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Agro-Climatic Change, Crop Production and Mitigation Strategies-Case Studies in Arkansas, USA and Kenya

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Agro-Climatic Change, Crop Production and Mitigation Strategies-Case Studies in Arkansas, USA and Kenya

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ABSTRACT

Although climate change impacts vary geographically and temporally, studies at local levels are not readily available for stakeholders to better understand how their local communities would be affected and what remedial measures could be more effective in their local contexts. This dissertation has examined climate change and its impacts in two different local contexts: eastern Arkansas in the USA and Nyando in Kenya. The first part of this dissertation develops agro-meteorological indicators and examines the relationship between agro-meteorological indicators and crop yields in eastern Arkansas between 1960 and 2014. Results reveal that temperature based indicators were more strongly correlated to crop yield than precipitation based indicators. However, drought indices also performed very well. The second part projects future climate scenarios in eastern Arkansas using the agro-meteorological indicators developed in the first part. Results show slight increases in total precipitation, extreme precipitation and lengthening growing season duration. The last part identifies the socio-economic factors affecting the Agro-forestry (AFR) technology adoption in Kenya. Results reveal that farmers with more land, more income and/or more education are more likely to adopt agro-forestry technologies. Years of residence, access to information and reliance on crop income also positively affect the likelihood of using AFR technology. This study is very critical for Kenya where the national forest cover is less than 3%.

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DEDICATION

This dissertation is dedicated to my family: my wife Anne Adhiambo Okeyo for her belief in me even when I did not believe in myself. My son Curtis Clay Omondi for his smiles and energy that kept me going during hard times. Finally, I credit Christian Turner Omondi for the zeal and desire he inculcated in me to cross the finish line.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

Numerous independent lines of evidence confirm that global warming is unequivocal. The recent warming is extremely likely to be the result of human activities, predominantly the burning of fossil fuels (Stocker et al., 2013a). The temperature in the United States has also increased following the global warming. The temperature has increased by 0.7°C (1.3°F) to 1.0°C (1.9°F) since 1895, and most of this increase has occurred in the most recent 40 years (Melillo et al., 2014a). Overall precipitation over the US has also increased since 1900, although some areas had increases greater than the national average, while other regions had decreases (Melillo et al., 2014a). Following the recent trend of climate change, extreme weather and climate events in the US increased in recent decades (Melillo et al., 2014a). There is a consensus on the increased frequency of droughts and occurrence of more intense precipitation events (Alexander et al., 2006; Hall et al., 2008; Hatfield et al., 2011). The recent warming is ultimately projected for all parts of the US as well as the rest of the terrestrial areas. The southeastern US, specifically, is projected to warm 1˚C to 2˚C by the middle of this century (Alexander et al., 2006). By 2100, a low emission scenario is projected to cause 2˚C to 3˚C warming; while a high emission scenario will cause a 3˚C to 5˚C temperature rise in the southeast US (Alexander et al., 2006; Daly et al., 2008).

The impacts of warming and associated changes in extreme weather and climate events are already evident in many regions. The agricultural sector, specifically, is greatly affected by these changes. The negative effect of temperature increase will be most felt by crop production (o'Brien et al., 2004; Schmidhuber and Tubiello, 2007). If no mitigation measures are taken, climate change impacts may significantly reduce corn and soybean productivity. Historical records show that night temperatures have warmed more than day temperature.

Additionally, the number of record high temperatures have been greater than record cold events (Hatfield et al., 2011; Stocker et al., 2013a). Grain filling period is the most sensitive phase affected by drought induced high temperatures that substantially reduce crop yields (Mishra and Cherkauer, 2010). Due to increased temperature and reduced precipitation 10% to 20% declines in maize, sorghum, and ground nut yields in Africa is projected during the century (Schlenker and Lobell, 2010). The impacts of warming on crop production are overall negative but some water constrained areas might benefit from increased precipitation (Hall et al., 2008; Malcolm et al., 2012).

Irrigated agriculture accounts for 70% of world's fresh water withdrawals (Hightower and Pierce, 2008). In addition to increasing crop irrigation requirements, climate change will also affect supply of irrigation water in multiple ways due to increased variability in precipitation, temperature and evapotranspiration as well as increased occurrence of extreme events such as droughts and flooding (Cline, 2007; Parry et al., 2004). Possible impacts include changes in the timing of water availability due to changes in glaciers, snow and rainfall; changes in water demands due to increased temperatures; changes in surface water availability and groundwater storage; and an increased number and intensity of extreme climatic events such as droughts and floods (Rosegrant et al., 2014). For example, the major source of irrigation water in Arkansas, groundwater, is affected by variability in annual precipitation because it is partly recharged by rainwater (Czarnecki and Schrader, 2013a).

Conversion to surface water is one of the main strategies identified by the 2014 Arkansas Water Plan to prepare the state for reduced availability of groundwater. The heavy reliance on surface water, of course, means agricultural water supply will be more susceptible to volatility in precipitation (Fernandez-Cornejo et al., 2014; Malcolm et al., 2012; Rosenzweig et al., 2002). Volatility in water supply will affect crop yields and farm profits. Under-irrigation can cause yield reduction, over-irrigation is wasteful and can lead to lower profits, nutrient leaching and increased runoff (Bates et al., 2008; Parry, 2007). Sparse information is available for irrigation scheduling meaning that extreme effects of climate change will negatively affect irrigated agriculture (Nijbroek et al., 2003; Rijsberman, 2006).

Rain-fed agriculture will be even more affected by climate change. A good example is Sub-Saharan Africa, where agriculture is largely rain-fed and most economies in the region are highly dependent upon agriculture. For example, in Kenya, agriculture accounts for 24% of gross domestic product (GDP) and employs 70% of the rural workforce (Schlenker and Lobell, 2010). However, only 12% of Kenya's land is considered suitable for cultivation and intensive livestock production (Kabubo-Mariara and Karanja, 2007; Schlenker and Lobell, 2010). Growing population and increased urbanization will likely force more arable lands out of agriculture. Global climate models have predicted a 4˚C increase in temperature and an increase in the variability of rainfall up to 20% in Kenya by 2100, posing high risks of droughts and flooding (Hatfield et al., 2011; Kabubo-Mariara and Karanja, 2007). Both drying and intensive rainstorms will increase soil erosion. Crops grown on soils with limited water holding capacities are likely to experience risk of drought and crop failure due to increased water demand (Nayak et al., 2010; Walthall et al., 2012a). In addition, the impact of climate change will generally be more severe in areas with fewer crop alternatives, such as Kenya (Malcolm et al., 2012; Wheeler et al., 2012).

Most researchers agree that although average global crop production may not change much by 2050, climate change will continue to exacerbate global food insecurity due to its impacts on crop production. These impacts will differ dramatically across different geographical regions, with poor regions being particularly vulnerable to increased climate variability and extreme weather events (Rosenzweig and Tubiello, 2007). The case of US is unique because of its complex topography and varied climates; most regions of the country show annual mean temperatures increasing but changes in temperature will vary by season and region. For instance, Southern USA now receives more precipitation than 100 years ago (Hatfield et al., 2011). Alaska faces challenges of increased permafrost temperatures of between 2 ˚C - 4˚C due to warming in the last 50-100 years (Hinzman et al., 2005). California has wide range of climatic zones, limited water supply and economic dependence on agriculture. California has wide range of climatic zones, limited water supply and economic dependence on agriculture. The state will experience decreased precipitation, extreme heat and decreased winter precipitation resulting in reductions in snow pack in the Sierra Nevada Mountains, which will affect stream flow, water storage and supply (Hayhoea et al., 2004). The goal of this study is to fill these knowledge gaps by evaluating the impacts of climate change at local levels through analysis of agro-meteorological indicators on crop production and socio-economic factors affecting agroforestry technology adoption. Specifically, we focused on Arkansas, USA and Kenya in east Africa. Both regions face a myriad of contrasting challenges.

The United States is the world's largest producer and exporter of agricultural products, therefore, any impacts that alter local agriculture production affect global food supply and crop prices (Schlenker and Roberts, 2009; Trostle, 2008). This research studies four important crops (corn, soybean, rice and cotton). Arkansas is the largest producer of rice in the US (Sapkota et al., 2007; Schlenker and Roberts, 2009). It also ranks high nationwide in soybean production.

This research is of special importance to the study area in Arkansas. In 2010 and 2011, Arkansas experienced severe drought. After a wet year in 2009, there were extreme summer temperatures and severe drought in 2010, with the large water deficits occurring in Southern Arkansas, where precipitation was 20 inches below average. In 2011, record temperature and drought conditions continued in western and southern Arkansas while the remainder of the state experienced extreme flooding and precipitation surpluses (Watkins, 2012). Extremes in precipitation lead to variability in groundwater with water levels declining 1.62ft in eastern Arkansas. The sum of these impacts led to declines in ground water pumping, because farmers were unable to draw sufficient irrigation water from the alluvial aquifer (Czarnecki and Schrader, 2013a; Schrader, 2008). High night time temperatures greatly affected rice and increased incidence of bacterial panicle blight, while heat stress greatly affected rice kernel formation and rice quality (Gillip and Czarnecki, 2009; Watkins, 2012).

The impacts of climate change differ depending on the local context. Studying both Arkansas and Kenya offers different local contexts to examine climate change issues. In Arkansas, agriculture is capital intensive characterized by large farms in addition to being heavily subsidized by the government (Daberkow and McBride, 1999). In contrast, labor intensive, smallholder agriculture with little to no irrigation is the norm in developing countries like Kenya. Farms are generally small and farmers usually do not have secure land tenure and operate in marginal risky environments (Morton, 2007).

Studying climate change impacts in the developed world (USA) and the developing world (Kenya) offers a unique perspective on the challenges facing the world today and in the future. Remedies to local climate change are not universal. The same adaptive strategy may be effective in one region but not in another. For example, more efficient irrigation technologies, such as sprinkler irrigation, are often promoted as one of the main adaptive strategies for agricultural producers facing water shortage (Fussel, 2007; Howden et al., 2007). However, due to the requirement of large initial capital investment, sprinkler irrigation may not work in African countries where most farms are much smaller and most farmers are poorer than their US counterparts (Mirza, 2003; Vorosmarty et al., 2000). In Kenya, rain-fed agriculture also faces land degradation caused by soil erosion and other factors (Clay et al., 1998; Pender et al., 2006). In these areas, sustainable land use and a greater capability of managing natural resources are essential for climate change adaptation (Ramachandran Nair et al., 2009). Therefore, adaptive strategies suitable for the context of developed countries and developing countries will vary.

The main objectives of this dissertation are: 1) To develop a set of agro-meteorological indicators; 2) To examine the relationship between agro-meteorological indicators and crop yields in eastern Arkansas; 3) To project future climate scenarios in eastern Arkansas using agro-meteorological indicators; 4) To assess the impacts of future climate scenarios on agriculture in eastern Arkansas and 5) To identify the socio-economic factors affecting the Agro-forestry (AFR) technology adoption in Kenya. The research provides basic information such as past and present climate patterns and predicted climate change and how it will affect crop yields. Since all the information is at a local level, it can be readily used by policy makers to design policies to adapt to climate change.

A set of hypotheses were constructed to study the impact of local climate change on agriculture and to assess the relationship between various agro-meteorological indicators and crop production within the eleven counties of Eastern Arkansas. The following hypotheses were tested in this study:

Hypothesis 1

H_{o1}: Temperature has no relationship with soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha > 0.1$).

H_{A1}: Temperature has relationship with soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha > 0.1$).

Hypothesis 2

H_{o2} : Precipitation has no relationship with soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha > 0.1$).

H_{A2} : Precipitation has relationship with soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha > 0.1$).

Hypothesis 3

H_{o3}:There is no correlation between the three drought indices and soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha > 0.1$).

H_{A3}:There is correlation between the three drought indices and soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha > 0.1$).

Hypothesis 4

H_{o4} : There was no relationship between temperature driven indicators and future climate change projections within eleven counties in eastern Arkansas.

H_{A4} : There was relationship between temperature driven indicators and future climate change projections within eleven counties in eastern Arkansas.

Hypothesis 5

H_{o5} : There was no relationship between precipitation driven indicators and future climate change projections within eleven counties in eastern Arkansas.

H_{A5} : There was relationship between precipitation driven indicators and future climate change projections within eleven counties in eastern Arkansas.

Hypothesis 6

H_{o6} : There was no spatial change in temperature and precipitation driven indicators within eleven counties in eastern Arkansas.

H_{A6} : There was spatial change in temperature and precipitation driven indicators within eleven counties in eastern Arkansas.

The remainder of this dissertation is organized as follows. Chapter 2 develops a set of agro-meteorological indicators and examines the impact of temperature, precipitation and drought on soybean yields between 1960 and 2014 in eastern Arkansas. Chapter 3 uses daily weather data interpolated to individual grid cell levels and global climate models to project climate conditions in 2030 and 2060 as well as their impacts of climate change on agro-meteorological indicators such as growing degree days and frost days. Chapter 4 utilizes regression analysis to identify the socio-economic factors that influence adoption of Agro-forestry (AFR) technology. Finally, Chapter 5 summarizes research findings and draws broader conclusions that arise from the analysis conducted in Chapters 2-4.

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CHAPTER 2: IMPACT OF CLIMATE VARIATIONS ON SOYBEAN YIELD IN EASTERN ARKANSAS: 1960-2014

Abstract

Climate is the major factor affecting crop production; therefore, various agro-meteorological indicators have been frequently used to evaluate the impact of climate on crop production. In this study, we examined the temporal variations of agro-meteorological indicators (growing degree days, total precipitation, dry spells and drought indices) from 1960-2014 and their impact on soybean yields in eastern Arkansas. Results show an increasing trend in growing degree days (GDDs) and dry spells, although the total precipitation during the soybean growing season remained nearly unchanged during the study period. Generally, GDDs and dry spells show a strong correlation with yields. We also evaluated drought variability based on different drought indices, including the Palmer Drought Severity Index (PDSI), the Standardized Precipitation Index (SPI) and the Standardized Precipitation-Evapotranspiration Index (SPEI). The drought indexes are all negatively correlated to soybean yields. Overall, the one month SPEI showed the strongest impact on yields. After regression analysis, total precipitation and SPEI-1 were the only significant factors in the General Linear Model (GLM).

Keywords: Climate change, Agro-indicators, Drought indices

2.0 Introduction

Urbanization, salinization, climate change, and water scarcity all pose renewed challenges to agriculture (Fedoroff et al., 2010). Increases in crop yields are required to meet both domestic and commercial demands for food, but climate change and diminishing returns from technological advancements will limit potential success (Lobell and Asner, 2003). Temperatures above 30°C tend to diminish yields of most crops because of the photosynthetic threshold temperature. These elevated temperatures accelerate crop reproductive development thereby reducing accumulation of carbohydrates, fats and proteins that are major components of grains and fruits (Fedoroff et al., 2010). In fact, studies project 17% decreases in both corn and soybean yields for each degree rise in growing season temperature in the southeast United States (Lobell and Asner, 2003).

There is a general trend of early onset of spring and increasing growing degree days in the United States (Feng and Hu, 2004; Schwartz and Reiter, 2000). Previous satellite and climatological studies agree that there are shifts in timing and length of the growing season (Tucker et al., 2001). Increasing growing season length provides opportunities for earlier planting, ensuring maturation and possibilities of multiple cropping. However, higher temperatures could speed development and reduce time to accumulate dry mater, which in turn could cause slight decreases in yields (Assessment, 2004; Linderholm, 2006; Stocker et al., 2013a). Additionally, variation in crop yields is more influenced by regional weather and climate rather than large scale climate dynamics. Therefore, it is more important to develop agro-meteorological indicators at the regional level to study their relationship with individual crop yields (Mishra and Cherkauer, 2010).

The long term average, frequency, and extremes of several weather variables are the chief determinant of the general climate of a region (Patel et al., 2007). To evaluate the impact of climate on agriculture, multiple agro-meteorological indicators are used. Agro-meteorological indicators are constructed from climatic variables that have an impact on plant life. They are used to assess site suitability for crop growth, geographical limits of crop land use and to establish estimates of weather anomalies or trends (Confalonieri et al., 2010). The study of both temperature and precipitation based indicators has never been more critical because varying climate has and will continue to alter agricultural environment and affect crop productions (Feng and Hu, 2004).

There is a consensus that climate change will alter the frequency, timing and intensity of extreme events such as droughts (Greenough et al., 2001). In fact, climate model simulations indicate that the interiors of northern continents will become drier during summer over the next century (Wetherald and Manabe, 2002). Socio-economic and environmental effects of droughts are costly due to their spatial and temporal extent (Wilhite, 2000). Thus, increased severity and frequency of droughts is a major concern to many stakeholders, increasing the need to measure and study drought impacts on crop yields (Sheffield and Wood, 2008; Wang, 2005).

Drought is the least understood yet most complex of all natural hazards (Patel et al., 2007). Most elements of drought (onset, duration, intensity and end) are determined by moisture deficits (Kogan, 1997; Vicente-Serrano et al., 2010). Due to dependence on water resources and soil moisture for crop growth, agriculture is often the first sector to be affected by onset of drought, making reductions in crop yields a good indicator for the impact of drought on agriculture (Kogan, 1997; Narasimhan and Srinivasan, 2005). The costliest droughts occur during the grain filling period of most crops. Corn and soybean, for example, are most severely affected when drought occurs during the grain filling period (Mishra and Cherkauer, 2010). Nonetheless, lack of a universal drought monitoring framework makes it impossible to assess drought impacts across ecosystems and different countries' economies (Kogan, 1997).

Monitoring, early warning and assessment of consequences of drought are the most common tools used in drought mitigation. Most countries' drought watch systems are based on analysis of weather anomalies or domestic indices, which are formulated by integrating temperature, rainfall and evapotranspiration (Kogan, 1997; Patel et al., 2007). Drought indices must be associated with specific timescales to be useful for monitoring different types of drought (Patel et al., 2007; Vicente-Serrano et al., 2010). According to Vicente-Serrano et al (2009), PDSI was found to explain variability in production and activity of natural vegetation better than SPI. Patel et al (2007) also found that 3-month SPI could help assess in advance the decline in food and grain production caused by droughts in India (Gujarat State). In this paper, we considered three drought indices i.e. Palmer Drought Index (PDSI), Standardized Precipitation Index (SPI) and Standardized Precipitation and Evapotranspiration Index (SPEI).

