (Figure I – 1). The daily weather data from 1994 to 2012 were collected from Oklahoma Mesonet for all the active weather stations (119). Temperature data not available from 1994 to 1996 in the Oklahoma Mesonet were supplemented with data from the website of "National Oceanic and Atmospheric Administration (NOAA)" for Chickasha and Haskell. The weather variables collected include total solar radiation (MJ $m^2 d^{-1}$), maximum temperature (°F), minimum temperature (°F), average temperature (°F), total rainfall (in), average relative humidity (%) and evapotranspiration (mm day^{-1}) for warm season grass. The evapotranspiration data which were missing for Chickasha and Haskell (1994-1996) were calculated using the FAO "CropWAT" software. The growing degree day (GDD) was calculated using the equation $GDD = \frac{T_{Max}+T_{Min}}{2} - T_{Base}$ where the base temperature was assumed to be 50°F (Wang, Lebauer, and Dietze 2010). The weather from the closest Mesonet stations were associated to the experiment locations from where the yield data were collected. For the 14 experiment locations we had weather associated to 13 Mesonet Stations (Table I – 12). There was only one Mesonet Station that could be associated with the two experiment locations in Woodward County but for each of the other experiment locations unique Mesonet Stations could be associated.

Model Specification

The weather variables to be used in the models were determined using correlation analysis (Table I – 1) which shows the strength of linear relationship between yield and weather variables. We did correlation by growing season and individual months in the growing season using as many weather variables as available. The correlation analysis by growing season show that most of the weather variables are significantly correlated with yield. The most significantly correlated weather variable was relative humidity and total rainfall. Similar analysis by individual months show that all weather variables are significantly correlated with yield. The most significant of them were total solar radiation, relative humidity and total rainfall. The correlation coefficient was relatively higher in growing season than in individual months. All the weather variables appeared to have strong correlation with yield between the months of March and July. There was strong positive correlation with average relative humidity and total rainfall and there was strong negative correlation with total solar radiation, evapotranspiration and maximum temperature.

The correlation analysis shows only the linear relationship however the total rainfall and average temperature were non-linearly related with yield (Figure I – 7, 8, 9 and 10). Similar relationship between total rainfall and average temperature with yields was observed by Gunderson et al. 2008. We created several combination of weather variables by individual months, bi-monthly, tri-monthly, seasonal and annual etc. and pre-tested to identify significant weather variables. All weather variables except total rainfall and average temperature appeared non-significant in the pre-tested models. The rainfall and average temperature were significant only in summer months (May-July) and therefore we use total rainfall and average temperature only for these months in the empirical model estimations. Most of the trial locations received below average rainfall in 1998, 2006, 2011 and 2012 and above average rainfall in 2006. Makaju et al. 2013 mentions that May – August are the critical growth period of switchgrass and therefore any departures from normal rainfall would affect switchgrass growth.

Because our yield trial data included different nitrogen treatments and ecotypes (upland and lowland varieties) we use nitrogen and ecotype dummy variables as the predictor variables in the estimated model along with total rainfall and average temperature. Including nitrogen and ecotype as the predictor variables allowed us to include yield data from all the locations in the empirical model estimations. Wullschleger et al. 2010 did not use yield data from some plots where applied nitrogen exceeded 400 kg ha^{-1} (Thomason et al. 2004) citing those rates far exceeded nitrogen applied in other plots and exerted disproportionate leverage on model fit. Out dataset included the exact same data from Thomason et al. 2004 (Figure I – 5) where we observed similar problems and therefore we did not use yield data where nitrogen application exceeded 400 kg ha^{-1} in all of our empirical model estimations.

The standard general regression model indexed *i* for location, *j* for applied level of nitrogen and/or ecotype and *t* for year can be expressed as

(1.2) $$y_{ijt} = \alpha + \beta \boldsymbol{X}_{it} + \mu N_{ij} + \nu ET_{jt} + \theta_i + \gamma_t + \varepsilon_{ijt}$$

with $$\varepsilon_{ijt} = \rho \boldsymbol{W}_{\varepsilon} + \xi_{ijt}$$

where y_{ijt} is the yield of switchgrass, $\boldsymbol{X}_{it}$ is the vector of weather variables (mean temperature and total rainfall), N is the level of nitrogen applied, ET is the dummy variable for ecotype , θ_i is the random effect for location where $\theta_i \sim iid(0, \sigma_\theta^2)$, γ_t is the random effect for year where $\gamma_t \sim iid(0, \sigma_\gamma^2)$, ε_{ijt} is the random error term where $\varepsilon_{ijt} \sim iid(0, \sigma_\varepsilon^2)$, $\boldsymbol{W}_\varepsilon$ is a $N \times N$ spatial weights matrix for cross-sectional dimension, ρ is a parameter that determines spatial autocorrelation and ξ_{ijt} is the uncorrelated random error term where $\xi_{ijt} \sim iid(0, \sigma_\xi^2)$.

We used random effect for year and location to account for year to year and location to location variability that may not have been accounted for by the fixed effects.

The following three alternative functional forms are considered in the study and compared to see how well the models fit:

(1.3) $$y_{ijt} = \alpha + \beta \boldsymbol{X}_{it} + \mu N_{ij} + \nu ET_{jt} + \theta_j + \gamma_t + \varepsilon_{jt}$$ (Linear)

(1.4) $$y_{ijt} = \alpha + \beta \boldsymbol{X}_{it} + \delta \boldsymbol{X}_{it}^2 + \mu N_{ij} + \omega N_{ij}^2 + \nu ET_{jt} + \theta_j + \gamma_t + \varepsilon_{jt}$$ (Quadratic)

(1.5) $$\ln(y)_{ijt} = \alpha + \beta \ln(\boldsymbol{X}_{it}) + \mu \ln(N_{ij}) + \nu \ln(ET_{jt}) + \theta_j + \gamma_t + \varepsilon_{jt}$$ (Double Log)

All three functional forms are tested for spatial autocorrelation using

$$\varepsilon_{ijt} = \rho \boldsymbol{W}_{\varepsilon} + \xi_{ijt}.$$

The W matrix for cross sectional dimension used for testing spatial autocorrelation depends on distance rather than contiguity because the experiment stations are not close enough and they are separated by distance.

Empirical Procedure

The models were first tested for no spatial autocorrelation. PROC MIXED procedure in SAS 9.2 was used with location and year as random effects. The residuals from PROC MIXED was used in PROC VARIOGRAM in SAS to determine the presence of spatial autocorrelation. PROC VARIOGRAM gives Moran's I which is used to test the hypothesis of no spatial autocorrelation. Moran's I is the most common test for testing spatial autocorrelation (Griffith, 1987). We failed to reject the null hypothesis of no spatial autocorrelation ($\boldsymbol{H_0}: \boldsymbol{\rho = 0}$) at the 5% significance level in all three yield models (Table I –

1). We therefore continue using the general forms of model specified in (1.3), (1.4) and (1.5) ignoring spatial error.

Table I – 1. Test of No Spatial Autocorrelation of Residuals.

Yield Models	Moran's Index	Expected Index	Standard Deviation	Z	P-Value
Linear	-0.00309	-0.00231	0.00154	-0.506	0.6128
Quadratic	-0.00369	-0.00231	0.00154	-0.892	0.3721
Double Log	-0.00255	-0.00231	0.00154	-0.151	0.8798

We further tested the models for normality using the Shapiro-Wilk test using PROC UNIVARIATE procedure in SAS 9.2. We reject the null hypothesis of normality at the 5% significance level in all three models (Table I – 2). The test of normality was followed by a test of heteroskedasticity which was performed using the Lagrange Multiplier (LM) test. The LM test was done using the Ordinary Least Square (OLS) procedure in SAS 9.2 with PROC REG. Fixed effects for location and year were used. The residuals from PROC REG were squared and another OLS was run with the squared residuals against rainfall, average temperature, nitrogen, ecotype dummy and fixed effects of location and year. The $LM = TR^2$ is compared with $\chi^2_{33,0.05} = 55.75$. The results show that $LM = TR^2$ is greater than the χ^2 critical value at the 5% level. We reject the null hypothesis of homoskedasticity in all three models. To handle non-normality and heteroskedasticity, PROC GLIMMIX procedure in SAS was used with EMPIRICAL option specified. The GLIMMIX procedure uses generalized method of moments (GMM) that produces classical sandwiched estimators which are robust to non-normality and heteroskedasticity.

Table I – 2. Test of Normality and Heteroskedasticity of Residuals.

Models	Normality		Heteroskedasticity
	Shapiro-Wilk	P-value	Lagrange Multiplier ($LM = TR^2$)
Linear	0.9695	<0.0001	93.44
Quadratic	0.970901	<0.0001	273.17
Double Log	0.925985	<0.0001	99.33

Results

All parameters remained significant in the quadratic model after the use of GLIMMIX procedure while the average temperature was not significant in linear and double log models. We re-evaluated several combinations of rainfall and average temperature by month, season and growing season and tested for significance of these variables in all three models. None of the combinations would make both rainfall and average temperature significant in all three models. The models were therefore not compared for a better fit because not all the predictors were significant in the linear and double log models. We continue to use summer rainfall and average temperature in the quadratic models and predict switchgrass yields using the quadratic model only.

Table I – 3. Yield Estimates (Linear, Quadratic and Double Log Functional Forms).

Variable	Linear		Quadratic		Double Log	
	Estimate	P-value	Estimate	P-value	Estimate	P-value
Intercept	-8.6053	0.5213	-433.88	0.0011	-8.8293	0.0258
ET	2.6410	<.0001	3.0261	<.0001	0.2496	<.0001
Nitrogen	0.0169	0.0036	0.06126	<.0001		
Rain	0.4145	<0.0001	0.7788	0.0003		
Avg. Temp	0.1556	0.3503	10.7773	0.0008		
$Nitrogen^2$			-0.00025	0.0006		
$Rain^2$			-0.01253	0.0260		
$Avg. Temp^2$			-0.06675	0.0009		
Log (Nitrogen)					0.09373	<.0001
Log (Rain)					0.6391	<.0001
Log (Avg. Temp)					2.0951	0.1780
-2 Log Likelihood	2546.59		2521.07		699.86	

Note: The dependent variable is switchgrass yield (Mg ha^{-1}) and ET is the ecotype dummy.

A residual analysis was performed comparing the 433 observed yields with the yields predicted using the quadratic model for these data points. The deviations of yields were higher in the lowland ecotype than the upland ecotype. The median residual for the lowland variety was -0.2959 Mg ha^{-1} with a range of -11.5165 to 15.06921 Mg ha^{-1} and for the upland variety the median residual was -0.54988 Mg ha^{-1} with a range of -7.10609 to 7.529971 Mg ha^{-1}. The lowland variety had a wide range of residuals because the model predicted low yields in places where the observed yields were sometimes high (>22 Mg ha^{-1}) and the model predicted low yields in places where the observed yields were sometimes low. There were some high yields in western Oklahoma where the model predicted low yields. There was one low yield observed in Central Oklahoma where the predicted yields and the other observations at those locations were relatively higher. One possible reason for unusual yields at those locations may be the type of genotype being tested in those experiments. In our quadratic model the switchgrass yields are not affected significantly by nitrogen. For each 10 Kg ha^{-1} additional application of nitrogen starting from 50 Kg ha^{-1} to 160 Kg ha^{-1}the model shows an increment in yield between 0.1-0.4 Mg ha^{-1}. The model indicated a maximum yield between 110-140 Kg ha^{-1} applications of nitrogen.

We further fit a simple linear regression model using the predicted and observed yields both for lowland and upland ecotypes (Figure I – 11 and 12). Spatial autocorrelation was tested in these models as well. The Moran's I indicated that there are no spatial autocorrelation in both models. The null hypothesis of no spatial autocorrelation was rejected at the 5% significance level in both models. The R-square was relatively higher in the upland (0.410) than the lowland ecotype (0.288).

Table I – 4. Test of No Spatial Autocorrelation in the Lowland and Upland Predicted Vs. Observed Linear Models.

Yield Models	Moran's Index	Expected Index	Standard Deviation	Z	P-Value
Lowland	-0.00525	-0.00365	0.00211	-0.757	0.4491
Upland	-0.0114	-0.00637	0.00479	-1.04	0.2963

In addition to fitting a regression model of predicted and observed yields using overall data, the observed and predicted yields were plotted with total rainfall and average temperature (May-July) for Stillwater for localized analysis (Figure I – 2). Stillwater was selected because a longer time series of yield data was available compared to other location. Only six years data were plotted because either yield or weather data were unavailable for other years. The observed and predicted yield showed similar pattern with rain except in 2010 where with higher total rainfall the observed yield was fairly low while the predicted yield based on the rainfall pattern was higher.

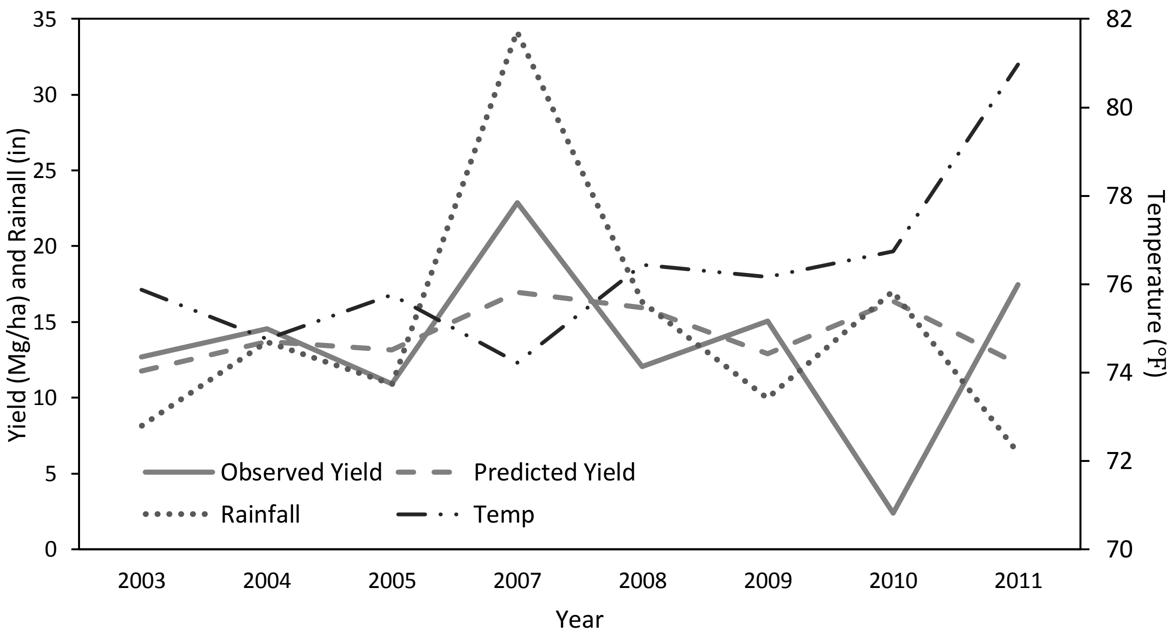

Figure I - 2. Stillwater, Oklahoma : Actual and Predicted Switchgrass Yields with Summer Rainfall and Temperature

Spatial Distribution of Switchgrass Yields

The quadratic model using summer rainfall and average temperature was used to predict annual yields from 2001 to 2012 for all the active Mesonet stations in Oklahoma. The yields were predicted for both lowland and upland ecotype using 100 Kg N ha^{-1}. We compared these yields with those from previous studies which specified an ecotype. We also averaged the yields across the two ecotypes to obtain yield for each Mesonet station which could be compared with those from studies which did not specify the ecotype. The predicted switchgrass yields very well correlated with the rainfall pattern in Oklahoma. The lowland yields were greater than upland yields by approximately 3 Mg ha^{-1}. The yields were lower in western Oklahoma and gradually increased towards eastern Oklahoma (Figure I – 3). The spatial distribution of switchgrass yields were similar to the spatial distribution of predicted yields from the previous studies (Gunderson et al. 2008; Jager et al. 2010; BETYdb). The magnitude of predicted switchgrass yields however differ across these studies and the BETYdb (Table I – 5). The "BETYdb" is a database of switchgrass and other forage yields by counties in the U.S. maintained by The Energy Bioscience Institute, Urbana, Illinois and is an abbreviation of "Biofuel Ecophysiological Traits and Yields Database". The data included in the database is a collection of switchgrass yields collected from published literature, ongoing research and from the collaborators (LeBauer et al. 2011). For an assumed 100 Kg ha^{-1} application of nitrogen, the estimated model predicted a minimum yield of 5.3 Mg ha^{-1} and maximum yield of 15.3 Mg ha^{-1} for lowland ecotype and a minimum yield of 2.4 Mg ha^{-1} and maximum yield of 12.2 Mg ha^{-1} for the upland ecotype.

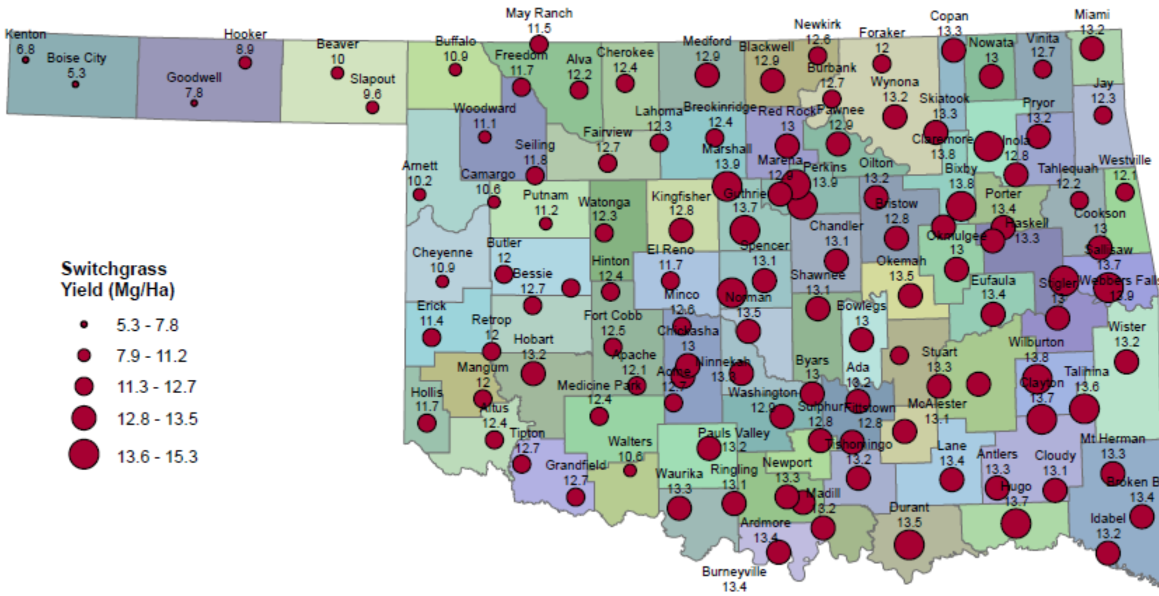

Figure I – 3. Mean Predicted Lowland Switchgrass Yields (2001-2012) with 100 Kg N ha^{-1}.

Yearly Variation of Switchgrass Yields

The year to year variability in switchgrass yields was analyzed for three broad regions in Oklahoma – West, Central and East (Figure I – 4). The annual predicted yield from 2001 to 2012 show that yields are comparatively less variable in the West and more variable in the Central region. The yields were predicted using three summer months – May, June and July. The yearly variability in yields in these three regions were a direct effect of the variability in rainfall pattern in these three regions. Rainfall was highly variable in Central and it was least variable in the West. Counties grouped in each regions are presented in Table I – 15.

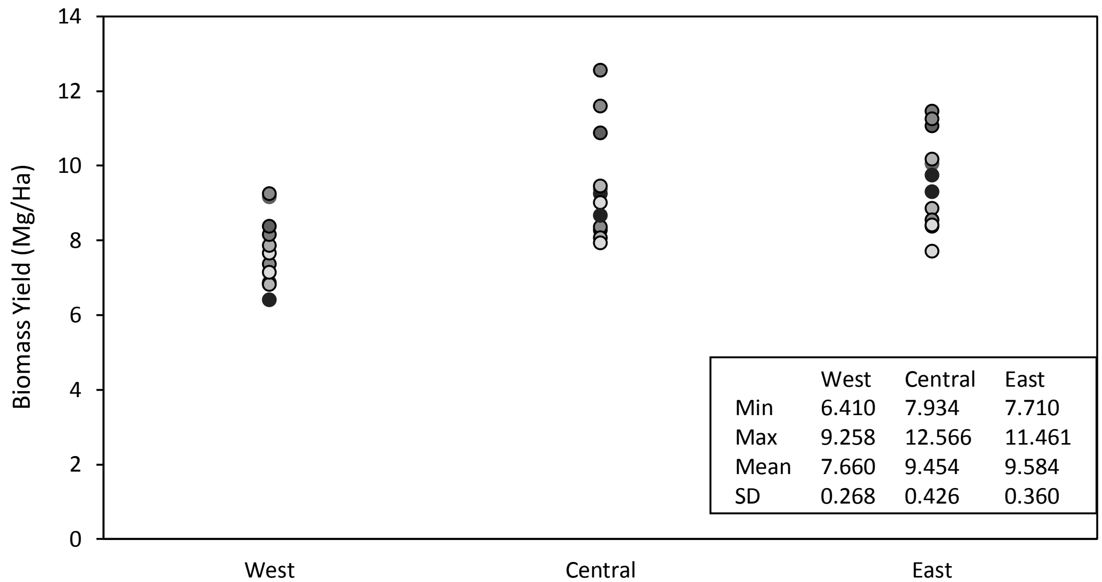

Figure I - 4. Year to Year (2001-2012) Variation in Predicted Switchgrass Yields in Oklahoma.

Comparison with Other Studies

The yields predicted in this study were compared with both the observed yield at the experiment stations and predicted yields by other studies. Makaju et al. 2013 conducted a field trial at the agronomy station in Stillwater, Oklahoma with no nitrogen application and observed monthly winter harvest (Nov-Mar) from 2007-2010. The observed monthly average winter switchgrass yield in the first, second and third year of harvest was 3.9, 6.4 and 7.6 Mg ha^{-1}. The observed winter yields by Makaju et al. 2013 were lower than the yields predicted by the estimated model which predicted 13.3, 12.3 and 9.3 Mg ha^{-1} of switchgrass biomass yield for the closest Mesonet Stations for that ecotype with no nitrogen application for the year 2007, 2008 and 2009. The estimated model predicted yield using data which were harvested before November while Makaju et al. 2013 observed yields only after November which is generally expected to be low. On the contrary, the yields observed by Makaju et al. 2013 do not show any consistent correlation between winter yields with rainfall.

We further compared predicted switchgrass yield in this study with the yields predicted by three other studies (Gunderson et al. 2008; Jager et al. 2010; Debnath, Stoecker and Epplin 2012) and with the yield data available in the BETY database. We choose to compare these three studies and the BETY database because switchgrass yield data were available from these sources only. Gunderson et al. 2008 and Jager et al. 2010 predicted county level switchgrass yields throughout the US using quantile regression and logit type models. Debnath, Stoecker, and Epplin (2012) predicted switchgrass yields for 30 counties in Oklahoma using EPIC simulation. The yields were compared across studies and the BETY database using paired t-test with the null hypothesis that the mean difference between the predicted yields and yields from other studies and the BETY database are zero ($\boldsymbol{H_0}: \boldsymbol{\mu_D} = \mathbf{0}$) (Table I – 5). PROC TTEST procedure in SAS 9.2 was used for this purpose. Yields were compared by ecotype only with Gunderson et al. 2008 as they predict yields for both ecotypes. All other comparisons were made with the predicted lowland yields and the average of the lowland and uplands yields in this study.

Table I – 5. Comparison of Yields from Other Sources with the Predicted Yield from the Current Study Using Paired T-test.

Switchgrass Yields from Other Sources	Lowland Yield			Upland Yield			Average Yield		
	Mean Diff	SD	P-Value	Mean Diff	SD	P-Value	Mean Diff	SD	P-Value
Gunderson et al. 2008 (Lowland Yields)	-10.783	0.930	<0.0001						
Gunderson et al. 2008 (Upland Yields)				-3.468	1.204	<0.0001			
Jager et al. 2010	0.320	1.728	0.1084				-1.193	1.726	<0.0001
Debnath, Stoecker, and Epplin 2012	-1.895	0.861	<0.0001				-3.409	0.861	<0.0001
BETYdb, Illinois	1.54	2.489	<0.0001				0.028	2.49	0.922

We fail to reject the null hypothesis ($\boldsymbol{H_0: \mu_D = 0}$) that the mean difference is equal to zero at the 5% significance level in two comparisons – one with predicted lowland yields and prediction from Jager et al. 2012 and the other with predicted average yields and the BETY database. We reject the null hypothesis in all other comparisons. The paired t – test was followed by a correlation analysis between the predicted yields with yields from three studies and the BETY database. The predicted yields were highly correlated with the yields predicted by Gunderson et al. 2008 and the yield data from the BETY database. The EPIC simulated yields correlated fairly low with the predicted yields in this study. While the yields predicted by Jager et al. 2010 did not correlate with the predicted yields at all. This indicates that the mean lowland yield is similar to yield predicted by Jager et al. 2010 but the pattern of yield is different; the composite of mean yield and pattern both are similar with the BETY database while the mean yield is different with the rest of the studies but the pattern of yields are similar.

Table I – 6. Relationship of Yields from Other Sources with the Predicted Yield from the Current Study Using Correlation Coefficients.

Switchgrass Yields from Other Sources	Lowland Yield		Upland Yield		Average Yield	
	Correlation Coefficient	P-Value	Correlation Coefficient	P-Value	Correlation Coefficient	P-Value
Gunderson et al. 2008 (Lowland Yields)	0.72832	<0.0001				
Gunderson et al. 2008 (Upland Yields)			0.62245	<0.0001		
Jager et al. 2010	-0.00332	0.9771			-0.00344	0.9763
Debnath, Stoecker, and Epplin 2012	0.39383	0.0313			0.39383	0.0313
BETYdb, Illinois	0.70415	<0.0001			0.70441	<0.0001

We compared our yield estimates with the estimates from several previous studies and the BETY database to suggest that our estimates are centered around the consensus estimates for switchgrass yield. The contribution of our model is that, through the use of weather data, our estimates can be adjusted for location and modeled over time. Our predicted lowland yields are similar with the predicted yields from Jager et al. 2010. Similarly, our predicted average yields (composite of upland and lowland) are similar with the predicted yields from the BETY database. Our research, which was based on all available yield trial data, confirms the yields predicted by Jager et al. 2010 and the yields available in the BETY database. Our model could be used to predict mean yields for any county in Oklahoma and would likely apply across the Southern Plains. As more field trial data becomes available our weather variable forecast model can likely be further refined.

Conclusion

Switchgrass yield trial data is available for a very limited number of locations and time periods. Modeling the geographic and year-to-year variation in switchgrass yields could assist supply chain managers in determining plant location, land leasing decisions, long term contracts and storage strategies. The regression model estimated switchgrass yields using average temperature and total rainfall during summer months and nitrogen. The fitted model agrees well with available yield data and the estimated yields were consistent with most previous studies. The model's results indicated lower average yields and lower year-to-year variation in yields in the Western region with higher yields and higher year-to-year variation in the Central region. Maximum switchgrass yield was observed between 110-140 Kg ha^{-1} application of nitrogen.

Weather based models appear to have the potential to provide reliable and cost effective predictions of switchgrass yields. They could be useful in predicting switchgrass yields in locations without historical yield trial data and in estimating yield risk for a proposed supply chain. The model developed in this study shows a promising result which could be adapted to other regions. As more switchgrass yield data becomes available, it is likely that the model can be further refined.

Limitations

While the limited data on switchgrass yields was the driving force behind our exploration of weather data based yield forecasting, it is also acknowledged as a limitation to our study. Switchgrass yield data was available for only fourteen locations in Oklahoma and for a relatively short time series. These data limitations likely hampered the accuracy and robustness of our fitted model. There are however several field trials currently underway on switchgrass in Oklahoma. Future research may incorporate upcoming yield data expanding the current database and may better predict switchgrass yields. Finally, we should also note that switchgrass yields, like other crop yields, are impacted by numerous factors outside of the weather variables we modeled including insects, disease and extreme weather events such as hail storms.

References

Anselin, L., and A.K. Bera. 1998. "Spatial Dependence in Linear Regression Models with an Introduction to Spatial Economics." In Ullah, A. and D.E.A. Giles, editors, Handbook of Applied Economic Statistics, pages 237-289. New York, Marcel Dekker, Inc.

Aravindhakshan, S.C., F.M. Epplin and C.M. Taliaferro. 2011. "Switchgrass, Bermudagrass, Flaccidgrass and Lovegrass Biomass Yield Response to Nitrogen for Single and Double Harvest." *Biomass and Bioenergy* 35: 308-319.

Boyer, C.N., D.D. Tyler, R.K. Roberts. B.C. English and J.A. Larson. 2012. "Switchgrass Yield Response Functions and Profit-Maximizing Nitrogen Rates on Four Landscapes in Tennessee." *Agronomy Journal* 104(6):1579-1588.

Caddel, J., N. Walker, G. Kakani, J. Warren, D. Porter, Y. Wu, D. Redfearn and H. Zhang. 2010. "*Switchgrass Production Guide for Oklahoma*." E-1012 Oklahoma Cooperative Extension Service. Division of Agricultural Sciences and Natural Resources. Oklahoma State University.

Christensen, C.A. and G. Koppenjan. 2010. "Planting and Managing Switchgrass as a Dedicated Energy Crop." 2nd ed. Blade Energy Crops. Available at: http://www.bladeenergy.com/Bladepdf/Blade-Switchgrass-Mgmt_2ed.pdf

Debnath, D., A.L. Stoecker and F.M. Epplin. 2012. "Managing Expected Switchgrass Biomass Yield Variability by Strategically Selecting Land to Lease." Paper presented at AAEA Annual Meeting, Seattle WA, 12-14 August.

Fuentes, R.G. and C.M. Taliaferro. 2002. "Biomass Yield Stability of Switchgrass Cultivars." In: Janick J., Whipkey A., editors. *Trends in New Crops and New Uses* 276-82.

Graham, R.L., and M.E. Walsh. 1999. "A National Assessment of Promising Areas for Switchgrass, Hybrid Poplar, or Willow Energy Crop Production." Oak Ridge National Laboratory: Oak Ridge, Tennessee.

Griffith, A.P., F.M. Epplin, S.D. Fuhlendorf and R. Gillen. 2011. "A Comparison of Perennial Polycultures and Monocultures for Producing Biomass for Biorefinery Feedstock." *Agronomy Journal* 103(3): 617-627.

Griffith, D.A. 1987. "Spatial Autocorrelation." Washington, D.C.: Association of American Geographers.

Gunderson, C.A., E.B. Davis, H.I. Jager, T.O. West, R.D. Perlack, C.C. Brandt, S. Wullschleger, L. Baskaran, E. Wilkerson and M. Downing. 2008. "Exploring Potential US Switchgrass Production for Ligno-cellulosic Ethanol." ORNL/TM-2007/183, Oak Ridge National Laboratory: Oak Ridge, Tennessee.

Guretzky, J.A., J.T. Biermacher, B.J. Cook, M.K. Kering and J. Mosali. 2011. "Switchgrass for Forage and Bioenergy: Harvest and Nitrogen Rate Effects on Biomass Yields and Nutrient Composition." *Plant and Soil* 339(1-2):69-81.

Haque, M., J.T. Biermacher, M.K. Kering and J.A. Guretzky. 2013. "Economics of Alternative Fertilizer Supply Systems for Switchgrass Produced in Phosphorus-Deficient Soils for Bioenergy Feedstock." *Bioenergy Research* 6:351-357.

Heaton, E., T. Voigt and S.P. Long. 2004. "A Quantitative Review Comparing the Yields of Two Candidate C_4 Perennial Biomass Crops in Relation to Nitrogen, Temperature and Water." *Biomass and Bioenergy* 27(1):21-30.

Jager, H. I., L.M. Baskaran, C.C. Brandt, E.B. Davis, C.A. Gunderson and S.D. Wullschleger. 2010. "Empirical Geographic Modeling of Switchgrass Yields in the United States." *GCB Bioenergy* 2(5):248-257.

Kering, M.K., J.T. Biermacher, T.J. Butler, J. Mosali and J.A. Guretzky. 2012. "Biomass Yield and Nutrient Responses of Switchgrass to Phosphorus Application." *Bioenergy Research 5*(1):71-78.