Our study focused on eleven counties in eastern Arkansas, where the majority of agricultural activity in the state occurs. Arkansas is a major agricultural producer and the largest producer of rice in the nation, with other major crops including soybean, corn, wheat and cotton (Nickerson et al., 2011). Arkansas's agriculture is heavily irrigated and is the fourth largest user of groundwater for irrigation in the nation (Holland, 2007; Schaible and Aillery, 2012b). The climate of Arkansas is humid sub-tropical, with average temperatures of about 15.8˚C (Feng et al., 2014). The major rainy seasons in Arkansas occurs from March to May and then from October to December. Climate change may affect Arkansas' agriculture both directly through its effect on crop growth and indirectly through its effect on irrigation water supply.

The goal of this project was to explore the relationship between, agro-meteorological indicators and crop yields within eleven counties of Eastern Arkansas. The objectives of this study were: - 1) To develop a set of agro-meteorological indicators; 2) To examine the relationship between agro-meteorological indicators and soybean yields within the eleven counties of Eastern Arkansas and 3) To compare the performance of three drought indices within the soybean growing season. To fulfill the above objectives, a set of hypotheses were constructed:

(H_{o1}) was that temperature has no relationship with soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha > 0.1$).

(H_{o2}) was that precipitation has no relationship with soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha > 0.1$).

(H_{o3}) was that there is no correlation between the three drought indices and soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha > 0.1$).

2.1 Data and methods

2.1.1 Study Region

The study sites encompass three eight-digit hydrological unit code watersheds (L'anguille, Big, and the Lower White), within the farming region of the Arkansas Delta where the Mississippi alluvial aquifer is most depleted. The study area consists of 11 counties located in eastern Arkansas (Figure 1). It lies within latitudes 35.99 and 33.95 degrees North and longitudes 90.29 and 91.34 degrees West. The area is geographically homogenous-a predominantly flat alluvial plain in the Mississippi River Valley in eastern Arkansas. This region is the most productive region in Arkansas which produces rice, soybean, corn, wheat and cotton.

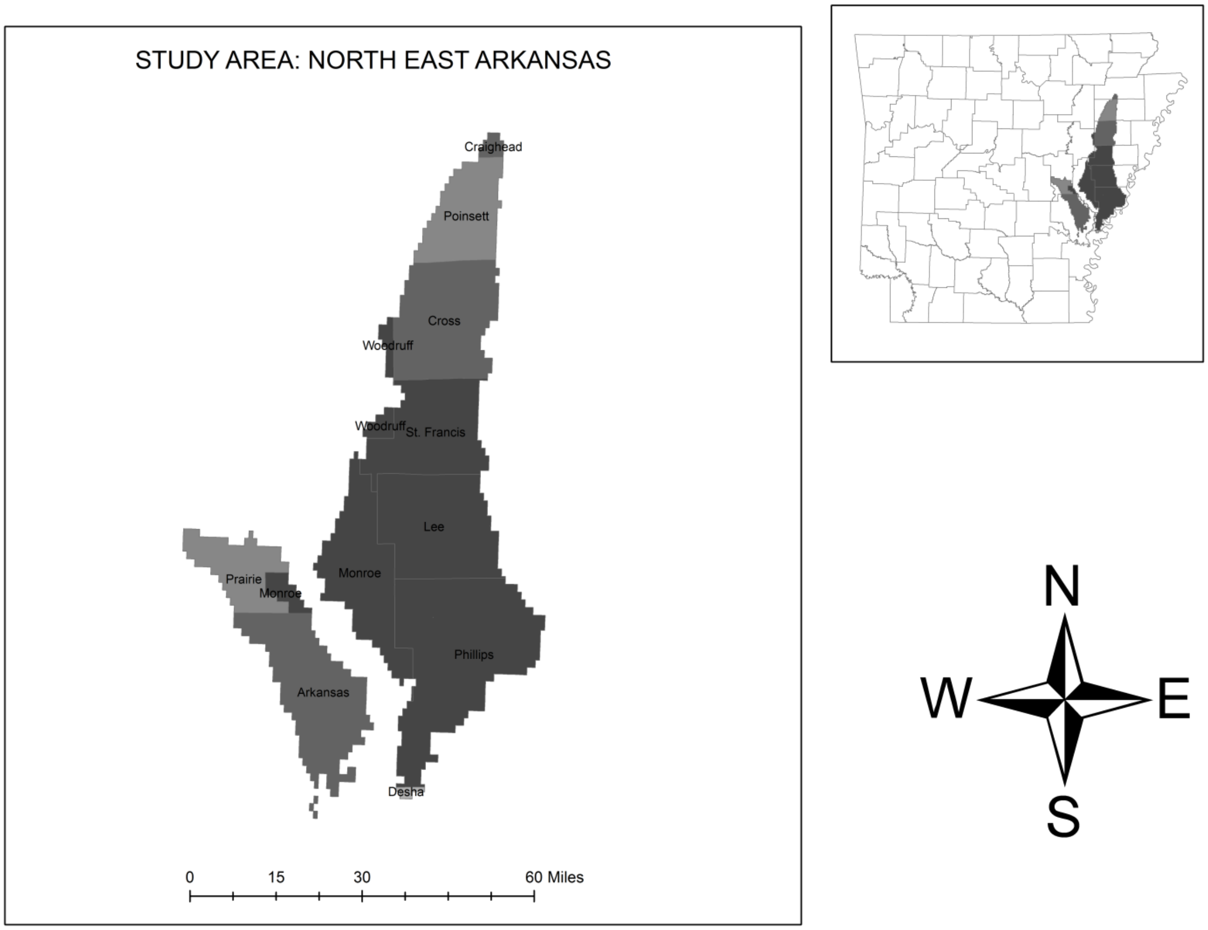

Figure 1: Study area in Eastern Arkansas

2.1.2 Data

The daily temperature (minimum, maximum and mean) and precipitation from the 11 counties in the study regions from 1960 to 2014 were obtained from National Oceanic and Atmospheric Administration (NOAA) (DeGaetano et al., 2015). Soybean was chosen for the study due to ease of non-irrigated soybean data availability. The LOESS regression method was used to remove trends in soybean crop yield arising from genetic and management improvements (Mishra and Cherkauer, 2010).

2.1.3 Temperature Based Indicators

Growth events of crops such as flowering and maturity depend on the accumulation of specific quantities of heat or thermal time (Miller et al., 2001). Growing Degree Days (GDDs) is therefore a measure of heat accumulation necessary for maturity (Feng and Hu, 2004; Hassan et al., 2007).

The calculation of thermal time (TT) in the unit of GDD is given by the following equation:-

$$TT = \sum_{Pb}^{Pe} \frac{(T_{max} + T_{min})}{2} - T_b$$

where T_{max} and T_{min} are the daily maximum and minimum surface air temperature; P_b and P_e are the beginning and ending dates of the growth season (Feng and Hu, 2004). The threshold temperatures (T_b) for growth were set as 10˚C and 30˚C for soybean (Feng and Hu, 2004; Sarma et al., 2008). The growing season (June, July, August, September & part of October/JJASO) for soybean was set between June 1st (P_b) and October 16th (P_e) from University of Arkansas Division of Agriculture Cooperative Extension Services (http://www.uaex.edu/).

2.1.4 Precipitation Indicators

Growing season total precipitation was calculated from daily precipitation data representing cumulative rainfall totals for the growing season (Kunkel et al., 1999). Dry spells during the growing season were defined as consecutive dry days without precipitation or when precipitation is below 1mm (Piani et al., 2010). Dryness and wetness are relative to historical average rather than absolute total of precipitation for given areas (Patel et al., 2007).

2.1.5 Drought indices

Different drought indexes were used to evaluate the impact of the drought on crop yields (Heim Jr, 2002). The three frequently used drought indexes are the Palmer Drought Severity Index (Alley, 1984; Wells et al., 2004), the Standardized Precipitation Index (McKee et al., 1993; Patel et al., 2007) and the Standardized Precipitation-Evapotranspiration Index (Begueria et al., 2014).

The PDSI is the most common meteorological index used in USA. It is a standardized measure, ranging from -10(dry) to + 10(wet)(Dai et al., 2004). Since PDSI has a time span of 9 months or longer, it does not allow detection of droughts over different periods at multiple time scales and differentiation among different drought types (Hayes et al., 1999; Vicente-Serrano et al., 2010). For these reasons, PDSI responds slowly to drought and can retain values reflecting drought even after climatological recovery from drought has occurred (Hayes et al., 1999).

SPI is produced by standardizing the probability of observed precipitation for a given duration. Moreover, SPI is designed to detect drought over different periods at multiple time scales (1, 3 and 6 months) in this study. Positive values of SPI indicate greater mean precipitation while negative values indicate less than the mean precipitation (Patel et al., 2007). The main undoing of SPI is that it only uses precipitation in its formulation. Therefore, It does not consider other variables that can influence droughts like temperature, evapotranspiration, wind speed and soil water holding capacity (Vicente-Serrano et al., 2010).

On the other hand, SPEI (1, 3 and 6 months) is based on precipitation and potential evapotranspiration (PET). SPEI combines sensitivity of PDSI to changes in evaporation demand (caused by temperature variations and trends) with the simplicity of calculation and the multi-temporal nature of the SPI. Therefore, use of drought indices that include temperature data in the formulation is preferable. SPEI is particularly well suited for detecting monitoring and exploring the consequences of global warming on drought conditions (Vicente-Serrano et al., 2010). Based on daily temperature and precipitation, the monthly mean temperature and monthly precipitation totals in individual counties were computed and then used to calculate the PDSI, SPI and SPEI for Soybean growing season in this study.

2.1.6 Data analysis

The response variable, soybean yield, and all the other predictor variables i.e. Growing Degree Days (GDDs), Growing Season Length (GSL), Dry spell and SPEI-1 were screened for possible outliers to confirm the normality of data distribution (Royston, 1992). Correlation analysis was done to assess individual agro-climatic indicators performance against soybean yields for individual counties and the entire study area. Pearson Correlation analysis was also done for all three drought indices to establish their relationship with soybean yield during the growing season for each county and study area. Finally, Multiple Linear Regression (MLR) was used to fit General Linear Models (GLM) for individual counties and the study area using JMP Pro 12 (Preacher et al., 2006).

2.2 Results

2.2.1 Agro-climatic indicators and yield anomalies

Soybean yields for the study area (figure 2) have increased steadily from the 1960s to 2014. These increases in yields have been attributed to scientific improvement through breeding and improved scientific management (Feng and Hu, 2004; Mishra and Cherkauer, 2010). Figure 3 shows agro-indicator anomalies for the study area. Results reveal that the soybean yields are negatively correlated to dry spells during the 1980s late 1990s and 2000s.

GDDs were highly correlated with dry spells, with longer dry spells corresponding to longer GDDs. In addition, total precipitation was positively correlated with yields.

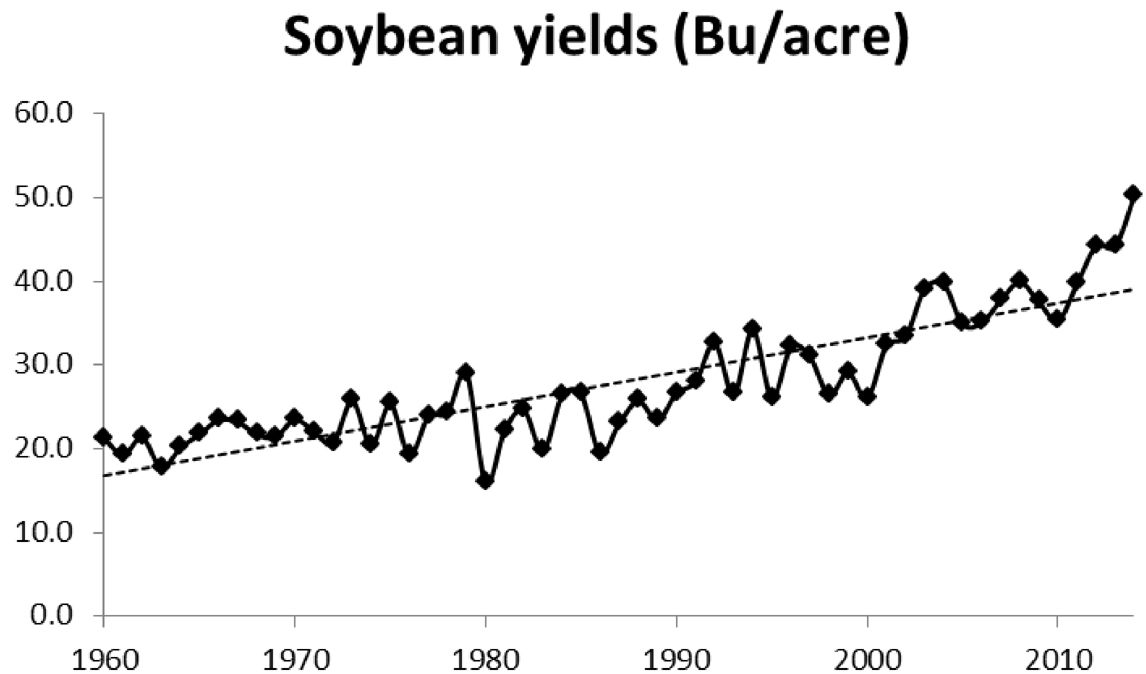

Figure 2: Soybean yields for the study area (1960-2014)

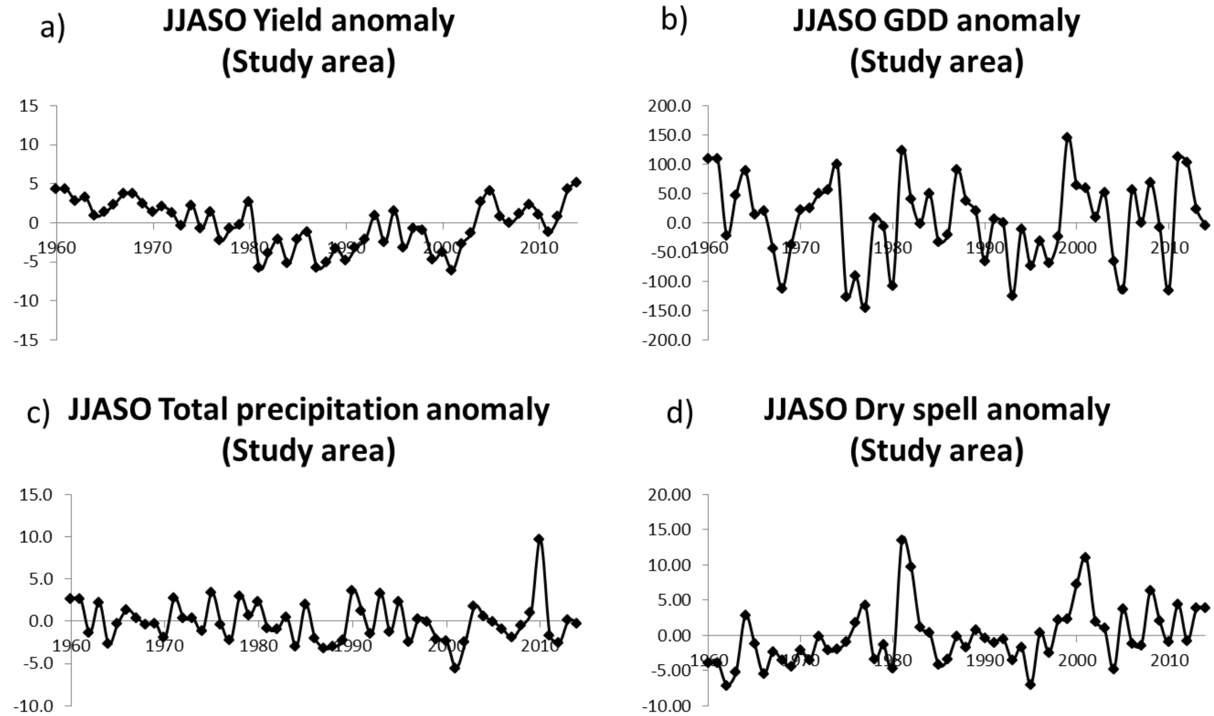

Figure 3: a) JJASO Soybean yield anomalies (1960-2014), b) JJASO GDD anomalies (1960-2014), c) JJASO Total precipitation anomaly (1960-2014), and d) JJASO Dry spell anomalies (1960-2014) for eastern Arkansas.

The correlation between agro-indicators and soybean yields is shown in table 1. Growing season GDDs and Dry spells are negatively correlated with yields while total precipitation and SPEI-1 are positively correlated. These results show that both precipitation and temperature indicators have significant effect on soybean yields. Accordingly, the increase in dry spells resulting in accumulation of GDDs during the growing season is the factor most responsible for reduction in soybean yields in eastern Arkansas.

Table 1: Correlation between (JJASO) Agro-climatic indicators and Soybean yields (1960-2014)

County	GDD	Total precipitation	Dry spells	SPEI-1
Arkansas	**-0.197***	0.119	-0.044	**0.588*****
Craighead	-0.180	**0.328****	-0.033	**0.26****
Cross	-0.085	0.126	**-0.328*****	**0.201***
Desha	**-0.51*****	**0.210***	**-0.344*****	**0.412*****
Lee	**-0.211***	0.154	**-0.198***	**0.247***
Monroe	**-0.430*****	0.23	-0.075	**0.235***
Phillips	**-0.550*****	**0.314****	**-0.252***	**0.484*****
Poinsett	**-0.200***	**0.212***	**-0.283****	**0.313****
Prairie	-0.180	0.156	-0.188	**0.294****
St Francis	**-0.470*****	0.094	-0.086	0.121
Woodruff	-0.120	0.188	**-0.246****	**0.203***
Study area	**-0.311****	0.135	**-0.282****	**0.302****

*s indicates significance levels. * means *p*-value <0.10, ** means *p*-value<0.05, *** means *p*-value<0.001.

2.2.3 Drought Indices and yield anomalies

Figure 4 shows PDSI and the 1-, 3- and 6- month SPEI and SPI for eastern Arkansas between 1960 and 2014. PDSI reveals major drought episodes in the 1960s, 1980s, mid- 1990s, and late 2005 and 2010. Although strongly correlated, SPEI and SPI also indicated drought during these time periods.

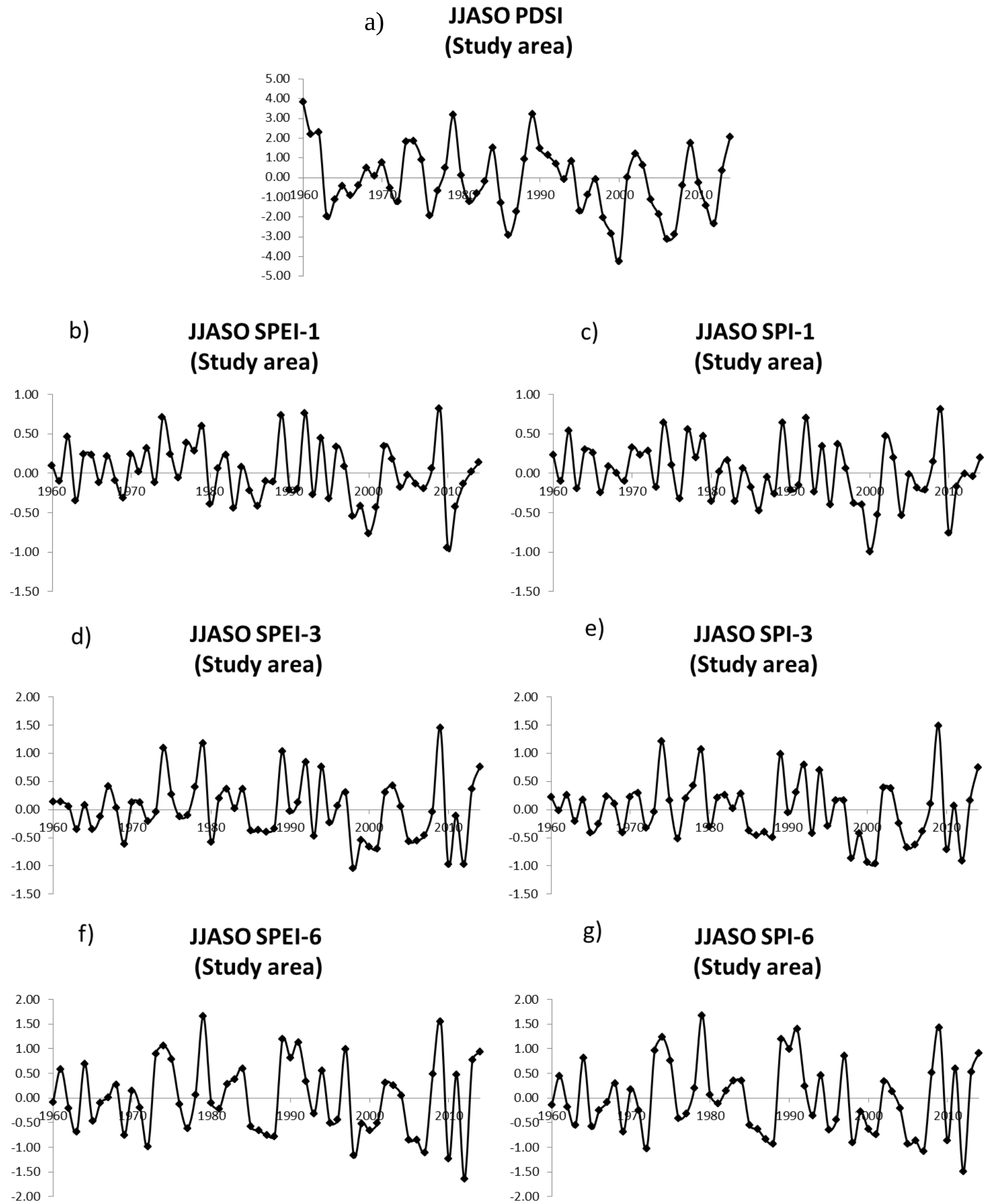

Figure 4: a) JJASO PDSI (1960-2014), b) JJASO SPEI-1month (1960-2014), c) JJASO SPI-1month (1960-2014), d) JJASO SPEI-3months (1960-2014), e) JJASO SPI-3 months (1960-2014), f) JJASO SPEI-6 months (1960-2014) and g) JJASO SPI-6 months (1960-2014).

The JJASO drought indices were correlated with corresponding yield anomalies for each county (Table 2) of the soybean growing season for 1960-2014. The results showed significant positive correlation between these indices and de-trended Soybean anomalies for 8 of the 11 counties in the study area. Craighead county particularly had very high correlations (r >0.5) for all the three indices (PDSI, SPEI-1 and SPI-1).

Table 2: Correlation between JJASO Drought indicators and de-trended Soybean yield anomaly (1960-2014)

County	PDSI	SPEI-1 month	SPEI-3 months	SPEI-6 Months	SPI-1 month	SPI-3 months	SPI-6 months
Arkansas	0.022	**0.232***	0.141	0.047	0.160	0.077	0.054
Craighead	**0.512*** **	**0.501*** **	**0.459*** **	**0.368*** **	**0.537*** **	**0.468*** **	**0.368*** **
Cross	**0.531*** **	**0.444*** **	**0.371*** **	**0.261** **	**0.397*** **	**0.338** **	**0.237***
Desha	0.078	0.154	0.061	0.097	0.165	0.073	0.085
Lee	**0.332*** **	**0.469*** **	**0.505*** **	**0.434*** **	**0.410*** **	**0.446*** **	**0.395*** **
Monroe	**0.320*** **	**0.508*** **	**0.426*** **	**0.303** **	**0.463*** **	**0.402** **	**0.278***
Phillips	0.071	**0.282** **	**0.238***	0.141	**0.226***	0.176	0.081
Poinsett	**0.317** **	**0.408*** **	**0.345*** **	**0.312** **	**0.397*** **	**0.311** **	**0.270** **
Prairie	**0.445*** **	**0.433*** **	**0.463*** **	**0.326** **	**0.392*** **	**0.424** **	**0.306** **
St Francis	0.061	0.203	0.078	0.068	0.154	0.009	0.023
Woodruff	**0.267** **	**0.282** **	**0.238***	0.202	0.195	0.030	0.004
Study area	**0.367*** **	**0.393*** **	**0.345*** **	**0.261** **	**0.414*** **	**0.334*** **	**0.221***

*s indicates significance levels. * means *p*-value <0.10, ** means *p*-value<0.05, *** means *p*-value<0.001.

PDSI performed well in this study; it was positively correlated with seven instances of departures in soybean yields—six at the 99% confidence level and once at the 95% confidence level. SPEI-1, and was closely correlated to the yields for eight of the counties studied. Six of the counties were correlated at the 99% confidence level and while two were correlated at the 95% confidence level. SPEI-3 was also correlated with eight counties, but at lower confidence levels. Performance of the SPEI-6 was only significantly correlated to yields in 6 counties. These results reveal that SPEI based indices did better than PDSI save for SPEI-6. It is also important to note that the explanatory power of the SPEI diminishes as the time frame increases. For SPI, SPI-1 performed better with strong correlation in seven cases, six at the 99% confidence level. The explanatory power of the SPI indices also diminished as the time frame increased.

2.2.4 Multiple Linear Regression

Table 3: General Linear Models for individual counties and study area (JJASO)

County	**Intercept**	**GDD**	**Total Precipitation**	**Dry Spell**	**SPEI-1**
Arkansas	-10	**0.02***	0.022	0.002	-2.298
Craighead	47.62	-0.018	**0.11***	0.042	**-10.05***
Cross	30	0.07	0.042	**0.28****	-5.57
Desha	-44	**0.028*****	**0.07****	**0.21***	-4.82
Lee	12.81	0.02	0.044	0.091	**-5.39***
Monroe	-21.38	**0.076***	0.07	0.51	**-6.74***
Phillips	-5.61	**0.04***	0.04	0.022	**-7.43***
Poinsett	28.89	0.006	0.038	**0.207***	**-6.65****
Prairie	30.69	0.008	**0.105****	0.044	**-13.29****
St Francis	-18.51	**0.02***	0.07	0.018	**-5.27***
Woodruff	19.22	0.002	0.06	**0.105***	-1.34
Study area	0.15	0.17	0.005	**0.08***	**-10.29***

*s indicates significance levels. * means *p*-value <0.10, ** means *p*-value<0.05, *** means *p*-value<0.001.

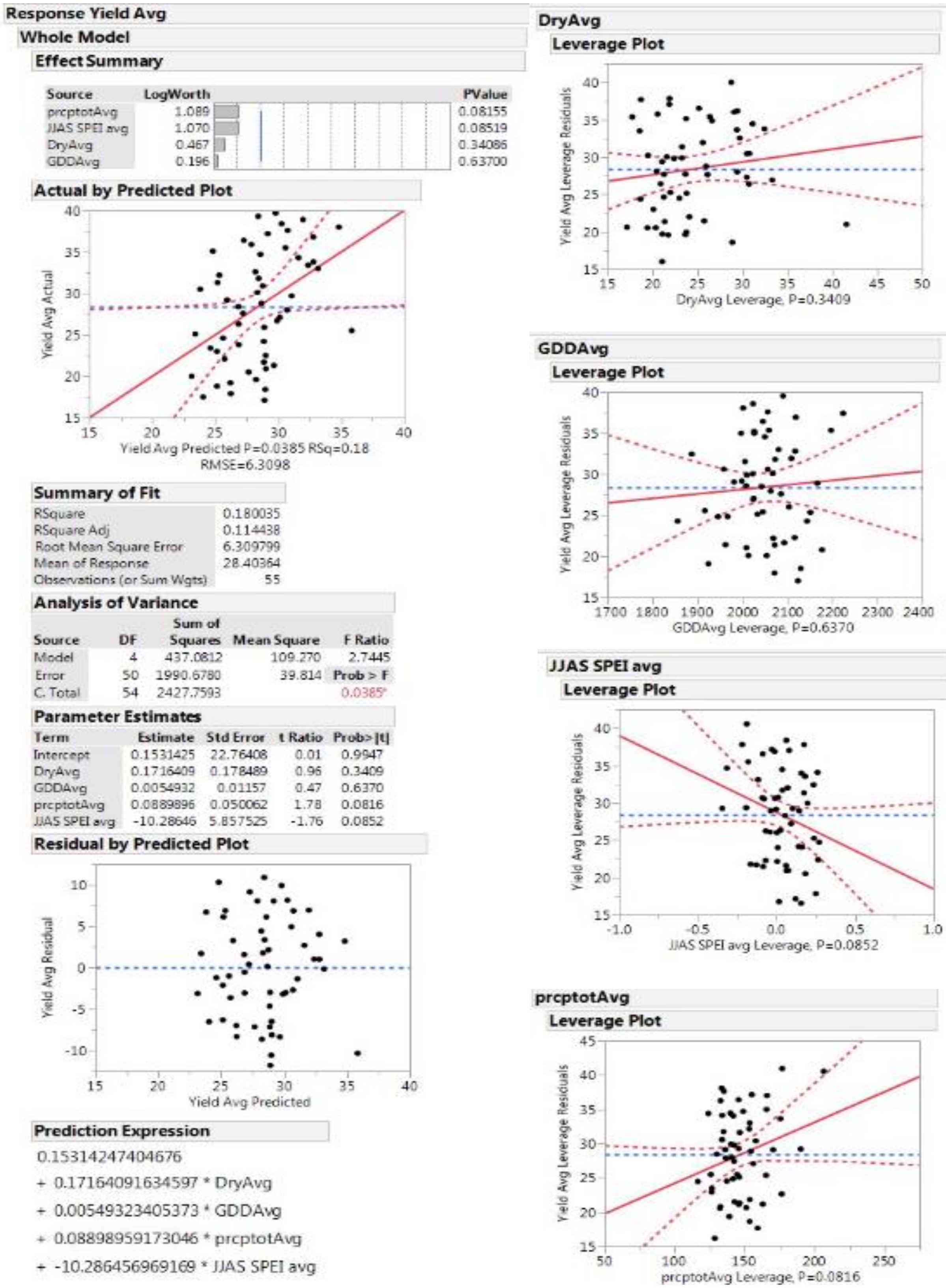

Figure 5: General Linear Model for soybean yields (1960-2014) for eastern Arkansas (JJASO)

Multiple linear regression was performed with four agro-meteorological indicators (GDD, total precipitation, dry spell and SPEI-1) to establish a GLM for each county and study area. Regression results for the counties and study area are shown in Tables 3. Total precipitation and SPEI-1 were the only factors explaining yield departures of soybean at 90% the confidence level in the final model for study area (figure 5). The final model is shown below: -

$$\boldsymbol{Soybean\,Yield = b_0 + b_1 Dry\ Spell + b_2 GDD + b_3 PRECIPITATION * - b_4 SPEI - 1} *$$

Where, b_0 is the intercept, b_1, $b_{2,}$ b_3 and b_4 are the parameters of Dry spell, GDD, Total precipitation and SPEI-1 respectively. Figure 4 shows that the model is significant with p value < α (i.e. 0.0385), the total precipitation is significant at α = 0.08 and SPEI-1 significant at α = 0.08. The parameter estimates suggests, b_0 = 0.15, b_3 =0.089 and b_4 = -10.29.

2.3 Discussion

Based on the results above, we can draw some general conclusions about the agro-meteorological indicators. Results reveal that temperature based indicators were more strongly correlated to crop yield than precipitation based indicators. Higher yields were observed when there was a considerable increase in total precipitation. Similar studies by Feng and Hu (2004) also revealed that dry and wet spells had the largest effect on dry-land corn yield in Nebraska. Accordingly, the increase in dry spells resulting in accumulation of GDDs during the growing season is the factor most responsible for reduction in soybean yields in eastern Arkansas. Based on these results, it is very likely that global climate change will have great impact on agriculture through changes in precipitation and temperature.

In comparison, most of the studied drought indices performed well. PDSI performed even better than SPI despite its long term reference. SPEI indices were the best of the three indices probably due to the effect of temperature on its formulation. The explanatory power of the SPEI and SPI indices on agricultural drought diminished as the time frame increased.

However, 1-month SPEI and SPI still remained the best indices for short term agricultural drought studies. Both SPI and SPEI were very strongly correlated; revealing that, in circumstances where low variability of temperature occurs, both SPEI and SPI indices respond mainly to precipitation. These results are similar to those of Vicente-serrano et al. (2010).

In summary, SPEI indices outperformed PDSI and SPI. PDSI performed better than SPI, probably due to the inclusion of temperature in its computation. Short-term agricultural drought is best correlated to SPEI-1 and SPI-1. There are cases when drought indices do not exhibit meaningful correlation, as illustrated by their failure to indicate significant drought impact on yields in three of the 11 counties in the study area, where soybean was likely irrigated to mitigate drought impact. The absence of significant correlation for these counties may also result from low data quality of local weather stations. Differences in soybean planting dates during the crop growing season may explain the difference in correlations between the counties in the study area (Narasimhan and Srinivasan, 2005). The results also reveal that drought indices may be a valuable instrument for forecasting soybean grain yield loss resulting from meteorological drought.

2.4 Conclusion

The goal of this project was to explore the relationship between, agro-meteorological indicators and crop yields within eleven counties of Eastern Arkansas. The following objectives were met: 1) To develop a set of agro-meteorological indicators, 2) To examine the relationship between agro-meteorological indicators and soybean yields within the eleven counties of Eastern Arkansas and 3) To compare the performance of three drought indices within the soybean growing season. To fulfill the above objectives, a set of hypotheses were tested:

(H_{o1}) Temperature has no relationship with soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha > 0.1$).

After correlation and regression analysis, results revealed that GDDs were negatively correlated to yields. In fact, most counties of the study area produced p values ($\alpha < 0.1$). Therefore, the null hypothesis was rejected, confirming that temperature was strongly associated with soybean yields within the study area.

(H_{o2}) was that precipitation has no relationship with soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha > 0.1$).

Although total precipitation yielded mixed results after correlation and regression analysis, results revealed that dry spells were negatively correlated to yields. Some counties of the study area produced p values ($\alpha > 0.1$). Given the mixed results from precipitation analysis, we failed to reject the null hypothesis.

(H_{o3}) was that there is no correlation between the three drought indices and soybean yields within eleven counties in eastern Arkansas, and that correlation results will yield p values ($\alpha > 0.1$).

After correlation analysis, results revealed that PDSI, SPEI and SPI were positively correlated to yields. In fact, most counties of the study area produced p values ($\alpha < 0.1$). Therefore, the null hypothesis was rejected.

This study was carried out to explore the relationship between, Agro-meteorological indicators, drought indices and soybean yields within eleven counties of Eastern Arkansas. There was positive correlation between total precipitation and yields. Furthermore, GDDs and dry spells were negatively correlated with the yields. Total precipitation and SPEI-1 were the only factors explaining yield departures of soybean from the normal values in our multi-linear regression model developed for the study area. The increases in GDDS and dry spell during the crop growing season will serve to lower yields and increase the cost of doing agriculture in the study area. Coupled with global change, increased costs due to irrigation demands will hurt farmers by putting pressure on ground water.

While PDSI's efficacy was restricted to explanation of long-run drought impacts, it performed better than SPI indices. SPEI indices out performed both SPI and PDSI indices. SPEI and SPI indices, especially the one and three month indices, were closely correlated. PDSI was closely correlated to the SPEI-6 and SPI-6 indices. Importantly, short-term agricultural drought is best explained by SPEI-1 and SPI-1.

In cases where temperature trends are not apparent (relatively uniform), there was little difference in values obtained by precipitation indices like SPI or those formulated by potential evapotranspiration like SPEI. It is fair to conclude that in similar cases; precipitation data could be used to compute agricultural drought. SPI and SPEI-6 were strongly correlated to PDSI, suggesting that precipitation was the most dominant factor in long term drought conditions. Due to negative effects of drought on agriculture and environment, agro meteorological indicators will play a critical role in long term studies for policy makers.

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CHAPTER 3: ANALYSIS OF FUTURE CLIMATE SCENARIOS AND THEIR IMPACT ON AGRICULTURE IN EASTERN ARKANSAS

Abstract

The impact of climate change on crop growth is dynamic and difficult to quantify due to heterogeneity of the associated effects and their interactions within the Earth system. The main objective of this study is to establish how future climate change might affect agriculture through an assessment of temperature and precipitation driven parameters. These parameters include; 1) percentage of rainy days with extreme precipitation, 2) total annual precipitation ,3) percentage of extreme precipitation relative to wet days, 4) first fall frost days, 5) last spring frost days, 6) growing season length and 7) growing degree days. Results show that, percent of rainy days with extreme precipitation and total annual precipitation remained nearly unchanged representing a 0.03% and 0.5% rise under 2060 (RCP 8.5) scenarios. However, there was a significant rise in percent of extreme precipitation relative to wet days accounting for a 1.25% rise by 2060 under (RCP 8.5) scenario. It is also anticipated that, there would be late first fall frost days, early last spring frost days and increased growing season length by up to 2 weeks in 2060. Additionally, growing degree days are projected to increase under all scenarios for all crops, with cotton showing the largest increase of up to 37% relative to the baseline period.