Kiniry, J. R., M.R. Schmer, K.P. Vogel and R.B. Mitchell. 2008. "Switchgrass Biomass Simulation at Diverse Sites in the Northern Great Plains of the US." *BioEnergy Research*, 1(3-4):259-264.

LeBauer, D., D. Wang, and M. Dietze, 2010. "Biofuel Ecophysiological Traits and Yields Database Version 1.0." Energy Biosciences Institute, Urbana, IL. http://ebi-forecast.igb.uiuc.edu/bety

Lee, B.H., P. Kenkel, and B.W. Brorsen. 2013. "Pre-harvest Forecasting of County Wheat Yield and Wheat Quality Using Weather Information." *Agricultural and Forest Meteorology* 168:26-35.

Lee, D.K. and A. Boe. 2005. "Biomass Production of Switchgrass in Central South Dakota." *Crop Science* 45(6): 2583-2590.

Lee, D.K., V.N. Owens and J.J. Dolittle. 2007. "Switchgrass and Soil Carbon Sequestration Response to Ammonium Nitrate, Manure and Harvest Frequency on Conservation Reserve Program Land." *Agronomy Journal* 99:462-468.

Lobell, D.B. and M.B. Burke. 2010. "On the Use of Statistical Models to Predict Crop Yield Responses to Climate Change." *Agricultural and Forest Meteorology* 150:1443-1452

Makaju, S.O., Y.Q. Wu, H. Zhang, V.G. Kakani, C.M. Taliaferro and M.P. Anderson. 2013. "Switchgrass Winter Yield, Year-Round Elemental Concentrations, and Associated Soil Nutrients in a Zero Input Requirement." *Agronomy Journal* 105(2):463-470.

Mooney, D.F., R.K. Roberts, B.C. English, D.D. Tyler and J.A. Larson. 2009. "Yield and Breakeven Price of 'Alamo' Switchgrass for Biofuels in Tennessee." *Agronomy Journal* 101:1234-1242.

Muir, J., M. Sanderson, W. Ocumpaugh, R. Jones and R. Reed. 2001. "Biomass Production of Alamo Switchgrass in Response to Nitrogen, Phosphorus, and Row Spacing." *Agronomy Journal* 93:896–901.

National Oceanic and Atmospheric Administration (NOAA). Daily Weather Data. Available at: http://gis.ncdc.noaa.gov/map/viewer/#app=cdo&cfg=cdo&theme=daily&layers=111

Oklahoma Mesonet. Daily Climate Data. Available at: http://www.mesonet.org/index.php/weather/daily_data_retrieval

Sanderson, M.A., P.R. Adler, A.A. Boateng, M.D. Casler, and G. Sarath. 2006. "Switchgrass as a Biofuels Feedstock in the USA." *Canadian Journal of Plant Science* 86:1315-25.

SAS Institute. 2011. The GLIMMIX Procedure. *SAS 9.3 Help and Documentation.* Cary. NC.

SAS Institute. 2011. The MIXED Procedure. *SAS 9.3 Help and Documentation.* Cary. NC.

SAS Institute. 2011. The REG Procedure. *SAS 9.3 Help and Documentation.* Cary. NC.

SAS Institute. 2011. The TTEST Procedure. *SAS 9.3 Help and Documentation.* Cary. NC.

SAS Institute. 2011. The UNIVARIATE Procedure. *SAS 9.3 Help and Documentation.* Cary. NC.

SAS Institute. 2011. The VARIOGRAM Procedure. *SAS 9.3 Help and Documentation.* Cary. NC.

Sripathi, R. 2011. "Genotypic Variations and Genotype x Environment (G x E) Interactions among New Switchgrass (*Panicum Virgatum* L.) Populations in Oklahoma." MS Thesis. Oklahoma State University.

Taliaferro, C.M. and M. Das. 2002. "Breeding and Selection of New Switchgrass Varieties for Increased Biomass Production." *ORNL/SUB-02-19XSY162C/01.* Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Thomason, W.E., W.R. Raun, G.V. Johnson, C.M. Taliaferro, K.W. Freeman, K.J. Wynn and R.W. Mullen. 2005. "Switchgrass Response to Harvest Frequency and Time and Rate of Applied Nitrogen." *Journal of Plant Nutrition* 27:1199-1226.

Thomson, A.M., R.C. Izarrualde, T.O. West, D.J. Parrish, D.D. Tyler and J.R. Williams. 2009. "Simulating Potential Switchgrass Production in the United States." PNNL-19072, 20 pp.

Todd, J. 2011. "Study of the Diversity, Inbreeding Potential, and Sward Heritability of Switchgrass." PhD Dissertation. Oklahoma State University.

U.S. Environmental Protection Agency (EPA). 2010. Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA-420-R-10-006.

Wagle, P and V.G. Kakani. 2013. "Seasonal Variability in Net Ecosystem Carbon Dioxide Exchange over a Young Switchgrass Stand." *GCB Bioenergy* http://dx.doi.org/10.1111/gcbb.12049.

Walker, G.K. 1989. "Model for Operational Forecasting of Western Canada Wheat Yield." *Agricultural and Forest Meteorology* 44:339-351.

Wang, D., D.S. Lebauer, and M.C. Dietze. 2010. "A Quantitative Review Comparing the Yield of Switchgrass in Monocultures and Mixtures in Relation to Climate and Management Factors." *GCB Bioenergy* 2(1):16-25.

White, M.J. and D.E. Storm. "Predicted Switchgrass Yields in Oklahoma by Soil and Climate Region." Biosystems and Agricultural Engineering Department. Division of Agricultural Sciences and Natural Resources. Oklahoma State University. Available at: http://www.ars.usda.gov/SP2UserFiles/ad_hoc/62060505MikeWhite/pdfs/Switchgrass.pdf

Wilson, T. 2011. "Carbon Stocks in Perennial Biofuel Feedstock Management Systems." MS Thesis. Oklahoma State University.

Wullschleger, S.D., E.B. Davis, M.E. Borsuk, C.A. Gunderson and L. Lynd. 2010. "Biomass Production in Switchgrass across the United States: Database Description and Determinants of Yield." *Agronomy Journal* 102(4):1158-1168.

Appendix I – A: Tables

Table I – 7. Correlation of Switchgrass Yield (Mg ha^{-1}) with Weather Variables.

	Total Solar Radiation (Mj/m^2)	Avg. Relative Humidity (%)	Total Rain (in)	Avg. Temp. (°F)	Max Temp. (°F)	Min Temp. (°F)	Evapotranspiration (in)	Growing Degree Days (GDDs)
March	-0.178	0.253	0.196	0.192	-0.048	0.177	-0.232	0.039
	0.0002	<.0001	<.0001	<.0001	0.3165	0.0002	<.0001	0.4101
April	-0.261	0.430	0.324	0.098	-0.155	0.095	-0.294	-0.041
	<.0001	<.0001	<.0001	0.0396	0.0011	0.0461	<.0001	0.384
May	-0.499	0.502	0.180	0.179	-0.154	0.273	-0.230	0.064
	<.0001	<.0001	0.0001	0.0002	0.0011	<.0001	<.0001	0.1744
June	-0.313	0.424	0.284	-0.052	-0.264	0.010	-0.302	-0.165
	<.0001	<.0001	<.0001	0.2784	<.0001	0.8392	<.0001	0.0005
July	-0.348	0.429	0.244	-0.102	-0.332	-0.124	-0.353	-0.294
	<.0001	<.0001	<.0001	0.0315	<.0001	0.009	<.0001	<.0001
August	0.066	0.293	0.054	0.077	-0.114	-0.033	-0.166	-0.080
	0.1661	<.0001	0.2591	0.1056	0.0161	0.4922	0.0004	0.0901
September	-0.291	0.393	0.320	0.164	-0.104	0.217	-0.203	0.077
	<.0001	<.0001	<.0001	0.0005	0.0277	<.0001	<.0001	0.106
Growing Season	-0.430	0.528	0.456	0.098	-0.259	0.132	-0.313	-0.110
	<.0001	<.0001	<.0001	0.038	<.0001	0.0054	<.0001	0.0202

Table I – 8. Source of Switchgrass Yield Data and their Description.

Source	Publication Type	County	Location	Years	No. of Cultivars	No. of Observations
Fuentes and Taliaferro, 2002	Journal	Grady	Chickasha	1994-2001	10	80
		Muskogee	Haskell	1994-2001	12	96
Griffith et al. 2011	Journal	Woodward	Ft. Supply	2005-2007	1	3
			Woodward	2004-2007	1	4
Guretzky et al. 2010	Journal	Love	Burneyville	2008-2011	1	192
		Tillman	Frederick	2008-2011	1	192
Haque et al. 2012	Journal	Carter	Ardmore	2008-2011	1	128
		Jefferson	Waurika	2008-2011	1	128
Kering et al. 2013	Journal	Carter	Ardmore	2008-2011	1	128
Taliaferro, 2002	Journal	Grady	Chickasha	1997-2000	32	156
		Payne	Perkins	1997-2000	24	96
Thomason, 2004	Journal	Grady	Chickasha	1997-2000	1	87
		Payne	Perkins	1998-2000	1	69
Wagle and Kakani, 2013	Journal	Grady	Chickasha	2011-2012	1	6
J. Todd	Dissertation	Payne	Perkins	2008-2010	2	6
			Stillwater	2010-2011	2	4
R. Sripathi	Thesis	Atoka	Lane	2011	21	21
		Grady	Chickasha	2011	21	21
		Payne	Stillwater	2011	21	21
		Woodward	Woodward	2011	21	21
T. Wilson	Thesis	Payne	Stillwater	2007-2009	9	27
C.M. Taliaferro[1]	Personal contact	Payne	Perkins	2003-2005	36	108
			Stillwater	2003-2005	36	108
J. Biermacher[2]	Personal contact	Carter	Ardmore	2009-2011	1	72
M. Buser[3]	Personal contact	Garvin	Maysville	2010-2012	1	7
		Texas	Guymon	2009-2012	5	71

[1] Professor (Retired), Department of Plant and Soil Science, Oklahoma State University.
[2] Associate Professor, The Samuel Roberts Noble Foundation, Ardmore, Oklahoma.
[3] Assistant Professor, Department of Biosystems and Ag. Engineering, Oklahoma State University.

Table I – 9. Average Observed Switchgrass Yield (Mg ha^{-1}) from Research Stations by County and Year.

Year	Atoka	Carter	Garvin	Grady	Jefferson	Love	Muskogee	Payne	Texas	Tillman	Woodward
1994				11.4			19.0				
1995				18.5			18.5				
1996				10.5			15.4				
1997				16.4			9.8	8.6			
1998				12.2			13.5	11.4			
1999				16.0			11.0	11.8			
2000				13.2			15.1	10.1			
2001				7.0			10.2				
2003								13.5			
2004								14.3			5.4
2005								12.4			6.5
2006											4.0
2007								19.6			9.8
2008		11.0			12.6	9.4		10.1		7.9	
2009		12.2			9.2	12.8		11.7	1.8	11.3	
2010	1.1	11.4	9.2	3.9	15.4	13.9		5.1	1.8	11.7	3.6
2011	9.2	5.7	1.5	9.2	2.8	9.5		20.2	0.0	1.5	4.9
2012			6.7	15.8					0.8		
Average	5.2	10.1	5.8	12.2	10.0	11.4	14.1	12.4	1.1	8.1	5.7

Table I – 10. Classification of Cultivars by Ecotype.

Ecotype	Cultivars						
Lowland	Alamo	Kanlow	Kanlow + Alamo	NL 92-1	NL 93-1	NL 93-2	NL 94 C2-1
	NL 94 C2-2	NL 94 C2-3	NL 94 C2-4	NL 94-1	NL 94-2001-1	NL C0	NL C1
	NL C2	NL-94	NL94 18-24	NL94 2001-1	NL94 2001-2	NL94 2001-3	NL94 2001-4
	NL94 27-23	NL94 28-22	NSL 2001-1	NSL 2001-10	NSL 2001-11	NSL 2001-12	NSL 2001-13
	NSL 2001-2	NSL 2001-3	NSL 2001-4	NSL 2001-5	NSL 2001-6	NSL 2001-7	NSL 2001-8
	NSL 2001-9	NSL 2009-1	NSL 2009-2	NSL 2009-3	NSL 2009-4	PMT 279	SL 92-1
	SL 93 2001-1	SL 93 C2-1	SL 93 C2-2	SL 93 C2-3	SL 93 C2-4	SL 93-1	SL 93-2
	SL 93-3	SL 94-1	SL C0	SL C1	SL C2	SL C3	SL-93
	SL93 10-13	SL93 2001-1	SL93 2001-2	SL93 2001-3	SL93 2001-4	SL93 2001-5	SL93 2001-6
	SL93 2001-7	SL93 5-16	SL93 6-8	SWG 2007-1	SWG 2007-2	SYN NL94-1	SYN SL93-3
	SYN SL94-1						
Upland	Blackwell	Cave-in-rock	NSU 95-2001-1	NU 92-1	NU 94-1	NU 94-2	NU C0 (Pathfinder)
	NU C1	NU C2	NU C3	Shelter	SNU 98 LMBP C1-1	SNU 98 LMBP C1-2	SNU 98 LMBP C1-3
	SU 92-1	SU 94-1	SU C1	SU C2	SU C3	SU C0 (Caddo)	SU93 12-19
	Summer	SWG 2007-3	SWG 2007-4	Trailblazer			
Mixtures	Alamo + Summer	Blackwell + Kanlow	EG1101	Late Synthetic High Yield	Alamo + Bluestem		

Table I – 11. Average Observed Switchgrass Yield (Mg ha^{-1}) from Research Stations by County, Location and Ecotype.

SN	County	Location	Lowland	Upland
1	Atoka	Lane	5.9	3.2
2	Carter	Ardmore1	7.4	
		Ardmore2	14.8	
3	Garvin	Maysville	4.4	
4	Grady	Chickasha	15.0	9.8
5	Jefferson	Waurika	10.0	
6	Love	Burneyville	11.4	
7	Muskogee	Haskell	16.6	11.2
8	Payne	Perkins	12.6	8.3
		Stillwater	13.7	10.0
9	Texas	Guymon	0.9	1.6
10	Tillman	Frederick	8.4	
11	Woodward	Ft. Supply		7.5
		Woodward	4.8	3.6

Table I – 12. Experiment Location by County and Mesonet Station ID.

SN	County	Location	Mesonet Station ID	Latitude	Longitude
1	Atoka	Lane	LANE	34.3	-96.0
2	Carter	Ardmore1	ARD2	34.2	-97.1
		Ardmore2	NEWP	34.2	-97.2
3	Garvin	Maysville	PAUL	34.7	-97.2
4	Grady	Chickasha	CHIC	35.0	-97.9
5	Jefferson	Waurika	RING	34.2	-97.6
6	Love	Burneyville	BURN	33.9	-97.3
7	Muskogee	Haskell	HASK	35.7	-95.6
8	Payne	Perkins	PERK	36.0	-97.0
		Stillwater	STIL	36.1	-97.1
9	Texas	Guymon	GOOD	36.6	-101.6
10	Tillman	Frederick	GRA2	34.2	-98.7
11	Woodward	Ft. Supply	WOOD	36.4	-99.4
		Woodward	WOOD	36.4	-99.4

Table I – 13. Predicted Switchgrass Yields (Mg ha^{-1}) by the Current and Other Studies and Switchgrass Yields (Mg ha^{-1}) in the BETY Database.

SN	County	Current Study				Gunderson et al. 2008		Debnath, Stoecker, and Epplin 2012	Jager et al. 2010	BETYdb
		Lowland		Upland						
		0KgN ha^{-1}	100Kg N ha^{-1}	0KgN ha^{-1}	100Kg N ha^{-1}	Lowland	Upland			
1	Adair	8.5	12.1	5.4	9.1	25.0	15.7		16.0	16.1
2	Alfalfa	8.8	12.4	5.8	9.4	23.5	13.1		12.1	7.8
3	Atoka	9.8	13.4	6.8	10.4	23.3	13.0	14.9	11.7	14.1
4	Beaver	6.2	9.8	3.2	6.8	20.6	10.3		12.8	7.6
5	Beckham	7.8	11.4	4.8	8.4	22.4	11.5		12.2	9.6
6	Blaine	8.7	12.3	5.7	9.3	23.2	12.5		12.3	5.8
7	Bryan	9.9	13.5	6.9	10.5	22.7	12.4		11.0	14.9
8	Caddo	8.7	12.3	5.7	9.3	23.3	12.5		11.8	10.6
9	Canadian	8.1	11.7	5.1	8.7	23.7	13.1	14.2	12.2	13.0
10	Carter	9.7	13.3	6.7	10.3	22.5	11.8		10.7	14.2
11	Cherokee	8.9	12.6	5.9	9.5	24.8	15.0		14.3	12.2
12	Choctaw	10.0	13.7	7.0	10.6	22.8	12.4		11.4	15.2
13	Cimarron	2.5	6.0	0.6	3.1	18.2	8.7		12.0	0.9
14	Cleveland	9.8	13.5	6.8	10.4	23.8	13.3	16.2	11.9	13.0
15	Coal	9.4	13.1	6.4	10.0	23.4	13.0	14.2	11.7	12.3
16	Comanche	8.8	12.4	5.8	9.4	22.8	12.0		11.2	9.9
17	Cotton	7.0	10.6	4.0	7.6	21.5	10.7		9.7	11.7
18	Craig	9.1	12.7	6.0	9.7	24.9	15.4		14.4	13.2
19	Creek	9.4	13.0	6.4	10.0	24.4	14.1	12.8	12.8	11.8
20	Custer	8.6	12.2	5.6	9.2	23.1	12.4		12.4	5.5
21	Delaware	8.6	12.3	5.6	9.2	25.0	15.4		15.2	11.8
22	Dewey	7.3	10.9	4.3	7.9	23.0	12.5		12.9	6.7
23	Ellis	6.5	10.2	3.5	7.1	21.9	11.5		13.2	5.8
24	Garfield	8.8	12.4	5.7	9.4	24.0	13.6		12.2	9.3
25	Garvin	9.5	13.1	6.5	10.1	23.4	12.8	15.3	11.3	14.0
26	Grady	9.3	12.9	6.2	9.9	23.4	12.7	14.7	11.8	11.9
27	Grant	9.3	12.9	6.2	9.9	24.0	13.7		12.2	12.2
28	Greer	8.4	12.0	5.4	9.0	22.4	11.4		10.8	11.7
29	Harmon	8.1	11.7	5.1	8.7	21.6	10.7		10.3	5.0
30	Harper	7.3	10.9	4.3	7.9	22.0	11.4		12.4	4.3
31	Haskell	9.3	13.0	6.3	9.9	24.2	14.0	15.8	12.4	11.1
32	Hughes	8.7	12.4	5.7	9.3	23.9	13.6	15.0	12.2	11.4
33	Jackson	8.8	12.4	5.8	9.4	21.8	10.9		9.8	11.4
34	Jefferson	9.6	13.2	6.6	10.2	21.4	10.7		10.0	12.3
35	Johnston	9.6	13.2	6.6	10.2	23.1	12.6	15.1	11.2	15.5
36	Kay	9.1	12.7	6.1	9.7	24.5	14.5		12.6	12.5
37	Kingfisher	9.2	12.8	6.2	9.8	23.6	13.0		11.7	10.6
38	Kiowa	9.6	13.2	6.6	10.2	22.7	11.9		11.2	11.8
39	Latimer	10.1	13.8	7.1	10.7	24.3	14.4	14.5	13.4	12.4
40	Le Flore	9.7	13.4	6.7	10.3	24.3	14.4		13.6	10.9
41	Lincoln	9.5	13.1	6.4	10.1	24.0	13.6	15.0	12.3	12.2

Table I – 13. Continued..

SN	County	Current Study				Gunderson et al. 2008		Debnath, Stoecker, and Epplin 2012	Jager et al. 2010	BETYdb
		Lowland		Upland						
		0KgN ha^{-1}	100Kg N ha^{-1}	0KgN ha^{-1}	100Kg N ha^{-1}	Lowland	Upland			
42	Logan	10.2	13.8	7.1	10.8	23.8	13.3	14.9	11.9	12.4
43	Love	9.8	13.4	6.7	10.4	21.9	11.3		10.4	13.1
44	Major	8.9	12.5	5.8	9.5	23.1	12.5		12.0	3.2
45	Marshall	9.6	13.2	6.6	10.2	22.5	12.1		10.6	14.2
46	Mayes	9.6	13.2	6.5	10.2	24.8	14.9		13.7	12.8
47	McClain	9.3	12.9	6.3	9.9	23.6	13.1	14.6	11.8	12.1
48	McCurtain	9.7	13.3	6.6	10.3	23.6	13.6		13.2	14.1
49	McIntosh	9.8	13.4	6.8	10.4	24.2	14.0	15.1	12.5	15.9
50	Murray	9.1	12.8	6.1	9.7	23.4	12.9	15.2	11.7	8.7
51	Muskogee	9.8	13.4	6.8	10.4	24.4	14.2	15.6	12.6	13.2
52	Noble	9.3	13.0	6.3	9.9	24.3	14.1	13.6	12.3	11.9
53	Nowata	9.3	13.0	6.3	9.9	24.8	15.1		13.8	10.5
54	Okfuskee	9.9	13.5	6.8	10.5	24.2	13.9	16.6	12.5	12.3
55	Oklahoma	10.8	14.4	7.7	11.4	23.7	13.2	16.6	12.1	9.9
56	Okmulgee	9.5	13.1	6.5	10.1	24.3	14.1	14.9	12.8	11.7
57	Osage	9.2	12.8	6.2	9.8	24.7	14.9	14.6	13.2	12.1
58	Ottawa	9.6	13.2	6.5	10.2	25.0	15.6		15.0	12.1
59	Pawnee	9.3	12.9	6.3	9.9	24.5	14.4	14.7	12.7	13.9
60	Payne	9.8	13.4	6.8	10.4	24.3	14.1	14.5	12.6	11.5
61	Pittsburg	9.6	13.2	6.6	10.2	24.1	13.9	15.3	12.5	13.1
62	Pontotoc	9.4	13.0	6.4	10.0	23.6	13.2	14.4	12.0	15.4
63	Pottawatomie	9.5	13.1	6.5	10.1	23.8	13.3	15.5	11.9	11.7
64	Pushmataha	9.8	13.4	6.8	10.4	23.9	13.9		13.0	12.4
65	Roger Mills	7.2	10.9	4.3	7.8	22.3	11.7		13.0	10.0
66	Rogers	9.7	13.3	6.7	10.3	24.7	14.9		13.5	11.3
67	Seminole	9.4	13.0	6.4	10.0	23.8	13.4	15.6	11.9	14.2
68	Sequoyah	10.0	13.7	7.0	10.6	24.4	14.3		13.4	12.3
69	Stephens	9.7	13.3	6.7	10.3	22.8	12.1		11.1	10.9
70	Texas	4.7	8.3	1.8	5.3	19.2	9.0		12.6	2.3
71	Tillman	9.0	12.7	6.0	9.6	21.5	10.7		9.7	11.7
72	Tulsa	10.2	13.8	7.1	10.8	24.6	14.5	14.9	13.1	14.3
73	Wagoner	9.8	13.4	6.8	10.4	24.6	14.5	17.7	12.9	12.5
74	Washington	9.7	13.3	6.6	10.3	24.7	14.8		13.3	10.5
75	Washita	8.7	12.3	5.7	9.3	23.0	12.2		11.8	7.8
76	Woods	8.2	11.8	5.2	8.8	22.9	12.4		12.2	6.6
77	Woodward	7.9	11.5	4.9	8.5	22.4	12.0		12.8	5.1

Table I – 14. Observed Switchgrass Yield (Mg ha^{-1}) by Year, Location, Cultivar and Level of Fertilizers Applied.

SN	Year	County	Location	Cultivar	Ecotype	Latitude	Longitude	Kg Ha^{-1}			Yield (Mg Ha^{-1})
								N	P	K	
1	1994	Grady	Chickasha	Alamo	Lowland	35.0	-97.9	78	0	0	13.6
2	1994	Grady	Chickasha	Blackwell	Upland	35.0	-97.9	78	0	0	13.5
3	1994	Grady	Chickasha	Caddo	Upland	35.0	-97.9	78	0	0	11.1
4	1994	Grady	Chickasha	Cave-in-rock	Upland	35.0	-97.9	78	0	0	5.6
5	1994	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	78	0	0	11.0
6	1994	Grady	Chickasha	Late Syn High Yield	Upland	35.0	-97.9	78	0	0	12.4
7	1994	Grady	Chickasha	PMT 279	Lowland	35.0	-97.9	78	0	0	12.0
8	1995	Grady	Chickasha	Alamo	Lowland	35.0	-97.9	78	0	0	21.4
9	1995	Grady	Chickasha	Blackwell	Upland	35.0	-97.9	78	0	0	11.8
10	1995	Grady	Chickasha	Caddo	Upland	35.0	-97.9	78	0	0	15.2
11	1995	Grady	Chickasha	Cave-in-rock	Upland	35.0	-97.9	78	0	0	9.5
12	1995	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	78	0	0	26.5
13	1995	Grady	Chickasha	Late Syn High Yield	Upland	35.0	-97.9	78	0	0	16.9
14	1995	Grady	Chickasha	PMT 279	Lowland	35.0	-97.9	78	0	0	21.2
15	1996	Grady	Chickasha	Alamo	Lowland	35.0	-97.9	78	0	0	12.5
16	1996	Grady	Chickasha	Blackwell	Upland	35.0	-97.9	78	0	0	9.5
17	1996	Grady	Chickasha	Caddo	Upland	35.0	-97.9	78	0	0	8.1
18	1996	Grady	Chickasha	Cave-in-rock	Upland	35.0	-97.9	78	0	0	8.2
19	1996	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	78	0	0	10.1
20	1996	Grady	Chickasha	Late Syn High Yield	Upland	35.0	-97.9	78	0	0	10.8
21	1996	Grady	Chickasha	PMT 279	Lowland	35.0	-97.9	78	0	0	9.5
22	1997	Grady	Chickasha	Alamo	Lowland	35.0	-97.9	71	0	0	13.9
23	1997	Grady	Chickasha	Alamo	Lowland	35.0	-97.9	78	0	0	9.8
24	1997	Grady	Chickasha	Blackwell	Upland	35.0	-97.9	71	0	0	9.8
25	1997	Grady	Chickasha	Blackwell	Upland	35.0	-97.9	78	0	0	9.0
26	1997	Grady	Chickasha	Caddo	Upland	35.0	-97.9	71	0	0	10.0
27	1997	Grady	Chickasha	Caddo	Upland	35.0	-97.9	78	0	0	6.3
28	1997	Grady	Chickasha	Cave-in-rock	Upland	35.0	-97.9	71	0	0	10.1
29	1997	Grady	Chickasha	Cave-in-rock	Upland	35.0	-97.9	78	0	0	7.1
30	1997	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	0	224	560	22.2
31	1997	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	78	0	0	9.4
32	1997	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	112	224	560	17.4
33	1997	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	224	224	560	16.4
34	1997	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	448	224	560	16.9
35	1997	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	896	224	560	20.3
36	1997	Grady	Chickasha	Late Syn High Yield	Upland	35.0	-97.9	78	0	0	7.8
37	1997	Grady	Chickasha	Lowland Type	Lowland	35.0	-97.9	71	0	0	12.2
38	1997	Grady	Chickasha	Pathfinder	Upland	35.0	-97.9	71	0	0	8.6
39	1997	Grady	Chickasha	PMT 279	Lowland	35.0	-97.9	78	0	0	9.0
40	1997	Grady	Chickasha	Upland Type	Upland	35.0	-97.9	71	0	0	9.7
41	1998	Grady	Chickasha	Alamo	Lowland	35.0	-97.9	71	0	0	14.8
42	1998	Grady	Chickasha	Alamo	Lowland	35.0	-97.9	78	0	0	6.7
43	1998	Grady	Chickasha	Blackwell	Upland	35.0	-97.9	71	0	0	8.4
44	1998	Grady	Chickasha	Blackwell	Upland	35.0	-97.9	78	0	0	6.3
45	1998	Grady	Chickasha	Caddo	Upland	35.0	-97.9	71	0	0	7.2
46	1998	Grady	Chickasha	Caddo	Upland	35.0	-97.9	78	0	0	5.2
47	1998	Grady	Chickasha	Cave-in-rock	Upland	35.0	-97.9	71	0	0	6.1
48	1998	Grady	Chickasha	Cave-in-rock	Upland	35.0	-97.9	78	0	0	5.0
49	1998	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	0	224	560	16.6
50	1998	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	71	0	0	7.2

Table I – 14. Continued..

51	1998	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	78	0	0	7.5
52	1998	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	112	224	560	14.1
53	1998	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	224	224	560	15.8
54	1998	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	448	224	560	17.2
55	1998	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	896	224	560	10.0
56	1998	Grady	Chickasha	Late Syn High Yield	Upland	35.0	-97.9	78	0	0	6.0
57	1998	Grady	Chickasha	Lowland Type	Lowland	35.0	-97.9	71	0	0	14.8
58	1998	Grady	Chickasha	Pathfinder	Upland	35.0	-97.9	71	0	0	6.7
59	1998	Grady	Chickasha	PMT 279	Lowland	35.0	-97.9	78	0	0	7.2
60	1998	Grady	Chickasha	Upland Type	Upland	35.0	-97.9	71	0	0	8.0
61	1999	Grady	Chickasha	Alamo	Lowland	35.0	-97.9	71	0	0	20.5
62	1999	Grady	Chickasha	Alamo	Lowland	35.0	-97.9	78	0	0	13.9
63	1999	Grady	Chickasha	Blackwell	Upland	35.0	-97.9	71	0	0	13.9
64	1999	Grady	Chickasha	Blackwell	Upland	35.0	-97.9	78	0	0	12.4
65	1999	Grady	Chickasha	Caddo	Upland	35.0	-97.9	71	0	0	12.5
66	1999	Grady	Chickasha	Caddo	Upland	35.0	-97.9	78	0	0	11.6
67	1999	Grady	Chickasha	Cave-in-rock	Upland	35.0	-97.9	71	0	0	11.9
68	1999	Grady	Chickasha	Cave-in-rock	Upland	35.0	-97.9	78	0	0	10.4
69	1999	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	0	224	560	10.9
70	1999	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	71	0	0	19.0
71	1999	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	78	0	0	15.0
72	1999	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	112	224	560	15.0
73	1999	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	224	224	560	16.2
74	1999	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	448	224	560	19.1
75	1999	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	896	224	560	11.4
76	1999	Grady	Chickasha	Late Syn High Yield	Upland	35.0	-97.9	78	0	0	10.4
77	1999	Grady	Chickasha	Lowland Type	Lowland	35.0	-97.9	71	0	0	19.8
78	1999	Grady	Chickasha	Pathfinder	Upland	35.0	-97.9	71	0	0	12.8
79	1999	Grady	Chickasha	PMT 279	Lowland	35.0	-97.9	78	0	0	14.1
80	1999	Grady	Chickasha	Upland Type	Upland	35.0	-97.9	71	0	0	13.2
81	2000	Grady	Chickasha	Alamo	Lowland	35.0	-97.9	71	0	0	15.5
82	2000	Grady	Chickasha	Alamo	Lowland	35.0	-97.9	78	0	0	11.8
83	2000	Grady	Chickasha	Blackwell	Upland	35.0	-97.9	71	0	0	13.5
84	2000	Grady	Chickasha	Blackwell	Upland	35.0	-97.9	78	0	0	10.6
85	2000	Grady	Chickasha	Caddo	Upland	35.0	-97.9	71	0	0	11.8
86	2000	Grady	Chickasha	Caddo	Upland	35.0	-97.9	78	0	0	10.8
87	2000	Grady	Chickasha	Cave-in-rock	Upland	35.0	-97.9	71	0	0	11.1
88	2000	Grady	Chickasha	Cave-in-rock	Upland	35.0	-97.9	78	0	0	7.5
89	2000	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	71	0	0	16.8
90	2000	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	78	0	0	12.4
91	2000	Grady	Chickasha	Late Syn High Yield	Upland	35.0	-97.9	78	0	0	10.8
92	2000	Grady	Chickasha	Lowland Type	Lowland	35.0	-97.9	71	0	0	15.3
93	2000	Grady	Chickasha	Pathfinder	Upland	35.0	-97.9	71	0	0	11.6
94	2000	Grady	Chickasha	PMT 279	Lowland	35.0	-97.9	78	0	0	10.6
95	2000	Grady	Chickasha	Upland Type	Upland	35.0	-97.9	71	0	0	12.9
96	2001	Grady	Chickasha	Alamo	Lowland	35.0	-97.9	78	0	0	7.6
97	2001	Grady	Chickasha	Blackwell	Upland	35.0	-97.9	78	0	0	6.9
98	2001	Grady	Chickasha	Caddo	Upland	35.0	-97.9	78	0	0	6.6
99	2001	Grady	Chickasha	Cave-in-rock	Upland	35.0	-97.9	78	0	0	5.3
100	2001	Grady	Chickasha	Kanlow	Lowland	35.0	-97.9	78	0	0	7.8
101	2001	Grady	Chickasha	Late Syn High Yield	Upland	35.0	-97.9	78	0	0	5.9
102	2001	Grady	Chickasha	PMT 279	Lowland	35.0	-97.9	78	0	0	7.9
103	2011	Grady	Chickasha	Alamo	Lowland	35.0	-98.0	75	0	0	4.7
104	2011	Grady	Chickasha	Alamo	Lowland	35.1	-97.5	85	0	0	11.3
105	2011	Grady	Chickasha	Cave-in-rock	Upland	35.1	-97.5	85	0	0	5.9

Table I – 14. Continued..

106	2011	Grady	Chickasha	Lowland Type	Lowland	35.1	-97.5	85	0	0	10.9
107	2011	Grady	Chickasha	Upland Type	Upland	35.1	-97.5	85	0	0	7.4
108	2012	Grady	Chickasha	Alamo	Lowland	35.0	-98.0	75	0	0	15.8
109	2009	Texas	Guymon	Alamo	Lowland	36.4	-101.2	0	0	0	1.4
110	2009	Texas	Guymon	Blackwell	Upland	36.4	-101.2	0	0	0	2.2
111	2009	Texas	Guymon	Kanlow	Lowland	36.4	-101.2	0	0	0	1.7
112	2009	Texas	Guymon	Trailblazer	Upland	36.4	-101.2	0	0	0	1.9
113	2010	Texas	Guymon	Alamo	Lowland	36.4	-101.2	0	0	0	0.3
114	2010	Texas	Guymon	Blackwell	Upland	36.4	-101.2	0	0	0	3.0
115	2010	Texas	Guymon	Kanlow	Lowland	36.4	-101.2	0	0	0	1.4
116	2010	Texas	Guymon	Trailblazer	Upland	36.4	-101.2	0	0	0	1.6
117	2011	Texas	Guymon	Alamo	Lowland	36.4	-101.2	0	0	0	0.0
118	2011	Texas	Guymon	Blackwell	Upland	36.4	-101.2	0	0	0	0.0
119	2011	Texas	Guymon	Kanlow	Lowland	36.4	-101.2	0	0	0	0.0
120	2011	Texas	Guymon	Trailblazer	Upland	36.4	-101.2	0	0	0	0.0
121	2012	Texas	Guymon	Alamo	Lowland	36.4	-101.2	68	0	0	0.5
122	2012	Texas	Guymon	Blackwell	Upland	36.4	-101.2	68	0	0	0.9
123	2012	Texas	Guymon	Kanlow	Lowland	36.4	-101.2	68	0	0	0.0
124	2012	Texas	Guymon	Trailblazer	Upland	36.4	-101.2	68	0	0	2.6
125	1994	Muskogee	Haskell	Alamo	Lowland	35.7	-95.6	90	0	0	26.6
126	1994	Muskogee	Haskell	Blackwell	Upland	35.7	-95.6	90	0	0	16.8
127	1994	Muskogee	Haskell	Caddo	Upland	35.7	-95.6	90	0	0	18.6
128	1994	Muskogee	Haskell	Cave-in-rock	Upland	35.7	-95.6	90	0	0	15.8
129	1994	Muskogee	Haskell	Kanlow	Lowland	35.7	-95.6	90	0	0	20.2
130	1994	Muskogee	Haskell	Late Syn High Yield	Upland	35.7	-95.6	90	0	0	16.9
131	1994	Muskogee	Haskell	PMT 279	Lowland	35.7	-95.6	90	0	0	17.4
132	1994	Muskogee	Haskell	Shelter	Upland	35.7	-95.6	90	0	0	15.2
133	1994	Muskogee	Haskell	Summer	Upland	35.7	-95.6	90	0	0	8.0
134	1995	Muskogee	Haskell	Alamo	Lowland	35.7	-95.6	90	0	0	17.1
135	1995	Muskogee	Haskell	Blackwell	Upland	35.7	-95.6	90	0	0	20.3
136	1995	Muskogee	Haskell	Caddo	Upland	35.7	-95.6	90	0	0	16.9
137	1995	Muskogee	Haskell	Cave-in-rock	Upland	35.7	-95.6	90	0	0	21.1
138	1995	Muskogee	Haskell	Kanlow	Lowland	35.7	-95.6	90	0	0	17.9
139	1995	Muskogee	Haskell	Late Syn High Yield	Upland	35.7	-95.6	90	0	0	19.3
140	1995	Muskogee	Haskell	PMT 279	Lowland	35.7	-95.6	90	0	0	18.5
141	1995	Muskogee	Haskell	Shelter	Upland	35.7	-95.6	90	0	0	18.9
142	1995	Muskogee	Haskell	Summer	Upland	35.7	-95.6	90	0	0	10.6
143	1996	Muskogee	Haskell	Alamo	Lowland	35.7	-95.6	90	0	0	15.7
144	1996	Muskogee	Haskell	Blackwell	Upland	35.7	-95.6	90	0	0	11.4
145	1996	Muskogee	Haskell	Caddo	Upland	35.7	-95.6	90	0	0	12.2
146	1996	Muskogee	Haskell	Cave-in-rock	Upland	35.7	-95.6	90	0	0	14.0
147	1996	Muskogee	Haskell	Kanlow	Lowland	35.7	-95.6	90	0	0	18.7
148	1996	Muskogee	Haskell	Late Syn High Yield	Upland	35.7	-95.6	90	0	0	11.6
149	1996	Muskogee	Haskell	PMT 279	Lowland	35.7	-95.6	90	0	0	18.4
150	1996	Muskogee	Haskell	Shelter	Upland	35.7	-95.6	90	0	0	10.9
151	1996	Muskogee	Haskell	Summer	Upland	35.7	-95.6	90	0	0	10.5
152	1997	Muskogee	Haskell	Alamo	Lowland	35.7	-95.6	90	0	0	13.0
153	1997	Muskogee	Haskell	Blackwell	Upland	35.7	-95.6	90	0	0	6.6
154	1997	Muskogee	Haskell	Caddo	Upland	35.7	-95.6	90	0	0	7.3
155	1997	Muskogee	Haskell	Cave-in-rock	Upland	35.7	-95.6	90	0	0	5.9
156	1997	Muskogee	Haskell	Kanlow	Lowland	35.7	-95.6	90	0	0	13.4
157	1997	Muskogee	Haskell	Late Syn High Yield	Upland	35.7	-95.6	90	0	0	5.9
158	1997	Muskogee	Haskell	PMT 279	Lowland	35.7	-95.6	90	0	0	13.7
159	1997	Muskogee	Haskell	Shelter	Upland	35.7	-95.6	90	0	0	6.0
160	1997	Muskogee	Haskell	Summer	Upland	35.7	-95.6	90	0	0	5.2

Table I – 14. Continued..

161	1998	Muskogee	Haskell	Alamo	Lowland	35.7	-95.6	90	0	0	16.8
162	1998	Muskogee	Haskell	Blackwell	Upland	35.7	-95.6	90	0	0	12.5
163	1998	Muskogee	Haskell	Caddo	Upland	35.7	-95.6	90	0	0	10.8
164	1998	Muskogee	Haskell	Cave-in-rock	Upland	35.7	-95.6	90	0	0	9.2
165	1998	Muskogee	Haskell	Kanlow	Lowland	35.7	-95.6	90	0	0	17.8
166	1998	Muskogee	Haskell	Late Syn High Yield	Upland	35.7	-95.6	90	0	0	10.5
167	1998	Muskogee	Haskell	PMT 279	Lowland	35.7	-95.6	90	0	0	20.0
168	1998	Muskogee	Haskell	Shelter	Upland	35.7	-95.6	90	0	0	8.1
169	1998	Muskogee	Haskell	Summer	Upland	35.7	-95.6	90	0	0	8.0
170	1999	Muskogee	Haskell	Alamo	Lowland	35.7	-95.6	90	0	0	13.4
171	1999	Muskogee	Haskell	Blackwell	Upland	35.7	-95.6	90	0	0	9.4
172	1999	Muskogee	Haskell	Caddo	Upland	35.7	-95.6	90	0	0	10.5
173	1999	Muskogee	Haskell	Cave-in-rock	Upland	35.7	-95.6	90	0	0	7.9
174	1999	Muskogee	Haskell	Kanlow	Lowland	35.7	-95.6	90	0	0	15.5
175	1999	Muskogee	Haskell	Late Syn High Yield	Upland	35.7	-95.6	90	0	0	8.6
176	1999	Muskogee	Haskell	PMT 279	Lowland	35.7	-95.6	90	0	0	13.0
177	1999	Muskogee	Haskell	Shelter	Upland	35.7	-95.6	90	0	0	7.5
178	1999	Muskogee	Haskell	Summer	Upland	35.7	-95.6	90	0	0	8.0
179	2000	Muskogee	Haskell	Alamo	Lowland	35.7	-95.6	90	0	0	16.5
180	2000	Muskogee	Haskell	Blackwell	Upland	35.7	-95.6	90	0	0	12.7
181	2000	Muskogee	Haskell	Caddo	Upland	35.7	-95.6	90	0	0	12.6
182	2000	Muskogee	Haskell	Cave-in-rock	Upland	35.7	-95.6	90	0	0	11.9
183	2000	Muskogee	Haskell	Kanlow	Lowland	35.7	-95.6	90	0	0	20.7
184	2000	Muskogee	Haskell	Late Syn High Yield	Upland	35.7	-95.6	90	0	0	11.9
185	2000	Muskogee	Haskell	PMT 279	Lowland	35.7	-95.6	90	0	0	16.0
186	2000	Muskogee	Haskell	Shelter	Upland	35.7	-95.6	90	0	0	10.1
187	2000	Muskogee	Haskell	Summer	Upland	35.7	-95.6	90	0	0	14.6
188	2001	Muskogee	Haskell	Alamo	Lowland	35.7	-95.6	90	0	0	12.1
189	2001	Muskogee	Haskell	Blackwell	Upland	35.7	-95.6	90	0	0	10.7
190	2001	Muskogee	Haskell	Caddo	Upland	35.7	-95.6	90	0	0	9.2
191	2001	Muskogee	Haskell	Cave-in-rock	Upland	35.7	-95.6	90	0	0	8.4
192	2001	Muskogee	Haskell	Kanlow	Lowland	35.7	-95.6	90	0	0	10.7
193	2001	Muskogee	Haskell	Late Syn High Yield	Upland	35.7	-95.6	90	0	0	8.7
194	2001	Muskogee	Haskell	PMT 279	Lowland	35.7	-95.6	90	0	0	9.7
195	2001	Muskogee	Haskell	Shelter	Upland	35.7	-95.6	90	0	0	6.7
196	2001	Muskogee	Haskell	Summer	Upland	35.7	-95.6	90	0	0	8.9
197	2011	Atoka	Lane	Alamo	Lowland	34.2	-95.6	85	0	0	10.8
198	2011	Atoka	Lane	Cave-in-rock	Upland	34.2	-95.6	85	0	0	5.2
199	2011	Atoka	Lane	Lowland Type	Lowland	34.2	-95.6	85	0	0	10.5
200	2011	Atoka	Lane	Upland Type	Upland	34.2	-95.6	85	0	0	6.2
201	2010	Garvin	Maysville	Alamo	Lowland	34.5	-97.3	0	0	0	9.2
202	2011	Garvin	Maysville	Alamo	Lowland	34.5	-97.3	0	0	0	1.5
203	2012	Garvin	Maysville	Alamo	Lowland	34.5	-97.3	68	0	0	6.7
204	1997	Payne	Perkins	Alamo	Lowland	36.0	-97.0	71	0	0	12.3
205	1997	Payne	Perkins	Blackwell	Upland	36.0	-97.0	71	0	0	6.1
206	1997	Payne	Perkins	Caddo	Upland	36.0	-97.0	71	0	0	6.4
207	1997	Payne	Perkins	Cave-in-rock	Upland	36.0	-97.0	71	0	0	6.6
208	1997	Payne	Perkins	Lowland Type	Lowland	36.0	-97.0	71	0	0	11.4
209	1997	Payne	Perkins	Pathfinder	Upland	36.0	-97.0	71	0	0	5.8
210	1997	Payne	Perkins	Upland Type	Upland	36.0	-97.0	71	0	0	6.1
211	1998	Payne	Perkins	Alamo	Lowland	36.0	-97.0	71	0	0	14.9
212	1998	Payne	Perkins	Blackwell	Upland	36.0	-97.0	71	0	0	9.0
213	1998	Payne	Perkins	Caddo	Upland	36.0	-97.0	71	0	0	7.8
214	1998	Payne	Perkins	Cave-in-rock	Upland	36.0	-97.0	71	0	0	7.4
215	1998	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	0	224	560	10.6

Table I – 14. Continued..

216	1998	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	112	224	560	8.4
217	1998	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	224	224	560	10.2
218	1998	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	448	224	560	11.9
219	1998	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	896	224	560	10.4
220	1998	Payne	Perkins	Lowland Type	Lowland	36.0	-97.0	71	0	0	15.8
221	1998	Payne	Perkins	Pathfinder	Upland	36.0	-97.0	71	0	0	7.1
222	1998	Payne	Perkins	Upland Type	Upland	36.0	-97.0	71	0	0	8.6
223	1999	Payne	Perkins	Alamo	Lowland	36.0	-97.0	71	0	0	16.2
224	1999	Payne	Perkins	Blackwell	Upland	36.0	-97.0	71	0	0	9.6
225	1999	Payne	Perkins	Caddo	Upland	36.0	-97.0	71	0	0	8.8
226	1999	Payne	Perkins	Cave-in-rock	Upland	36.0	-97.0	71	0	0	11.2
227	1999	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	0	224	560	7.0
228	1999	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	112	224	560	9.7
229	1999	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	224	224	560	7.2
230	1999	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	448	224	560	9.1
231	1999	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	896	224	560	10.5
232	1999	Payne	Perkins	Lowland Type	Lowland	36.0	-97.0	71	0	0	17.8
233	1999	Payne	Perkins	Pathfinder	Upland	36.0	-97.0	71	0	0	8.4
234	1999	Payne	Perkins	Upland Type	Upland	36.0	-97.0	71	0	0	11.0
235	2000	Payne	Perkins	Alamo	Lowland	36.0	-97.0	71	0	0	10.6
236	2000	Payne	Perkins	Blackwell	Upland	36.0	-97.0	71	0	0	7.5
237	2000	Payne	Perkins	Caddo	Upland	36.0	-97.0	71	0	0	4.4
238	2000	Payne	Perkins	Cave-in-rock	Upland	36.0	-97.0	71	0	0	7.7
239	2000	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	0	224	560	9.9
240	2000	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	112	224	560	8.5
241	2000	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	224	224	560	11.7
242	2000	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	448	224	560	9.9
243	2000	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	896	224	560	12.6
244	2000	Payne	Perkins	Lowland Type	Lowland	36.0	-97.0	71	0	0	10.9
245	2000	Payne	Perkins	Pathfinder	Upland	36.0	-97.0	71	0	0	5.9
246	2000	Payne	Perkins	Upland Type	Upland	36.0	-97.0	71	0	0	6.7
247	2003	Payne	Perkins	Alamo	Lowland	36.0	-97.0	100.8	0	0	13.3
248	2003	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	100.8	0	0	11.3
249	2003	Payne	Perkins	Lowland Type	Lowland	36.0	-97.0	100.8	0	0	13.6
250	2003	Payne	Perkins	Upland Type	Upland	36.0	-97.0	100.8	0	0	15.7
251	2004	Payne	Perkins	Alamo	Lowland	36.0	-97.0	100.8	0	0	12.9
252	2004	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	100.8	0	0	11.5
253	2004	Payne	Perkins	Lowland Type	Lowland	36.0	-97.0	100.8	0	0	13.8
254	2004	Payne	Perkins	Upland Type	Upland	36.0	-97.0	100.8	0	0	16.9
255	2005	Payne	Perkins	Alamo	Lowland	36.0	-97.0	100.8	0	0	14.1
256	2005	Payne	Perkins	Kanlow	Lowland	36.0	-97.0	100.8	0	0	12.8
257	2005	Payne	Perkins	Lowland Type	Lowland	36.0	-97.0	100.8	0	0	13.9
258	2005	Payne	Perkins	Upland Type	Upland	36.0	-97.0	100.8	0	0	15.8
259	2008	Payne	Perkins	Lowland Type	Lowland	35.6	-97.0	224	0	0	2.3
260	2009	Payne	Perkins	Lowland Type	Lowland	35.6	-97.0	224	0	0	4.0
261	2010	Payne	Perkins	Lowland Type	Lowland	35.6	-97.0	224	0	0	5.2
262	2003	Payne	Stillwater	Alamo	Lowland	36.1	-97.1	100.8	0	0	13.8
263	2003	Payne	Stillwater	Kanlow	Lowland	36.1	-97.1	100.8	0	0	10.7
264	2003	Payne	Stillwater	Lowland Type	Lowland	36.1	-97.1	100.8	0	0	13.5
265	2003	Payne	Stillwater	Upland Type	Upland	36.1	-97.1	100.8	0	0	12.9
266	2004	Payne	Stillwater	Alamo	Lowland	36.1	-97.1	100.8	0	0	15.4
267	2004	Payne	Stillwater	Kanlow	Lowland	36.1	-97.1	100.8	0	0	13.4
268	2004	Payne	Stillwater	Lowland Type	Lowland	36.1	-97.1	100.8	0	0	14.9
269	2004	Payne	Stillwater	Upland Type	Upland	36.1	-97.1	100.8	0	0	15.2
270	2005	Payne	Stillwater	Alamo	Lowland	36.1	-97.1	100.8	0	0	11.8

Table I – 14. Continued..

271	2005	Payne	Stillwater	Kanlow	Lowland	36.1	-97.1	100.8	0	0	10.1
272	2005	Payne	Stillwater	Lowland Type	Lowland	36.1	-97.1	100.8	0	0	10.9
273	2005	Payne	Stillwater	Upland Type	Upland	36.1	-97.1	100.8	0	0	11.8
274	2007	Payne	Stillwater	Alamo	Lowland	36.1	-97.1	90	0	0	23.3
275	2007	Payne	Stillwater	Blackwell	Upland	36.1	-97.1	90	0	0	11.3
276	2007	Payne	Stillwater	Cave-in-rock	Upland	36.1	-97.1	90	0	0	11.6
277	2007	Payne	Stillwater	Kanlow	Lowland	36.1	-97.1	90	0	0	21.0
278	2007	Payne	Stillwater	Lowland Type	Lowland	36.1	-97.1	90	0	0	24.3
279	2007	Payne	Stillwater	Upland Type	Upland	36.1	-97.1	90	0	0	12.1
280	2008	Payne	Stillwater	Alamo	Lowland	36.1	-97.1	90	0	0	11.7
281	2008	Payne	Stillwater	Blackwell	Upland	36.1	-97.1	90	0	0	8.4
282	2008	Payne	Stillwater	Cave-in-rock	Upland	36.1	-97.1	90	0	0	8.0
283	2008	Payne	Stillwater	Kanlow	Lowland	36.1	-97.1	90	0	0	10.8
284	2008	Payne	Stillwater	Lowland Type	Lowland	36.1	-97.1	90	0	0	13.6
285	2008	Payne	Stillwater	Upland Type	Upland	36.1	-97.1	90	0	0	9.2
286	2009	Payne	Stillwater	Alamo	Lowland	36.1	-97.1	90	0	0	13.5
287	2009	Payne	Stillwater	Blackwell	Upland	36.1	-97.1	90	0	0	11.3
288	2009	Payne	Stillwater	Cave-in-rock	Upland	36.1	-97.1	90	0	0	8.6
289	2009	Payne	Stillwater	Kanlow	Lowland	36.1	-97.1	90	0	0	14.7
290	2009	Payne	Stillwater	Lowland Type	Lowland	36.1	-97.1	90	0	0	17.0
291	2009	Payne	Stillwater	Upland Type	Upland	36.1	-97.1	90	0	0	10.0
292	2010	Payne	Stillwater	Lowland Type	Lowland	35.6	-97.0	224	0	0	2.4
293	2011	Payne	Stillwater	Alamo	Lowland	36.1	-97.1	85	0	0	26.5
294	2011	Payne	Stillwater	Cave-in-rock	Upland	36.1	-97.1	85	0	0	12.8
295	2011	Payne	Stillwater	Lowland Type	Lowland	35.6	-97.0	224	0	0	1.7
296	2011	Payne	Stillwater	Lowland Type	Lowland	36.1	-97.1	85	0	0	24.3
297	2011	Payne	Stillwater	Upland Type	Upland	36.1	-97.1	85	0	0	16.5
298	2004	Woodward	Woodward	Blackwell	Upland	36.3	-99.2	0	0	0	5.4
299	2005	Woodward	Ft. Supply	Blackwell	Upland	36.3	-99.2	0	0	0	5.8
300	2005	Woodward	Woodward	Blackwell	Upland	36.3	-99.2	0	0	0	7.2
301	2006	Woodward	Ft. Supply	Blackwell	Upland	36.3	-99.2	0	0	0	5.9
302	2006	Woodward	Woodward	Blackwell	Upland	36.3	-99.2	0	0	0	2.1
303	2007	Woodward	Ft. Supply	Blackwell	Upland	36.3	-99.2	0	0	0	10.8
304	2007	Woodward	Woodward	Blackwell	Upland	36.3	-99.2	0	0	0	8.7
305	2011	Woodward	Woodward	Alamo	Lowland	36.3	-99.2	85	0	0	5.0
306	2011	Woodward	Woodward	Cave-in-rock	Upland	36.3	-99.2	85	0	0	4.0
307	2011	Woodward	Woodward	Lowland Type	Lowland	36.3	-99.2	85	0	0	5.5
308	2011	Woodward	Woodward	Upland Type	Upland	36.3	-99.2	85	0	0	3.4

Note: Not all observations used in the study are presented in the above table.

Table I – 15. Counties Classified by Region for Yearly Yield Variation.

SN	West	Central	East
1	Alfalfa	Canadian	Adair
2	Beaver	Carter	Atoka
3	Beckham	Cleveland	Bryan
4	Blaine	Coal	Cherokee
5	Caddo	Creek	Choctaw
6	Cimarron	Garfield	Craig
7	Comanche	Garvin	Delaware
8	Cotton	Grady	Haskell
9	Custer	Grant	Latimer
10	Dewey	Hughes	LeFlore
11	Ellis	Jefferson	Mayes
12	Greer	Johnston	McCurtain
13	Harmon	Kay	McIntosh
14	Harper	Kingfisher	Muskogee
15	Jackson	Lincoln	Nowata
16	Kiowa	Logan	Okmulgee
17	Major	Love	Ottawa
18	Roger Mills	Marshall	Pittsburg
19	Texas	McClain	Pushmataha
20	Tillman	Murray	Rogers
21	Washita	Noble	Sequoyah
22	Woods	Okfuskee	Tulsa
23	Woodward	Oklahoma	Wagoner
24		Osage	Washington
25		Pawnee	
26		Payne	
27		Pontotoc	
28		Pottawatomie	
29		Seminole	
30		Stephens	

Appendix I – B: Figures

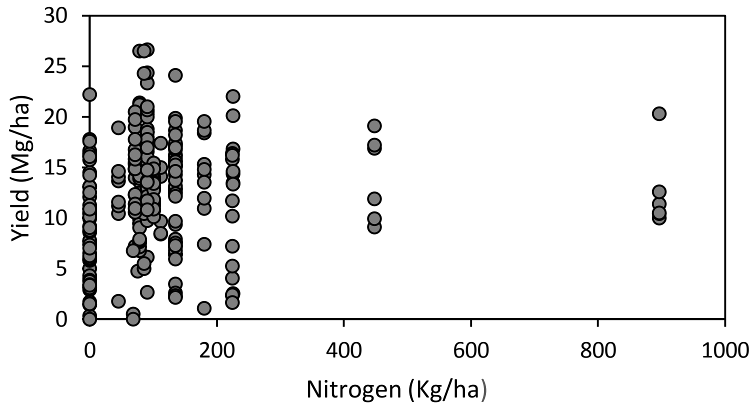

Figure I - 5. Lowland Switchgrass Response to Nitrogen.

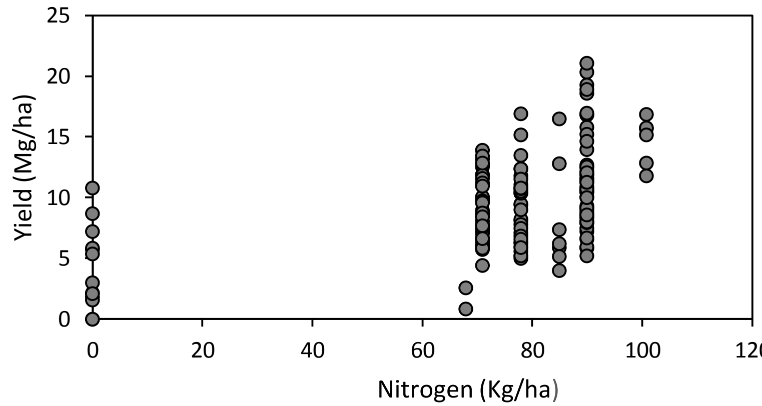

Figure I - 6. Upland Switchgrass Response to Nitrogen.

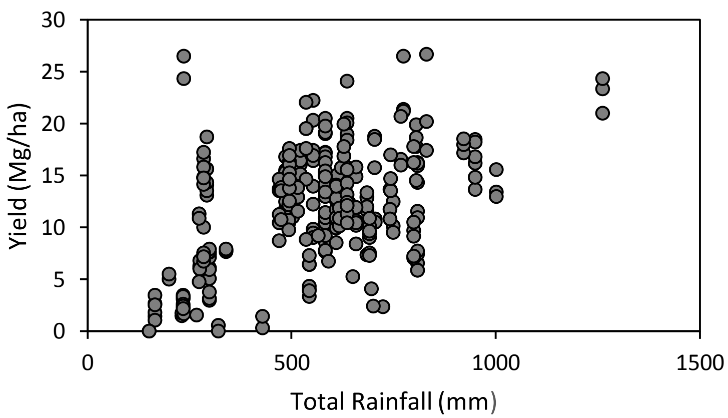

Figure I - 7. Lowland Switchgrass Response to Growing Season Rainfall.

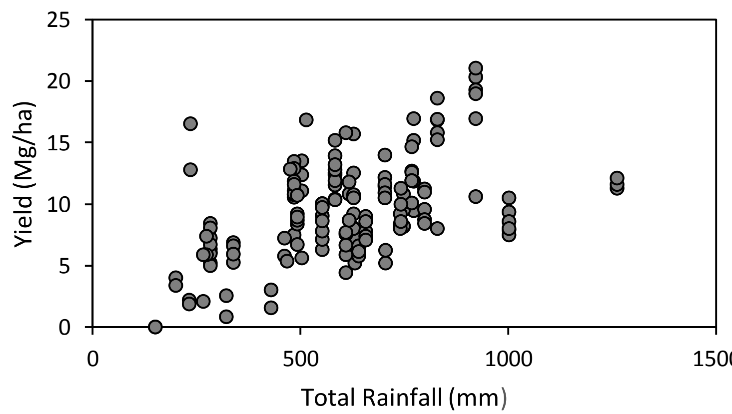

Figure I - 8. Upland Switchgrass Response to Growing Season Rainfall.

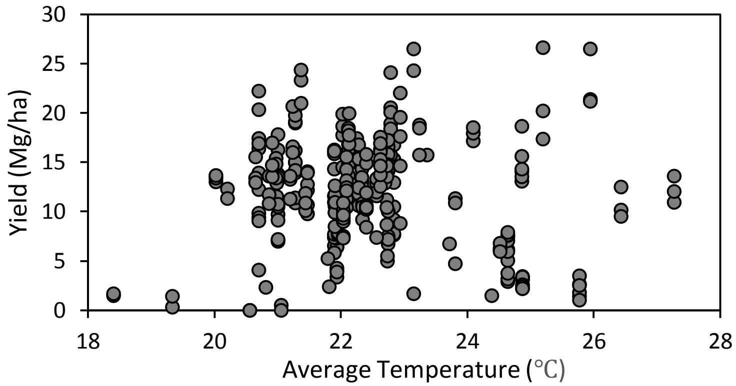

Figure I - 9. Lowland Switchgrass Response to Growing Season Temperature.

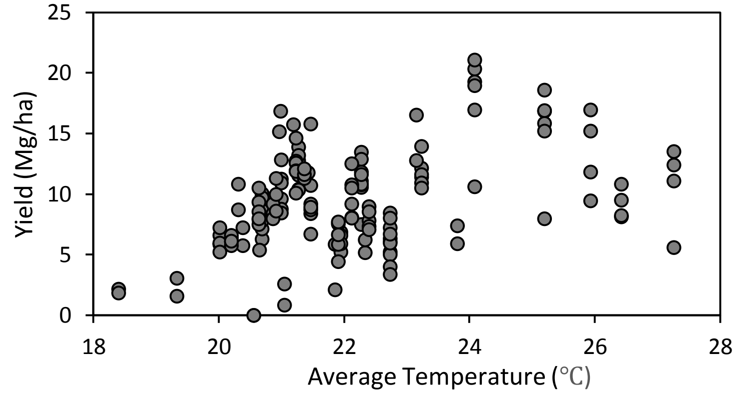

Figure I - 10. Upland Switchgrass Response to Growing Season Temperature.

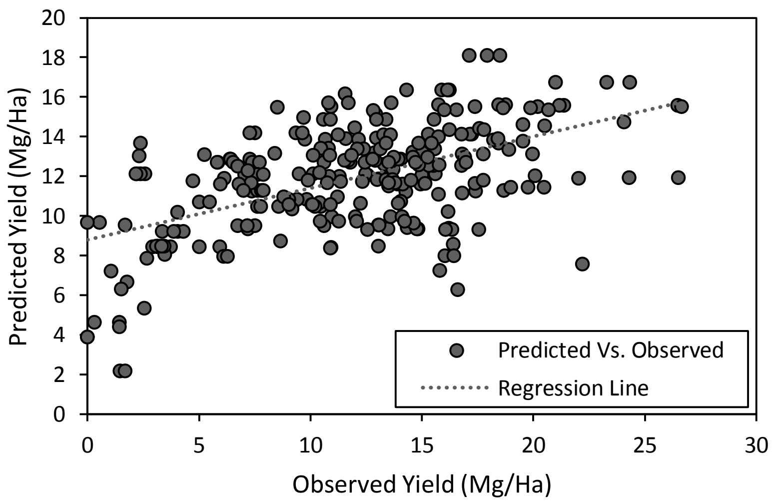

Figure I - 11. Lowland Switchgrass - Predicted and Observed Yield.

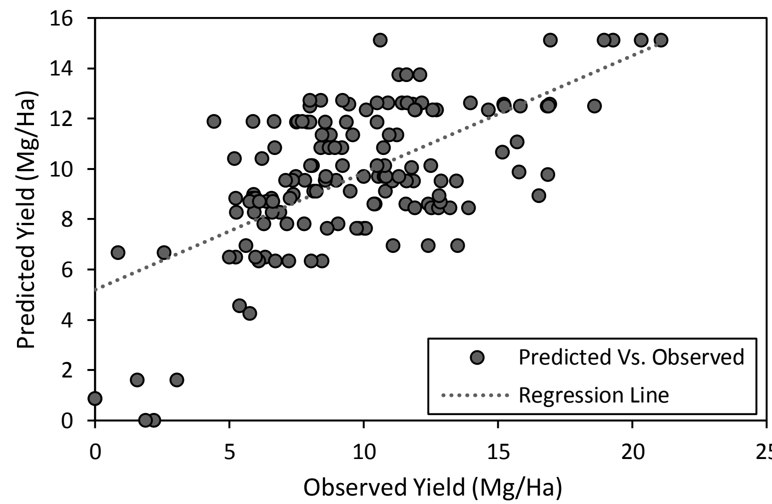

Figure I - 12. Upland Switchgrass - Predicted and Observed Yield.