Keywords: Crop growth, temperature, precipitation, Representation Concentration Pathway (RCP), frost days

3.0 Introduction

Climate is the most dominant factor influencing the agricultural production environment. Climate change has been manifested through an increase in global average surface temperatures by approximately 0.7˚C in the 20th century (Melillo et al., 2014b). Most of this change occurred since the 1970s (Feng and Hu, 2004; Moonen et al., 2002). Even in the most optimistic scenario where greenhouse gases were held constant, the Earth's surface would warm by about 0.6˚C over the course of the 21st century, relative to the year 2000 (Stocker et al., 2013a). Due to elevated greenhouse gases (GHGs), future atmospheres will be warmer and capable of holding more moisture (Drake et al., 1997; Morison and Gifford, 1984). In fact, the atmosphere can retain approximately 7% more water vapor for every extra degree of air temperature (Stocker et al., 2013a). Therefore, more intense precipitation is anticipated in a future warmer climate (Alexander et al., 2006; Hatfield et al., 2011; Zhang et al., 2007b).

Future precipitation projections are less certain than projections for temperature due to local physiographic and atmospheric effects (Ingram et al., 2013). Increases in precipitation can still be undone through heat stress projected to reduce crop productivity coupled with drought effects (Karl and Melillo, 2009). In addition, temperature effects will lead to increased transpiration from plants and evaporation from soils and water reserves depending on the saturation state of the atmosphere. Hence, there will be reduced water availability due to increased evaporative losses from rising temperatures subject to overall moisture saturation in the atmosphere (Ingram et al., 2013).

Many studies claim that climate change has altered the agricultural environment and affected crop production through factors such as shifts in growing season, changes in planting dates or extreme weather events (Feng and Hu, 2004; Moonen et al., 2002). The general consensus is that climate change will lower yields for many important crops, including; corn, soybean, and wheat (Blanc et al., 2013). Impacts on water resources include changes in the timing of water availability due to changes in snow and rainfall. Additionally, shifts in water demands caused by increased temperatures together with changes in surface water availability and groundwater storage will have negative impacts on agriculture (Moonen et al., 2002; Rosegrant et al., 2009). Therefore, alterations in temperature and precipitation may affect the demand for irrigation water both by quantity and timing as well as supply of water for irrigation (Elliott et al., 2014; Schewe et al., 2014; Schlenker et al., 2007).

This study focuses on Arkansas because its agriculture relies heavily on irrigation. Arkansas is a major agricultural producer and the largest producer of rice in the nation, with other major crops including soybean, corn, wheat and cotton (Nickerson et al., 2011). Arkansas's agriculture is heavily irrigated and is the fourth largest user of groundwater in the nation (Holland, 2007; Schaible and Aillery, 2012a). The climate of Arkansas is humid sub-tropical, with average temperatures of about 15.8˚C (Feng et al., 2014). The major rainy season in Arkansas occurs from March to May and then from October to December according to Offices of the Arkansas State Climatologist, (2014).

Climate change may affect Arkansas' agriculture both directly through its effect on crop growth and indirectly through its effect on irrigation water supply. The growth of rice is highly sensitive to temperatures in the phenological stages. Temperatures below 20˚C or above 35˚C will cause floral or spikelet sterility reducing yields (Satake and Hayase, 1970; Walthall et al., 2012b). It is also anticipated that soybean will have increased photosynthesis and reduced respiration for higher temperatures (Bernacchi et al., 2006; Leakey et al., 2009; Walthall et al., 2012b). Soybean yields are projected to drop by approximately 2.4% in the 21^{st} century under climate change (Hatfield et al., 2011; Walthall et al., 2012b). In addition, research projects a 1.3% drop in soybean yields for every 1˚C rise in temperature (Lobell and Field, 2007).

A 0.8˚C rise in temperature over the next 30 years would cause a 2 to 3% fall in corn yield excluding effects of soil and moisture deficits. These are just conservative estimates and do not consider interactions of temperature and water availability. A further 8.3% drop in corn yields would be anticipated for every 1˚C rise in temperature (Lobell and Field, 2007). For wheat, warmer temperature will increase development, shorten crop cycle and duration of filling (Porter and Gawith, 1999).

Cotton is also very sensitive to high temperatures during phenological stages, especially during the reproductive development and anthesis. Flowering is the most sensitive to temperature of all the phenological stages (Mitra, 2001; Snider et al., 2013). Above average temperatures can reduce carbohydrate formation from photosynthesis, boll retention and seed development (Loka and Oosterhuis, 2010; Walthall et al., 2012b). In addition to crop growth, climate change will affect Arkansas' irrigated agriculture through its impact on water resources. The major source of irrigation water in Arkansas is groundwater from Alluvial aquifer, which is affected by the variability in annual precipitation due to rainwater recharge (Czarnecki and Schrader, 2013b).

Droughts in Arkansas in 2010 and 2011 shed light on the future of the state's agriculture in the face of climate change. After a wet 2009, extreme summer temperatures led to a drought in 2010. Southern Arkansas was the most severely hit region with precipitation as low as -17.85 to -20.51 inches below the yearly norms (Watkins, 2012). Western, northeast and central Arkansas witnessed mean deviations of -8.6, -13.96 and -14.4 inches of precipitation from yearly totals, respectively. In 2011, record temperatures and drought conditions continued in western and southern Arkansas, while the rest of the state experienced extreme flooding and precipitation surpluses (Watkins, 2012). Diminished availability of water from surface reservoirs in the drought stricken regions of the state put tremendous pressure on groundwater resources, leading to higher pumping cost. Heat stress resulting from high night temperatures greatly affected rice kernels and reduced rice quality due to increased incidences of bacterial panicle blight (Gillip and Czarnecki, 2009; Watkins, 2012).

The goal of this project was to examine projected changes in agro-meteorological indices due to climate change and how these changes impact agriculture within the eleven counties of Eastern Arkansas. This study included five crops—rice, corn, soybean, wheat and cotton. Projected agro-meteorological changes were; 1) distribution of precipitation, 2) first and last frost days, 3) growing season length and 4) growing degree days shifts under various scenarios of climate change in 2030 and 2060. Climate scenarios considered were, representative concentration pathways (RCP) 4.5, 6.0 and 8.5 for 2030 and 2060 (Stocker et al., 2013a).

The objectives of this study were: - 1) To project future climate scenarios within eleven counties of Eastern Arkansas; 2) To assess the impacts of future climate scenarios on agriculture within eleven counties of Eastern Arkansas and 3) To assess temporal and spatial change of agro-meteorological indicators within the eleven counties of Eastern Arkansas. To fulfill the above objectives, a set of hypotheses were constructed:

(H_{o4}) was that there was no relationship between temperature driven indicators and future climate change projections within eleven counties in eastern Arkansas.

(H_{o5}) was that there was no relationship between precipitation driven indicators and future climate change projections within eleven counties in eastern Arkansas.

(H_{o6}) was that there was no spatial change in temperature and precipitation driven indicators within eleven counties in eastern Arkansas.

3.1. Data and methods
3.1.2 Study Region

The study sites encompass three eight-digit hydrological unit code watersheds (L’anguille, Big, and the Lower White), within farming region of the Arkansas Delta where the Mississippi Alluvial aquifer is most depleted. The study area consists of 2,725 grid cells averaging 600 acres each (Figure 1). It lies within latitudes 35.99 and 33.95 degrees North and longitudes 90.29 and 91.34 degrees West. The study area is less differentiated geographically; most of it lies in the Mississippi river valley in eastern Arkansas, a predominantly flat alluvial plane.

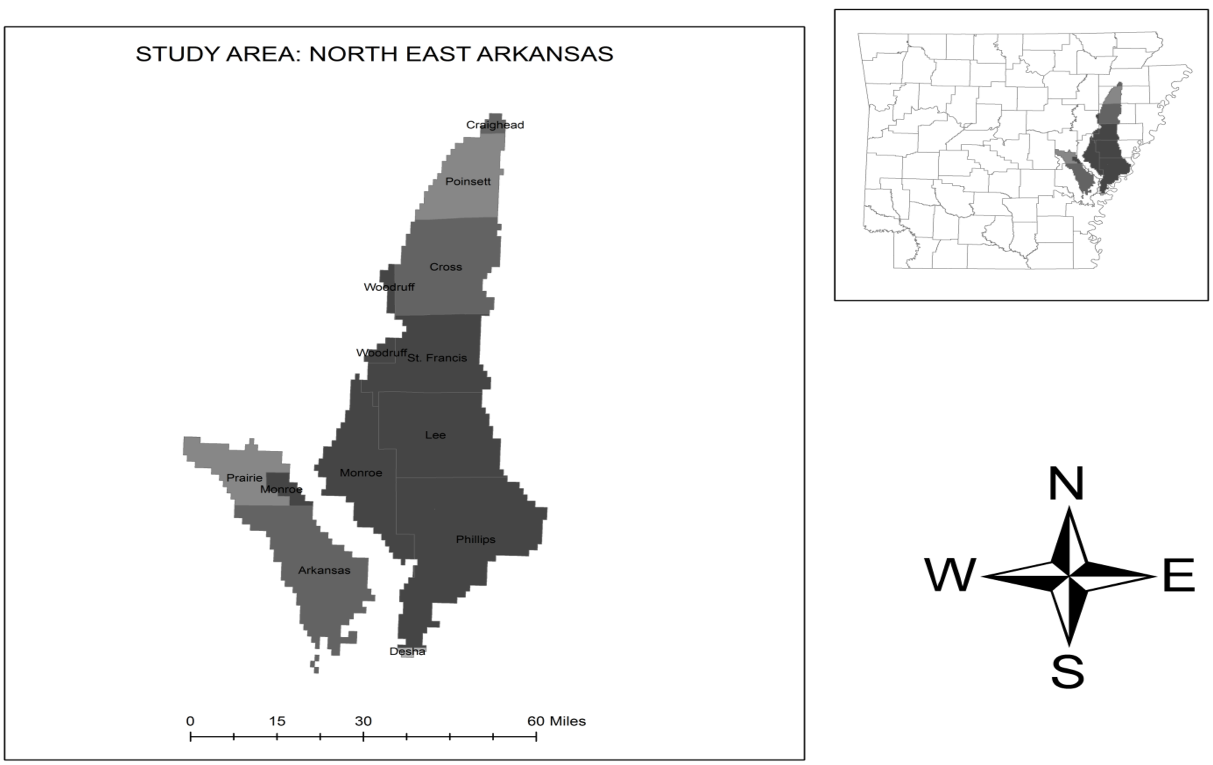

Figure 1: Study area in Eastern Arkansas

3.1.3 Data

The daily temperature (minimum, maximum and mean) and precipitation on 2725 grid points in the study regions during the baseline (1981-2010) were obtained from National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP-NCAR) reanalysis data derived from the 50-year global meteorological forcing datasets, developed by Sheffield et al, (2006).

The daily temperature and precipitation during 2030 and 2060 under three greenhouse concentration trajectories (RCP 4.5, RCP 6.0 and RCP 8.5) were used in this study. These scenarios were chosen because they represent mild, moderate and severe trajectories for climate change (Stocker et al., 2013b). The future climate data were derived from the ensemble of forty global climate models. The daily data for the three future scenarios were obtained through a perturbation process with Decision Support System for Agro Technology transfer (DSSAT) perturb tool (Mereu et al., 2012).

It should be noted that the perturbed data for 2030 were delegates of the 30 year period centered at 2030 (2016-2045). It is not the actual time series from 2016 to 2045. The same is true for the period 2060, which is a statistical representation of years between 2046 and 2075. The climate data were generated for all 2,725 grid cells in the study site. All the variables for the 30 year period for each scenario in each grid cell were averaged to represent the probable climate scenario for 2030 and 2060 (Figure 1).

3.1.4. Data analysis

3.1.4.1 Precipitation Indicators

Three precipitation related measures were constructed from the daily precipitation data; annual total precipitation, number of days with extreme precipitation and extreme precipitation. Extreme precipitation is defined as any precipitation above 1 inch (25.4mm) in a single day for the study area based on upper 10 percentiles in the precipitation distribution (Kunkel et al., 1999).

3.1.4.2 Temperature Based Indicators

The growth of a plant is nonlinear in the whole range of temperature; linear relationship is only observed between crop specific lower and upper threshold temperatures (Schlenker et al., 2005). Below the threshold temperature or above the upper threshold temperature, crop growth stops, resulting in no additional Growing Degree Days (GDDs), a measure of heat accumulation (Hassan et al., 2007). For instance, yield increases for corn were observed up to 29˚C,but temperatures above the threshold was found to be harmful (Schlenker and Roberts, 2009). The calculation of thermal time in the unit of GDD is given by the following equation:-

$$TT = \sum_{Pb}^{Pe} \frac{(T_{max} + T_{min})}{2} - T_b$$

where T_{max} and T_{min} are the daily maximum and minimum surface air temperature; P_b and P_e are the beginning and ending dates of the growth season (Feng and Hu, 2004). Threshold temperatures (T_b) are set for different crops (rice, corn, soybean, wheat and cotton). Beyond the threshold temperatures, crop growth is suppressed and so this is factored when calculating thermal time for individual crops because they do not accumulate additional GDDs (Feng and Hu, 2004; McMaster and Wilhelm, 1997).

The threshold temperatures were set to be 10˚C and 30˚C for rice and soybean; and 10˚C and 29˚C for corn (Feng and Hu, 2004; Sarma et al., 2008). Wheat had a base temperature of 15.5 ˚C and an upper threshold temperature of 35 ˚C (Pathak et al., 2003). For cotton the lower and upper threshold temperatures were 15.6˚C and 35˚C respectively (Howell et al., 2004; Pathak et al., 2003; Snowden et al., 2013). Since different crops grow during different times of the year, the planting and harvesting dates were obtained from University of Arkansas Division of Agriculture Cooperative Extension Services (http://www.uaex.edu/). The crop specific *Pbs* and *Pes* are shown in Table 1.

Table 1: Planting and harvesting dates for respective crops (University of Arkansas Extension Services)

Crop	**Planting date** (P_b)	**Maturity date** (P_e)
Rice	May 1st	September 14th
Soybean	June 1st	October 16th
Corn	April 1st	September 1st
Wheat	November 1st	June 15th following year
Cotton	May 1st	October 6th

Growing season length was a temperature defined variable. The length of growing season is defined as the number of days between the last frost day in spring and the first frost day in autumn (Moonen et al., 2002). Therefore, frost free days are synonymous with growing season length. Alternatively, growing season length is the period between the date of the last spring freeze and first autumn freeze (Linderholm, 2006).

3.1.5 Analysis

After calculating the agro-meteorological indicators for specific grid cells, within respective time series of each baseline, 2030 and 2060, the results were averaged to depict the climate of each scenario. Baselines plots were generated for trend analysis of the study area (Figure 2). Closely related grid cell values were aggregated to obtain spatial representation of the agro-meteorological indicators for the study area. The model results were linked to coordinates for each grid cell to create a geodatabase and contour maps generated by ESRI ArcGIS Desktop (ESRI, 2004). The contour ranges remained consistent within each variable across model runs to allow for simple visual interpretation (Figure 4).

3.2 Results

3.2.1 Trends in precipitation

Figure 2a shows the annual total precipitation for the baseline period. It depicts a slightly decreasing trend from 1981 to 2010. The inter-annual variations of the annual total precipitation during the period 2000-2010 is stronger than in the two earlier decades, suggesting an increase in precipitation variability. However, there is a marginally increasing trend of rainy days with extreme precipitation over the same period (Figure 2b). As a result, the percentage of extreme precipitation relative to the total precipitation is slightly increasing during the baseline period (Figure 2c).

The total precipitation in 2030 under different RCP scenarios are quite similar by spread, range and skewness. The median values increase steadily with higher GHG concentration scenarios of climate change or RCP (4.5, 6.0 and 8.5) relative to baseline (Figure 3a). The number of rainy days with extreme precipitation indicates little changes between baseline and RCP 4.5 and 6.0; albeit the datasets are more skewed to the left. Compared to the other scenarios, total precipitation in RCP 8.5 exhibits a smaller spread and symmetric distribution. The median values of percent rainy days with extreme precipitation increase marginally under higher scenarios (Figure 3b). For percentage of extreme precipitation relative to total precipitation, there is no major difference between baseline and the 2030 scenarios, although RCP 8.5 has a smaller spread and range. Median values of the scenarios increase with respect to higher RCP projections (Figure 3c).

The median values of total precipitation show steady increase for higher RCP scenarios in 2060 (Figure 3a). The number of rainy days with extreme precipitation follows a similar trend, except that RCP 4.5 has a larger spread and range (Figure 3b). For percent of extreme precipitation relative to total precipitation, the RCP 6.0 has a smaller spread while RCP 8.5 is more skewed to the right with a few outliers (Figure 3c).

Generally, there is a slight increase in total precipitation (Figure 3a), number of rainy days with extreme precipitation (Figure 3b) and percent of extreme precipitation relative to total precipitation (Figure 3c) under all future scenarios. Relative to the baseline, the RCP 8.5 projected an average increase of 42mm in precipitation totals which is approximately 0.03% change relative to baseline period (Figure 3a). On the other hand, there is a negligible rise in the percent of rainy days with extreme precipitation which is approximately 0.5% for RCP 8.5 (Figure 3b). Furthermore, extreme precipitation exhibits a slightly increasing trend for future scenarios representing a 1.25% rise from baseline period under RCP 8.5 in 2060 (Figure 3c).