PAPER II

FEASIBILITY ASSESSMENT OF BIOMASS HARVESTING COOPERATIVE

Introduction

The renewable fuel standard provisions of the Energy Independence and Security Act (EISA 2007) mandates 16 billion gallons of fuel to be derived from advanced biofuels such as lingo-cellulosic biomass by 2022. This mandate has contributed to the continued growth of grain based ethanol plants. The first generation ethanol plants accessed grain feedstocks that could be easily purchased from the open market. Second generation biofuel industries will use dedicated energy crops like switchgrass for which a supply chain must be developed. Potential alternatives for supply of biomass to a biorefinery are: (1) producers grow, harvest and store biomass and provide it to the biorefinery on the basis of spot market prices or long term contracts, (2) biorefinery leases land from landholders and operates a large scale integrated production, harvest and storage operation and (3) producers form a biomass harvesting cooperative which provides economies of scale in harvesting, transportation and storage (Epplin et al. 2007; Turhollow and Epplin, 2012). The structure of the harvesting, storage and transportation aspects of biomass supply chain has implications for agricultural producers and rural communities. A study of the economic impact of farmer-owned ethanol plants concluded that the contribution of a farmer-owned plant to the local economy is over 50% larger than an absentee owned corporate plant (Urbanchuk and Director, 2006). One less job is created in a local community with one percent reduction in ethanol plant ownership (Miranowski et al. 2008). In the early stages of the grain-based ethanol industry, projects were funded by local producers and rural investors (Kenkel and Holcomb, 2009). However, as the scale and capital requirements of ethanol projects increased the investment shifted to institutional investors and equity funds (Kenkel and Holcomb, 2009). Second generation biofuel plants are projected to have a much higher capital cost per gallon of capacity relative to grain based projects which may limit producer ownership of biorefineries (Taheripour and Tyner, 2008). Participating in production, harvest and storage activities may be the best opportunities for producers and rural residents to benefit from the emerging cellulosic ethanol industry. The need to perform these activities under an efficient structure is critical because feedstock logistic costs are a significant cost component for cellulosic ethanol (Larson et al. 2010).

An efficient, coordinated biomass harvesting, transportation and storage infrastructure can be developed while maximizing benefits to agricultural producers and rural communities by the creation of biomass harvesting cooperatives. Farm equipment cooperatives have been common in Europe and Canada for many years and have been very successful in reducing machinery cost. Research done by Harris and Fulton, 2000 in Saskatchewan found machinery cooperatives had expected machinery cost savings of 35% per acre relative to individual ownership. Similar research in the Southern Plains (Long and Kenkel, 2007) concluded that wheat producers could achieve machinery related cost savings of 23-54% through the formation of machinery cooperatives.

A recent national survey of farmers interested in growing switchgrass found that 77% were interested in participating in a farmer owned cooperative that harvests, stores and markets switchgrass (Jensen et al. 2011). In light of this apparent interest of producers in biomass cooperatives, there is a need to examine the structure and benefits of biomass supply through cooperatives. Previous research on the costs of harvesting, storing and transporting lingo-cellulosic feedstock have not evaluated these costs in a cooperative framework (Popp and Hogan, 2007; Epplin, 1996; Thorsell et al. 2004; Bransby et al. 2005; Kumar and Sokhansanj 2007; Mapemba et al. 2007; Perrin et al. 2008).

The main objective of this research is to assess the potential cost savings in harvesting and transporting biomass in a cooperative structure relative to an individual operation. Switchgrass which has been identified as a model energy crop to produce ethanol (Caddel et al. 2009) is considered the source of biomass in this study. The study examines the capital investment requirement and appropriate machinery complements for both the producer and cooperative operations. It compares itemized variable and fixed cost savings and cost savings by operations. It investigates alternative structures for the cooperative including the minimum size needed to capture scale economies and the harvesting and transportation costs of an optimal (least cost) scaled cooperative. Sensitivity analysis is used to examine the impact of total hectares, impact of distance between cooperative members, impact of biomass yield, impact of equipment operating speeds and impact of labor rates.

Materials and Methods

An economic engineering approach in the form of a feasibility template developed using MS Excel is used to compare the harvest and transport cost of biomass in an individual producer versus a cooperative scenario. While the template is designed as a decision tool for producers investigating the formation of a biomass harvesting cooperative, it also provides a convenient platform to project harvesting and transportation costs under individual ownership and cooperative structures. The template models all costs of harvesting and field transportation of biomass and creates a complete set of pro-forma financial statements. The template is available free of charge from the Bioenergy Center at Oklahoma State University. The harvest operation include mowing, raking, baling and stacking. Pre-harvest production costs and storage costs are not considered. The template is user adapted and can be modified based on the situation of user. The template uses machinery data which are based on the information collected from the respective machinery websites (Massey Ferguson and Stinger). Other data are based on the assumptions which are discussed in the following sections. For details on itemized cost calculations and calculations for machineries refer to appendix A, B and C.

Cooperative Structure and Assumptions

The cost comparisons are based on a set of base-line assumptions. We model a small cooperative of five members with 20% share of ownership. Each cooperative members and individual producer are assumed to have 400 hectares of land with field size of 40 hectares giving the cooperative 2,000 hectares to harvest. Several studies have used and assumed different size and weight for round and rectangular bales (Jannasch et al. 2001; Duffy 2007; Griffith et al. 2010; Cundiff et al. 2011; Kemmerer and Liu 2012; Turhollow and Epplin 2012; Rasnake et al. 2013). Because of potential economy of size advantage rectangular bales are advantageous for cooperatives than individual producer (Larson et al. 2010). We assume round bales 1.2m in width and 1.5m in diameter weighing 400 kg for individual producer and rectangular bale $0.9\text{m} \times 1.2\text{m} \times 2.4\text{m}$ weighing 550 kg for cooperative. Biomass yield is assumed to be 9 Mg ha^{-1}. Only one cutting is assumed because single cutting per year is suggested for switchgrass if bioenergy is the primary use (Perlack et al. 2011). We assume labor rate of $10 per hour for individual producer and $20 per hour for cooperative with 10 hour work per day. We do not assume any cost for land and buildings.

The equipment complement of both the cooperative and individual producer was assumed to be financed with 50% debt with a loan term of 5 years and an interest rate of 6 %. In the baseline scenario the cooperative charged each member a fee of $259 per hectare ($105 per acre) to finance the fixed and variable costs of harvest machinery operation. In accordance with typical cooperative structure, the fee is set higher than the anticipated costs resulting in a small annual profit to the cooperative which is distributed back to the members as a 90% cash patronage refund and 10% stock patronage refund. The income tax rate, insurance rate and inflation rate are assumed to be 50%, 1% and 2% respectively. Fuel price is assumed to be $0.95 per liter and trucking (hauling) cost is assumed to be $1.88 per km. We assume machineries used by both the individual producers and member cooperative will be replaced every five years. The distance from stacking to warehouse is assumed to be 35 km for both the individual producer and cooperatives. A semi-trailer is assumed to haul 34 round bales and 42 square bales from stacking to warehouse. The machineries are shared between members in a cooperative. Because of the relatively short distance between the member's farms we did not assume any trucking is necessary to transport the machines instead we assume they would be driven directly. The cooperative member's farming operations are assumed to be 35 km away from each other.

Baseline Equipment and Complements

Different equipment complements were modeled for the individual producer and cooperative. We assume that the individual producer will harvest round bales (1.2m × 1.5m) and cooperative will harvest rectangular bales (0.9m 1.2m × 2.4m). Details on equipment complements, models, machinery specifications and value for machineries used by individual producer and cooperative are presented in Table II – 1.

Individual Producer

The selection of tractors depends on the types of mower, rake and balers. We assume that the individual producer will use 90 HP Base Tractor and 120 HP Tractor with a front end loader. Switchgrass will be mowed by a pull type mower-conditioner with a 12 ft width (3.66 m) header and 85 PTO HP. The mowed biomass will be raked by a side delivery rake with 27 PTO HP. Switchgrass is a heavier material relative to typical hay and therefore we assume the side delivery rake will only form one windrow. The width covered by the side-delivery rake and round baler will be the same as covered by the mower-conditioner. The annual hours of operation are therefore calculated using the same width for rake and baler as the header width of the mower-conditioner. From the single windrow formed by the rake, the round baler will pick the biomass to package into round bales. The round baler modeled has a recommended 65 PTO HP. The bales are loaded by the tractor with a front end loader in a self-dumping wagon that has a capacity of 10 bales. The self-dumping wagon will be pulled in the field and to the edge of the field by another tractor (90 HP). The bales are unloaded at the edge of the field using the self-dumping mechanism of the wagon without the use of front end loader. It is assumed that only one labor will operate the wagon and the front end loader.

Cooperative

The cooperatives are assumed to have two tractors - 90 HP and 240 HP. Two sets of a complement of self-propelled windrower, side delivery rake and large rectangular baler are modeled for harvesting. The self-propelled windrowers modeled have a 14 ft width (4.26 m) header and 190 HP. The rake used is similar to the rake used by the individual producer. The baler modeled produces a $0.9\text{m} \times 1.2\text{m} \times 2.4\text{m}$ (3ft. x 4ft. x 8ft.) rectangular bale and has a recommended 195 PTO HP. In calculating field area covered, the width of the rake and baler is kept same as the header width of the windrower assuming that only one windrow is formed by the rake. The bales will be picked by a self-loading and unloading stacker which has a 305 HP engine horse power and can hold 12 bales per load. The stacker was assumed to self-unload the bales at the edge of the field.

Table II – 1. Equipment Complement for Individual Producer and Cooperative.

Equipments	Model*	HP	Width	Speed	Capacity	Field Eff. (%)	Tractor Used	Value
Producer								
Tractor 1	4609 Base Tractor	90						$ 33,257
Tractor 2	5612 Tractor (90 PTO HP)	120						$ 88,950
Mower, Rotary Disc	1372 (85 PTO HP)		12 ft	10 kph		80	120 HP Tractor	$ 38,535
Rake, Side Delivery	RK 3802 (27 PTO HP)		12 ft	16 kph		80	85 HP Tractor	$ 7,506
Baler, Round	2846 (65 PTO HP)		12 ft	6 kph		65	85 HP Tractor	$ 42,754
Dump Wagon				10 kph	10 bales	65	85 HP Tractor	$ 10,000
Front End Loader				10 kph		80	120 HP Tractor	$ 5,289
Cooperative								
Tractor 1	4609 Base Tractor	90						$ 33,257
Tractor 2	MF7626 (195 PTO HP)	240						$ 176,676
Windrower, Self-propelled	WR9735, 9146 Header	190	14 ft	13 kph		80		$ 133,441
Rake, Side Delivery	RK 3802 (27 PTO HP)		14 ft	16 kph		80	85 HP Tractor	$ 7,506
Baler, Large Rectangular	2170 XD Baler		14 ft	10 kph		80	240 HP Tractor	$ 171,830
Stacker	Stinger 6500	305		8 kph	12 bales	80		$ 230,000

*Model information is for illustration only and is not intended to endorse any particular manufacturer.

Results and Discussion

The results provide interesting insights into the structure of the cooperatives to harvest and transport biomass. Tables II – 2 and 4 provide a summary of itemized cost and operation cost for both enterprises. Table II – 3 provide detailed itemized cost for each machinery. With the current equipment complements and baseline assumptions, there is \$3.47 Mg^{-1} cost savings in cooperative compared to the individual producer. With no hauling (transporting bale from field to warehouse) the cost savings is \$1.48 Mg^{-1} because hauling alone has a cost saving of \$1.99 Mg^{-1}. The cost savings of the base case increase if the machinery used by cooperative is used more intensively. With the current equipment complements and assumptions cooperatives would be most profitable if 4,000 to 4,400 hectares were harvested which would require 10-12 members at the baseline farm size per member (Figure II – 1). The next sections provide results of the study along with discussion of the previous estimates by other similar studies. Comparison are however difficult because of differences in the methods and assumptions.

Itemized cost

The itemized cost include cost itemized for variable and fixed cost (Table II – 2). Fuel and lube cost, labor cost and repair and maintenance cost are variable cost which depend on number of hours the machineries are used. Fixed cost are insurance, interest, property tax and depreciation which depend on the purchased price of machinery, inflation rates and depreciation rates. As discussed previously, the largest cost difference between the producer and cooperative scenario was in the transportation of the bales from the field to warehouse.

Table II – 2. Summarized Itemized Cost Mg^{-1}.

Items	Producer	Cooperative
Fuel & Lube	$ 4.34	$ 3.77
Hired Labor	$ 2.33	$ 2.45
Repair & Maintenance	$ 2.44	$ 2.29
Total Variable Costs	$ 9.11	$ 8.51
Insurance & Housing	$ 1.32	$ 1.24
Interest	$ 1.26	$ 0.86
Property Tax	$ 0.33	$ 0.31
Depreciation	$ 6.64	$ 6.25
Total Fixed Costs	$ 9.54	$ 8.66
Total Cost	$ 18.65	$ 17.17
Hauling Cost	$ 4.84	$ 2.85
Grand Total	$ 23.49	$ 20.02

Perlack et al. 2011 estimated range of costs for switchgrass production and harvesting in southeast U.S. for three years. The estimated fuel and lube cost for year 1-3 for harvest range from \$1.64-\$4.42 Mg^{-1} which is quite consistent with our estimates but the estimated repair cost for year 1-3 range from \$2.24-\$6.35 Mg^{-1} which is higher than our estimates.

Table II – 3 show a summary of annual hours of usage for each machinery and the itemized cost for each machineries. The fuel and lube cost and labor cost for tractors are not included in the table because these costs are shared in the respective machinery used. Depreciation is the largest cost component and appears to be the most expensive followed by fuel and lube, labor and repairs. Insurance, interest and property tax are not major contributors to the overall costs. In terms of equipment, the baler is the most expensive machine for both the producer and cooperative. The round baler has a lower per acre cost relative to rectangular baler but that cost difference is more than offset by the higher costs of transporting round bales from field to warehouse. The combined cost of mower and rake in individual producer was similar to the cost of windrower. Similarly, the combined cost of wagon and loader in the individual producer complement of equipment did not drastically differ from the cost of operating the stacker in the cooperative equipment complement.

Table II – 3. Individual Producer and Cooperative Machinery Annual Hours and Variable and Fixed Cost Mg^{-1}.

	Annual Hours		Variable Cost			Fixed Cost				Total Cost
	Field	Transport	Fuel and Lube	Hired Labor	Repair and Maintenance	Insurance	Interest	Property Tax	Depreciation	
Producer										
Tractor 1 (90 HP)		465			$0.07	$0.19	$0.18	$0.05	$0.98	$1.47
Tractor 2 (120 HP)		337			$0.10	$0.52	$0.49	$0.13	$2.61	$3.85
Mower-Conditioner		139	$0.88	$0.40	$0.21	$0.22	$0.21	$0.06	$1.13	$3.12
Rake		87	$0.41	$0.25	$0.02	$0.04	$0.04	$0.01	$0.22	$1.00
Baler, Round		285	$1.35	$0.83	$1.93	$0.25	$0.24	$0.06	$1.25	$5.91
Dump Wagon		94	$0.44	$0.27	$0.11	$0.06	$0.06	$0.01	$0.29	$1.24
Front End Loader		198	$1.25	$0.58	$0.004	$0.03	$0.03	$0.01	$0.16	$2.06
Total Cost			$4.34	$2.33	$2.44	$1.32	$1.26	$0.33	$6.64	$18.65
Cooperative										
Tractor 1 (90 HP)	372	14			$0.01	$0.04	$0.03	$0.01	$0.20	$0.28
Tractor 2 (240 HP)	594	14			$0.05	$0.21	$0.14	$0.05	$1.04	$1.49
Windrower	457	15	$0.95	$0.66	$0.50	$0.31	$0.21	$0.08	$1.57	$4.27
Rake	372	14	$0.37	$0.54	$0.04	$0.02	$0.01	$0.004	$0.09	$1.06
Baler, Rectangular	594	14	$1.54	$0.85	$1.42	$0.40	$0.28	$0.10	$2.02	$6.60
Stacker	285	2	$0.92	$0.40	$0.28	$0.27	$0.18	$0.07	$1.35	$3.47
Total Cost			$3.77	$2.45	$2.29	$1.24	$0.86	$0.31	$6.25	$17.17

Note: Tractors fuel and lube cost and labor cost are included as part of other machinery which use the respective tractors.
Hauling cost is not included in the total cost.

Operation Cost

The cost analyzed by field operation are provided in Table II – 4. As suggested in cost breakdown by machinery component, the distribution of the total costs across operations was similar but the cooperative structure achieved a lower total cost. Baling is the most expensive operation for both the cooperative and individual producer. Significant cost saving ($2.42 Mg^{-1}) was found in cooperative in infield transport (bale collecting and stacking). There are some cost saving ($1.99 Mg^{-1}) in bale transport as well. Mowing cost is slightly cheaper in cooperative while raking cost was almost identical. The cooperative have an extra cost of $0.40 Mg^{-1} for equipment transport because of machinery sharing between members.

Table II – 4. Summarized Operation Cost Mg^{-1}.

Operation	Producer	Cooperative
Mowing	$ 4.70	$ 4.13
Raking	$ 1.28	$ 1.29
Baling	$ 6.81	$ 7.97
Equipment Transport		$ 0.40
Bale Collecting and Stacking	$ 5.86	$ 3.44
Bale Transport-Stacking to Warehouse	$ 4.84	$ 2.85
Total Cost	$ 23.49	$ 20.02

Mowing, Raking and Baling

Several studies have estimated switchgrass harvesting and stacking cost (Thorsell et al. 2004; Duffy, 2007; Kumar and Sokhansanj, 2007; Griffith et al. 2010; Larson et al. 2010; Cundiff et al. 2011; Turhollow and Epplin 2012) while some have analyzed capacity of mower, rake, baler and stacker (Kemmerer and Liu 2012; Grisso et al., 2013). It is difficult to compare these estimates because the choice of equipments and equipment productivity assumptions differ. The total annual throughput assumed also has a significant impact on the cost estimate because at low throughput the fixed cost per hectare is much higher. Turhollow and Epplin, 2012 and Kumar and Sokhansanj, 2007 estimated harvesting and stacking cost for round and rectangular bales. Turhollow and Epplin, 2012 report harvesting and stacking costs for both systems under two different capacity assumptions. Their lower capacity case of 4.5 to 5.4 Mg/hour for round balers and 10-11 Mg/hour for rectangular baler was based on Larson and English 2009. Their higher productivity case of 16.7 Mg/hour for round baler and 20.7 Mg/hour for rectangular baler was based on Shinners et al. 2010. In our study, we model a round baler productivity of 13.6 Mg per hour (34 bales per hour) and a rectangular baler productivity of 30 Mg per hour (54 bales per hour) which is more consistent with their high productivity case. Thorsell et al. 2004 did not estimate mowing, raking, baling and stacking cost separately but estimated total cost using agricultural machinery program AGMACH$ and MACHSEL. Cundiff et al. 2011 only estimated baling cost. Other studies (Duffy 2007; Griffith et al. 2010) estimated harvesting and stacking cost only for rectangular bales.

The mowing and raking cost estimated in our study is similar to all the other studies except Larson et al. 2010 who estimated a higher cost of mowing and raking ($9.95 Mg^{-1}) for both round and rectangular bales. The estimated cost of bailing switchgrass varies significantly across studies, in part due to the previous discussed differences in assumed hourly throughput. The lowest estimated baling cost was reported by Cundiff et al. 2011 which was $1.22 for round bale and $4.04 for rectangular bale. Their baling cost however do not include the ownership and operating cost of tractors used by balers. Baling costs in the other studies tend to fall into two categories, a lower category of $6.00-$8.00/hectare for a rectangular baler and a higher cost category of $22.00-$29/hectare. The estimated baling cost in our study falls in the lower baling cost category.

Previous studies are also not in consensus as to which bailing system (round or rectangular) is more economical. Our results are consistent with Cundiff et al. 2011 showing a lower per hectare cost for round baling while Kumar and Sokhansanj, 2007, Turhollow and Epplin, 2012 and Larson et al. 2010 conclude that the rectangular bale system has a lower per hectare cost. Rectangular baling equipment generally has a higher potential annual capacity so the difference in the cost comparison is largely explained by whether the rectangular baler was assumed to operate near its annual full capacity because of different assumptions on equipment complements and throughput.

Bale collecting and stacking

Our cost estimate for collecting and stacking round bales of $5.85Mg^{-1} is consistent with previous studies which reported costs ranging from $4.08-$7.26 Mg$^{-1.}$ The exception is Larson et al. 2010 which estimated a much higher cost of $21.51 Mg^{-1}. Our estimate of $3.44 Mg^{-1} for collecting and stacking rectangular bales is on low end of previous estimates which range from $3.48-$12.42 Mg^{-1}. Many of these previous studies have modeled a dump wagon with a resulting throughput of 31 bales per hour. We model a self-propelled loader/stacker (a somewhat newer technology) with an assumed throughput of 116 rectangular bales per hour.

Hauling

We estimate bale transport cost (stacking to warehouse) separately for round and rectangular bales for a distance of 35 km which were $4.84 Mg^{-1} for round bale and $2.85

Mg^{-1} for rectangular bale. On a distance basis this is \$0.13 Mg^{-1} km^{-1} and \$.08$Mg^{-1}km^{-1}$ respectively. Duffy and Nanhou, 2002 estimates transportation cost of \$0.11 Mg^{-1} $mile^{-1}$ for a distance of less than 50 miles (80.5 km). Our study shows a transportation cost of \$0.08-\$0.13 Mg^{-1} km^{-1}. Larson et al. 2010 estimate transport cost of \$13.17 and \$ 10.84 for round and rectangular bales respectively for a distance of 60 km. They mention a transportation cost of \$4.57 Mg^{-1} for a distance of about 30 miles (48.3 km). Brechbill and Tyner 2008 estimate a series of transportation costs for a range of 5-50 miles (8-80 km) for different field sizes. Their cost estimates for 20 miles (32 km) is \$5.81 for 500 acres (202.3 ha), \$5.22 for 1000 acres (404.6 ha), \$5.03 for 1500 acres (607 ha) and \$4.93 for 2000 acres (809 ac). Rasnake et al. 2013 assume one way hauling cost of \$12.67 Mg^{-1} for a distance less than 50 miles (80.5 km) to transport switchgrass. Perlack et al. 2011 suggest \$12.12 Mg^{-1} is a common assumption for transport cost.

Machinery days

Switchgrass is harvested between November 1 and March 1 (Larson et al. 2010) and there are about 60 total days which are suitable for harvest operation. The estimated machinery days show that biomass harvest and transport could be completed within 60 days in both the enterprises. The machinery days were significantly lower in cooperative than individual producers compared to the hectares they own. By forming a biomass harvesting cooperative producers could save a significant number of days of field operation time which they could use for other farm activities.

Table II – 5. Estimated Machinery Days.

Operation	Producer (400 hectares)		Cooperative (2,000 hectares)	
	Equipment	Machinery Days	Equipment	Machinery Days
Mowing	Mower	14	Windrower-2	47
Raking	Rake	9	Rake-2	39
Baling	Round Baler	28	Rect. Baler-2	61
Collecting and Stacking	Wagon + Loader	29	Stacker	29
Total		80		175

Sensitivity Analysis

The sensitivity analysis evaluated impacts on total cost by yields, bale weight, total hectares, distance between cooperative members, speed of stacker and labor rate per hour (Tables II – 6 and 7). Yield was found to have the largest impact on total cost. One Mg per hectare change in yield changed the total cost from \$2.00 to \$8.00 Mg^{-1}. The change in total cost was higher for lower yields and lower for higher yields. The change in total cost decreased in decreasing rate as yield increased. Changes in field size (which impacts the logistics of in-field transport) had little impact on total cost. However, the total hectares harvested did significantly impact total cost because the fixed cost of the equipment ownership was spread over a lower volume. With the increase in total hectares the total cost decreased rapidly in cooperative but in individual producer the cost decrease up to a certain extent and after which it increased. This was due to the capacity of the producer's equipment complement and the projected repair costs. Cost decreased as the fixed costs were spread over more hectares but then increased when the projected repair increase outweighed the effect of per hectare fixed costs. At baseline, the cooperative's complement of equipment was further from the utilization level where repair costs increased dramatically. Total cost was sensitive to both round and rectangular bale weight but the round bale weight had more impact on total costs relative to the weight of the rectangular bale. On average, the total cost of the round bale system decreased \$1.41 Mg^{-1} for every 100 Kg $Bale^{-1}$ increase in weight while the cost of the rectangular system decreased \$0.61 Mg^{-1} for a similar increase in bale weight.

Table II – 6. Sensitivity Analysis – Impact of Yield, Bale Weight and Total Hectares.

	Total Cost Mg^{-1}			
	Producers		Cooperative	
*Impact of Yield (*Mg ha^{-1})				
5		\$ 36.35		\$ 32.75
7		\$ 28.09		\$ 24.62
9[a]		\$ 23.49		\$ 20.09
11		\$ 20.57		\$ 17.21
13		\$ 18.54		\$ 15.22
Impact of Total Hectares				
	Hectares	Cost Mg^{-1}	Hectares	Cost Mg^{-1}
	400[b]	\$ 23.49	2,000[c]	\$ 20.09
	800	\$ 20.46	2,400	\$ 18.99
	1,200	\$ 20.44	2,800	\$ 18.29
	1,600	\$ 21.12	3,200	\$ 17.86
	2,000	\$ 22.04	3,600	\$ 17.59
Impact of Bale Weight				
	Kg $Bale^{-1}$	Cost Mg^{-1}	Kg $Bale^{-1}$	Cost Mg^{-1}
	300	\$ 25.96	450	\$ 20.97
	400[d]	\$ 23.49	550[e]	\$ 20.09
	500	\$ 22.01	650	\$ 19.37
	600	\$ 21.02	750	\$ 18.88
	700	\$ 20.31	850	\$ 18.52

[a]Baseline yield; [b]Baseline hectares -producer; [c]Baseline hectares - cooperative members; [d]Baseline weight - round bale; [e]Baseline weight – rectangular bale;

The distance between the cooperative members could impact costs because of the transportation costs and time loss in transferring equipment between members. However, the results were not sensitive to distance between member cooperatives. There was an increment in total cost of only \$0.22 Mg^{-1} for cooperative members who are 55 km away compared to members who are 25 km away. Fuel use in agricultural equipment is modeled based on hours of operation. Field speed can therefore effect the per ton variable cost because more units are handled per hour. The impact of field speed on total cost depends on how significant this impact is relative to the total costs. The field speed of the balers was found to have a fairly significant impact on total cost. With the increment in speed by 1 km the cost decreased in the range of \$0.31-\$1.49 Mg^{-1}. The total cost decreased in both type of balers but in decreasing rate. The decrease in cost was higher in rectangular baler than round baler. The field speed (bale picking) of the stacker did not show as much impact on total cost. When its field speed was increased from 6 kph to 10 kph the total cost decreased by \$0.34 Mg^{-1}.

Table II – 7. Sensitivity Analysis – Impact of Distance, Speed and Labor Rate.

	Total Cost Mg^{-1}			
	Producers		Cooperative	
Impact of distance between member cooperatives				
25 km				\$20.02
35 km[f]				\$20.09
45 km				\$20.17
55 km				\$20.24
Impact of Baler Speed	Round Baler	Cost Mg^{-1}	Rectangular Baler	Cost Mg^{-1}
	6 kph	\$23.49	6 kph	\$23.74
	7 kph	\$22.70	8 kph	\$21.32
	8 kph[g]	\$22.15	10 kph[g]	\$20.02
	9 kph	\$21.74	12 kph	\$19.23
	10 kph	\$21.43	14 kph	\$18.70
Impact of Stacker Speed			Stacker	Cost Mg^{-1}
			4 kph	\$20.67
			6 kph	\$20.23
			8 kph[g]	\$20.02
			10 kph	\$19.89
			12 kph	\$19.81
Impact of Hired Labor Rate				
	Rate	Cost Mg^{-1}	Rate	Cost Mg^{-1}
	\$8	\$23.03	\$16	\$19.53
	\$10[h]	\$23.49	\$18	\$19.78
	\$12	\$23.96	\$20[h]	\$20.02
	\$14	\$24.42	\$22	\$20.27
	\$16	\$24.89	\$24	\$20.51

[f]Baseline distance between member cooperatives; [g]Baseline speed; [h]Baseline labor rate.

Labor wage rates can obviously impact total cost of machinery operation. The impacts of labor rates were analyzed separately for cooperative and individual producers as two different labor rates were used (Table II – 7). The sensitivity for both wage rates did not show much impact on the total cost. With similar labor rate of \$10/hour, the labor cost was

$1.11 Mg^{-1} lower in cooperative than the individual operations and with the similar labor rate of $20/hour, the labor cost was $2.21 Mg^{-1} lower in the cooperative than the individual producer.

Optimal Members in Cooperative

As a harvesting cooperative increases in size with more members and more hectares it obviously has the potential for greater costs savings. We did a sensitivity to determine the optimal number of members (optimal total hectares) in the cooperative. Our baseline scenario involved 5 members and 2,000 hectares. We observe that with the current equipment complements and baseline assumptions maximum cost savings could be made with 11 members representing 4,400 hectares. The cost savings slowly declined when number of members were increased to more than 11 due to increasing repair costs. With 11 members we have a total of 4,400 hectares processing 71,986 bales as compared to the baseline of 2,000 hectares processing 32,721 bales with 5 members. In addition to illustrating the sensitivity of total cost to the throughput assumption, these results also underscore the conservative nature of our analysis. We selected a machinery complement for the individual producers which was utilized close to its design capacity while modeling the cooperative's complement at a lower percent of potential capacity. Our estimates of the potential cost savings with the cooperative structure were therefore quite conservative. Because of our assumptions on modeling the machinery complements, the machinery cooperative was shown to have more potential of increased cost savings with additional throughput. If we had modeled the cooperative operating at 4,400 hectares we would have found even higher cost savings relative to the individual operations.

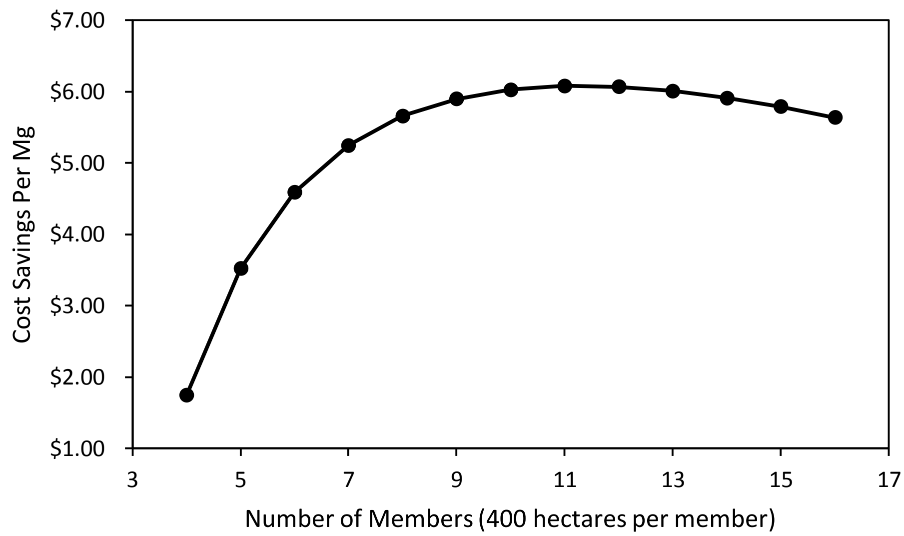

Figure II – 1. Optimal Number of Members in Cooperative.

Round versus Rectangular Bales

Among individual producers, the round bale system is the most popular hay harvesting system while the large rectangular bale technologies are used by custom operations and other large scale operations. That raises the question as to whether the cost savings we projected for the cooperative structure were due to the different technology assumptions. We therefore did a cost comparison between the two enterprises assuming both would package rectangular bales. Round versus round bales were not compared because the stacker which we model in the cooperative equipment complement (and which creates much of the field transportation efficiencies) is only suitable for rectangular bales. For the rectangular bale comparison we assumed individual producer would bale $0.9\text{m} \times 0.9\text{m} \times 2.4\text{m}$ size bale weighing 400 kg. The baler modeled is MF Hesston 2150 baler which uses MF 7620 190 HP tractor. All other equipment complements and assumptions were same as before.

Table II – 8. Comparison of Itemized Cost Mg^{-1} – Round and Rectangular Bales.