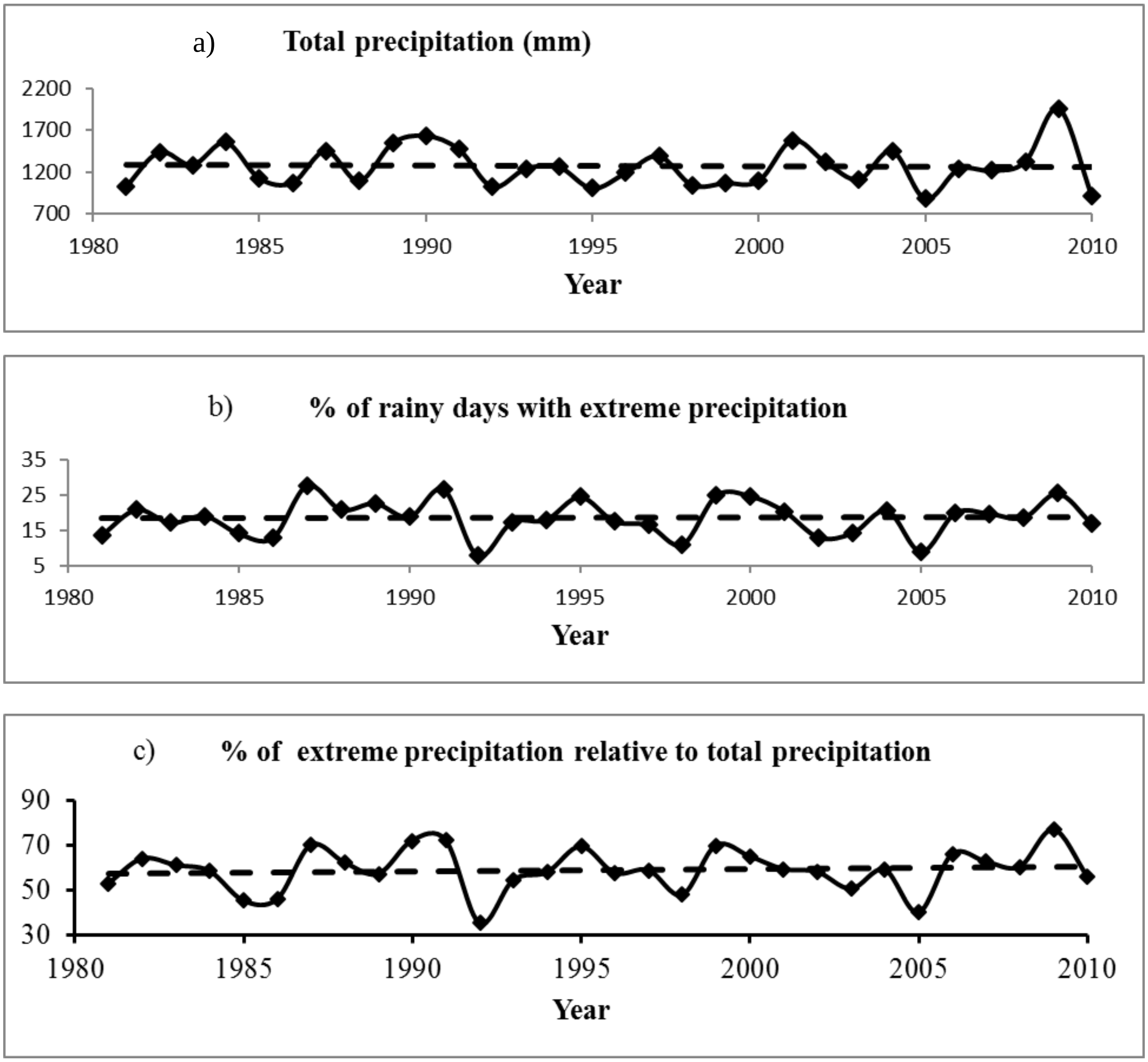

Figure 2: Time trend of baseline period (1981-2010): a) Total precipitation, b) percent of rainy days with extreme precipitation and c) percent of extreme precipitation relative to total precipitation.

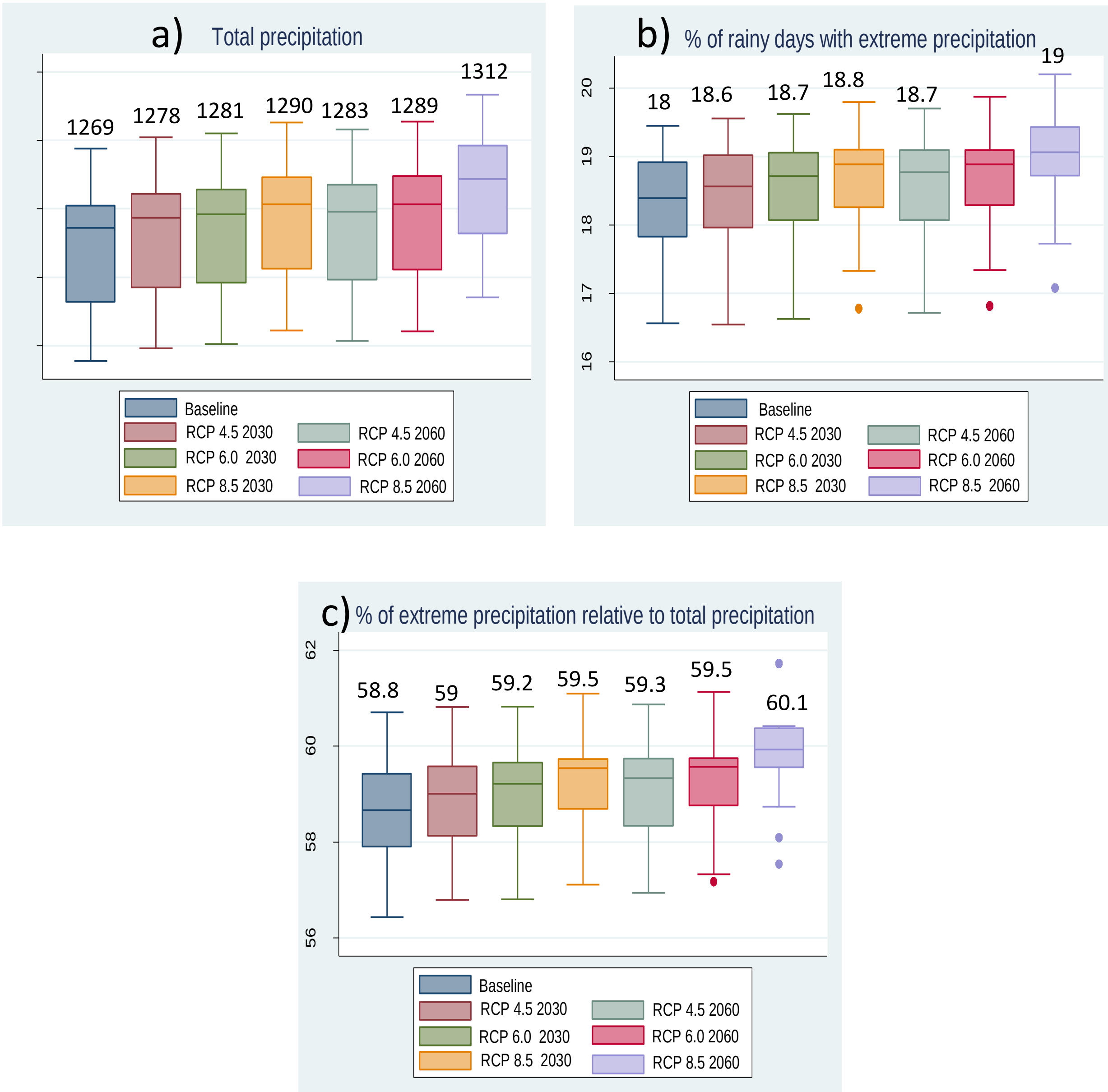

Figure 3: Future scenarios under climate change and mean values; a) mean total precipitation, b) mean percent of rainy days with extreme precipitation and c) mean percent of extreme precipitation relative to total precipitation.

On average the southern region of the study area receives more precipitation than the north. Future projections suggest greater increase in total precipitation in the northern parts of the study region in 2030 (Figure 4b, c and d). The number of rainy days with extreme precipitation is more expressed in the north for the baseline period but 2030 scenarios project an increase of those days in the southern parts Figure 5(b, c and d). Similarly, percentage of extreme precipitation is more pronounced on the north of the study area (Figure 6a), with 2030 scenarios increases being more prominent on the south side albeit marginally Figure 6 (b, c and d).

Under 2060 scenarios, the trend of increasing total precipitation persists Figure 4(e, f and g). The number of rainy days with extreme precipitation relative to baseline shows a steady increase for the RCP 4.5 and 6.0 scenarios, with the greatest increase occurring in the central region of the study area for RCP 8.5 (Figure 5g). The percentage of extreme precipitation increases marginally under RCP 4.5 and 6.0 in the southern region of the study area Figure 6(e and f) but the highest increases occur in the central region of the study area under RCP 8.5 (Figure 6g). Based on these results, we can conclude that total precipitation and number of days with extreme precipitation will increase only marginally, while the percentage of extreme precipitation relative to total precipitation will increase substantially.

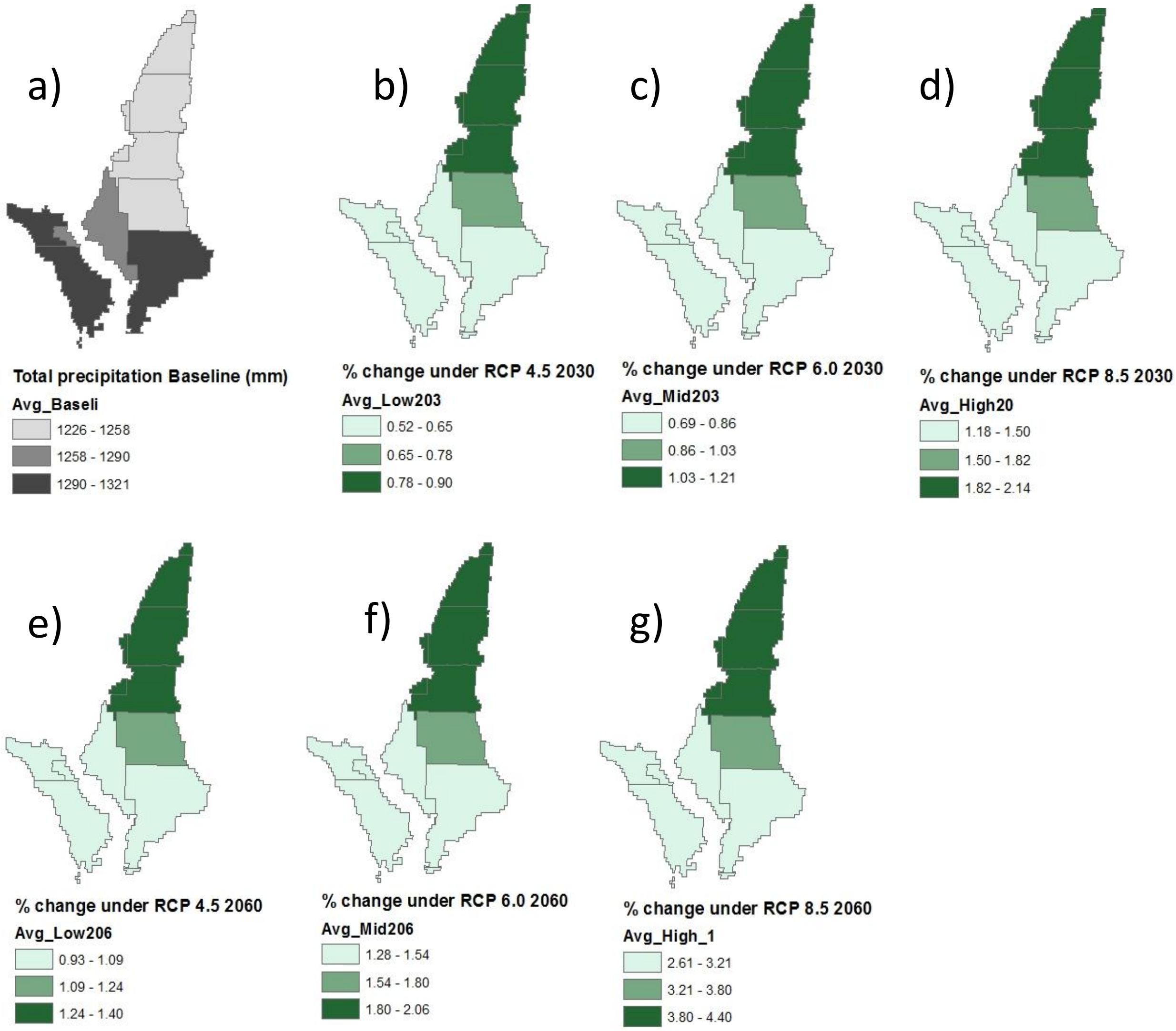

Figure 4: Total precipitation in baseline period and percent spatial change of total precipitation above the baseline under scenarios of climate change.

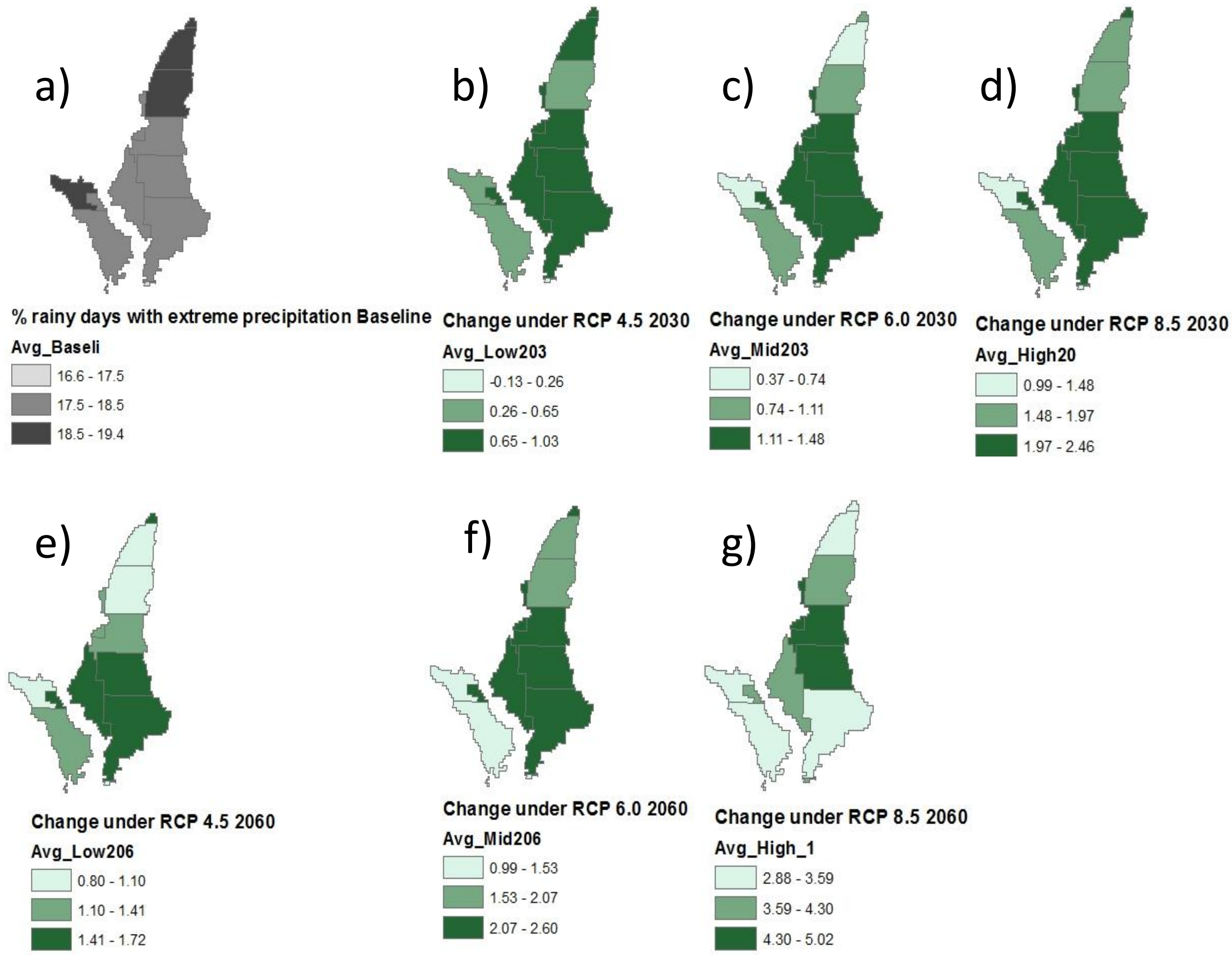

Figure 5: Percent of rainy days with extreme precipitation in baseline period and spatial change above baseline under scenarios of climate change.

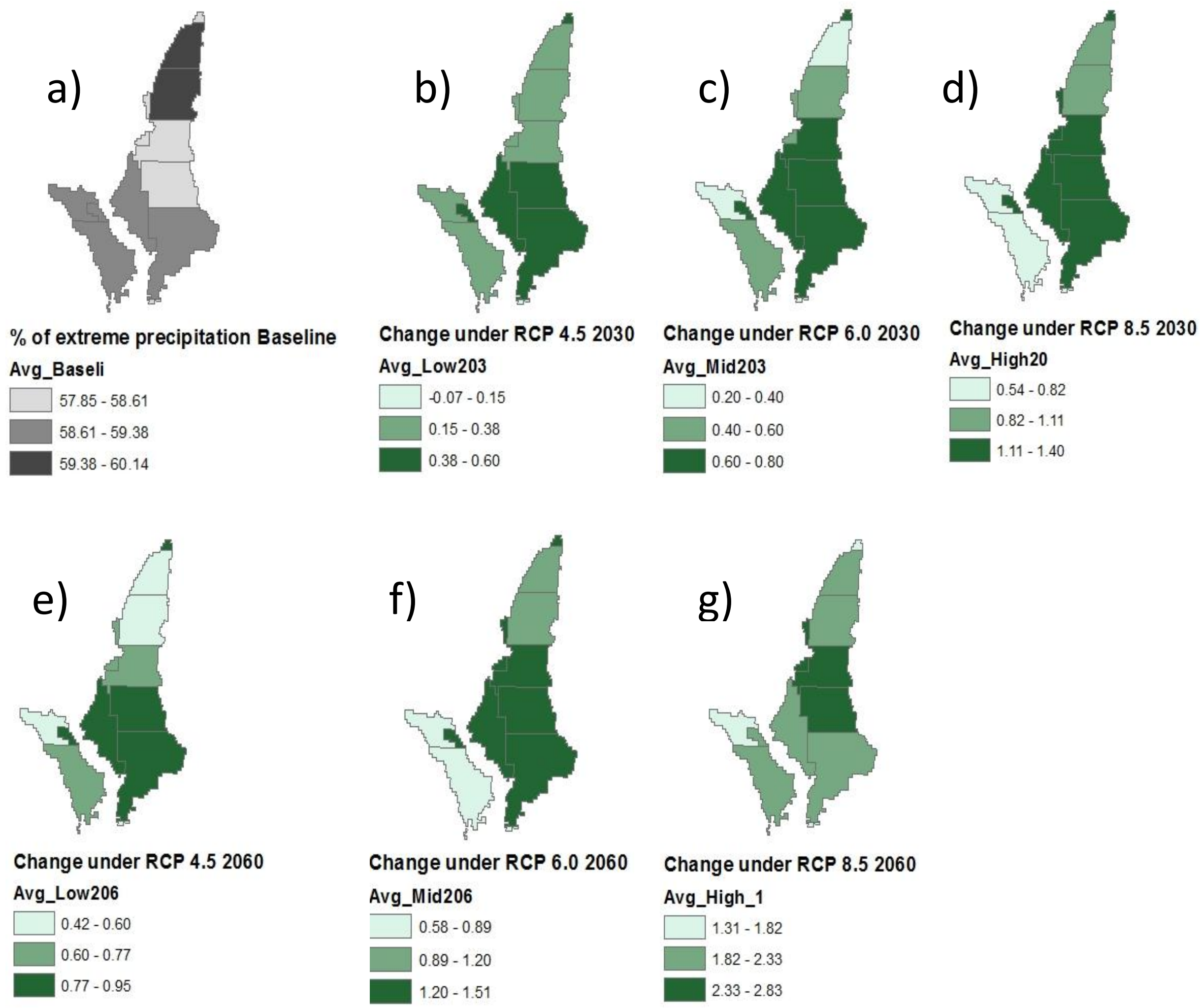

Figure 6: Percent of extreme precipitation in baseline period and spatial change above baseline under scenarios of climate change.

3.2.2 Growing Degree days

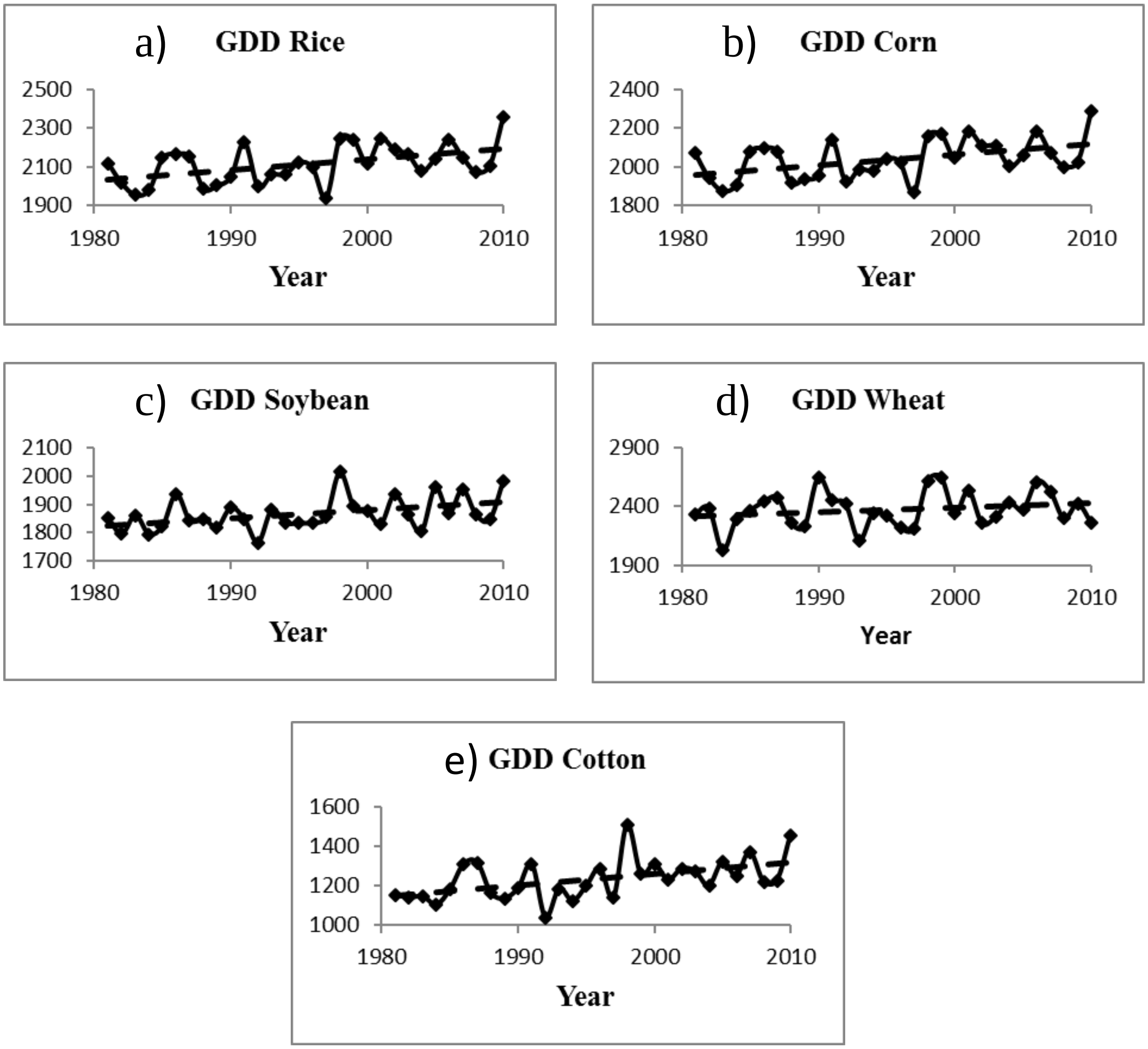

Figure 7: Trend analysis for baseline period; a) growing degree days for rice, b) growing degree days for corn, c) growing degree days for soybean, d) growing degree days for wheat and e) growing degree days for cotton.

Crop growth events such as flowering and maturity depend on the accumulation of specific quantities of heat (Miller et al., 2001). For all crops studied, GDDs have been steadily increasing during the last 30 years (Figure 7). The growing degree days are projected to increase for all crops under all RCP scenarios. The highest increase is projected for RCP 8.5 scenario during 2030 and 2060 (Figure 8).

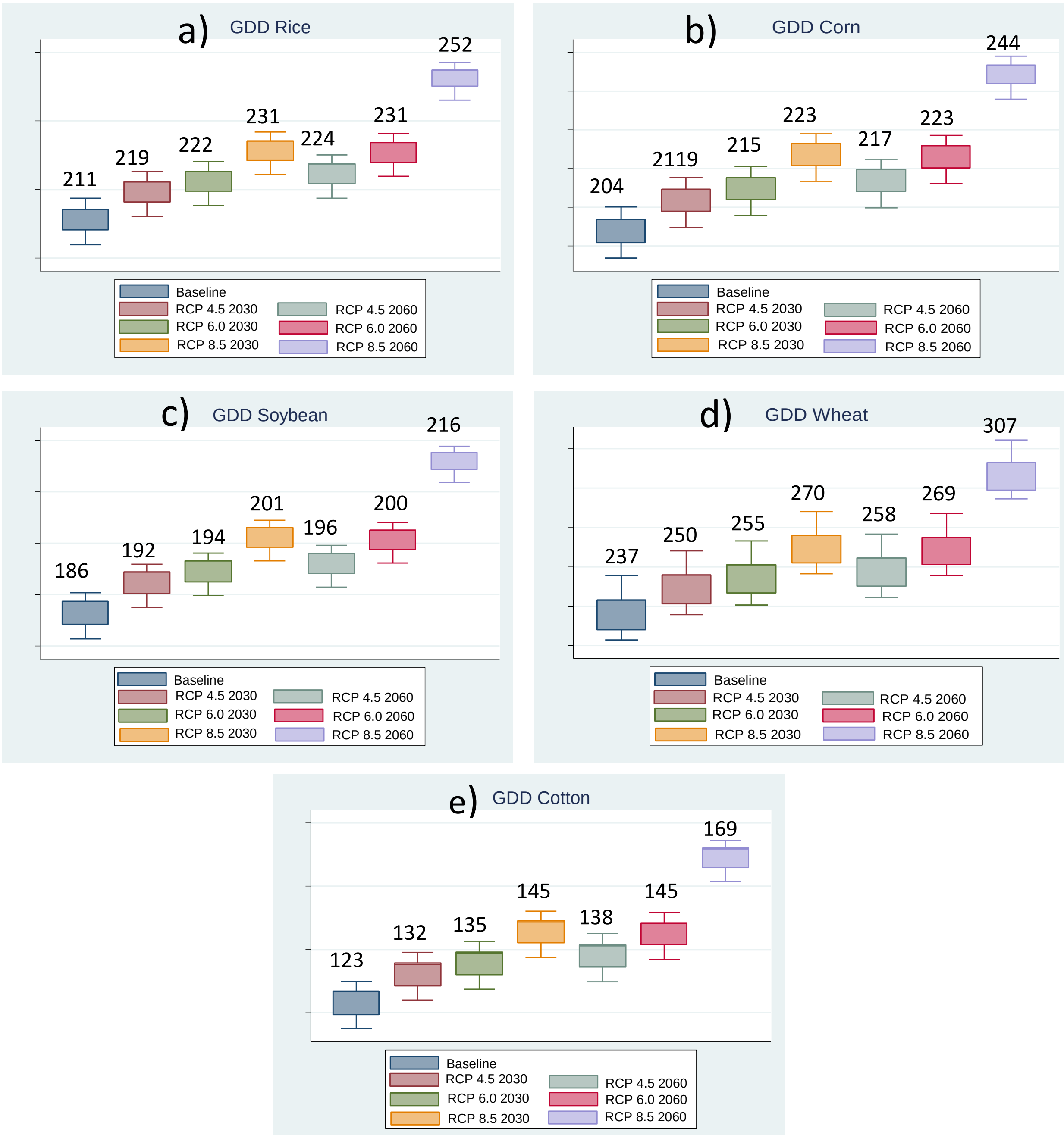

Figure 8: Future scenarios under climate change and mean values; a) growing degree days for rice, b) growing degree days for corn, c) growing degree days for soybean, d) growing degree days for wheat and e) growing degree days for cotton.

Distributions of GDDs in 2030 (Figure 8), show estimates with approximately equal ranges and symmetrical distributions for each of the RCP scenarios. Nonetheless, the distributions depict a marked upward trend in GDDs for each crop (rice, corn, soybean, wheat and cotton) as the GHG concentration increases across RCP scenarios. Based on the results (Figure 8), it is very likely that there will be at least a 9% average rise in GDDs for rice and corn in 2030 under RCP 8.5. Soybean GDD will rise by 7.8%, wheat by 14% and cotton by 18% under RCP 8.5 in 2030. For 2060, the RCP 8.5 scenario leads to a 19% rise in GDDs of rice and corn with soybean GDD increasing by 16%. Wheat and cotton are the biggest gainers at 30% and 37% respectively.

The southern part of the study area has more growing degree days on average than northern parts in the baseline period (Figure 9). The patterns are similar for all other crops (figures 10, 11, 12 and 13). The northern portion of the study area would witness the greatest change in GDDs. For rice, corn, soybean, wheat and cotton, there is a steady rise in GDDs for 2030 projections. These changes are more manifested in the northern region of the study area although with a small margin.

The changes predicted in the 2060 scenario are consistent with those in the 2030 scenario, except with a larger magnitude. Rice, corn and soybean GDDs are in the teens for RCP 6.0 and RCP 8.5. However, wheat and cotton GDDs reveal highest percentage spatial change under RCP 8.5. Results show that the southern farmers will be the greatest beneficiaries of increases in GDDs for all crops under scenarios of climate change in 2030 and 2060. Farmers will also plant longer season varieties. It is also interesting to hypothesize that more wheat and cotton would be planted instead of soybean, corn and rice.

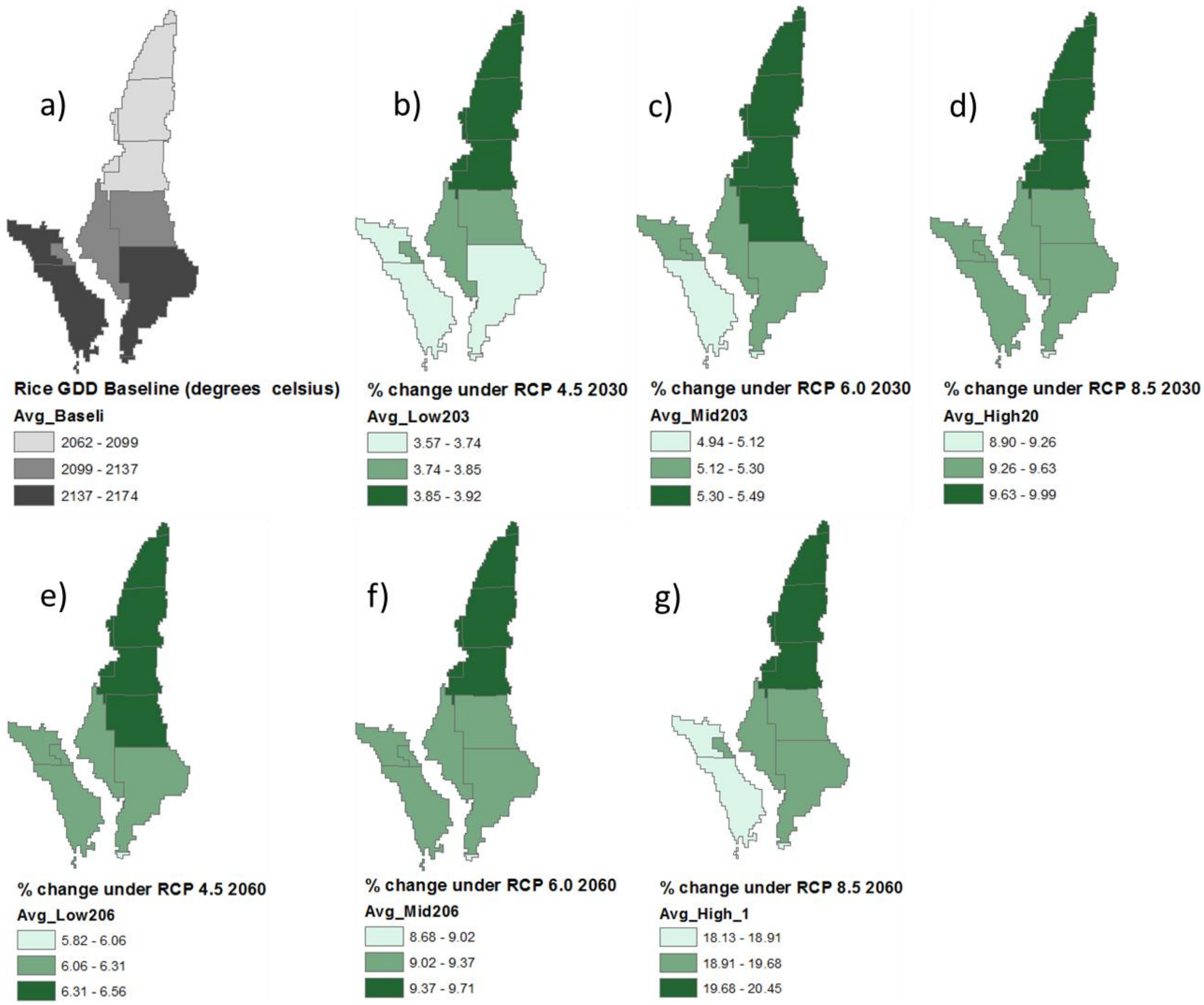

Figure 9: Rice GDD in baseline period and percent spatial change above baseline under scenarios of climate change.

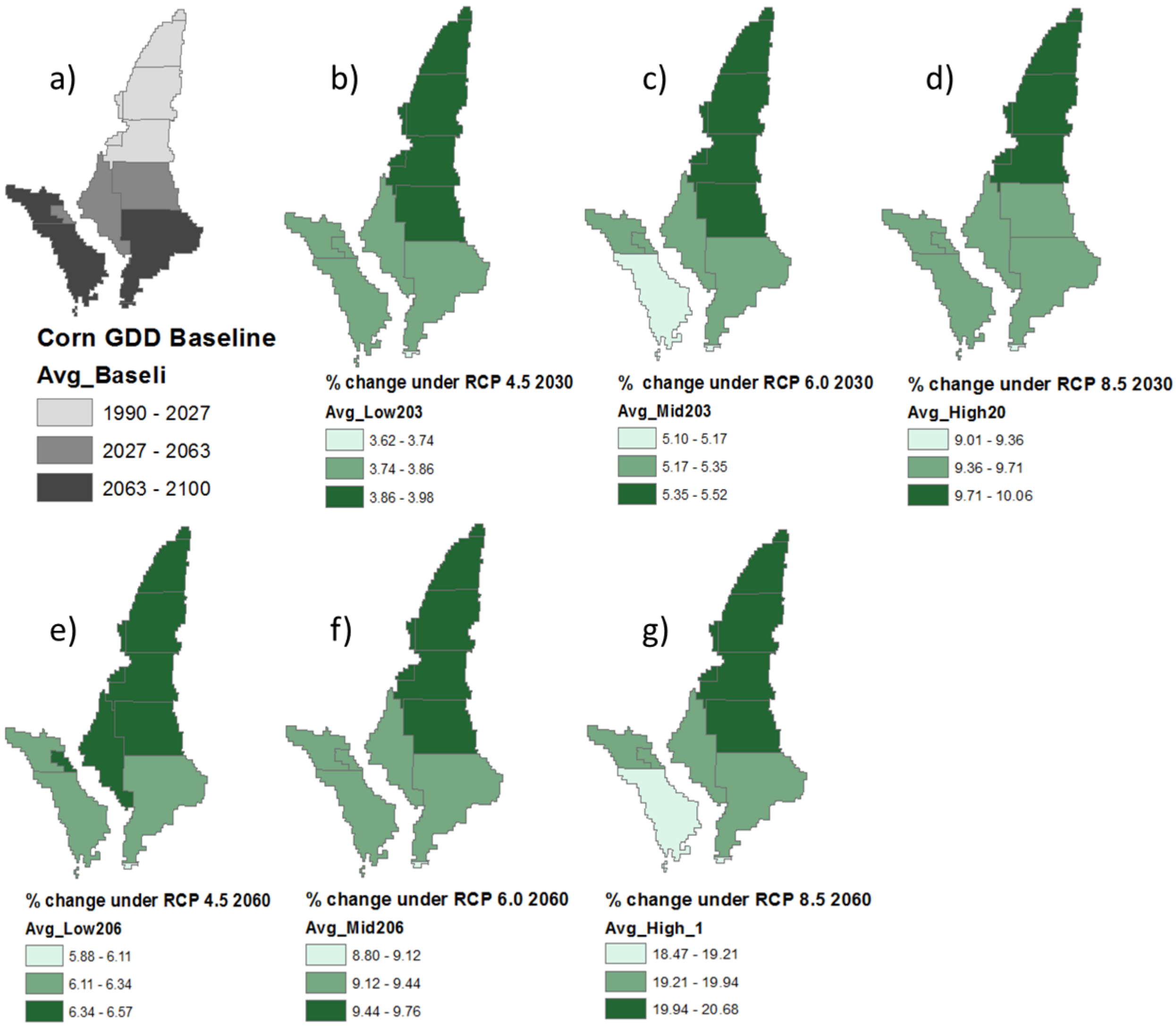

Figure 10: Corn GDD in baseline period and percent spatial change above baseline under scenarios of climate change.