Items		Producer	
		Round	Rectangular
Fuel & Lube		$ 4.34	$ 4.08
Hired Labor		$ 2.33	$ 2.01
Repair & Maintenance		$ 2.44	$ 1.07
	Total Variable Costs	$ 9.11	$ 7.31
Insurance & Housing		$ 1.32	$ 2.08
Interest		$ 1.26	$ 1.96
Property Tax		$ 0.33	$ 0.52
Depreciation		$ 6.64	$ 10.50
	Total Fixed Costs	$ 9.54	$ 15.05
	Total Cost	$ 18.65	$ 22.36
Hauling Cost		$ 4.84	$ 4.84
	Grand Total	$23.49	$27.21

The results show that rectangular bales are $3.72 more expensive for individual producers compared to round bales. All the itemized variable cost decreased but all the itemized fixed cost increased. The notable increase was the depreciation cost which increased by $3.86 Mg^{-1} and the notable decrease was the repairs cost which decreased by $1.37 Mg^{-1}. The changes in other itemized cost were less than one dollar. In terms of operation, baling appeared to be most expensive with an increase of $2.32 Mg^{-1} followed by infield transport (bale collecting and stacking) with an increase of $0.77 Mg^{-1}. The cost changed because of higher investment in rectangular bales which required expensive baler and tractor. The costs for the individual rectangular bale operation would be reduced if a larger farm size/higher throughput was assumed.

Table II – 9. Comparison of Operation Cost Mg^{-1} – Round and Rectangular Bales.

Operation		Producer	
		Round	Rectangular
Mowing		$ 4.70	$ 4.93
Raking		$ 1.28	$ 1.68
Baling		$ 6.81	$ 9.13
Bale Collecting and Stacking		$ 5.86	$ 6.63
Bale Transport-Stacking to Warehouse		$ 4.84	$ 4.84
	Total Cost	$ 23.49	$ 27.21

Conclusion

Meeting the renewable fuel standard mandate for advanced biofuels will require the commercialization of cellulosic ethanol and other advanced fuels using biomass feedstocks. This will necessitate the creation of a dedicated feedstock supply chain. Second generation ethanol plants are forecasted to cost 3-4 times more than grain based ethanol. This may limit farmer ownership of the actual processing plant. The best avenue for farmer participation and value-added returns may be farmer ownership in the supply chain. A commonly suggested structure for the biomass supply chain is an integrated business model owned by the biorefinery. Producer ownership of harvesting operations generates increased economic impact for producers and rural communities. However, this structure fails to capture the economies of scale in equipment ownership and operations. Another alternative is the formation of biomass harvesting and transportation cooperatives. This paper has attempted to model the cost of harvesting and transporting biomass (switchgrass) in this type of cooperative structure. A cost comparison with equipment ownership and operations by individual producers is provided. The results show that small scale biomass harvesting cooperative (10-12 members) could have substantial cost savings versus individual member operations. For a five member cooperative the cost savings was not significant compared to the individual producers. With five members the cost savings was \$3.47 Mg^{-1} while cost savings was \$6.08 Mg^{-1} with eleven members. The cost savings are more if machineries are brought to enough use which could be obtained either by increasing the number of members in cooperative or by increasing the total hectares or by renting the machineries. Sensitivity analysis indicated that biomass yield, total hectares and number of members in cooperative had significant impact on per Mg cost while minimal impacts were observed for field size, distance between producers, labor rates and field speed of the bale picker. Sharing of equipments and forming a cooperative to harvest and transport biomass allows spread of costs among producers and helps achieve economies of scale. Similar cost savings could therefore be achieved and wider economic impact could be made by involving local producers and forming cooperative rather than harvesting and transporting biomass individually.

References

ASABE. 2011a. D497.7, A. MAR2011. Agricultural Machinery Management Data. In: ASABE Standards, American Society of Agricultural and Biological Engineers, St Joseph, MI.

ASABE. 2011b. EP496.3, A. FEB2006. Agricultural Machinery Management Data. In: ASABE Standards, American Society of Agricultural and Biological Engineers, St Joseph, MI.

Bransby, D.I., H.A. Smith, C.R.Taylor and P.A. Duffy. 2005. "Switchgrass Budget Model: An Interactive Budget Model for Producing and Delivering Switchgrass to a Bioprocessing Plant." *Industrial Biotechnology* 1(2):122-125.

Brechbill, S.C. and W.E. Tyner. 2008. "The Economics of Biomass Collection, Transportation, and Supply to Indiana Cellulosic and Electric Utility Facilities." Department of Agricultural Economics, Purdue University.

Caddel, J., N. Walker, G. Kakani, J. Warren, D. Porter, Y. Wu, D. Redfearn and H. Zhang. 2010. "*Switchgrass Production Guide for Oklahoma.*" E-1012 Oklahoma Cooperative Extension Service. Division of Agricultural Sciences and Natural Resources. Oklahoma State University.

Cundiff, J., R. Grisso, and D. McCullough. 2011. "Comparison of Bale Operations for Smaller Production Fields in the Southeast." ASABE Paper.

Duffy, M. 2007. "Estimated Costs for Production, Storage and Transportation of Switchgrass." Iowa State University, Department of Economics.

Duffy, M.D. and V.Y. Nanhou. 2002. "Costs of Producing Switchgrass for Biomass in Southern Iowa." *Trends in New Crops and New Uses* 267-275.

Epplin, F.M. 1996. "Cost to Produce and Deliver Switchgrass Biomass to an Ethanol-Conversion Facility in The Southern Plains of the United States." *Biomass and Bioenergy* 11(6):459-467.

Epplin, F.M., C.D. Clark, R.K. Roberts and S. Hwang. 2007. "Challenges to the Development of a Dedicated Energy Crop." *American Journal of Agricultural Economics* 89(5):1296-1302.

Griffith, A., F.M. Epplin and D. Redfearn. 2010. "Cost of Producing Switchgrass for Biomass Feedstock." Oklahoma State University, Cooperative Extension Service.

Grisso, R., G. Moxley, E. Webb, J. Cundiff and S. Sokhansanj. 2013. "In-Field Performance of Hay Balers Using DGPS." Paper presented at the 2013 ASABE Annual International Meeting, Kansas City, MO.

Harris, A. and M. Fulton. 2000. "Farm Machinery Co-operatives: An Idea Worth Sharing." University of Saskatchewan, Centre for the Study of Co-operatives.

Jannasch, R., Y. Quan and R. Samson. 2001. "A Process and Energy Analysis of Pelletizing Switchgrass." Prepared by REAP-Canada for Natural Resources Canada.

Jensen, K.L., C.D. Clark, B.C. English, and R.J. Menard. 2011. "Preferences for Marketing Arrangements by Potential Switchgrass Growers." *Journal of Cooperatives* 25(2):16-43.

Kastens, T.L. 1997. "Farm Machinery Operation Cost Calculations." Kansas State University, Agricultural Experiment Station and Cooperative Extension Service.

Kemmerer, B. and J. Liu. 2012. "Large Square Baling and Bale Handling Efficiency—A Case Study." *Agric. Sci* 3(2):178-183.

Kenkel, P. and R.B. Holcomb. 2009. "Conditions Necessary for Private Investment in The Ethanol Industry." *Journal of Agricultural and Applied Economics* 41(2):455-464.

Kumar, A. and S. Sokhansanj. 2007. "Switchgrass (*Panicum Vigratum* L.) Delivery to a Biorefinery Using Integrated Biomass Supply Analysis and Logistics (IBSAL) Model." *Bioresource Technology* 98(5):1033-1044.

Larson, J.A. and B.C. English. 2009. "Risk Management for Energy Investments: Agricultural Policy and Extension Recommendations." Proceedings of the Role of Extension in Energy, Little Rock, AR.

Larson, J.A., T.H. Yu, B.C. English, D.F. Mooney and C. Wang. 2010. "Cost Evaluation of Alternative Switchgrass Producing, Harvesting, Storing and Transporting Systems and Their Logistics in the Southeastern USA." *Agricultural Finance Review* 70(2):184-200.

Long, G. and P.L. Kenkel. 2007. "Feasibility of Machinery Cooperatives in the Southern Plains Region." Paper presented at the Southern Agricultural Economics Association Annual Meeting, Mobile, Alabama.

Mapemba, L.D., F.M. Epplin, C.M. Taliaferro and R.L. Huhnke. 2007. "Biorefinery Feedstock Production on Conservation Reserve Program Land." *Applied Economic Perspectives and Policy* 29(2):227-246.

Miranowski, J., D. Swenson, L. Eathington, and A. Rosburg. 2008. "Biofuel, the Rural Economy, and Farm Structure." Paper presented at the Risk, Infrastructure and Industry Evolution, Berkeley, California.

Perlack, R., A. Turnhollow and L. Eaton. 2011. "Switchgrass Production in the USA Promising Resources and Systems for Producing Bioenergy Feedstocks." Oak Ridge, TN 37830: Oak Ridge National Laboratory.

Perrin, R., K. Vogel, M. Schmer and R. Mitchell. 2008. "Farm-Scale Production Cost of Switchgrass for Biomass." *BioEnergy Research* 1(1):91-97.

Popp, M. and R. Hogan Jr. 2007. "Assessment of Two Alternative Switchgrass Harvest Transport Methods." Paper presented at the Biofuels, Food and Feed Tradeoffs, St. Louis, MO.

Rasnake, M., M. Collins and R. Smith. 2013. "Switchgrass for Bioenergy." Crop Diversification and Biofuel Research Education Center: UK Cooperative Extension Service.

Shinners, K., G. Boettcher, R. Muck, P. Weimer and M. Casler. 2010. "Harvest and Storage of Two Perennial Grasses as Biomass Feedstocks." *Transactions of the ASAE (American Society of Agricultural Engineers)* 53(2):359.

Taheripour, F. and W.E. Tyner. 2008. "Ethanol Policy Analysis—What Have We Learned So Far." *Choices* 23(3):6-11.

Thorsell, S., F.M. Epplin, R.L. Huhnke and C.M. Taliaferro. 2004. "Economics of A Coordinated Biorefinery Feedstock Harvest System: Lignocellulosic Biomass Harvest Cost." *Biomass and Bioenergy* 27(4):327-337.

Turhollow, A. and F.M. Epplin. 2012. "Estimating Region Specific Costs to Produce and Deliver Switchgrass." In *Switchgrass* pp. 187-203. Springer, London.

U.S. Congress and House of Representatives. 2007. Section 111, Subtitle A, Renewable Fuels, Consumer Protection and Energy Efficiency Act of 2007, H.R. 6 (EAS).

Urbanchuk, J.M. and L. Director. 2006. "Economic Impacts on the Farm Community of Cooperative Ownership of Ethanol Production." Prepared for the National Corn Growers Association.

Appendix II – A: Itemized Cost Calculations

The itemized cost calculations for machineries are based on ASAE standards (EP496.3 FEB2006) and examples presented by Kastens (Kastens 1997). Fuel cost (FC) is calculated using price of fuel per gallon, HP of the machine, annual hours of usage and average fuel consumption per rated HP (0.06 gal/hour). The lubrication cost was assumed to be about 15% of the fuel costs.

$$\mathrm{FC} = \text{Price of Fuel} \times (0.06 \times \mathrm{HP} \times \text{Annual Hours}) \tag{A.1}$$

The labor cost (LC) is calculated using the total annual hours of machineries in field operation and labor rate. Hauling annual hours of machineries are included in cooperative. We assume that the actual labor hour is 20 percent more than the machine hour.

$$\mathrm{LC}\ (\text{Ind. Producer}) = \text{Field Ann. Hours} \times \text{Labor Cost} \times 1.20 \tag{A.2}$$

$$\mathrm{LC}\ (\text{Coop.}) = (\text{Field Ann. Hours} + \text{Hauling Ann. Hours}) \times \text{Labor Cost} \times 1.20 \tag{A.3}$$

The repair and maintenance cost (RMC) is calculated using the current price of machine, repair factors 1 and 2, hours of usage in the current year and accumulated hours of usage in the previous years.

$$\mathrm{RMC} = \left[\text{Price} \times \mathrm{RF}_1 \times \left[\frac{\text{Acc.Hrs.+ Curr.Hrs.}}{1000}\right]^{\mathrm{RF}_2}\right] - \left[\text{Price} \times \mathrm{RF}_1 \times \left[\frac{\text{Acc. Hrs.}}{1000}\right]^{\mathrm{RF}_2}\right] \tag{A.4}$$

The repair factors (RF1 and RF2) are based on the American Society of Agricultural Engineers (ASAE) standards (Table 10).

The housing and insurance cost (HIC) is calculated using the price of the machine, insurance rate and no. of machines.

$$\mathrm{HIS} = (\text{Price} \times \text{Insurance rate}) \times \text{No. of machines} \tag{A.5}$$

The interest cost (IC) is calculated using total interest expenses, price and number of machine and the value of total plant, property and equipment.

$$\mathrm{IC} = \frac{\text{Total Interest Expenses} \times \text{Price} \times \text{No. of machines}}{\text{Total Plant Property and Equipment}} \tag{A.6}$$

$$\text{where,} \quad \text{Total Interest Expenses} = \text{Loan amount} \times \text{Interest Rate} \tag{A.7}$$

The property tax (PT) is calculated using the price and number of machines and property tax rate.

$$\mathrm{PT} = (\text{Price} \times \text{Property Tax Rate}) \times \text{No. of machines} \tag{A.8}$$

The depreciation cost (DC) for any year n is calculated using a depreciation rate of 10%, price of the machine and inflation rate.

$$\mathrm{DC} = \text{Price} \times \text{Depreciation Rate} \times (1 + \text{Inflation Rate})^{n} \tag{A.9}$$

Appendix II – B: Calculation for Machineries

Field capacity and replacement cost are based on ASAE standards (EP496.3 FEB2006) and examples presented by Kastens, 1997.

Field capacity (FIC) is the hectares that the machinery can cover in an hour which is calculated as:

$$\mathrm{FIC} = \frac{\mathrm{Speed} \times \mathrm{Width} \times \mathrm{Efficiency\ Factor} \times 1{,}000}{10{,}000} \tag{B.1}$$

The efficiency factor is based on the ASAE standards (Table 10) which is used in decimal form in the above equation. The field efficiency as described in the ASAE standards (EP496.3 FEB2006) is the ratio between the productivity of a machine under field conditions and the theoretical maximum productivity. The number 1,000 is meter per kilometer and 10,000 is square meter per hectare which are used in the equation for balancing the units.

The replacement cost is calculated using the current price of the machinery, inflation rate and with an assumption that the machinery will be replaced in every five years.

$$\mathrm{Replacement\ Cost} = \mathrm{Current\ Price} \times (1 + \mathrm{Inflation\ Rate})^5 \tag{B.2}$$

The machinery annual hours are calculated separately as field and transport annual hours. The transport annual hours (TAH) is calculated only for cooperative as they have to be transported for use between members. The field annual hours (FAH) of mower, rake and baler is calculated by dividing the total hectares by the calculated field capacity of each machine.

The field annual hours for wagon, loader and stacker do not depend on field capacity and total hectares but on their speed, capacity, distance between bales and size and number of fields.

The field annual hours for wagon is the sum of total annual hours for unloading bales and total annual hours to stack and back.

The field annual hours for loader is the sum of total loading hours and infield transport hours.

The field annual hours for stacker is the sum of loading and unloading hours, stacking back and forth hours and infield transport hours.

The infield annual hours and stacking back and forth hours are calculated using the speed of respective machines and infield transport distance and distance to stacking and back.

The transport annual hours (TAH) is calculated using the average distance between the members, transport speed of each machines, number of machines and number of members in cooperative as:

$$\mathrm{TAH} = \left(\frac{\mathrm{Avg.\ Distance\ bet\ members}}{\mathrm{Transport\ Speed}}\right) \times \mathrm{No.of\ machines} \times \mathrm{No.of\ members} \tag{B.3}$$

The above equations were not used to calculate tractor hours. The tractor annual hours both field and transport would be the sum of the hours of each machineries which uses the respective tractors.

Therefore, the annual tractor hours are obtained by adding the hours of the machines which uses the respective tractors.

Appendix II – C. Calculation for Distance Covered (Stacker, Loader and Wagon)

Unlike mower, windrower, rake and baler the distance traveled by the stacker, loader and wagon don't depend on the total hectares and the field capacity of the machine but on the number of bales in the field and capacity of the wagon and stacker. The infield transport distance in this study is the distance traveled by the loader, wagon and stacker to load the bales and stack them to the edge of the field. This distance depends on the distance between the bales and the total number of bales in the field. The distance between the bales is calculated assuming the field as a grid and bales distributed uniformly over it. For example, if the total area of the field is 1 hectare (10,000 sq. meter) and there are 8 bales, the distance between the bales would be 35.4 m which is calculated using the following formula.

$$\text{Distance between Bales} = \sqrt{\frac{10{,}000}{\text{Bales Per Hectare}}} = \sqrt{\frac{10{,}000}{8}} = 35.4 \qquad \text{(C.1)}$$

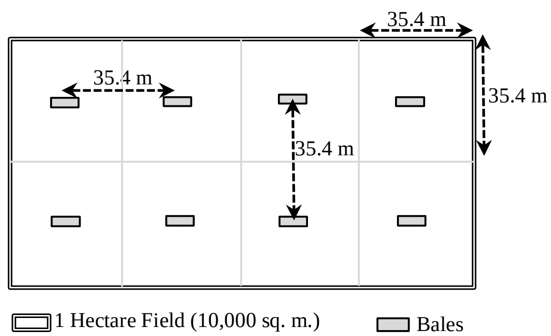

Figure II – 2. Diagram Showing Bales and Distance between Bales.

The stacker is a self-loading equipment which does not require an extra loader. The distance traveled by the stacker is separated as an infield transport distance and distance to stacking and back. The infield transport distance is calculated as the total no. of bales times the distance between the bales. The infield transport distance does not include the distance traveled by the stacker from field to stacking and back. Several checks were made to derive an equation that could give an approximate distance traveled by stacker from field to stacking. The closest and best approximation was based on the following equation and used to calculate the total distance to stacking and back.

$$\text{Total distance to stacking and back} = \sqrt{\frac{\text{Field Size} \times 10{,}000}{\text{No.of Loads/Field}}} \times \text{No. of Fields} \times \frac{\text{No.of Loads}}{\text{Field}} \qquad \text{(C.2)}$$

This equation was also used to calculate the distance traveled by the wagon from field to stacking.

The calculations for loader was different than the stacker or wagon. The distance traveled by the loader depend on the capacity of the wagon and the distance between the bales. Per load distance traveled by the loader was calculated for several capacities of the wagon. Continuing with our earlier assumptions that there are eight bales in a field and distance between the bales is 35.4 m and capacity of the wagon is eight bales then the wagon would be placed in such a location so as to have the shortest possible distance for the loader to pick and load the bales.

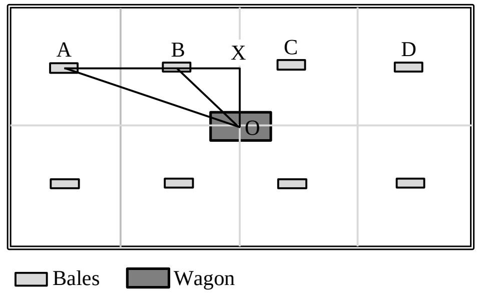

Figure II – 3. Diagram Showing Bales, Wagon and Shortest Possible Distance Traveled by the Loader.

The shortest distance for the loader to pick bale A is AO and to pick bale B is BO which are the hypotenuse of triangle AXO and BXO. The distance BX and XO are half the distance between the bales. Then, the hypotenuse can be calculated using the Pythagoras' Theorem. Other hypotenuse to pick the bales were calculated in similar fashion. The number of hypotenuse calculated are based on the number of bales the wagon can hold. The distance traveled by the loader per load are calculated for several capacities of the wagon using similar procedure. The loader does not need to go to the edge of the field because the wagon we assume is a self-dumping. However, the loader has to travel from one load to the other which is calculated as

$$\text{Distance between loads} = \sqrt{\text{Field Size} \times 10{,}000} \tag{C.3}$$

The total distance traveled by the loader is then the distance traveled per load times the number of loads and the distance it travels from one load to the other.

Appendix II – D: Tables

Table II – 10. Choice of Equipments with their Field Efficiency, Field Speed, Repair Factors and Depreciation Rates.

Type of Equipments	Field Efficiency		Field Speed		Repair Factors		Depreciation Rate
	Typical % EF	Range %	Typical MPH	Range MPH	RF1	RF2	
Tractors							
2WD, 0 to 79HP					0.007	2.0	10%
2WD, 80 to 149HP					0.007	2.0	10%
2WD, 150+HP					0.007	2.0	10%
4WD, 0 to 79HP					0.003	2.0	10%
4WD, 80 to 149HP					0.003	2.0	10%
4WD, 150+HP					0.003	2.0	10%
Harvest equipment-Self Propelled							
Windrower	80	70-85	5.00	3.0-8.0	0.06	2.0	10%
Forage Harvester	70	60-85	3.50	1.5-6.0	0.03	2.0	10%
Harvest equipment							
Baler, round	65	55-75	5.00	3.0-8.0	0.43	1.8	10%
Baler, small rectangular	75	60-85	4.00	2.5-6.0	0.23	1.8	10%
Baler, large rectangular	80	70-90	5.00	4.0-8.0	0.1	1.8	10%
Mower - Rotary	80	75-90	7.00	5.0-12.0	0.44	2.0	10%
Mower - Conditioner	80	75-85	5.00	3.0-6.0	0.18	1.6	10%
Rake, side delivery	80	70-90	6.00	4.0-8.0	0.17	1.4	10%
Swather	80	75-85	5.00	3.0-6.0	0.18	1.6	10%
Forage harvester, pull-type	70	60-85	3.00	1.5-5.0	0.15	1.6	10%
Post-harvest equipment							
Stacker	90			5.0-7.0	0.16	1.6	10%
Wagon	65				0.19	1.3	10%
Front End Loader	80				0.007	2.0	10%

Source: ASAE Standards 2011 (D497.7 MAR2011) except stacker. Field efficiency for stacker is assumed based on field knowledge, speed is based on stinger website and repair factors are assumed similar to forage wagon.

Appendix II – E:
Figure II – 4: Biomass Harvesting Cooperative Feasibility Template - Inputs Page.

Enter information for individual producer and machinery cooerative in green cells.					
Producer/Member Description	**Producer**	**Mach Coop.**		**Input Costs**	**Mach. Coop**
Number of members		*5*		*Fuel Price $/gallon of diesel*	*$3.60*
Total acres	*988*	*4942*		*Cooperative Fee Per Acre*	*$105.00*
Field Size	*99*	*99*			
Yield (Tons/acre)	*4*	*4*		**Labor Costs**	
Lbs/bale	*882*	*1212.54*		*Hired Labor Rate/Hour (Coop.)*	*$20.00*
No. of Cuttings	*1*	*1*		*Hired Labor Rate/Hour (Producer*	*$10.00*
Total no. of bales	*8998*	*32721*			
Total Sq Feet	*43,055,575*	*215,277,876*		**Profit Allocation**	
Share of Machinery Cooperative	*20%*	*100%*		*(all percentages relate to before tax income)*	
				Percentage to Cash Patronage Re	*90%*
Input Capital Structure and				*Percentage to Stock Patronage R*	*10%*
Expense Information				*Percentage Retained*	*0%*
Percent Financed	*50%*	*50%*			
Long Term Interest Rate	*6%*	*6%*			
Loan Term	*5*	*5*		**Machinery Sharing (Equip. Transportation)**	
Equipment Replacement Cycle	*5*	*5*		*Avg distance between producers (*	*22*
Total Equipment Cost	*$ 211,002*	*$ 1,065,487*		*Total equip transportation hours*	*46.02*
Loan Amount	*$ 105,501*	*$ 532,744*			
Current Equity Investment Individ	*$ 105,501*	*$ 532,744*		**Tax Information**	
Current Equity Investment Per Ac	*$ 106.7*	*$ 107.8*		*Property Tax as % of Property Val*	*0.5%*
Required Investment in Cooperat	*$ 106,549*	*$ 532,744*		*Income Tax Rate*	*50%*
Net Annual Fee in Cooperative	*$ 60,715*	*$ 303,575*			
Bale Transportaiton (Hauling)	**Producer**	**Mach Coop.**		**Other**	
	Round Bale	**Rectangular Bale**		*Inflation Rate*	*1%*
Avg distance-stacking to warehou	*22*	*22*		*Total Working Hours / Day*	*10*
Trucking Cost/Km	*$3.03*	*$3.03*		*Insurance Rate % of Property Valu*	*2%*
Capacity of trucks	*34*	*42*			

Figure II – 5: Biomass Harvesting Cooperative Feasibility Template - Individual Equipment Page.

Individual Equipment

Producer/Member

Tractors	HP	Age	Value	Annual Hours	Repair Factor 1	Repair Factor 2	Depreciation Rate	Replacement Cost
2WD, 80 to 149HP	90	0	$ 33,257.00	465	0.007	2	10%	$ 34,953.44
2WD, 80 to 149HP	120	0	$ 88,950.00	337	0.007	2	10%	$ 93,487.34
				0				$ -
				0				$ -

Harvest Equipment - Self Propelled	Width	Speed	HP	Age	Times Over	Value	Annual Hours	Field Capacity	Repair Factor 1	Repair Factor 2	Depreciation Rate	Replacement Cost
							0	0				$ -
							0	0				$ -
							0	0				$ -
							0	0				$ -

Harvest Equipment	Width	Speed	Age	Times Over	Value	% Tractor 1	% Tractor 2	% Tractor 3	% Tractor 4	Annual Hours	Field Capacity	Repair Factor 1	Repair Factor 2	Depreciation Rate	Replacement Cost
Mower - Conditioner	12	6	0	1	$ 38,535.00		100%			139	7	0.18	1.6	10%	$ 40,500.67
Rake, side delivery	12	10	0	1	$ 7,506.00	100%				87	11	0.17	1.4	10%	$ 7,888.88
Baler, round	12	4	0	1	$ 42,754.00	100%				285	3	0.43	1.8	10%	$ 44,934.88
										0	0				$ -
										0	0				$ -
										0	0				$ -

Post Harvest Equipment	Capacity (Bales)	Speed	Age	Times Over	Value	%Tractor 1	% Tractor 2	% Tractor 3	% Tractor 4	Loading time/Bale (s)	Unloading time/Bale (s)	HP	No. of loads per field	Dist bet bales (ft) Per Acre	Tot dist to stacking and back (m)
Dump Wagon	10	6	0	1	$ 10,000.00	100%					35		90	69.17	37.28
Front End Loader		6	0	1	$ 5,289.00		100%			60		120			

Figure II – 6: Biomass Harvesting Cooperative Feasibility Template - Cooperative Equipment Page.

Cooperative Equipment

Tractors	No.	HP	Age	Value	Annual Hours-Field	Annual Hours-Hauling	Repair Factor 1	Repair Factor 2	Depreciation Rate	Replacement Cost
2WD, 80 to 149HP	1	90	0	$ 33,257	372	14	0.007	2	10%	$ 34,953
4WD, 80 to 149HP	1	240	0	$176,676	594	14	0.003	2	10%	$185,688
					0	0				
					0	0				

Harvest Equipment	No.	Width	Field Speed	Transport Speed	HP	Age	Times Over	Value	Annual Hours-Field	Annual Hours-Hauling	Field Capacity	Repair Factor 1	Repair Factor 2	Depreciation Rate	Replacement Cost
Windrower, self-propelled	2	14	8	14	190	0	1	$133,441	457	15	10.81	0.06	2	10%	$ 140,248
									0	0					
									0	0					
									0	0					

Other Equipment	No.	Width	Field Speed	Transport Speed	Age	Times Over	Value	% Tractor 1	% Tractor 2	% Tractor 3	% Tractor 4	Annual Hours-Field	Annual Hours-Hauling	Field Capacity	Repair Factor 1	Repair Factor 2	Depreciation Rate	Replacement Cost
Rake, side delivery	2	14	10	15	0	1	$ 7,506	100%				372	14	13.30	0.17	1.4	10%	$ 7,889
Baler, large rectangular	2	14	6	15	0	1	$171,830		100%			594	14	8.31	0.1	1.8	10%	$180,595
												0	0					
												0	0					
												0	0					
												0	0					

Post Harvest Equipment	No.	Capacity (Bales)	Field Speed Picking	Field Speed Stacking	Transport Speed	Age	Times Over	Value	%Tractor 1	% Tractor 2	% Tractor 3	% Tractor 4	HP	Loading time/Bale (s)	Unloading time/Bale (s)	No. of loads per Field	Distance bet bales (ft) Per Acre	Tot dist to stacking and back (m)	tr
Stacker	1	12	5	15	50	0	1	$230,000					305	4	15	55	81.11	145.11	

Figure II – 7: Biomass Harvesting Cooperative Feasibility Template - Cost Comparison Page.

Cooperative Cost for each member	
Current Equity Investment Individually	$106,549
Current Equity Investment Per Acre	$108
Current Annual Machinery Cost	$61,812
Required Investment in Cooperative	$106,549
Required Coop Investment/acre	$22
Net Annual Fee in Cooperative	$60,715

	Mach Coop	Producer
Percent Savings	8%	8%
Total Labor Hours	1754	802
Required Working Days	175	80

Per Acre Covered Cost: Coop vs Individual Ownership	Mach Coop	Producer
Fuel & Lube	$ 13.75	$ 15.79
Hired Labor	$ 8.91	$ 8.49
Repair & Maintenance	$ 8.34	$ 8.89
Total Variable Costs	$ 31.00	$ 33.17
Insurance	$ 4.51	$ 4.79
Interest	$ 3.12	$ 4.58
Property Tax	$ 1.13	$ 1.20
Depreciation	$ 22.78	$ 24.19
Total Fixed Costs	$ 31.54	$ 34.76
Total Cost	$ 62.54	$ 67.93
Cooperative Fee	$ 105.00	
Net Fee After Cash Refund	$ 61.43	

Per Ton Cost: Coop vs Individual Ownership	Mach Coop	Producer
Fuel & Lube	$ 3.42	$ 3.93
Hired Labor	$ 2.22	$ 2.11
Repair & Maintenance	$ 2.08	$ 2.22
Total Variable Costs	$ 7.72	$ 8.26
Insurance	$ 1.12	$ 1.19
Interest	$ 0.78	$ 1.14
Property Tax	$ 0.28	$ 0.30
Depreciation	$ 5.68	$ 6.03
Total Fixed Costs	$ 7.86	$ 8.66
Total Cost	$ 15.58	$ 16.92

Per Ton Cost by Operation	Mach Coop	Mach Days	Producer	Mach Days
Mowing	$ 3.75	47	$ 4.27	14
Raking	$ 1.17	39	$ 1.16	9
Bailing	$ 7.17	61	$ 6.18	28
Equp Transport	$ 0.37			
Infield transport	$ 3.12	29	$ 5.32	29
Total	$ 15.58		$ 16.92	
Bale Transport	$ 2.59		$ 4.40	
Grand Total	$ 18.17		$ 21.32	

Coop	Operation/Ac	Equp Trans	Total/Acre	Total/Ton
Mowing	$ 15.05	$ 0.51	$ 15.56	$ 3.89
Raking	$ 4.71	$ 0.18	$ 4.89	$ 1.22
Bailing	$ 28.77	$ 0.69	$ 29.46	$ 7.36
Infield transport	$ 12.54	$ 0.10	$ 12.64	$ 3.16
Total		$ 1.47	$ 62.54	$ 15.63

PAPER III

REPLACEMENT AND EXPANSION OF GRAIN STORAGE INFRASTRUCTURE IN OKLAHOMA

Introduction

Replacement and upgrading of grain handling infrastructure is an important issue in Oklahoma and other grain producing states. According to the National Agricultural Statistics Service (NASS), there are about 225 off-farm storage structures in Oklahoma with over 225 million bushels of storage capacity. The grain elevators are concentrated in the prime grain producing areas of central and western Oklahoma. Off-farm storage facilities include both country elevators that have smaller capacities and receive grain by truck directly from farms and terminal elevators that are larger in capacity and receive grain from local elevators. In recent years, as more farmers transport grain in semi-trucks, producers also deliver directly to terminal elevators. A substantial portion of grain handling facilities are beyond their design life and will need to be renovated or replaced in the coming decade. The majority of the storage structures currently in operation were built in the 1940's-1960's while some structures date back to the early 1900's. The managers of the grain handling firms need information on the regional demand for grain infrastructure as they consider investments at specific locations. Historically, Oklahoma's total storage capacity (on-farm and off-farm) has exceeded total grain production (Figure III – 3). This is reasonable since producers and grain facility operators want to maintain the ability to handle above average crops. Due to weather patterns, the year-to-year yield variation in Oklahoma is much greater relative to the Corn Belt. Because it is a food crop, wheat is not typically stored on the ground in temporary storage, a common strategy for handling peak yields of feed grains. The number of off-farm storage facilities in Oklahoma has declined over time (340 in 1992 compared to 224 in 2012) while the total storage capacity has remained fairly constant (246 million bushels in 1992 compared to 235 million bushels in 2012). This reflects a shift to larger storage structures. Oklahoma's harvested grain acres has declined since a peak in the early 1990's as marginal crop land has been converted to pasture. However, the crop mix has also been shifting from continuous wheat to rotations with higher yielding summer crops such as corn and grain sorghum. All of these changes in crop mix, crop yields and land use have implications on the capacity and location of needed future infrastructure.