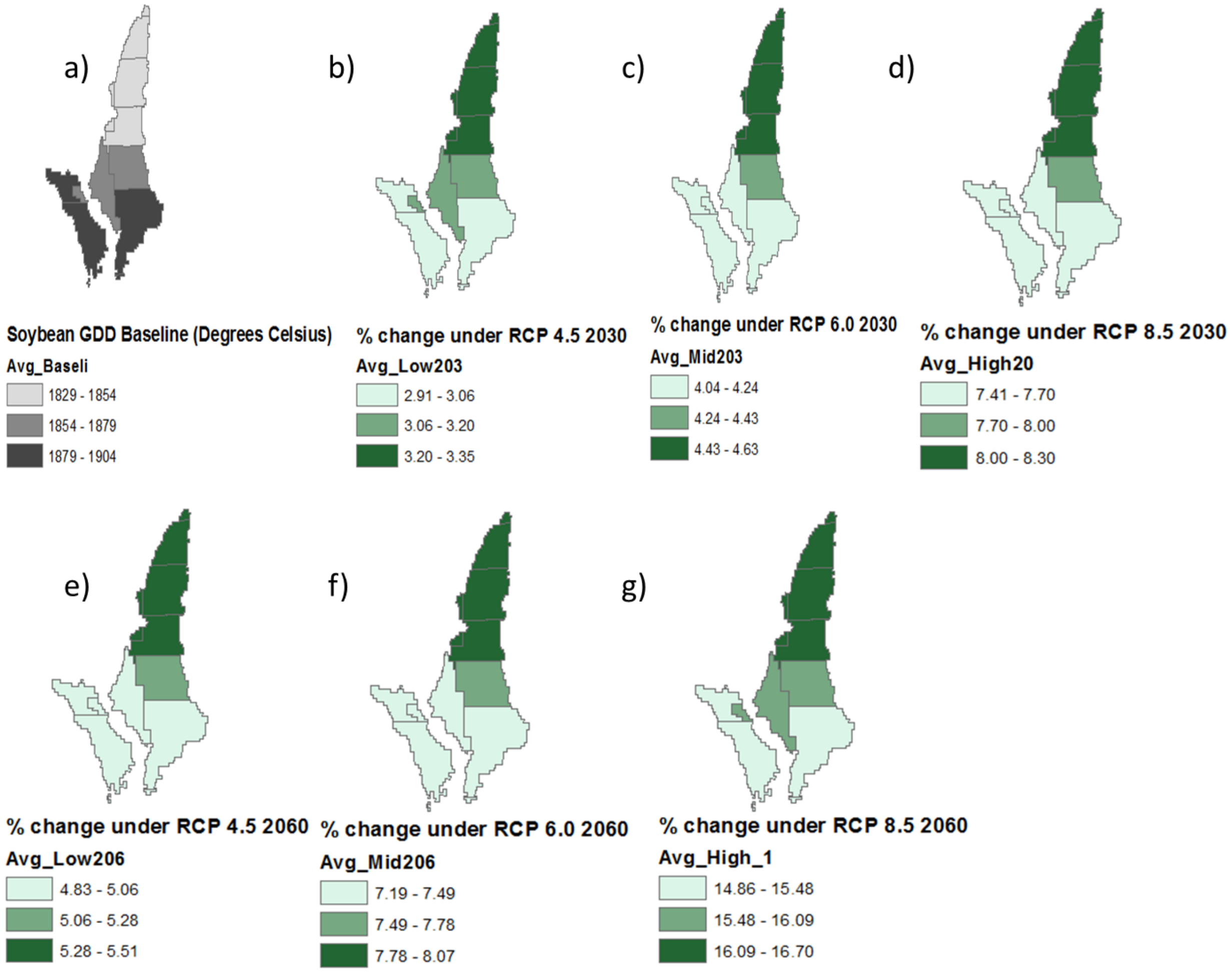

Figure 11: Soybean GDD in baseline period and percent spatial change above baseline under scenarios of climate change.

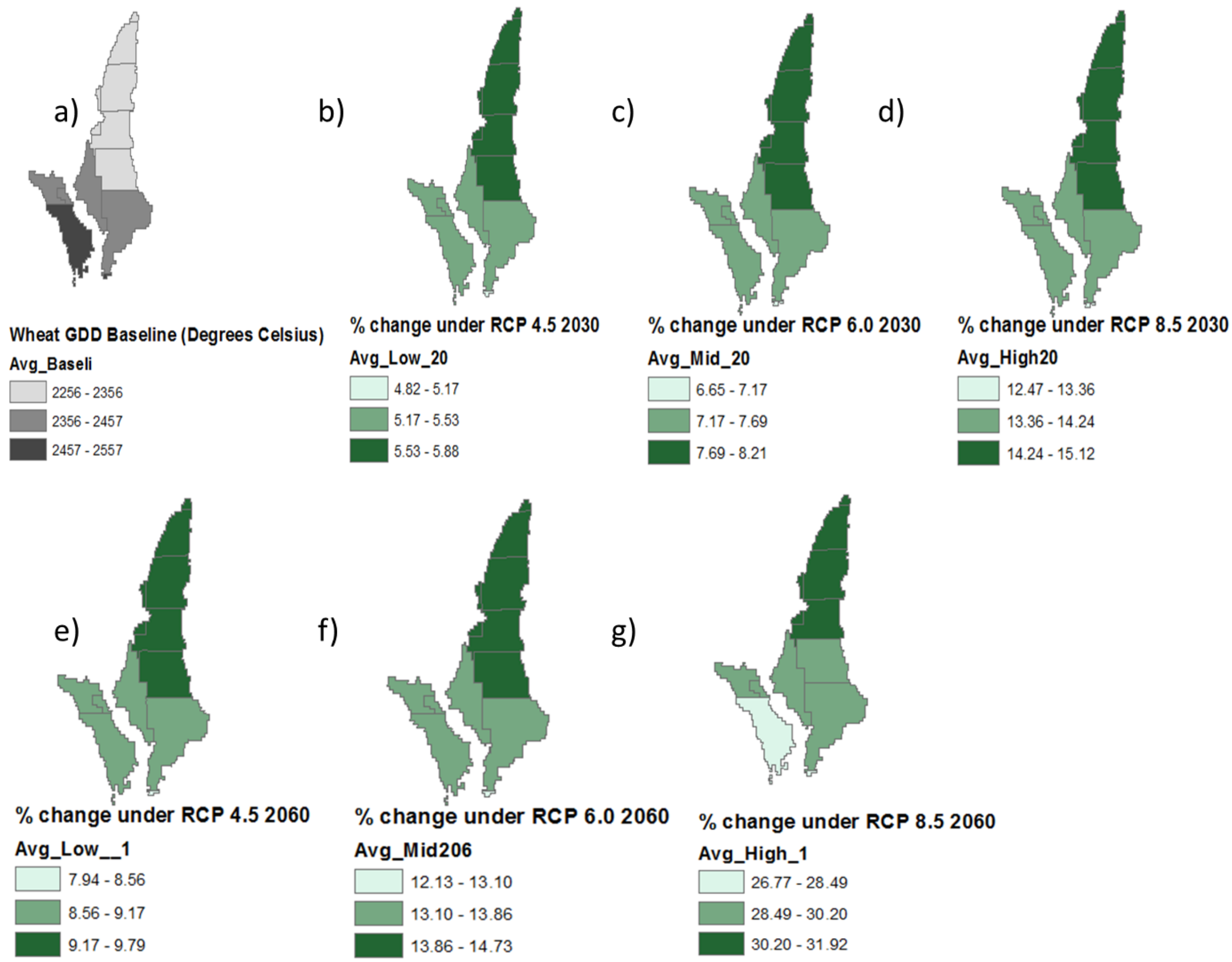

Figure 12: Wheat GDD in baseline period and percent spatial change above baseline under scenarios of climate change.

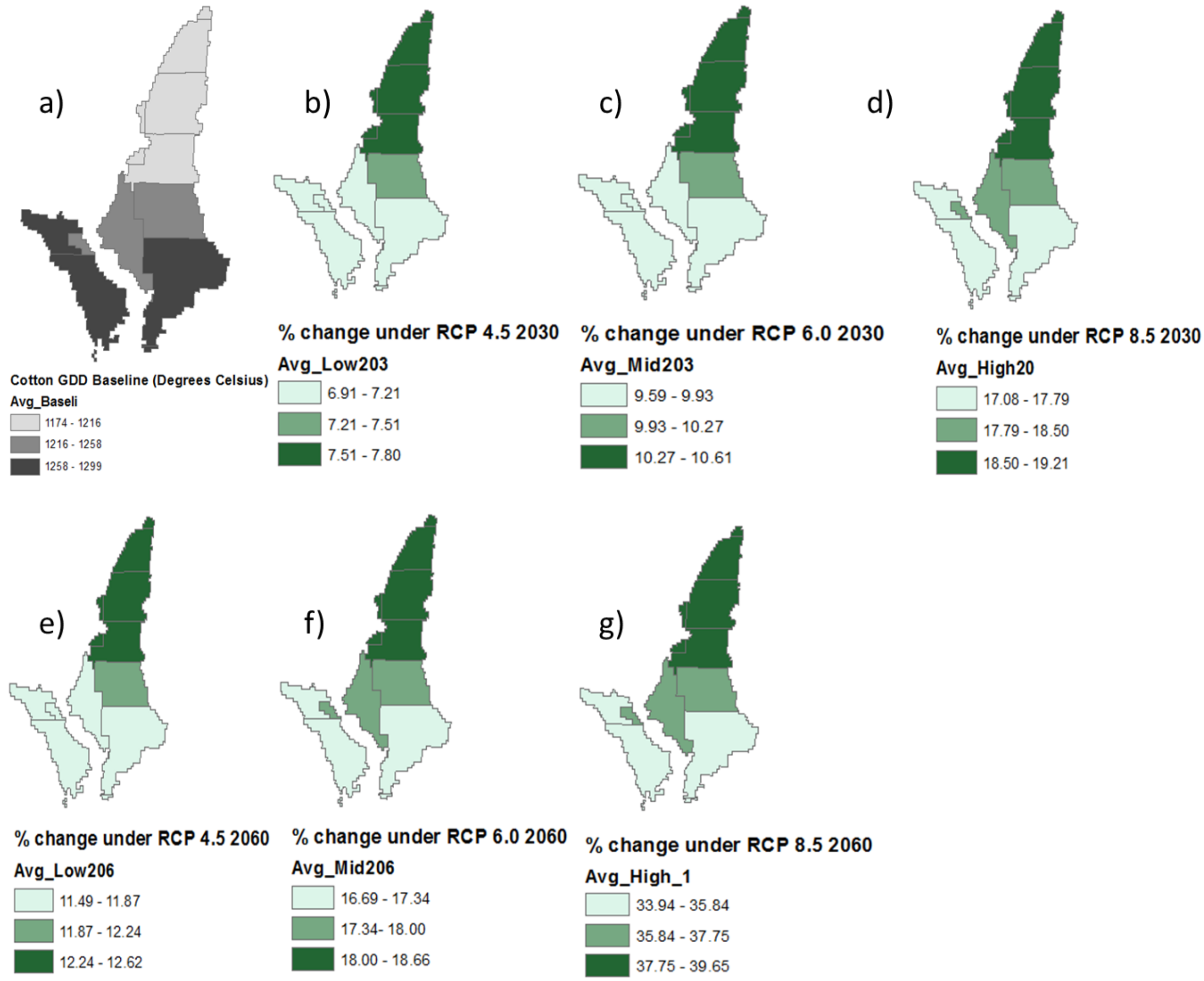

Figure 13: Cotton GDD in baseline period and percent spatial change above baseline under scenarios of climate change.

3.2.3 Frost Days

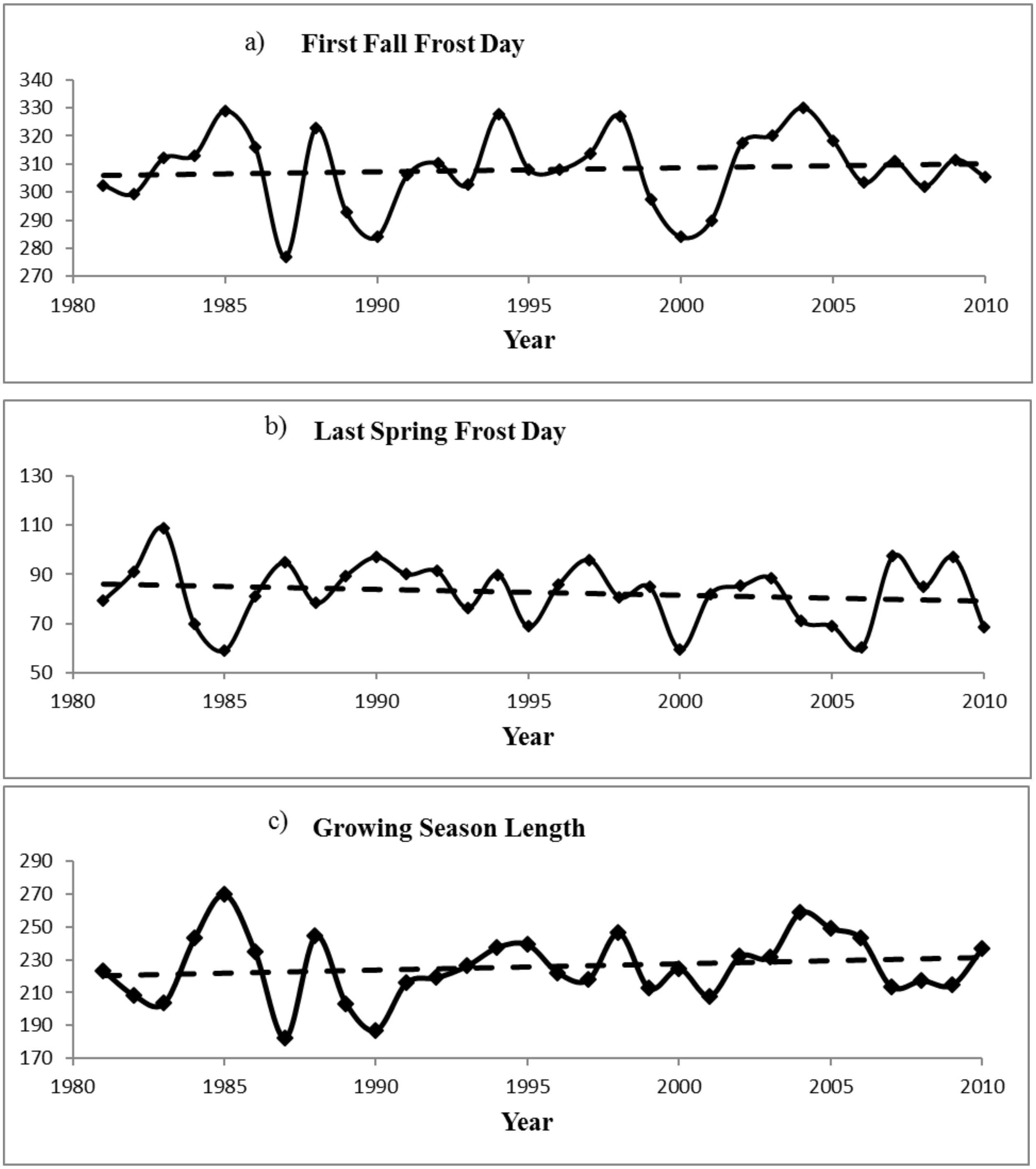

Figure 14: Time trend of baseline period (1981-2010): a) first fall frost day, b) last spring frost day and c) growing season length.

The temporal variations of the first fall frost day and last spring frost day are both shown in Figure 14. On average, the first fall frost day has been fluctuating but with a tendency of coming late in the baseline period (Figure 14a), while the last spring frost day exhibits a tendency of early arrival (Figure 14b). For the last 30 years (1981 to 2010), the first fall frost day has been on the 308th day on average (Figure 15a) with the last spring frost day coming on the 76th day of the following year (Figure 15b). The frost risk period is thus within 133 days and the average growing season length is 225 days. These results are quite consistent with similar studies by Feng et al, (2004) and those by Moonen et al, (2002); who projected increases in frost free days and lengthening of growing season in different parts of USA and Italy respectively.

For 2030, RCP 4.5 has the smallest range of first fall frost days, RCP 4.5 and 6.0 are right-skewed, while RCP 6.0 has the smallest spread. RCP 8.5 has a bigger range and larger median value. For 2060, RCP 4.5 data is less skewed with bigger spread but RCP 6.0 has the highest range. Median values for RCP scenarios also increase under higher RCP scenarios (Figure 15a). Last spring frost days in 2030 show a general decreasing mean under RCP 4.5, 6.0 and 8.5 (Figure 16b). RCP 8.5 has the largest range although it is skewed to the left. For 2060, RCP 6.0 has the largest range with RCP 8.5 having the largest inter-quartile range.