A recent report issued by Co-Bank examined the need for storage capacity and unloading speed in the Mid-West. The report forecasted the need for an additional 2.3 billion bushels of storage capacity in the 12 Corn Belt States (Kowalski, 2012). The report also indicated that with the faster rate of harvest there will be demands for newer facilities to have increased grain handling speeds. Because of the shift to summer crops such as corn and soybeans, we can expect an increasing demand for storage facilities in Oklahoma and other Southern Plain states. Most Oklahoma grain facilities do not place restrictions on how long producers can store grain, allowing them to weigh anticipated market price increases against storage fees. This results in a portion of the summer crops being still in storage in the elevator when the winter crops are received. Unlike corn and soybeans, there has been little increase in winter wheat yields over the last 20 years. However, several seed companies are examining the potential of hybrid wheat varieties and the commercialization of that technology could increase demand for storage facilities.

The most logical or "least cost" locations for grain facilities in Oklahoma is also an important issue. When most of Oklahoma's grain infrastructure was developed producers transported grain in small trucks over unimproved roads. Road infrastructure has improved and most producers now transport grain in semi-trailers or dual axle straight trucks. This has reduced the per bushel transportation cost (in real dollars). Because of the significant economies of size in grain structure construction, there is potential for structural change as local elevator facilities are consolidated into larger regional hubs. This could increase producers' cost of transporting grain. However, since over 50% of Oklahoma grain capacity is organized as farmer owned cooperatives, a more regionalized system which minimized the joint cost of grain transportation and grain facility construction might still benefit producers. Research on the optimal number, location and capacity of grain elevators, incorporating information on the trends in grain production would give insights into possible structural changes in the Oklahoma grain storage industry. This information would be useful to both grain facility operators and grain producers.

No previous studies have used a plant location optimization model to determine the optimal location, number and capacity of country storage infrastructure in Oklahoma. Baird 1990 carried out a detail survey of all the existing elevators in Western Oklahoma. The study very well documented details of all the existing storage structures but did not do further economic analysis. A study by Fuller et al. 1981 focused on minimizing transportation cost of export wheat from hard red winter wheat producing regions in Kansas, Oklahoma and Texas. Their study considered feasibility of operating unit trains to sea port locations from selected country elevators converted to sub terminals and feasibility of operating unit trains from inland terminal to sea ports. They did not consider transportation cost from grain producing regions to country elevators to sub-terminals. Tembo 1988 used a cost minimization model similar to the current study but his study focused on determining the optimal size and capacity of flour milling to meet the excess demand of flour in Oklahoma rather than the optimal capacity and location of grain storage infrastructure.

Plant location and transportation cost models have been used to determine the optimal location and capacity of grain storage structures in other regions. Araji and Walsh, 1969 conducted a study to determine the effect of grain sales densities and truck cost on marketing cost of grain and optimum size and location of grain elevators in Canada. They determine the optimum size and location of grain elevators by solving an equation for average total cost function of plant operation cost and assembly cost. They found that optimum elevator size could be 25-50% less of the size when only economies of size are considered. Ladd and Lifferth, 1975 used a transshipment plant location model to determine the number, size and location of new sub-terminals and expansion of existing country elevators and railway network maximizing net revenue from the grain distribution of corn and soybean in Iowa. They found that with fewer rail lines the total net revenue would increase by 1-2%. Monterosso et al. 1985 used a plant size location problem to determine the optimum location and size of grain storage minimizing transportation cost in Brazil. Unlike most of the previous studies which found that more regionalized structures minimized total costs, they found that smaller units closer to farmers were optimal.

Jessup et al. 1998 used Geographic Information System (GIS) and General Algebraic Modeling System (GAMS) to obtain a grain transportation optimization model of Eastern Washington State for wheat and barley. Similar to the current study, they used township as their primary source of grain origin but they used only twenty grain production counties. Their shipment of grains are to grain elevators and then to final destination such as feedlots, ocean ports, consumption and export while in our study the shipment of grains are only to country elevators or sub-terminals. Their study found that the transportation cost with barge access are lower and the flow of trucks are on few routes than on several corridors to river ports. Nardi et al. 2007 used GIS and GAMS to develop a methodology that would minimize the transportation and storage costs for soybeans and its by-products in Argentina. Their model would determine optimum routes and modes (truck, rail and barge), production and storage locations, crushing facilities and exporting ports. Their two key findings are that the commodities from lower cost supply chains would ship to the crushing plants and export ports and that the country elevators without a railroad or which are distant from the crushing facility and export ports would have higher shipping and storage costs. In the case of Oklahoma, most of the grain shipped from grain storage facilities is transported by truck to a variety of regional flour mills, river ports and feedlots. We concluded that the transportation costs from grain storage firms to end users would likely have minimal impact on the optimal replacement of grain storage structures.

The main objective of this study is to determine the current grain storage infrastructure in Oklahoma (on farm and commercial) and the level and location of additional infrastructure investment under a number of foreseeable scenarios.

Specific objectives include:

- Determine long term trends in grain production at the county or sub-county level.
- Determine existing grain storage capacity at the county and sub-county level along with the age of the facilities.
- Determine excess or deficit grain storage at the county or sub-county level.
- Determine the change in location and size of grain structures that would be projected to occur as the oldest structures are sequentially replaced and assess the implications of the resulting structure on total transportation and construction costs.
- Determine the size and location of grain storage structures that is projected to occur after older facilities are sequentially replaced with the size and locations that would occur if all structures, regardless of age, were considered for replacement.

Model

Mixed integer type cost minimization models are frequently used to determine optimal location and size of plants. The current study uses a mixed integer model to minimize total cost of grain transportation from the point of production to the point of storage and construction cost of the storage facilities. The grain flow in Oklahoma is generally trucked by producers to country elevators and sub-terminals with some producers delivering directly to terminal elevators. The majority of grain received by country elevators and sub-terminals is trucked to regional demand points such as flour mills and river elevators. Some country elevators are equipped to ship by rail but rail shipments have become much less important. The current study does not consider transportation cost from the country elevator to final demand point because grain is primarily shipped by truck and the outbound transportation cost is not considered to impact the optimal size and location of elevators. Outbound transportation costs are also very difficult to model as shipment distances vary with market opportunities. The focus of our study is only on replacement and expansion of country elevators and sub-terminals. Wheat, canola, corn, grain sorghum and Soybean are the five crops used in the study. The storage structures considered for replacement are upright concrete and steel. For the purpose of determining useful life and replacement costs, flat structures are grouped under steel structures.

The model used is recursive or what some might term, myopic. We considered replacement decisions in three stages and we assumed that the structures that were replaced in the initial periods were fixed, and therefore out of the choice variables for the subsequent stages. We did not assume that the impact on the subsequent decisions were considered in the initial choice as to whether to replace or not replace an obsolete structure. It would be perhaps possible to construct a dynamic programming model that considered the decisions with perfect foresight. However, there are several difficulties with that approach in terms of the grain industry structure being analyzed. First, a dynamic approach assumes that the industry participants are willing and able to systematically make investments over time according to an optimal path. The current industry situation was a result of grain firms failing to invest in grain facilities which resulted in the majority of the structures operating past their design life. In this sense the grain industry participants have been myopic. Rather than assume that the industry firms suddenly adopt a systematic and optimally forward looking (perfect foresight) reinvestment strategy, we choose to model the implications of the recursive investment decisions that are most likely to occur. The other difficulty in developing a meaningful perfect foresight model is that the time path of the continued use and total obsolescence of the structures is difficult to determine. An engineering approach would assume that the structures remain in use until the end of their design life. However, the majority of the structures in use are already beyond that time point. It would be difficult to accurately model the time period of catastrophic failure to determine the time path for mandatory replacement. For example, the assumption that structures could remain in operation 5 years past their design life would lead to a different dynamic model from one based on an assumption of 10 or 15 years of post-design life service. In light of all of these factors the recursive model was deemed most appropriate.

Mathematically, the objective function can be written as:

$$\text{(3.1)} \quad Min\ Z = \sum_{i=1}^{2,047} \sum_{j=1}^{210} \sum_{k=1}^{5} TC_{ij}\, Q_{ijk} + \sum_{j=1}^{210} \sum_{s=1}^{J_s} CC_{js}\, BETA_{js}$$

which is subject to the following constraints:

$$\text{(3.2)} \quad \sum_{j=1}^{210} \sum_{k=1}^{5} Q_{ijk} - PRODU_{ik} = 0 \qquad \text{(Production Constraints)}$$

$$\text{(3.3)} \quad \sum_{i=1}^{2,047} \sum_{j=1}^{210} Wheat_{ij} + \sum_{i=1}^{2,047} \sum_{j=1}^{210} Canola_{ij} - \sum_{s=1}^{13} CAP_{js}\, BETA_{js} \leq 0 \qquad \text{(Winter Crop Capacity Constraints)}$$

$$\text{(3.4)} \quad \begin{aligned} &\sum_{i=1}^{2,047} \sum_{j=1}^{210} Corn_{ij} + \sum_{i=1}^{2,047} \sum_{j=1}^{210} Sorgh_{ij} + \sum_{i=1}^{2,047} \sum_{j=1}^{210} Soy_{ij} + 0.5 * \sum_{i=1}^{2,047} \sum_{j=1}^{210} Wheat_{ij} \\ &\qquad + 0.5 * \sum_{i=1}^{2,047} \sum_{j=1}^{210} Canola_{ij} - \sum_{s=1}^{13} CAP_{js}\, BETA_{js} \leq 0 \end{aligned} \qquad \text{(Summer Crop Capacity Constraints)}$$

$$\text{(3.5)} \quad BETA_{js} = 0\ or\ 1, \qquad \text{(Binary Constraints)}$$

(3.6) $Q_{ijk}, Wheat_{ij}, Canola_{ij}, Corn_{ij}, Sorgh_{ij}, Soy_{ij} \geq 0$ for all i, j, k (Non-negativity Constraints)

The variables used in the objective function and constraints are described in Table III – 1. The model has primarily two constraints - production and capacity. The production constraints force the model to ship all the production to the storage structures while the capacity constraints force the model to ship less than or equal to the capacity of the storage structures. The capacity constraints are separated as winter and summer crops capacity constraints. Wheat and canola are winter crops and corn, soybean and grain sorghum are summer crops. We assume that the winter storage capacity is used only for winter crops. While in summer, we assume half of the winter crops remain in storage and half of the winter receipts have been shipped to the terminal elevators or final demand points. This assumption is consistent with typical grain flows. The binary constraints allows the model to retain or eliminate storage structures and the non-negative constraints forces selected variables to remain positive.

Table III – 1. Description of Variables Used in the Objective Function and Constraints.

Variables	Description
Z	Total cost of grain transportation and construction cost of storage structure;
Q_{ijk}	Quantity of crop *k* shipped from source *i* to storage structure at location *j*;
$PRODU_{ik}$	Quantity of crop *k* produced at source *i;*
$Wheat_{ij}$	Quantity of wheat shipped from source *i* to storage structure at location *j*;
$Canola_{ij}$	Quantity of canola shipped from source *i* to storage structure at location *j*;
$Corn_{ij}$	Quantity of corn shipped from source *i* to storage structure at location *j*;
$Sorgh_{ij}$	Quantity of grain sorghum shipped from source *i* to storage structure at location *j*;
Soy_{ij}	Quantity of soybean shipped from source *i* to storage structure at location *j*;
TC_{ij}	Transportation cost of crop *k* shipped from source *i* to storage structure at location *j* per bushel per mile;
CC_{js}	Construction cost of storage structure of *s* type (Concrete or Steel) at location *j*;
$BETA_{js}$	Binary variable for building storage structure of *s* type (Concrete or Steel) at location *j*, 1 indicates storage structures which are not eliminated and 0 indicates otherwise;
CAP_{js}	Capacity of storage structure of *s* type (Concrete or Steel) at location *j*;

Data

Grain Elevators

Direct field visits and personal contacts were used to collect grain elevator data from privately-owned elevator companies, and which include information on storage capacity by location for each type of structure and their age. The data were also obtained from a cooperative insurance company that insures all of the grain cooperatives in Oklahoma. Beside storage capacity, location and age of structures, we also obtained information on the number of dump pits and the speed of handling equipment. However, the grain handling system information was not used in this study. The data we collected did not include any on-farm capacities.

The collected data covered 477 total storage structures or bins spread in 210 locations (Figure III – 1). Out of the nine crop reporting districts our data did not include storage structures in three eastern crop reporting districts. There were no storage structures in East Central and South East. There were a few structures in North East but their data could not be obtained and was not considered for this study. Grain production in the North East district is low so ignoring the few structures from this region should not severely affect our optimal solution. Available web facility was used to convert the physical address of each storage facility to a precise location by latitude and longitude so they could be mapped and be used to calculate a distance matrix.

Township and Distance Matrix

Grain production was estimated for each township and transportation distances were calculated from each township to all storage structure locations. Townships are geographical areas which are further sub-division of counties. The Oklahoma township shapefile was obtained from the website of "Oklahoma Center for Geospatial Information" at Oklahoma State University. There were 2,047 townships in total. A matrix of distance from each township to each elevator was generated using Quantum Geographic Information System (QGIS 1.8) software. The dimension of the distance matrix was 2,047 by 210.

Grain Production Data

Satellite Imagery Data for Crop Acreage

NASS maintains an online resource of historical satellite imagery data of several crops called the "CropScape - Cropland Data Layer". This is a web based application for exploring and disseminating geospatial cropland data products throughout the US (Han et al. 2012). We used "CropScape" to obtain raster files (image) of each crop to get acreage for each township. The raster files were first converted to vector file in ArcGIS 10 and the area of each polygon was calculated. The vector files were then intersected with townships which were then dissolved to get the total acres of crops produced under each township. We used this procedure to obtain the acres of crop produced in each township for each of the five crops in our study.

Grain Production by Townships

County estimates of wheat, canola, corn, soybean and sorghum production (bushels) were obtained from NASS for the 2008 to 2012 time period. The county production was averaged for the five years to obtain an overall average of crop production for four crops (wheat, corn, sorghum and soybean). We calculated proportionate acreage by townships in each county using GIS satellite imagery. The production for each township was then calculated using the proportionate acres of each township and the county average crop production (bushels). Canola production by townships was calculated using the state average (2009-2012) production (pounds) rather than the county average because canola production data was available only by state.

Transportation and Construction Cost

The capacity of a grain semi-trailer is typically slightly under 900 bushels with some variation across commodities. We assume a trucking cost of $5 per loaded mile or $0.0056 per bushel per mile.

Grain storage structures in Oklahoma are usually upright concrete and steel structures. There are some flat steel structures but they are typically only used for overflow due to the higher handling costs. In terms of useful life, we grouped flat structures with steel structures. In terms of replacement costs we only considered construction cost for concrete and steel structures. We assumed that existing steel structures would be replaced with concrete structures and existing round steel and flat steel structures would be replaced with round steel structures. Construction cost estimates were based on discussions with managers of local grain elevators who had recently completed construction projects. The assumed construction cost is $3.0 per bushel for a steel structure and $3.3 per bushel for a concrete structure. This cost was assumed for a storage facility with a capacity of 100,000 bushels. The construction cost for several other facilities with varying capacities was determined using the exponent method (Dysert, 2003) as below.

$$C = C_n \times \left(\frac{O}{O_n}\right)^m \tag{3.7}$$

where C is the construction cost of facility to be determined with a capacity of O. C_n is the known cost of facility with known output level O_n and m is a scale factor. To determine the construction cost of other facilities with varying capacities we used the known cost of $3.0 per bushel for steel and $3.3 per bushel for concrete with the known capacity of 100,000 bushel and 0.7 as the scale factor.

Procedure

We first analyzed the location, capacity and age of existing off-farm grain storage structures along with the trends in grain production in Oklahoma. We then ran series of optimization models written in GAMS to solve the general objective function specified in 3.1. The model was first tested with a few grain structure locations and few crops. An excel solver was set up to solve the objective function with the exact same details as in GAMS and we confirmed that the GAMS and excel solver solutions exactly matched. The full model was then solved with GAMS using crop production data for all five crops by townships, capacity of existing elevators, distance matrix, transportation cost/bushel/mile and construction cost/bushel. We used GAMS/CPLEX solver to solve the optimization problem. Because grain facility managers plan infrastructure to handle above average or “peak” crop years we used 120% of average historical grain volume as the baseline case in the model. We performed sensitivity analysis to consider differences in the optimal solution for higher or lower yields.

As discussed in the data section, grain transportation cost was estimated at \$0.0056/bushel/mile and grain bin construction cost was estimated at \$3.00/bushel and \$3.30/bushel for steel and concrete structures, respectively, with scale factor adjustment for smaller and larger sizes. Because the model minimized annual costs, an amortization factor representing 6% interest and a 10 year loan was used to convert the total construction costs to an annualized amount. This choice of the interest rate and term was based on conversation with the regional office of Co-Bank, a major lender to grain cooperatives.

Six scenarios were examined. The first scenario, a baseline, determined the least cost system of transporting and storing grain with no construction cost applied to the existing structures. Using age as a basic criteria we created four additional scenarios for sequential replacement as grain structure reached the end of their useful life. Concrete and steel structures were categorized separately for sequential replacement because of differences in their life spans. Generally, concrete structures last longer than steel structures. We assume concrete structures last 50 years and steel structures last 30 years. The concrete structures were categorized assuming 50 year life spans and therefore concrete structures built before 1939, 1949, 1959 and 1969 were categorized in Scenarios II, III, IV and V respectively. Similarly, the steel structures were categorized assuming a 30 year life span and therefore steel structures built before 1959, 1969, 1979 and 1989 were categorized in Scenarios II, III, IV and V respectively. In each scenario the grain capacity represented by structures reaching the end of their useful life could be retained only if the model selected a construction activity with the associated construction cost. In each location of an obsolete structure the model could select from the existing capacity or two additional capacities, one with 50% and another with 100% increment over the existing capacity. This way if needed, the model could build up to 250% of existing capacity at any location of an obsolete structure. The model was forced to retain the reconstructed capacity selected in a given scenario in all subsequent scenarios since those structures were now new and not reaching the end of their useful life. A final scenario investigated the least cost structure with no restrictions on the timing of obsolescent. In other words, it imposed a construction cost to retain any of the structures designated as obsolete in the previous scenarios. It therefore reflected the structure that would occur if the grain industry was redesigned to minimize the combined cost of transportation and storage construction without considering the remaining useful life of existing structures. In the context of an individual business this is commonly referred to as a "green field approach". The purpose of the scenario was to investigate whether a different industry structure would occur if grain facility managers looked forward in their strategic planning and invested in the complement of infrastructure that would ultimately be the most cost efficient. It should be noted that the most recently constructed existing grain structures were assumed to be retained in the final scenario so it represents a "near green field" but not "total green field" approach.

Results

Overview of Grain Storage Infrastructures

Grain elevators in Oklahoma are strategically located in prime grain producing areas of the state. Wheat being the major crop, the grain structures are mostly centered in major wheat producing areas. Many of the older storage facilities were built alongside the railway network so that the stored grain could be easily and directly shipped to the terminal elevators or barge for export. Grain elevators in Oklahoma are usually upright concrete and upright and flat steel structures. Most of the flat steel storage structures were built during the period of time when the USDA Commodity Credit Corporation (CCC) program provided storage payments for grain held for producers. Flat storage is slightly cheaper to construct on a per bushel basis relative to round steel bins but has much higher handling costs. Many flat grain storage structures have been converted from grain storage to other warehouse uses. However, our data only reflects the flat storages which are still included in the facilities grain license. There are slightly more steel structures than concrete in terms of both the number of facilities and total capacities (Table III – 2).

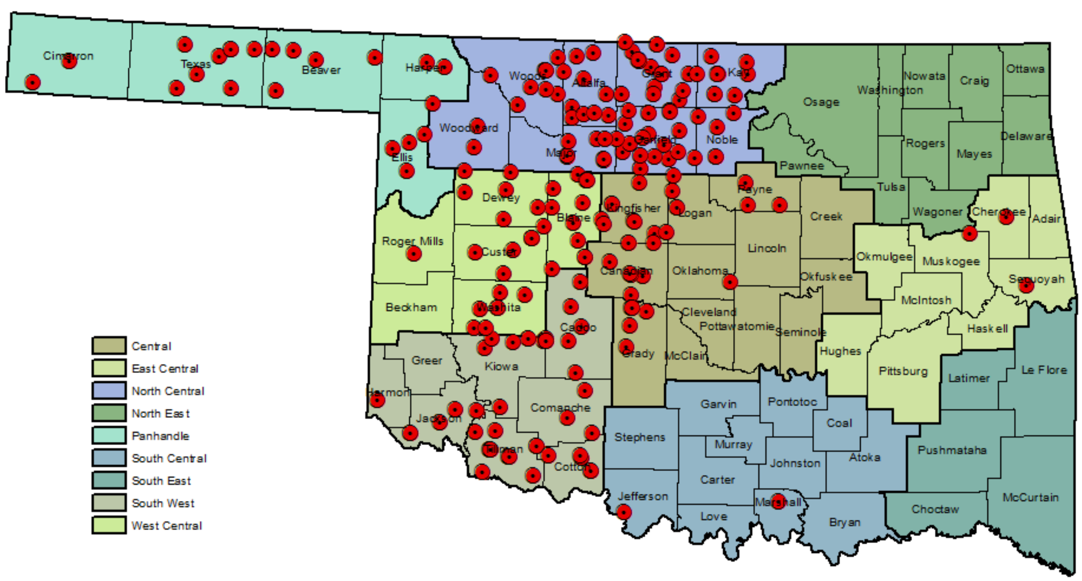

Figure III – 1. Grain Elevators in Oklahoma

The regional distribution of grain elevators show that North Central and South West have the majority of storage structures while there are very few storage structures in the eastern part of the state. In terms of capacity, North Central alone has about 40% of the total storage capacity followed by Central, Panhandle, South West and West Central each having about 10-15% of the total storage capacity. North Central alone has more than half of the total storage capacity in concrete structures and about 40% of the total storage capacity in steel structure. In terms of Counties, Garfield County (North Central) has the highest storage capacity of 21.7%, followed by Texas County (Panhandle) with 8.23%, Grant County (N Central) with 6.21 % and all other counties having less than 5% of the total storage capacity.

Table III – 2. Number and Capacity of Structures by Type and Crop Reporting Districts.

Crop Reporting District	Concrete Structure		Steel Structure[1]		Total	
	No.	Capacity (Bu)	No.	Capacity (Bu)	No.	Capacity (Bu)
Central	23	6,824,000	32	8,137,307	55	14,961,307
East Central	0	-	3	2,313,572	3	2,313,572
North Central	127	38,307,783	73	28,247,205	200	66,554,988
Panhandle	17	8,715,540	32	9,025,507	49	17,741,047
South Central	0	-	2	360,000	2	360,000
South West	26	6,517,089	78	16,801,127	104	23,318,216
West Central	32	8,902,516	32	10,315,961	64	19,218,477
Total	225	69,266,928	252	75,200,679	477	144,467,607

[1]Flat structures are grouped under steel structures.

Table III – 3 classifies storage structures by their age. The table show that a large number and capacity of storage structures were built between 1940 and 1989. The majority of the concrete structures (about 56%) were built between 1950 and 1959 after which the construction of new concrete structures sharply declined. The majority of steel structures (about 40%) were built between 1980 and 1989 but unlike the concrete structures there was no sharp decline in addition of new steel structures. A few structures still in operation date back as far as 1900’s. There has been investment in new structures during the last 10 years and during the last three years, with the majority of those structures being round steel bins. The relative price of steel and concrete storage structures varies over time. Each type of storage has advantages and disadvantages in terms of stored grain management.

Table III – 3. Number and Capacity of Structure by Type and Years.

Year	Concrete Structure		Steel Structure[2]		Total	
	No.	Capacity (Bu)	No.	Capacity (Bu)	No.	Capacity (Bu)
1900-1909	2	266,244	8	1,706,450	10	1,972,694
1920-1929	1	77,210	0	-	1	77,210
1930-1939	16	1,915,874	3	193,417	19	2,109,291
1940-1949	58	14,678,439	6	1,002,733	64	15,681,172
1950-1959	108	39,318,944	21	3,934,947	129	43,253,891
1960-1969	19	6,679,658	25	3,938,328	44	10,617,986
1970-1979	3	858,588	54	5,413,523	57	16,272,111
1980-1989	8	2,089,945	69	30,577,344	77	32,667,289
1990-1999	1	24,000	22	5,160,016	23	5,184,016
2000-2009	3	1,170,026	28	6,458,300	31	7,628,326
2010-2013	6	2,188,000	16	6,815,621	22	9,003,621
Total	225	69,266,928	252	75,200,679	477	144,467,607

[2]Flat structures are grouped under steel structures.

Overview of Grain Production in Oklahoma

The historical grain production in Oklahoma do not show a consistent trend (Figure III – 2). The range of grain production show a minimum of 93 million bushels to a maximum of 257 million bushels with a five year average of 118 million bushels. Wheat is the major crop in the state with majority share of about 78% of the total crop production. The other major crops after wheat are corn and sorghum which share about 18% of the total crop production. Canola and soybean share about 3% and 1% of the total crop production.

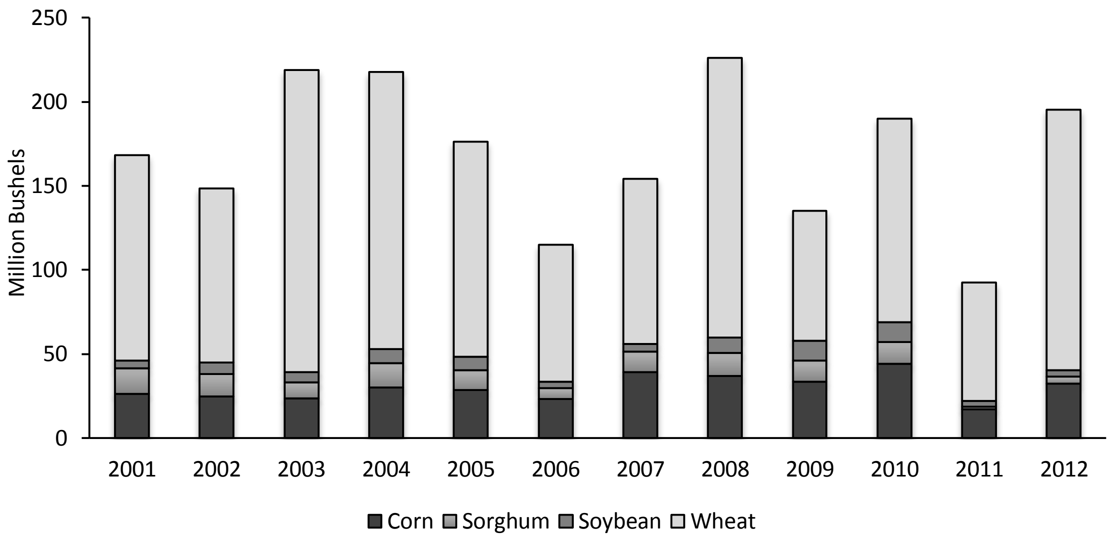

Figure III - 2. Historical Grain Production in Oklahoma.

The production of canola however is in rapid rise. In 2009, canola production was 962,000 bushels which almost doubled to 1.7 million bushels in 2010 and 2011 and it again doubled to 3.2 million bushels in 2012 (Figure III – 3).

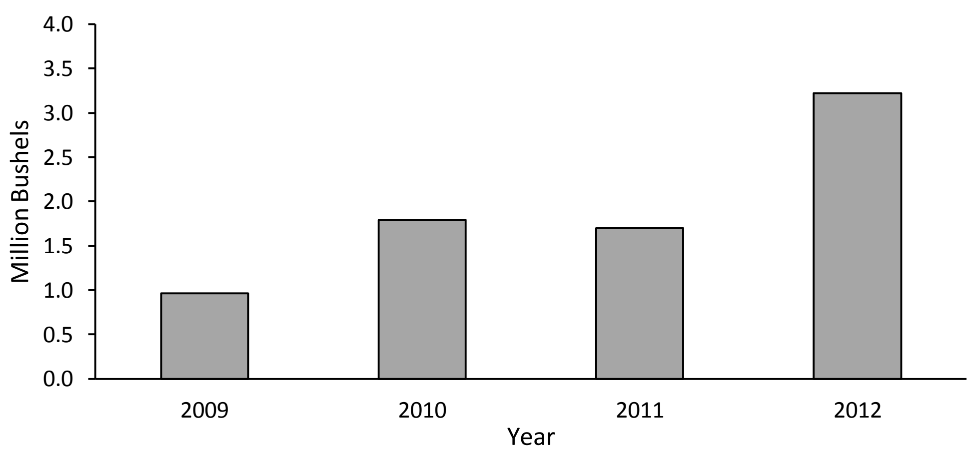

Figure III - 3. Historical Canola Produciton in Oklahoma.

The on-farm and off-farm capacity data collected from NASS show that historically Oklahoma has never been deficit in storage capacities (Figure III – 4). The off-farm capacity have almost been consistent at about 235 million bushels and on-farm capacity is consistent at 75 million bushels after 2003. Based on our personal contacts with grain facility managers, the NASS data appears to overstate actual grain storage capacity. As discussed previously, there was at one time a large amount of flat storage in Oklahoma due to incentives from the CCC grain storage program. Much of that capacity is not used for grain storage but may still be reflected on the NASS data. There are also several large terminal elevators in Enid, Oklahoma with combined storage capacity over 40 million bushels that have not been in use for many years. Prior to the mid 1970's rail road commonly offered a "transit billing privilege" that allowed grain to be shipped and stored at terminal elevators in route to eventual shipment to export facilities at the same cost as direct shipment to export (Warman, 1994). This created an economic rationale to stage grain at inland terminals such as Enid, Oklahoma. When the transit billing privilege was eliminated the demand for terminal storage decreased. However, the abandoned terminal capacity is still reflected on the NASS storage data. Similar issues impact on-farm capacity. Many producers constructed flat grain warehouses or quonset structures when CCC storage payments and subsidized loans for on-farm grain storage were available. Oklahoma is a high risk storage environment due to temperature and insect pressure. Because of this, most producers shifted to commercial grain storage. Unfortunately, there are no reliable estimates of the amount of grain actually stored on farm. For the purpose of our study we did not consider on-farm grain storage.

Figure III - 4. Historical Grain Production Vs. Grain Storage in Oklahoma.

Regional Shifts in Grain Production

We analyzed wheat production by county from 1981 to 2008. Unlike the mid-west Corn Belt where corn yields have maintained a consistent growth trend line, no definite or consistent trend of wheat production was found in any counties; a similar trend observed by Epplin, 1997 for Oklahoma wheat yield in the years 1986 to 1995. Our analysis showed no regional shift in production between minor wheat production to major wheat producing counties or vice-versa. The only discernible trends in production were in the minor wheat producing regions in Oklahoma such as East Central, North East, South Central and South East which had a declining trend. Similar analysis with corn (1981-2012) show an increasing trend of corn production in counties like Beaver (Panhandle region) Garfield, Grant, Kay (North Central Region), and McCurtain, Muskogee, Ottawa, (Northeast Region) but the production in these counties was less than 2 million bushels per year. There was a significant and consistent rise of corn production in Texas County with 2 million bushels in 1981 to 15 million bushels in 2012. There was a similar increasing trend of corn production in Cimarron County (also in the Panhandle Region) until 1999 when production reached 8 million bushels but corn production declined after that time period. In the Oklahoma Panhandle most of the crop production is irrigated out of the Ogallala aquifer and it accounts for the majority of Oklahoma corn production with an average production of more than 15 million bushels. While accounting for a much smaller portion of total corn production, corn yields are increasing in most of the other crop reporting districts in the state. There was negligible corn production in West Central.

The analysis with grain sorghum show that Cimarron and Texas Counties in the Panhandle District are the major producers of grain sorghum. Both counties however show a declining trend in sorghum production, likely due to a shift from grain sorghum to corn. Cimarron County had 6 million bushels of sorghum production in 1981 which sharply decline to less than a million bushels in 2012. Likewise Texas County had about 8 million bushels of sorghum production in 1981 which also declined to less than a million bushels in 2012. Beaver County (in the Panhandle district), and Grant and Kay counties (in the North Central District) have sorghum production of about 1 million bushels but they also have a slightly declining trend. Alfalfa and Garfield (in the North Central District) are the only two counties to have an upward trend of sorghum production but their production which is about 1 million bushels is very low compared to Cimarron and Texas Counties in the Panhandle Region. The yield trends with Soybeans show that Wagoner, Sequoyah, Ottawa, Muskogee, McCurtain, Le Flore and Kay Counties (all in the North Central and North East Regions) are the major soybean producers. Some counties show declining trend in production while others show increasing trend. Counties such as Alfalfa, Grant, Kay and Washington show increasing trend while counties such as Le Flore, McCurtain and Rogers show a declining trend. The productions by region show that soybean production is concentrated in North East. A trend analysis show an increasing trend of production in North Central and a decreasing trend in South East.

Canola production data by county was not available rather a short time series of state production was available. The trend show a rapid rise of canola production in Oklahoma. The production was almost four times more in 2012 than the production in 2009.

Sequential Replacement of Older Structures

Table III – 4 shows the number of structures replaced and retained in sequential replacement of older structures. In Scenario I, there were no construction costs imposed on any structures and the model retained and calculated the transportation costs to the 477 existing grain structures. This provided an approximation of the transportation cost currently incurred by Oklahoma grain producers. In subsequent scenarios, structures older than the specified age were considered obsolete and construction costs were imposed if that capacity or additional capacity was selected at the location. Fifty seven structures were considered obsolete in the first scenario. The cumulative number of structures considered obsolete in each scenario is shown in Table III – 4. In general, the model rebuilt capacity at most but not all obsolete locations and at times did so by increasing capacity. Out of the 57 locations with obsolete storage in Scenario II, the model rebuilt capacity at 50 of those locations. By Scenario V, the total number of structures was reduced from 477 to 293 but total capacity increased from 162.5 million bushels to 170.8 million bushels (Table III – 5).

Table III – 4. Number of Structures Replaced and Retained in Subsequent Scenarios.

Scenarios	Number of Structures Replaced			Number of Structures Retained		
	Obsolete structures	Additional structure options provided	Total	Structures retained	Structures not obsolete	Total
Scenario II	57	114	171	50	420	470
Scenario III	140	280	420	85	337	422
Scenario IV	302	604	906	163	175	338
Scenario V	390	780	1,170	206	87	293

Note: There are 477 total storage structures with 144,467,607 bushels capacity.

The regional distribution of number and capacity of structures retained show that the majority of structure locations which were eliminated were in the North Central and Central regions which was also true with the elevator locations (Table III – 14) while additional capacity was added in South Central and Panhandle Regions. In part, this results reflects the excess capacity in terminal elevators near Enid Oklahoma (North Central Region) due to changes in CCC storage programs and rail rate structures. The shortage of capacity in the Panhandle reflects increased corn acreage and yields.

Table III – 5. Number and Capacities of Structures Retained in Subsequent Scenarios.

Crop Reporting Districts	Number of Structures Retained					Capacity Retained (Million Bushels)				
	Existing Structures	Scenario II	Scenario III	Scenario IV	Scenario V	Existing Capacity	Scenario II	Scenario III	Scenario IV	Scenario V
Central	55	49	42	32	24	15.0	14.2	12.1	12.6	12.9
N Central	200	176	133	86	70	66.6	63.2	56.7	55.0	53.6
S Central	2	4	4	4	4	0.4	1.4	1.4	1.4	1.4
W Central	64	66	60	48	44	19.2	21.3	21.3	22.6	23.3
E Central	3	3	3	5	4	2.3	2.3	2.3	10.4	10.4
Panhandle	49	57	70	65	62	17.7	19.8	38.0	38.4	38.4
S West	104	115	110	98	85	23.3	29.0	30.6	30.4	30.9
Total	477	470	422	338	293	144.5	151.3	162.5	170.9	170.8

Table III – 12 and 13 in the appendix show similar results by county. Capacities were eliminated in most of the counties in North Central and counties like Kingfisher and Canadian in Central regions. There was a significant increase in the number of structures in Texas County in the Panhandle Region and Tillman County in the South West Region. The trend in changes in storage capacity followed the same pattern.

Table III – 6 show the effect of sequential replacement of older infrastructure on transportation and construction costs. Transportation cost is a function of distance travelled, quantity of grain shipped and cost per bushel per mile. A priori, we anticipated that transportation costs would increase as larger structures were constructed in pursuit of scale economies. However, contrary to our expectations, transportation costs declined even though there were fewer structures in the subsequent scenarios. In the existing structure of elevators, there is insufficient capacity in some locations. The cost of transporting the excess grain to other locations was reflected in the base scenario. In the subsequent scenarios, there were few total structures but capacity was increased in previously deficit storage space locations.

Table III – 6. Transportation and Construction Cost with Sequential Replacement of Older Infrastructures.

Crop	Transportation Cost (Million Dollars)					Annualized Construction Cost (Million Dollars)			
Reporting Districts	Scenario I	Scenario II	Scenario III	Scenario IV	Scenario V	Scenario II	Scenario III	Scenario IV	Scenario V
Central	5.4	3.7	3.5	1.1	1.2	1.9	4.5	11.0	15.8
N Central	17.0	13.1	8.4	4.0	3.4	5.2	17.5	52.3	64.2
S Central	0.1	0.8	0.9	0.7	0.7	0.4	0.0	0.0	0.0
W Central	11.4	10.4	1.4	1.5	1.5	1.7	3.6	14.3	16.4
E Central	0.8	0.8	0.8	3.8	3.9	0.0	0.0	1.7	0.0
Panhandle	3.9	4.6	5.2	4.3	4.0	1.1	6.4	5.8	9.2
S West	6.7	6.4	4.0	2.5	2.4	3.6	3.3	12.5	18.6
Total	45.5	39.8	24.2	17.8	17.1	14.0	35.3	97.5	124.3

Table III – 7 show excess winter and summer capacity with sequential replacement of older storage infrastructures. In the baseline case (Scenario I), the existing storage capacity was slightly higher than the assumed grain flow (120% of average yields). The winter storage capacity was the closest to crop demand with only 2.5 million bushels of excess capacity. Since the model had to incur construction cost to retain or increase capacity at obsolete storage locations we had no a priori expectations as to whether total storage capacity would increase or remain near the level of crop production. Total storage capacity increased in all of the four subsequent scenarios indicating that the transportation cost savings from increasing capacity at some locations offset the construction cost for increasing capacity. In the last scenario, where all of the existing structures except the very newest structures had the opportunity to be replaced, winter excess storage capacity increased to 29 million bushels, a more than tenfold increase over the baseline scenario representing the existing structure.

Table III – 7. Excess Capacities with Sequential Replacement of Older Infrastructures.

Crop Reporting Districts	Existing Capacity (Mil Bu)	Excess Capacities (Mil Bu)									
		Scenario I		Scenario II		Scenario III		Scenario IV		Scenario V	
		Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Central	15.0	0	1.4	0	1.8	0	0.9	0.2	3.4	0	3.3
E Central	2.3	0.2	0	0.3	0	0.2	0	7.6	0	7.7	0
N Central	66.6	1.1	7.8	6.1	9.9	0	10.7	0.2	14.0	0	13.2
Panhandle	17.7	1.2	0	2.9	0	20.3	0	21.1	0.5	21.3	0.6
S Central	0.4	0	0	0	0	0	0	0	0	0	0
S West	23.3	0	4.0	0	7.5	0	10.9	0	12.4	0	12.8
W Central	19.2	0	0.6	0	1.4	0	9.3	0	9.8	0	10.2
Total	144.5	2.5	13.8	9.3	20.6	20.5	31.7	29.1	40.1	29.0	40.2

Note: The excess capacity is calculated by subtracting the retained capacity with the total quantity of grains shipped in that region.

Unrestricted Replacement of Older Structures

The last case examined represented a near "Greenfield" scenario where almost all of the existing structures were considered eligible for replacement. This scenario investigated what would happen to the grain storage industry structure if the grain industry looked forward and implemented the least cost structure even though some facilities would be replaced prior to the end of their useful life. In this scenario, not only was their no restriction on sequentially replacing the oldest structures first, but the model also had no restrictions on the amount of capacity that could be added at a location. In order to examine the sensitivity to grain production, a second case with a 25% increase in grain yield was also examined in this unrestricted model. Table III – 8 provides a comparison of the existing grain industry structure and the cost minimizing structure under the near "green field" approach. The number of structures decreased from the current level of 477 to 81 and the elevator location decreased from 210 to 69 (Table III – 15) as the model selected fewer structure/locations with higher capacity structures. Most of the structures selected were above 1.5 million bushels capacity. Increasing the grain yield by 25% resulted in 103 structures at 85 locations (Table III – 15), still much more regionalized than the current industry structure, with the same pattern of fewer but larger regionalized locations. With base production, the solution represented a 9.1% increase in capacity relative to the existing industry structure and with 25% increase in assumed grain production the model solution represented a 40.7% increase over the existing capacity.

Table III – 8. No. of Structures Retained by Changes in Crop Production.

Capacity (Bu)	Existing Structures			Base Production	25% Increase in Base Production
	Concrete	Steel	Total		
3,000-100,000	39	63	102		
100,001-200,000	63	54	117		
200,001-300,000	62	63	125		
300,001-400,000	28	25	53		
400,001-500,000	9	14	23		
500,001-600,000	8	11	19		
600,001-700,000	2	6	8	2	1
700,001-800,000	1	5	6		
800,001-900,000	3	1	4	1	
900,001-1,000,000	2	3	5		
1000,001-1,500,000	3	2	5	1	3
>1,500,000	5	5	10	77	99
Total	225	252	477	81	103

Table III – 9 summarizes the regional impacts of the near "green field" scenario. Not surprisingly there would be regional losers and winners if the industry was reconstructed to minimize total system costs. With base production, the Central and North Central regions loses capacity while the South Central and East Central would see significant increase. The same pattern is evident even if the assumed grain flow increased by 25%. While there is a general trend toward increased capacity the largest increase remains in the South Central and East Central Regions.

Table III – 9. Capacity Retained (Million Bushels) with No Limit on Structure Size.

Crop Reporting Districts	Existing Capacity (Million Bushels)	Base Production		25% Increase in Base Production	
		Capacity Retained	%Capacity Gain/Loss	Capacity Retained	%Capacity Gain/Loss
Central	15.0	14.0	-6.4%	18.0	20.3%
N Central	66.6	46.0	-30.9%	60.0	-9.8%
S Central	0.4	2.6	622.2%	2.7	650.0%
W Central	19.2	22.0	14.5%	28.0	45.7%
E Central	2.3	10.0	332.2%	12.0	418.7%
Panhandle	17.7	39.0	119.8%	44.5	150.8%
S West	23.3	24.0	2.9%	38.0	63.0%
Total	144.5	157.6	9.1%	203.2	40.7%

Comparisons with Sequential and Unrestricted Replacement

We compared the industry configuration after sequential replacement of older bins with the unrestricted or "near green field" case of replacing bins without restrictions on age and with capacity unconstrained (Table III – 10). In order to compare system cost we calculated the total construction cost of sequential replacement and also included a construction costs for the most recently constructed elevators which were not included in the sequential scenarios. The selected 293 structures from sequential replacement were re-run with construction cost given to all 293 structures. The model retained 276 structures with

169.8 million bushels capacity. The results from this scenario were compared with the results from the unconstrained replacement which had 81 retained structures with 157.6 million bushels capacity. Not only was the industry in the "green field" case much more regionalized than the existing industry structure, it was much more regionalized than the structure that would occur if structures were sequentially replaced on an "oldest first" basis. As a means of visualizing this result we could consider a grain elevator firm with an elevator in the eastern and western area of its trade territory. If it considered the replacement of the oldest elevator, for example the western elevator, while maintaining the eastern elevator without a construction cost, it might conclude to replace the capacity at the western location. If it looked ahead and considered the fact that both structures would eventually need replacing it might decide to eliminate one location and increase capacity at the other. In the unrestricted or "green field" scenario transportation cost was higher relative to the sequentially replaced structure but total system costs (transportation plus construction) was lower.

Table III – 10. Cost Comparisons with Configuration after Sequential Replacement and Capacity Unconstrained.

Crop Reporting Districts	Configuration after sequential replacement (Million Bushels)			Unconstrained replacement (Million Bushels)		
	Transportation Cost	Construction Cost	Total	Transportation Cost	Construction Cost	Total
Central	1.15	3.16	4.31	1.43	2.39	3.83
N Central	3.46	11.53	14.99	4.20	7.87	12.07
S Central	0.65	0.39	1.04	1.56	0.49	2.05
W Central	1.51	5.74	7.26	2.56	3.76	6.32
E Central	3.92	1.50	5.42	6.79	1.71	8.50
Panhandle	4.37	8.81	13.18	7.76	6.78	14.53
S West	2.34	8.46	10.80	2.19	4.10	6.30
Total	17.41	39.60	57.01	26.50	27.10	53.61
Cost Per Bushel	0.086	0.196	0.283	0.131	0.134	0.266

Note: The construction cost is an annualized cost.

In terms of regional impact, there were more regional shifts in storage capacity with sequential replacement relative to the unrestricted structure. More structures and capacities were concentrated in North Central, Panhandle, South West and West Central while in unconstrained replacement there was more uniform distribution of capacities in relation to the quantity of crop produced. Few but large capacities structures were built in the unconstrained replacement while in sequential replacement large number of small sized structures were built. The total cost per bushel from both scenarios reflects the need to regionalize large capacity grain storage structures.

Table III – 11. No. of Structure and Retained Capacity Comparisons with Configuration after Sequential Replacement and Capacity Unconstrained.

Crop Reporting Districts	Base Production (Bushels)	Configuration after sequential replacement		Unconstrained replacement	
		No. of Structures	Retained Capacity (Bushels)	No. of Structures	Retained Capacity (Bushels)
Central	19,029,198	22	12,761,050	7	14,000,000
N Central	63,595,369	69	53,587,050	23	46,000,000
S Central	2,857,169	4	1,410,000	2	2,600,000
W Central	24,295,660	41	23,,204,960	11	22,000,000
E Central	3,539,925	3	10,350,000	5	10,000,000
Panhandle	45,845,940	56	37,948,480	21	39,000,000
S West	32,345,194	81	30,599,920	12	24,000,000
N East	7,432,103				
S East	2,693,009				
Total	201,633,567	276	169,861,460	81	157,600,000

Sensitivity Analysis

In addition to the previously described sensitivity analysis on the grain production assumptions we conducted sensitivity analysis on fuel cost, construction cost and amortization rates. Fuel and construction cost were changed by 25% and 50% of the base price and amortization factor of 10% and 12% representing longer term loans were used. We did not observe any significant changes to our previous results due to the change in fuel cost, construction cost and amortization factors.

Summary and Conclusion

Replacement and expansion of grain handling infrastructure is a critical issue in Oklahoma and other grain producing states. In many regions, a large portion of the infrastructure is nearing its design life and will need to be renovated or replaced in the coming decade. Changes in crop mix, crop yields and land use impacts the size and location of needed future infrastructure and could create a partial reconfiguration of the size and location of grain handling facilities. The managers of grain handling firms in Oklahoma need information on the regional demand for grain infrastructure as they consider investment at specific locations. This paper attempts to analyze current grain storage infrastructure in Oklahoma and determine the level and location of additional infrastructure investment under a number of foreseeable scenarios. The results of the analysis are relevant to agribusiness managers and producers across the Southern Plains.

A mixed integer type plant location model was developed using General Algebraic Modeling System (GAMS). Five crops (wheat, canola, corn, soybean and sorghum) were considered in the study. Satellite imagery data of crop production was processed using ArcGIS 10 to obtain crop production by townships in Oklahoma. Direct field visits and personal contacts were used to determine the location, capacity, age and type of existing grain storage facilities. Because over 90% of the grain produced in Oklahoma are stored in commercial facilities, on-farm storage was not considered.

The model minimized total cost of grain transportation (from the point of production at the township level) to the existing elevator locations and construction cost of storage structures. Several scenarios were created to sequentially replace older structures. The results of sequential replacement overtime indicated that there would be some abandonment of facilities and some shift to larger structures as fewer but large capacity structures were retained. The model eliminated 39% of the structures by the last scenario of sequential replacement where we had replaced all concrete structures built before 1969 and steel structures built before 1989. Surprisingly, producer's transportation cost did not increase as structures were sequentially replaced because storage capacity was added in locations which were currently storage deficit. The transportation cost decreased by 57% in the final replacement scenario which resulted in 293 total structures as compared to the initial scenario which represented the current industry of 477 structures. Total storage capacity increased after sequential replacement implying that additional construction is cost effective as it reduced transportation costs from locations which are currently storage deficit. The industry structure resulted from the sequential replacement of structures was compared to a near "green field" scenario in which all but the most recently built structures were simultaneously considered for replacement. This unrestricted model also had no limits on storage capacity at each location with 12 concrete and 12 steel structure size options and the possibility of up to 3 same size structures at each elevator location. The unrestricted or near "green field" model resulted in a much more regionalized industry structure with much fewer locations and large capacity structures. The "green field" scenario resulted in higher transportation costs but a lower combined cost of construction and transportation relative to structure resulting from sequentially replacing older structures. This suggests that the grain industry structure would be more regionalized if decision makers looked ahead and planned for the replacement of all of their older infrastructure. This would have implications for producers who would likely incur higher transportation costs. We performed sensitivity analysis on grain volume, construction cost, transportation cost and the amortization factor and concluded that the results were fairly robust to those assumptions.

The results of the study highlights the magnitude of the investment that must occur and suggest some trend towards regionalization. Grain industry decision makers are likely to replace bins sequentially on an “oldest first” basis due to capital constraints. If this is the case, the degree of regionalization will be limited. The infrastructure replacement will likely benefit producers since transportation costs will be reduced by adding capacity in locations which are currently storage deficit.

The industry structures created by market place competition and firm capital constraints do not always end up in achieving the lowest cost. The “green field” scenario that we examined investigated the structure that would minimize the total cost of construction and transportation without restrictions on replacing the oldest structures first. The resulting industry structure would have significantly lower total costs but would involve much more regionalization and higher transportation cost for the producer. While it is not plausible to assume that the grain industry would plan for the simultaneous reconstruction of its total capacity, the results do suggest that decision makers might want to implement a long term planning process. If grain managers considered both obsolete structures and soon to be obsolete structures as they determine capacity and location decisions they might find more opportunities for regionalization. Regardless of whether grain storage becomes more regionalized, it is clear that Oklahoma will need a large amount of investment to replace storage structures that have passed their design life. The replacement of all of the concrete structure built before 1939 and steel structures built before 1959 (the very oldest structures) will require 140 million dollars' worth of investment. The replacement of all the concrete structure built before 1969 and steel structures built before 1989 (all structures nearing the end of their useful life) will require an investment of around 1,240 million dollars. This study did not consider grain handling speed and unloading time. Infrastructure re-investment with or without regionalization, would likely result in higher grain handling speeds which would likely reduce the producers' waiting time during harvest. This represents another cost factor not quantified in this study. While the current study is focused only on Oklahoma, the methods and procedures are equally applicable across the grain belt.

References

Araji, A. A., and Walsh, R. G. 1969. "Effect of Assembly Costs on Optimum Grain Elevator Size and Location." *Canadian Journal of Agricultural Economics* 17(2):36-45.

Dysert, L.R. 2003. "Sharpen Your Cost Estimation Skills." *Cost Engineering* 45(6):22-30.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Epplin, F.M. 1997. "Wheat Yield Response to Changes in Production Practices Induced by Program Provisions." *Journal of Agricultural and Resource Economics* 22(2):333-344.

Fuller, S., O. Sorenson, M. Johnson and R. Oehrtman. 1981. "Alternative Wheat Collection and Transportation Systems for the Southern US Plains." *Western Journal of Agricultural Economics:* 91-101.

Han, W., Z. Yang, L. Di and R. Mueller. 2012. "CropScape: A Web Service Based Application for Exploring and Disseminating US Conterminous Geospatial Cropland Data Products for Decision Support." *Computers and Electronics in Agriculture* 84:111–123.

Jessup, E. L., J. Ellis and K. Casavant. 1998. "A GIS Commodity Flow Model for Transportation Policy Analysis: A Case Study of the Impacts of a Snake River Drawdown." EWITS Research Report Number 18. Washington State University.

Kowalski, D. 2012. "Change on the Rural Horizon: Managing the Expansion of Grain Storage in the Corn Belt." CoBank Knowledge Exchange.

Ladd, G. W., and D.R. Lifferth. 1975. "An Analysis of Alternative Grain Distribution Systems." *American Journal of Agricultural Economics 57*(3):420-430.

Matias G. Nardi, Stephen E. Sperry and Todd D. Davis. 2007. "Grain Supply Chain Management Optimization Using ArcGIS in Argentina." In 2007 ESRI User Conference Proceedings (pp 1-23). Redlands, CA: ESRI.

Monterosso, C. D., Wright, C. L., Lacerda, M. C. S., and Ofugi, N. 1985. "Grain Storage in Developing Areas: Location and Size of Facilities." *American Journal of Agricultural Economics* 67(1):101-111.

QGIS Development Team, 2013. QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org

Tembo, G., Holcomb, R. B., Kenkel, P., and Tilley, D. S. 1999. “Using Mixed-Integer Programming to Determine the Potential for Flour-Milling Industry Expansion.” *Journal of Food Distribution Research* 30(3):12-21.

[OCGIS] Oklahoma Center for Geospatial Information. 2013. Oklahoma State University/Strategic Consulting International. Townships Lines/Polygons for Oklahoma. Available at http://www.ocgi.okstate.edu/zipped/.

U. S. Department of Agriculture. 2013a. National Agricultural Statistics Service. Quick Stats. Available at http://www.quickstats.nass.usda.gov/.

U. S. Department of Agriculture. 2013b. National Agricultural Statistics Service. CropScape – Cropland Data Layer. Available at http://nassgeodata.gmu.edu/CropScape/.

Warman, M. 1994. “Cooperative Grain Marketing: Changes, Issues, and Alternatives.” United States Department of Agriculture. Agriculture Cooperative Service. Research Report 123.

[ ]. 2013. Postal Address Lookup with Google Maps. Available at http://ctrlq.org/maps/address/.

[ ]. 2013. Locate Point in Google Maps by Latitude and Longitude. Available at http://itouchmap.com/latlong.html.

Appendix III – A: Tables

Table III – 12. No. of Structures Retained with Sequential Replacement of Older Structures by Counties.

Crop Reporting Districts	Counties	Existing Number of Structures	Scenario II	Scenario III	Scenario IV	Scenario V
Central	Canadian	14	13	10	8	5
	Grady	8	8	8	8	7
	Kingfisher	21	19	17	12	8
	Logan	7	6	5	1	1
	Oklahoma	1	1	1	2	2
	Payne	4	2	1	1	1
E Central	Cherokee	1	1	1	1	0
	Muskogee	1	1	1	3	3
	Sequoyah	1	1	1	1	1
N Central	Alfalfa	28	24	18	9	8
	Garfield	61	50	42	24	10
	Grant	34	31	20	13	12
	Kay	23	21	17	18	17
	Major	16	13	10	7	7
	Noble	9	9	7	4	5
	Woods	24	23	15	9	9
	Woodward	5	5	4	2	2
Panhandle	Beaver	13	15	15	13	12
	Cimarron	5	5	7	8	10
	Ellis	5	7	7	4	3
	Harper	5	5	4	4	4
	Texas	21	25	37	36	33
S Central	Jefferson	1	3	3	3	3
	Marshall	1	1	1	1	1
S West	Caddo	27	27	26	16	12
	Comanche	8	8	6	4	2
	Cotton	9	11	11	8	8
	Harmon	2	4	3	3	3
	Jackson	13	12	11	14	11
	Kiowa	17	16	16	17	17
	Tillman	28	37	37	36	32
W Central	Blaine	18	18	15	6	5
	Custer	16	17	16	13	11
	Dewey	11	10	7	5	3
	Roger Mills	1	1	1	1	1
	Washita	18	20	21	23	24

Table III – 13. Capacities Retained with Sequential Replacement of Older Structures by Counties.

Crop Reporting Districts	Counties	Existing Number of Structures	Scenario II	Scenario III	Scenario IV	Scenario V
Central	Canadian	4.24	4.16	2.59	4.01	3.23
	Grady	2.11	2.11	2.11	2.11	2.63
	Kingfisher	6.43	5.87	5.50	4.33	4.87
	Logan	1.17	1.09	1.05	0.62	0.62
	Oklahoma	0.23	0.23	0.23	0.56	0.56
	Payne	0.79	0.74	0.68	1.01	1.01
E Central	Cherokee	0.01	0.01	0.01	0.01	0.00
	Muskogee	2.30	2.30	2.30	10.35	10.35
	Sequoyah	0.01	0.01	0.01	0.01	0.01
N Central	Alfalfa	6.02	5.66	4.76	4.63	4.59
	Garfield	31.38	30.38	29.56	22.51	17.78
	Grant	8.97	8.12	6.29	6.84	6.64
	Kay	6.17	5.77	5.58	7.67	7.35
	Major	3.42	2.79	1.66	2.84	3.66
	Noble	2.68	2.68	2.35	2.47	4.96
	Woods	6.31	6.23	4.96	6.82	7.35
	Woodward	1.62	1.62	1.54	1.27	1.27
Panhandle	Beaver	2.33	2.46	2.64	2.73	2.73
	Cimarron	0.88	0.88	2.26	3.18	3.65
	Ellis	1.53	2.80	2.80	1.94	1.69
	Harper	1.12	1.12	0.92	0.95	1.21
	Texas	11.89	12.58	29.38	29.58	29.07
S Central	Jefferson	0.30	1.35	1.35	1.35	1.35
	Marshall	0.06	0.06	0.06	0.06	0.06
S West	Caddo	7.18	7.18	7.08	4.95	5.53
	Comanche	1.72	1.72	1.59	1.32	1.19
	Cotton	1.60	2.19	2.19	2.40	2.40
	Harmon	0.10	0.31	0.27	0.27	0.27
	Jackson	2.96	2.93	2.90	4.32	3.98
	Kiowa	3.68	3.65	4.24	5.80	6.72
	Tillman	6.08	11.01	12.32	11.38	10.79
W Central	Blaine	7.34	8.04	7.44	6.79	6.62
	Custer	5.36	6.60	6.52	7.47	7.61
	Dewey	2.47	2.41	2.21	1.75	1.87
	Roger Mills	0.11	0.11	0.11	0.11	0.11
	Washita	3.93	4.17	5.06	6.49	7.12

Table III – 14. Number of Elevator Retained in Subsequent Scenarios.

Crop Reporting Districts	No. of Existing Elevators	Scenario II	Scenario III	Scenario IV	Scenario V
Central	31	30	27	22	18
E Central	3	3	3	3	2
N Central	82	79	68	51	43
Panhandle	21	21	21	19	17
S Central	2	2	2	2	2
S West	41	41	40	37	34
W Central	30	30	29	21	19
Total	210	206	190	155	135

Table III – 15. Number of Elevator Retained in Unrestricted Replacement.

Crop Reporting Districts	No. of Existing Elevators	Base Production	25% Increase in Base Production
Central	31	7	9
E Central	3	3	3
N Central	82	23	30
Panhandle	21	13	11
S Central	2	2	2
S West	41	12	18
W Central	30	9	12
Total	210	69	85

Appendix III – B: Figures

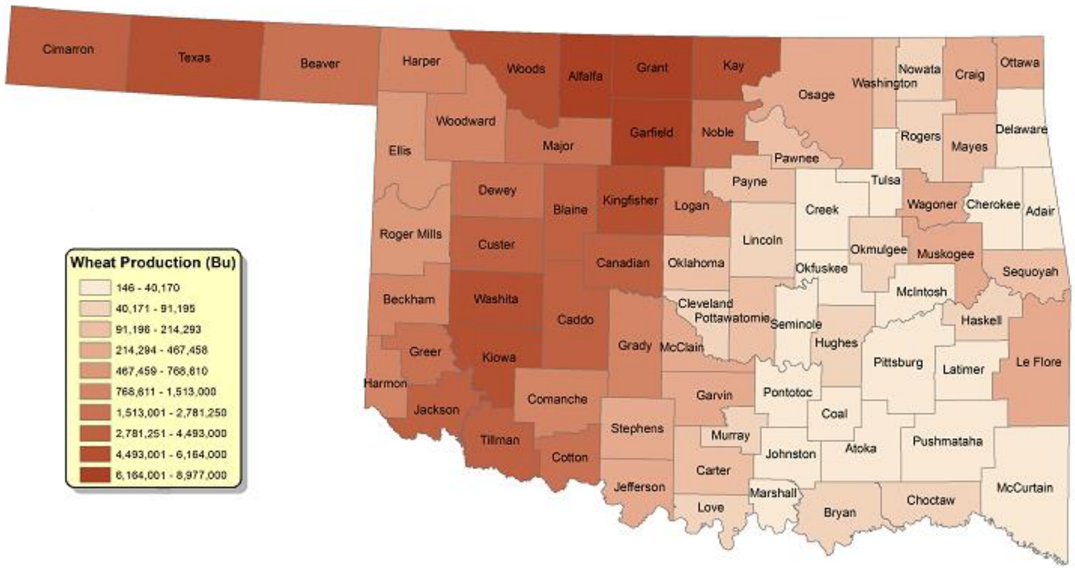

Figure III – 5. Average Wheat Production in Oklahoma (2008-2012).

Appendix III – C: GAMS/CPLEX Code for Scenario II

```
$OFFUPPER OFFSYMXREF OFFSYMLIST OFFUELLIST OFFUELXREF
OPTION LIMROW=0, LIMCOL=0;
OPTION OPTCR=0;
OPTION ITERLIM=150000;
SETS
 I Townships Crop Sources
 /T1,    T2,    T3,    T4,    T5,    T6,    T7,    T8,    T9,    T10,   T11,   T12,   T13,
  T14,   T15,   T16,   T17,   T18,   T19,   T20,   T21,   T22,   T23,   T24,   T25,   T26,
  T27,   T28,   T29,   T30,   T31,   T32,   T33,   T34,   T35,   T36,   T37,   T38,   T39,
  T40,   T41,   T42,   T43,   T44,   T45,   T46,   T47,   T48,   T49,   T50,   T51,   T52,
  T53,   T54,   T55,   T56,   T57,   T58,   T59,   T60,   T61,   T62,   T63,   T64,   T65,
  T66,   T67,   T68,   T69,   T70,   T71,   T72,   T73,   T74,   T75,   T76,   T77,   T78,
  T79,   T80,   T81,   T82,   T83,   T84,   T85,   T86,   T87,   T88,   T89,   T90,   T91,
  T92,   T93,   T94,   T95,   T96,   T97,   T98,   T99,   T100,  T101,  T102,  T103,  T104,
  T105,  T106,  T107,  T108,  T109,  T110,  T111,  T112,  T113,  T114,  T115,  T116,  T117,
  T118,  T119,  T120,  T121,  T122,  T123,  T124,  T125,  T126,  T127,  T128,  T129,  T130,
  T131,  T132,  T133,  T134,  T135,  T136,  T137,  T138,  T139,  T140,  T141,  T142,  T143,
  T144,  T145,  T146,  T147,  T148,  T149,  T150,  T151,  T152,  T153,  T154,  T155,  T156,
  T157,  T158,  T159,  T160,  T161,  T162,  T163,  T164,  T165,  T166,  T167,  T168,  T169,
  T170,  T171,  T172,  T173,  T174,  T175,  T176,  T177,  T178,  T179,  T180,  T181,  T182,
  T183,  T184,  T185,  T186,  T187,  T188,  T189,  T190,  T191,  T192,  T193,  T194,  T195,
  T196,  T197,  T198,  T199,  T200,  T201,  T202,  T203,  T204,  T205,  T206,  T207,  T208,
  T209,  T210,  T211,  T212,  T213,  T214,  T215,  T216,  T217,  T218,  T219,  T220,  T221,
  T222,  T223,  T224,  T225,  T226,  T227,  T228,  T229,  T230,  T231,  T232,  T233,  T234,
  T235,  T236,  T237,  T238,  T239,  T240,  T241,  T242,  T243,  T244,  T245,  T246,  T247,
  T248,  T249,  T250,  T251,  T252,  T253,  T254,  T255,  T256,  T257,  T258,  T259,  T260,
  T261,  T262,  T263,  T264,  T265,  T266,  T267,  T268,  T269,  T270,  T271,  T272,  T273,
  T274,  T275,  T276,  T277,  T278,  T279,  T280,  T281,  T282,  T283,  T284,  T285,  T286,
  T287,  T288,  T289,  T290,  T291,  T292,  T293,  T294,  T295,  T296,  T297,  T298,  T299,
  T300,  T301,  T302,  T303,  T304,  T305,  T306,  T307,  T308,  T309,  T310,  T311,  T312,
  T313,  T314,  T315,  T316,  T317,  T318,  T319,  T320,  T321,  T322,  T323,  T324,  T325,
  T326,  T327,  T328,  T329,  T330,  T331,  T332,  T333,  T334,  T335,  T336,  T337,  T338,
  T339,  T340,  T341,  T342,  T343,  T344,  T345,  T346,  T347,  T348,  T349,  T350,  T351,
  T352,  T353,  T354,  T355,  T356,  T357,  T358,  T359,  T360,  T361,  T362,  T363,  T364,
  T365,  T366,  T367,  T368,  T369,  T370,  T371,  T372,  T373,  T374,  T375,  T376,  T377,
  T378,  T379,  T380,  T381,  T382,  T383,  T384,  T385,  T386,  T387,  T388,  T389,  T390,
  T391,  T392,  T393,  T394,  T395,  T396,  T397,  T398,  T399,  T400,  T401,  T402,  T403,
  T404,  T405,  T406,  T407,  T408,  T409,  T410,  T411,  T412,  T413,  T414,  T415,  T416,
  T417,  T418,  T419,  T420,  T421,  T422,  T423,  T424,  T425,  T426,  T427,  T428,  T429,
  T430,  T431,  T432,  T433,  T434,  T435,  T436,  T437,  T438,  T439,  T440,  T441,  T442,
  T443,  T444,  T445,  T446,  T447,  T448,  T449,  T450,  T451,  T452,  T453,  T454,  T455,
  T456,  T457,  T458,  T459,  T460,  T461,  T462,  T463,  T464,  T465,  T466,  T467,  T468,
  T469,  T470,  T471,  T472,  T473,  T474,  T475,  T476,  T477,  T478,  T479,  T480,  T481,
  T482,  T483,  T484,  T485,  T486,  T487,  T488,  T489,  T490,  T491,  T492,  T493,  T494,
  T495,  T496,  T497,  T498,  T499,  T500,  T501,  T502,  T503,  T504,  T505,  T506,  T507,
  T508,  T509,  T510,  T511,  T512,  T513,  T514,  T515,  T516,  T517,  T518,  T519,  T520,
  T521,  T522,  T523,  T524,  T525,  T526,  T527,  T528,  T529,  T530,  T531,  T532,  T533,
  T534,  T535,  T536,  T537,  T538,  T539,  T540,  T541,  T542,  T543,  T544,  T545,  T546,
  T547,  T548,  T549,  T550,  T551,  T552,  T553,  T554,  T555,  T556,  T557,  T558,  T559,
  T560,  T561,  T562,  T563,  T564,  T565,  T566,  T567,  T568,  T569,  T570,  T571,  T572,
  T573,  T574,  T575,  T576,  T577,  T578,  T579,  T580,  T581,  T582,  T583,  T584,  T585,
  T586,  T587,  T588,  T589,  T590,  T591,  T592,  T593,  T594,  T595,  T596,  T597,  T598,
  T599,  T600,  T601,  T602,  T603,  T604,  T605,  T606,  T607,  T608,  T609,  T610,  T611,
  T612,  T613,  T614,  T615,  T616,  T617,  T618,  T619,  T620,  T621,  T622,  T623,  T624,
  T625,  T626,  T627,  T628,  T629,  T630,  T631,  T632,  T633,  T634,  T635,  T636,  T637,
  T638,  T639,  T640,  T641,  T642,  T643,  T644,  T645,  T646,  T647,  T648,  T649,  T650,
  T651,  T652,  T653,  T654,  T655,  T656,  T657,  T658,  T659,  T660,  T661,  T662,  T663,
  T664,  T665,  T666,  T667,  T668,  T669,  T670,  T671,  T672,  T673,  T674,  T675,  T676,
  T677,  T678,  T679,  T680,  T681,  T682,  T683,  T684,  T685,  T686,  T687,  T688,  T689,
  T690,  T691,  T692,  T693,  T694,  T695,  T696,  T697,  T698,  T699,  T700,  T701,  T702,
  T703,  T704,  T705,  T706,  T707,  T708,  T709,  T710,  T711,  T712,  T713,  T714,  T715,
  T716,  T717,  T718,  T719,  T720,  T721,  T722,  T723,  T724,  T725,  T726,  T727,  T728,
  T729,  T730,  T731,  T732,  T733,  T734,  T735,  T736,  T737,  T738,  T739,  T740,  T741,
  T742,  T743,  T744,  T745,  T746,  T747,  T748,  T749,  T750,  T751,  T752,  T753,  T754,
  T755,  T756,  T757,  T758,  T759,  T760,  T761,  T762,  T763,  T764,  T765,  T766,  T767,
  T768,  T769,  T770,  T771,  T772,  T773,  T774,  T775,  T776,  T777,  T778,  T779,  T780,
  T781,  T782,  T783,  T784,  T785,  T786,  T787,  T788,  T789,  T790,  T791,  T792,  T793,
  T794,  T795,  T796,  T797,  T798,  T799,  T800,  T801,  T802,  T803,  T804,  T805,  T806,
  T807,  T808,  T809,  T810,  T811,  T812,  T813,  T814,  T815,  T816,  T817,  T818,  T819,
  T820,  T821,  T822,  T823,  T824,  T825,  T826,  T827,  T828,  T829,  T830,  T831,  T832,
  T833,  T834,  T835,  T836,  T837,  T838,  T839,  T840,  T841,  T842,  T843,  T844,  T845,
  T846,  T847,  T848,  T849,  T850,  T851,  T852,  T853,  T854,  T855,  T856,  T857,  T858,
```

T859, T860, T861, T862, T863, T864, T865, T866, T867, T868, T869, T870, T871,
T872, T873, T874, T875, T876, T877, T878, T879, T880, T881, T882, T883, T884,
T885, T886, T887, T888, T889, T890, T891, T892, T893, T894, T895, T896, T897,
T898, T899, T900, T901, T902, T903, T904, T905, T906, T907, T908, T909, T910,
T911, T912, T913, T914, T915, T916, T917, T918, T919, T920, T921, T922, T923,
T924, T925, T926, T927, T928, T929, T930, T931, T932, T933, T934, T935, T936,
T937, T938, T939, T940, T941, T942, T943, T944, T945, T946, T947, T948, T949,
T950, T951, T952, T953, T954, T955, T956, T957, T958, T959, T960, T961, T962,
T963, T964, T965, T966, T967, T968, T969, T970, T971, T972, T973, T974, T975,
T976, T977, T978, T979, T980, T981, T982, T983, T984, T985, T986, T987, T988,
T989, T990, T991, T992, T993, T994, T995, T996, T997, T998, T999, T1000, T1001,
T1002, T1003, T1004, T1005, T1006, T1007, T1008, T1009, T1010, T1011, T1012, T1013, T1014,
T1015, T1016, T1017, T1018, T1019, T1020, T1021, T1022, T1023, T1024, T1025, T1026, T1027,
T1028, T1029, T1030, T1031, T1032, T1033, T1034, T1035, T1036, T1037, T1038, T1039, T1040,
T1041, T1042, T1043, T1044, T1045, T1046, T1047, T1048, T1049, T1050, T1051, T1052, T1053,
T1054, T1055, T1056, T1057, T1058, T1059, T1060, T1061, T1062, T1063, T1064, T1065, T1066,
T1067, T1068, T1069, T1070, T1071, T1072, T1073, T1074, T1075, T1076, T1077, T1078, T1079,
T1080, T1081, T1082, T1083, T1084, T1085, T1086, T1087, T1088, T1089, T1090, T1091, T1092,
T1093, T1094, T1095, T1096, T1097, T1098, T1099, T1100, T1101, T1102, T1103, T1104, T1105,
T1106, T1107, T1108, T1109, T1110, T1111, T1112, T1113, T1114, T1115, T1116, T1117, T1118,
T1119, T1120, T1121, T1122, T1123, T1124, T1125, T1126, T1127, T1128, T1129, T1130, T1131,
T1132, T1133, T1134, T1135, T1136, T1137, T1138, T1139, T1140, T1141, T1142, T1143, T1144,
T1145, T1146, T1147, T1148, T1149, T1150, T1151, T1152, T1153, T1154, T1155, T1156, T1157,
T1158, T1159, T1160, T1161, T1162, T1163, T1164, T1165, T1166, T1167, T1168, T1169, T1170,
T1171, T1172, T1173, T1174, T1175, T1176, T1177, T1178, T1179, T1180, T1181, T1182, T1183,
T1184, T1185, T1186, T1187, T1188, T1189, T1190, T1191, T1192, T1193, T1194, T1195, T1196,
T1197, T1198, T1199, T1200, T1201, T1202, T1203, T1204, T1205, T1206, T1207, T1208, T1209,
T1210, T1211, T1212, T1213, T1214, T1215, T1216, T1217, T1218, T1219, T1220, T1221, T1222,
T1223, T1224, T1225, T1226, T1227, T1228, T1229, T1230, T1231, T1232, T1233, T1234, T1235,
T1236, T1237, T1238, T1239, T1240, T1241, T1242, T1243, T1244, T1245, T1246, T1247, T1248,
T1249, T1250, T1251, T1252, T1253, T1254, T1255, T1256, T1257, T1258, T1259, T1260, T1261,
T1262, T1263, T1264, T1265, T1266, T1267, T1268, T1269, T1270, T1271, T1272, T1273, T1274,
T1275, T1276, T1277, T1278, T1279, T1280, T1281, T1282, T1283, T1284, T1285, T1286, T1287,
T1288, T1289, T1290, T1291, T1292, T1293, T1294, T1295, T1296, T1297, T1298, T1299, T1300,
T1301, T1302, T1303, T1304, T1305, T1306, T1307, T1308, T1309, T1310, T1311, T1312, T1313,
T1314, T1315, T1316, T1317, T1318, T1319, T1320, T1321, T1322, T1323, T1324, T1325, T1326,
T1327, T1328, T1329, T1330, T1331, T1332, T1333, T1334, T1335, T1336, T1337, T1338, T1339,
T1340, T1341, T1342, T1343, T1344, T1345, T1346, T1347, T1348, T1349, T1350, T1351, T1352,
T1353, T1354, T1355, T1356, T1357, T1358, T1359, T1360, T1361, T1362, T1363, T1364, T1365,
T1366, T1367, T1368, T1369, T1370, T1371, T1372, T1373, T1374, T1375, T1376, T1377, T1378,
T1379, T1380, T1381, T1382, T1383, T1384, T1385, T1386, T1387, T1388, T1389, T1390, T1391,
T1392, T1393, T1394, T1395, T1396, T1397, T1398, T1399, T1400, T1401, T1402, T1403, T1404,
T1405, T1406, T1407, T1408, T1409, T1410, T1411, T1412, T1413, T1414, T1415, T1416, T1417,
T1418, T1419, T1420, T1421, T1422, T1423, T1424, T1425, T1426, T1427, T1428, T1429, T1430,
T1431, T1432, T1433, T1434, T1435, T1436, T1437, T1438, T1439, T1440, T1441, T1442, T1443,
T1444, T1445, T1446, T1447, T1448, T1449, T1450, T1451, T1452, T1453, T1454, T1455, T1456,
T1457, T1458, T1459, T1460, T1461, T1462, T1463, T1464, T1465, T1466, T1467, T1468, T1469,
T1470, T1471, T1472, T1473, T1474, T1475, T1476, T1477, T1478, T1479, T1480, T1481, T1482,
T1483, T1484, T1485, T1486, T1487, T1488, T1489, T1490, T1491, T1492, T1493, T1494, T1495,
T1496, T1497, T1498, T1499, T1500, T1501, T1502, T1503, T1504, T1505, T1506, T1507, T1508,
T1509, T1510, T1511, T1512, T1513, T1514, T1515, T1516, T1517, T1518, T1519, T1520, T1521,
T1522, T1523, T1524, T1525, T1526, T1527, T1528, T1529, T1530, T1531, T1532, T1533, T1534,
T1535, T1536, T1537, T1538, T1539, T1540, T1541, T1542, T1543, T1544, T1545, T1546, T1547,
T1548, T1549, T1550, T1551, T1552, T1553, T1554, T1555, T1556, T1557, T1558, T1559, T1560,
T1561, T1562, T1563, T1564, T1565, T1566, T1567, T1568, T1569, T1570, T1571, T1572, T1573,
T1574, T1575, T1576, T1577, T1578, T1579, T1580, T1581, T1582, T1583, T1584, T1585, T1586,
T1587, T1588, T1589, T1590, T1591, T1592, T1593, T1594, T1595, T1596, T1597, T1598, T1599,
T1600, T1601, T1602, T1603, T1604, T1605, T1606, T1607, T1608, T1609, T1610, T1611, T1612,
T1613, T1614, T1615, T1616, T1617, T1618, T1619, T1620, T1621, T1622, T1623, T1624, T1625,
T1626, T1627, T1628, T1629, T1630, T1631, T1632, T1633, T1634, T1635, T1636, T1637, T1638,
T1639, T1640, T1641, T1642, T1643, T1644, T1645, T1646, T1647, T1648, T1649, T1650, T1651,
T1652, T1653, T1654, T1655, T1656, T1657, T1658, T1659, T1660, T1661, T1662, T1663, T1664,
T1665, T1666, T1667, T1668, T1669, T1670, T1671, T1672, T1673, T1674, T1675, T1676, T1677,
T1678, T1679, T1680, T1681, T1682, T1683, T1684, T1685, T1686, T1687, T1688, T1689, T1690,
T1691, T1692, T1693, T1694, T1695, T1696, T1697, T1698, T1699, T1700, T1701, T1702, T1703,
T1704, T1705, T1706, T1707, T1708, T1709, T1710, T1711, T1712, T1713, T1714, T1715, T1716,
T1717, T1718, T1719, T1720, T1721, T1722, T1723, T1724, T1725, T1726, T1727, T1728, T1729,
T1730, T1731, T1732, T1733, T1734, T1735, T1736, T1737, T1738, T1739, T1740, T1741, T1742,
T1743, T1744, T1745, T1746, T1747, T1748, T1749, T1750, T1751, T1752, T1753, T1754, T1755,
T1756, T1757, T1758, T1759, T1760, T1761, T1762, T1763, T1764, T1765, T1766, T1767, T1768,
T1769, T1770, T1771, T1772, T1773, T1774, T1775, T1776, T1777, T1778, T1779, T1780, T1781,
T1782, T1783, T1784, T1785, T1786, T1787, T1788, T1789, T1790, T1791, T1792, T1793, T1794,
T1795, T1796, T1797, T1798, T1799, T1800, T1801, T1802, T1803, T1804, T1805, T1806, T1807,
T1808, T1809, T1810, T1811, T1812, T1813, T1814, T1815, T1816, T1817, T1818, T1819, T1820,
T1821, T1822, T1823, T1824, T1825, T1826, T1827, T1828, T1829, T1830, T1831, T1832, T1833,
T1834, T1835, T1836, T1837, T1838, T1839, T1840, T1841, T1842, T1843, T1844, T1845, T1846,

```
  T1847, T1848, T1849, T1850, T1851, T1852, T1853, T1854, T1855, T1856, T1857, T1858, T1859,
  T1860, T1861, T1862, T1863, T1864, T1865, T1866, T1867, T1868, T1869, T1870, T1871, T1872,
  T1873, T1874, T1875, T1876, T1877, T1878, T1879, T1880, T1881, T1882, T1883, T1884, T1885,
  T1886, T1887, T1888, T1889, T1890, T1891, T1892, T1893, T1894, T1895, T1896, T1897, T1898,
  T1899, T1900, T1901, T1902, T1903, T1904, T1905, T1906, T1907, T1908, T1909, T1910, T1911,
  T1912, T1913, T1914, T1915, T1916, T1917, T1918, T1919, T1920, T1921, T1922, T1923, T1924,
  T1925, T1926, T1927, T1928, T1929, T1930, T1931, T1932, T1933, T1934, T1935, T1936, T1937,
  T1938, T1939, T1940, T1941, T1942, T1943, T1944, T1945, T1946, T1947, T1948, T1949, T1950,
  T1951, T1952, T1953, T1954, T1955, T1956, T1957, T1958, T1959, T1960, T1961, T1962, T1963,
  T1964, T1965, T1966, T1967, T1968, T1969, T1970, T1971, T1972, T1973, T1974, T1975, T1976,
  T1977, T1978, T1979, T1980, T1981, T1982, T1983, T1984, T1985, T1986, T1987, T1988, T1989,
  T1990, T1991, T1992, T1993, T1994, T1995, T1996, T1997, T1998, T1999, T2000, T2001, T2002,
  T2003, T2004, T2005, T2006, T2007, T2008, T2009, T2010, T2011, T2012, T2013, T2014, T2015,
  T2016, T2017, T2018, T2019, T2020, T2021, T2022, T2023, T2024, T2025, T2026, T2027, T2028,
  T2029, T2030, T2031, T2032, T2033, T2034, T2035, T2036, T2037, T2038, T2039, T2040, T2041,
  T2042, T2043, T2044, T2045, T2046, T2047/

J Elevator Locations
 /E001,E002,E003,E004,E005,E006,E007,E008,E009,E010,E011,E012,E013,E014,E015,E016,E017,E018,
  E019,E020,E021,E022,E023,E024,E025,E026,E027,E028,E029,E030,E031,E032,E033,E034,E035,E036,
  E037,E038,E039,E040,E041,E042,E043,E044,E045,E046,E047,E048,E049,E050,E051,E052,E053,E054,
  E055,E056,E057,E058,E059,E060,E061,E062,E063,E064,E065,E066,E067,E068,E069,E070,E071,E072,
  E073,E074,E075,E076,E077,E078,E079,E080,E081,E082,E083,E084,E085,E086,E087,E088,E089,E090,
  E091,E092,E093,E094,E095,E096,E097,E098,E099,E100,E101,E102,E103,E104,E105,E106,E107,E108,
  E109,E110,E111,E112,E113,E114,E115,E116,E117,E118,E119,E120,E121,E122,E123,E124,E125,E126,
  E127,E128,E129,E130,E131,E132,E133,E134,E135,E136,E137,E138,E139,E140,E141,E142,E143,E144,
  E145,E146,E147,E148,E149,E150,E151,E152,E153,E154,E155,E156,E157,E158,E159,E160,E161,E162,
  E163,E164,E165,E166,E167,E168,E169,E170,E171,E172,E173,E174,E175,E176,E177,E178,E179,E180,
  E181,E182,E183,E184,E185,E186,E187,E188,E189,E190,E191,E192,E193,E194,E195,E196,E197,E198,
  E199,E200,E201,E202,E203,E204,E205,E206,E207,E208,E209,E210/

 M County

/Alfalfa,Beaver,Blaine,Caddo,Canadian,Cherokee,Cimarron,Comanche,Cotton,Custer,Dewey,Elli
s,Garfield,Grady,Grant,Harmon,Harper,Jackson,Jefferson,Kay,Kingfisher,Kiowa,Logan,Major,M
arshall,Muskogee,Noble,Oklahoma,Payne,RogerMills,Sequoyah,Texas,Tillman,Washita,Woods,Woo
dward/

 JM(J,M) Elevator Location by County

/(E007,E019,E031,E038,E039,E040,E041,E077,E078,E079).Alfalfa,(E117,E118,E119,E121,E161).B
eaver,(E111,E127,E128,E129,E131,E172,E176,E178,E180).Blaine,(E026,E027,E035,E036,E109,E15
8,E197,E068,E072).Caddo,(E002,E003,E110,E124,E125,E177,E192,E208).Canadian,(E034).Cheroke
e,(E005,E006).Cimarron,(E012,E013,E014,E032,E140).Comanche,(E139,E141,E142,E143,E145).Cot
ton,(E017,E046,E048,E169,E171,E173).Custer,(E016,E057,E154,E182,E183,E185,E186).Dewey,(E1
48,E152,E205,E206).Ellis,(E004,E008,E009,E024,E029,E100,E101,E102,E103,E113,E115,E151,E16
0,E170,E202,E073,E086,E091,E095,E099).Garfield,(E030,E166,E167,E168,E207).Grady,(E011,E02
3,E025,E132,E150,E159,E080,E081,E082,E083,E084,E085,E087,E089,E090,E092,E093,E094).Grant,
(E106).Harmon,(E051,E062).Harper,(E047,E060,E061,E096,E098).Jackson,(E144).Jefferson,(E04
4,E050,E052,E053,E056,E063,E137,E153,E088).Kay,(E126,E179,E181,E184,E187,E193,E194,E195,E
196,E209).Kingfisher,(E055,E163,E164,E067,E069,E070,E071).Kiowa,(E028,E033,E112,E114).Log
an,(E104,E105,E130,E147,E157,E074,E075).Major,(E123).Marshall,(E201).Muskogee,(E049,E058,
E138,E146,E155,E204).Noble,(E116).Oklahoma,(E001,E010,E203).Payne,(E210).RogerMills,(E066
).Sequoyah,(E107,E108,E120,E122,E198,E199,E200,E076).Texas,(E015,E133,E134,E135,E136,E189
,E190,E191,E097).Tillman,(E037,E064,E065,E162,E165,E174,E188).Washita,(E020,E021,E022,E04
2,E043,E045,E054,E059,E175).Woods,(E018,E149,E156).Woodward/

 L Crop Reporting Districts
 /Central, EastCentral, NorthCentral, Panhandle, SouthCentral, SouthWest, WestCentral/

 ML(M,L) Elevator Location by Crop Reporting Districts

/(Canadian,Grady,Kingfisher,Logan,Oklahoma,Payne).Central,(Cherokee,Muskogee,Sequoyah).Ea
stCentral,(Alfalfa,Garfield,Grant,Kay,Major,Noble,Woods,Woodward).NorthCentral,(Beaver,Ci
marron,Ellis,Harper,Texas).Panhandle,(Jefferson,Marshall).SouthCentral,(Caddo,Comanche,Co
tton,Harmon,Jackson,Kiowa,Tillman).SouthWest,(Blaine,Custer,Dewey,RogerMills,Washita).Wes
tCentral/

 S Elevator Structure

/CS1A,CS1B,CS1C,CS2A,CS2B,CS2C,CS3A,CS3B,CS3C,CS4A,CS4B,CS4C,CS5A,CS5B,CS5C,SS1A,SS1B,SS1
C,SS2A,SS2B,SS2C,SS3A,SS3B,SS3C,SS4A,SS4B,SS4C,SS5A,SS5B,SS5C,SS6A,SS6B,SS6C,SS7A,SS7B,SS
7C,SS8A,SS8B,SS8C/
```

```
*CS=Concrete Structure, SS=Steel Structure*

 K Grain and Oilseed Crops
 /Wheat, Corn, Sorghum, Soybean, Canola/;

SCALAR F Shipping Cost in Dollars Per Mile /0.0056/;

TABLE PRODU(I,K) Quantity of Grain Supply from Each Quadrants in Bushels
$ONDELIM
$INCLUDE C:\Users\basnet\Desktop\gams data\production.csv
$OFFDELIM;

TABLE DIST(I,J) Distance from Source I to Elevator at Location J in Miles
$ONDELIM
$INCLUDE C:\Users\basnet\Desktop\gams data\distance.csv
$OFFDELIM;

TABLE CAP(J,S) Capacity of Elevator by Structure at Location J
$ONDELIM
$INCLUDE C:\Users\basnet\Desktop\gams data\mix data\capacityscii_m.csv
$OFFDELIM;

TABLE CONST(J,S) Structures which are Re-constructed
$ONDELIM
$INCLUDE C:\Users\basnet\Desktop\gams data\mix data\costscii_m.csv
$OFFDELIM;

PARAMETER
TC(I,J) Total Transportation Cost from Source I to Elevator J;
TC(I,J)=F*DIST(I,J);

VARIABLE
Q(I,J,K) Shipment Quantities in Bushels
Z Total Transportation Cost and Construction Cost in Dollars;

POSITIVE VARIABLE Q;

BINARY VARIABLE BETA;

EQUATIONS TOTALCOST, SUPPCONST(I,K), CAPCONST1(J),CAPCONST2(J);

TOTALCOST.. Z=E=SUM((I,J,K),TC(I,J)*Q(I,J,K))+SUM((J,S),CONST(J,S)*BETA(J,S));

SUPPCONST(I,K).. SUM((J),Q(I,J,K))-1.2*PRODU(I,K)=E=0;

CAPCONST1(J).. SUM((I),Q(I,J,"Wheat"))+SUM((I),Q(I,J,"Canola"))-
SUM((S),CAP(J,S)*BETA(J,S))=L=0;

CAPCONST2(J).. SUM((I),Q(I,J,"Corn"))+SUM((I),Q(I,J,"Sorghum"))+SUM((I),Q(I,J,"Soybean"))
        +SUM((I),0.5*Q(I,J,"Wheat"))+SUM((I),0.5*Q(I,J,"Canola"))-
SUM((S),CAP(J,S)*BETA(J,S))=L=0;

MODEL ELEVATOR /ALL/;

SOLVE ELEVATOR USING MIP MINIMIZING Z;

*************************RESULTS SUMMARY**********************

****************CALCULATING TRANSPORTATION COSTS**************
PARAMETER TRCOST Transportation Cost;
TRCOST(J)=SUM((I,K),(TC(I,J)*Q.L(I,J,K)));
PARAMETER TRCOSTCNT Transportation Cost by County;
TRCOSTCNT(M)=SUM(JM(J,M),TRCOST(J));
PARAMETER TRCOSTREG Transportation Cost by Region;
TRCOSTREG(L)=SUM(ML(M,L),TRCOSTCNT(M));

***************CALCULATING CONSTRUCTION COSTS*****************
PARAMETER CNSTCOST Construction Cost;
CNSTCOST(J)=SUM((S),CONST(J,S));
PARAMETER CNSTCOSTCNT Construction Cost by County;
CNSTCOSTCNT(M)=SUM(JM(J,M),CNSTCOST(J));
```

```
PARAMETER CNSTCOSTREG Construction Cost by Region;
CNSTCOSTREG(L)=SUM(ML(M,L),CNSTCOSTCNT(M));

**************CALCULATING QUANTITY OF CROP SHIPPED************
PARAMETER QUANT Quantity Shipped;
QUANT(J)=SUM((I,K),Q.L(I,J,K));
PARAMETER QUANTCROP Quantity Shipped BY Crop;
QUANTCROP(J,K)=SUM((I),Q.L(I,J,K));
PARAMETER QUANTCRCNT Quantity of Crop Shipped By County;
QUANTCRCNT(M,K)=SUM(JM(J,M),QUANTCROP(J,K));
PARAMETER QUANTCRREG Quantity of Crop Shipped By Region;
QUANTCRREG(L,K)=SUM(ML(M,L),QUANTCRCNT(M,K));

**************CALCULATING UNUSED CAPACITY*********************
PARAMETER UNUSEDWINT Unused Capacity in Winter;
UNUSEDWINT(J)=SUM((S),BETA.L(J,S)*CAP(J,S))-QUANTCROP(J,"Wheat")-QUANTCROP(J,"Canola");
PARAMETER UNUSEDWINTCNT Unused Winter Capacity by County;
UNUSEDWINTCNT(M)=SUM((JM(J,M)),UNUSEDWINT(J));
PARAMETER UNUSEDWINTREG Unused Winter Capacity by Region;
UNUSEDWINTREG(L)=SUM(ML(M,L),UNUSEDWINTCNT(M));

PARAMETER UNUSEDSUMM Unused Capacity in Summer;
UNUSEDSUMM(J)= SUM((S),BETA.L(J,S)*CAP(J,S))-QUANTCROP(J,"Sorghum")-
QUANTCROP(J,"Soybean")
       -QUANTCROP(J,"Corn")-0.5*QUANTCROP(J,"Wheat")-0.5*QUANTCROP(J,"Canola");
PARAMETER UNUSEDSUMMCNT Unused Summer Capacity by County;
UNUSEDSUMMCNT(M)=SUM((JM(J,M)),UNUSEDSUMM(J));
PARAMETER UNUSEDSUMMREG Unused Summer Capacity by Region;
UNUSEDSUMMREG(L)=SUM(ML(M,L),UNUSEDSUMMCNT(M));

**************CALCULATING NUMBER OF STRUCTURES SELECTED************
PARAMETER BETAELEVCNT No. of Elevators By County;
BETAELEVCNT(M)=SUM((JM(J,M),S),BETA.L(J,S));
PARAMETER BETAELEVREG No. of Elevators By Region;
BETAELEVREG(L)=SUM(ML(M,L),BETAELEVCNT(M));
PARAMETER BETAELEVTYP No. of Elevators By Type;
BETAELEVTYP(S)=SUM(ML(M,L),SUM((JM(J,M)),BETA.L(J,S)));

PARAMETER BETAELEVTYPREG No. of Elevators By Type and Region;
BETAELEVTYPREG(L,S)=SUM(ML(M,L),SUM((JM(J,M)),BETA.L(J,S)));

************CALCULATING OPTIMAL CAPACITY*************************
PARAMETER OPTLCAPCNT Optimal Capacity by County;
OPTLCAPCNT(M)=SUM((JM(J,M),S),CAP(J,S)*BETA.L(J,S));
PARAMETER OPTLCAPREG Optimal Capacity Region;
OPTLCAPREG(L)=SUM((ML(M,L)),OPTLCAPCNT(M));
PARAMETER OPTLCAPTYPREG Optimal Capacity By Type and Region;
OPTLCAPTYPREG(L,S)=SUM((ML(M,L)),SUM((JM(J,M)),CAP(J,S)*BETA.L(J,S)));

*************************************************************
DISPLAY TRCOSTCNT;
DISPLAY TRCOSTREG;
DISPLAY CNSTCOSTCNT;
DISPLAY CNSTCOSTREG;
DISPLAY QUANTCRCNT;
DISPLAY QUANTCRREG;
DISPLAY UNUSEDWINTCNT;
DISPLAY UNUSEDWINTREG;
DISPLAY UNUSEDSUMMCNT;
DISPLAY UNUSEDSUMMREG;
DISPLAY BETAELEVCNT;
DISPLAY BETAELEVREG;
DISPLAY BETAELEVTYP;
DISPLAY BETAELEVTYPREG;
DISPLAY OPTLCAPCNT;
DISPLAY OPTLCAPREG;
DISPLAY OPTLCAPTYPREG;
*************************************************************
```

VITA

Arjun Basnet

Candidate for the Degree of

Doctor of Philosophy

Thesis: THREE ESSAYS: SWITCHGRASS YIELD PREDICTION; BIOMASS HARVESTING COOPERATIVE; AND OKLAHOMA GRAIN INFRASTRUCTURE REPLACEMENT

Major Field: Agricultural Economics

Biographical:

Education:

Completed the requirements for the Doctor of Philosophy in Agricultural Economics at Oklahoma State University, Stillwater, Oklahoma in May, 2014.

Completed the requirements for the Master of Science in Agricultural Economics Oklahoma State University, Stillwater, Oklahoma in 2009.

Completed the requirements for the Bachelor of Science in Agriculture at Tribhuvan University, Rampur, Nepal in 2005.

Experience:

01/11-Present	Graduate Research Assistant, Department of Agricultural Economics, Oklahoma State University
01/10-12/10	Temporary Paraprofessional, Department of Agricultural Economics, Oklahoma State University
04/08-12/09	Graduate Research Assistant, Department of Agricultural Economics, Oklahoma State University
03/06-12/07	Project Officer, LI-BIRD, Nepal
08/05-02/06	Research Officer (Intern), LI-BIRD, Nepal

Professional Memberships: Agricultural and Applied Economics Association (AAEA), Southern Agricultural Economics Association (SAEA) and Gamma Sigma Delta.