The last spring frost day exhibits a decreasing trend. The last spring frost day is projected to be 11 days earlier than the baseline period by 2060 under R.C.P 8.5 (Figure 15b). The opposite trend is however exhibited for the first fall frost day, which will lead to delayed arrival of the first fall frost day. The greatest increases in the first fall frost days are under RCP 8.5 scenario during 2030 and 2060, each by 8 and 15 days relative to baseline period (Figure 15a).

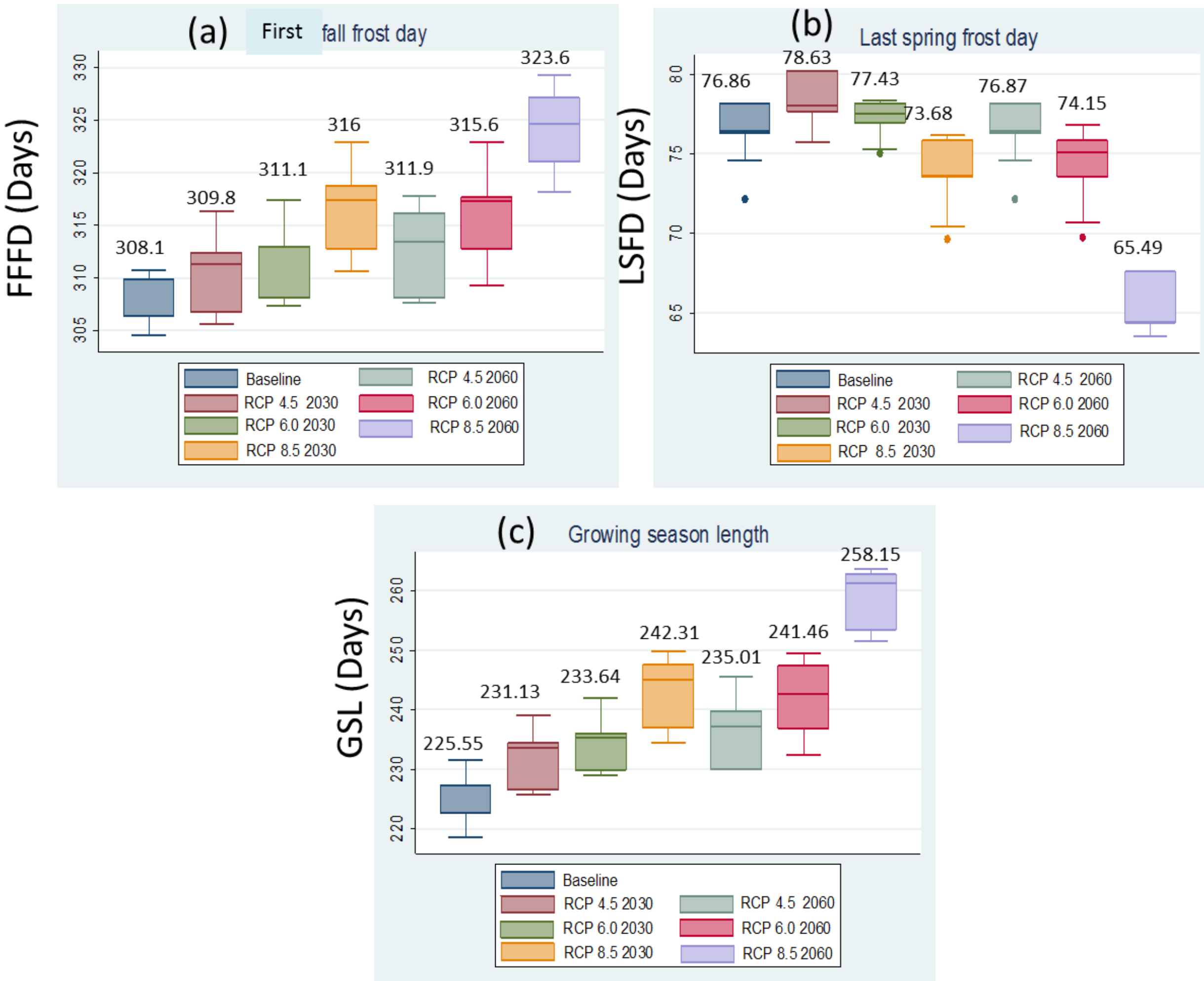

Figure 15: Future scenarios under climate change and mean values; a) mean first fall frost day, b) mean last spring frost day and c) mean growing season length.

The first fall frost day is coming late in the southern parts of the study area for baseline period (Figure 16a). Future projections reveal a lengthening frost free period for the entire study area with more positive change to the south Figure 16(b, c and d). The south side witnesses earlier last spring frost days on average than the northern parts (Figure 17a). For 2030, RCP 4.5 reveals marginal positive changes in the south side with most changes being north of the study area (Figure 17b). There is a drop on the last spring frost days for RCP 6.0, with RCP

8.5 showing even a larger drop and eventual negative percentage change relative to baseline period (Figure 17d).

First fall frost days are marginally increasing from north to south in 2060 Figure 16(e, f and g). Ironically, there is no change in the appearance of last frost period for RCP 4.5 in 2060 (Figure 17e). RCP 6.0 and 8.5 both reveal a steady drop in the last spring frost days Figure 17(f and g). On average, the last frost day will appear earlier on the southern part of the study area. Farmers in those areas will be the greatest beneficiaries of delayed frost period.

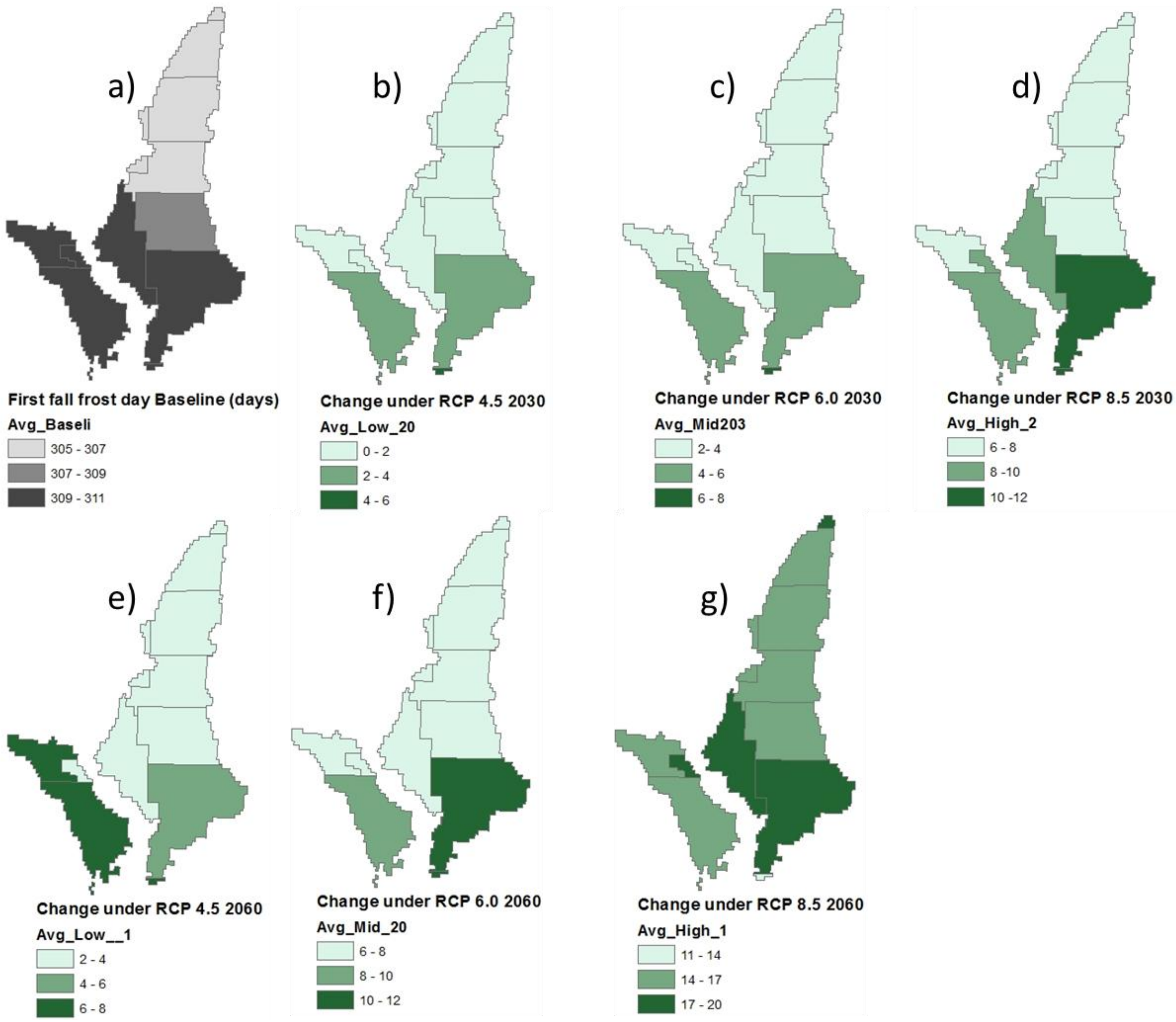

Figure 16: First fall frost day in baseline period and spatial change above baseline under scenarios of climate change.

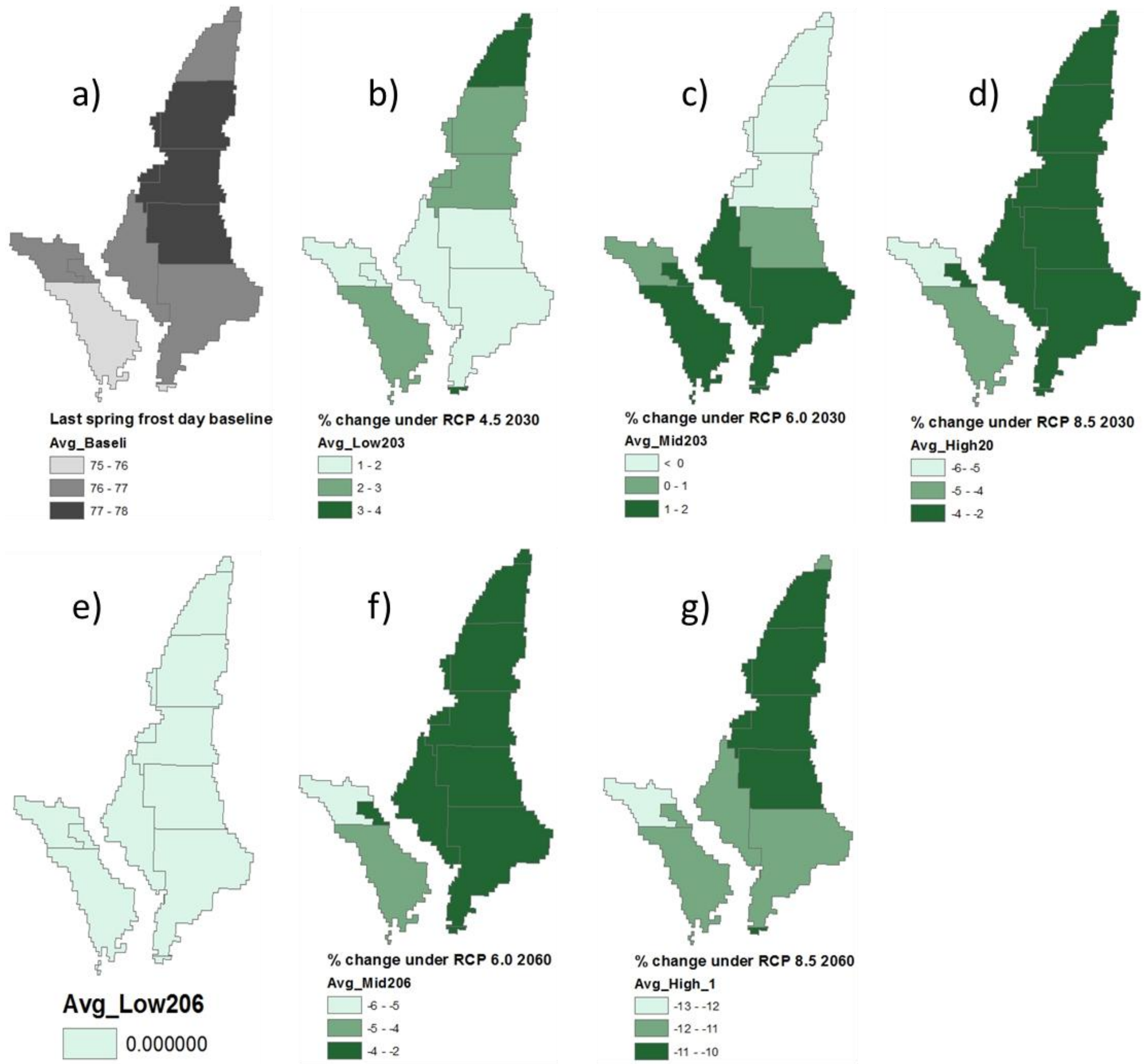

Figure 17: Last spring frost day in baseline period and percent spatial change above baseline under scenarios of climate change.

3.2.4 Growing Season Length

Over the last 30 years, the growing season has shown a slight increase, probably due to changes in frost days (Figure 14c). Results reveal that growing season length is increasing under all scenarios of climate change for 2030 and 2060 (Figure 15c). It is imperative to note that by 2030, the growing season is projected to increase by 10 days on average; while for 2060 there would be an increase of about 19 days (Figure 15c). Delayed frost in autumn and early start of growing season in the spring have been responsible for projected increase in growing season length under all scenarios of climate change for 2030 and 2060.

For 2030 (Figure 15c), baseline shows symmetric distribution while RCP 4.5 and 6.0 are more skewed to the right. RCP 8.5 has the highest range and spread. Mean values show a steady increase with higher RCP scenarios. However, for 2060, RCP 4.5 has a smaller spread but RCP 6.0 is more symmetric with a larger range. All the RCP scenarios of growing season length reveal a tendency for longer seasons with higher GHG emission scenarios. Spatial analysis shows that growing season is longest in the southern region of the study area under the baseline period and all RCP scenarios (Figure 18a-g). The projected increases in 2030 and 2060 are commensurate with the magnitude of GHG concentrations under the different RCP projections (Figure 18e, f and g). RCP 8.5 reveals the greatest increase in growing season length for the study area relative to baseline period.

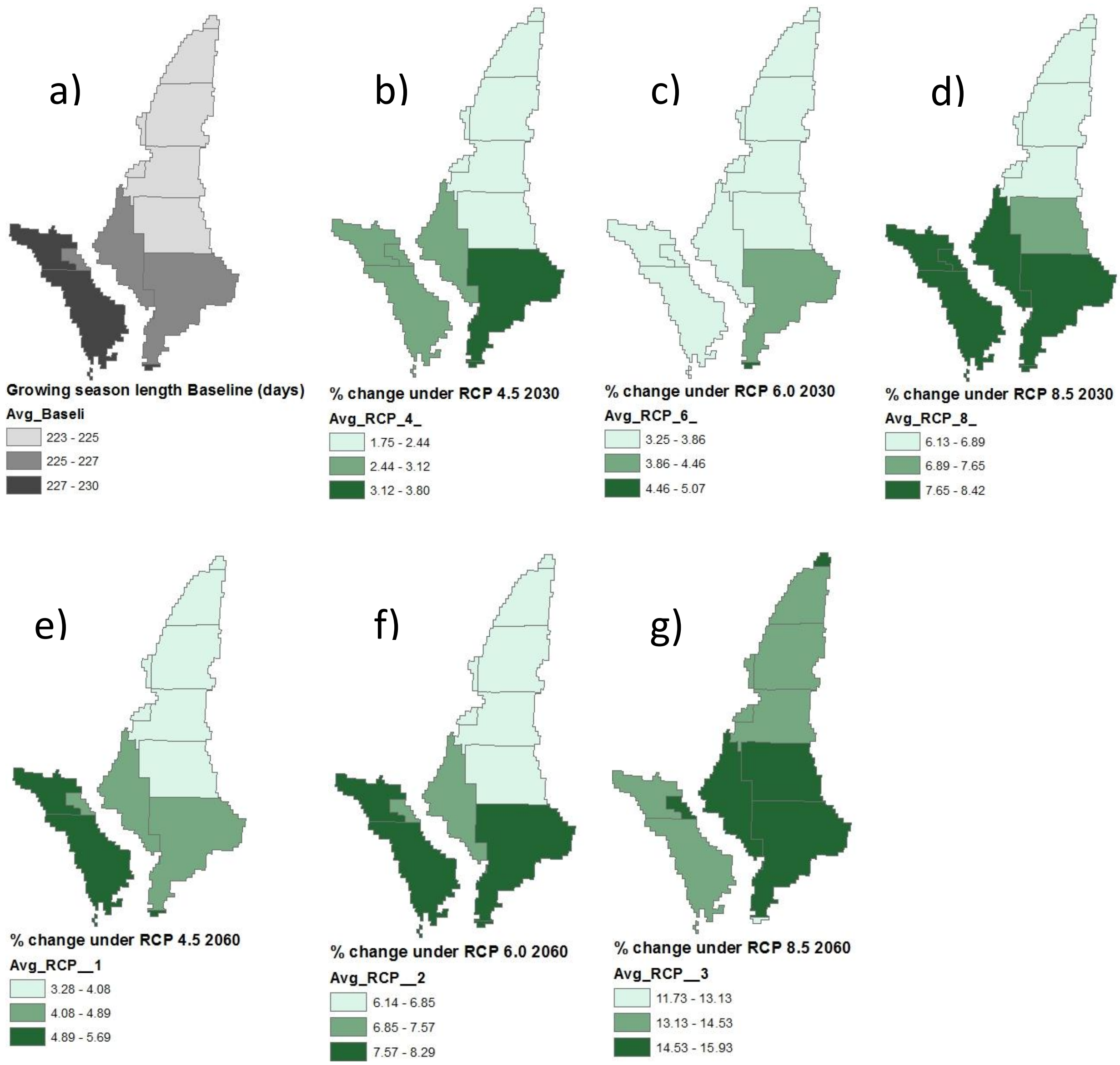

Figure 18: Growing season length in baseline period and percent spatial change above baseline under scenarios of climate change.

3.3 Discussion

From the results, the study area has been and will continue to witness precipitation variability. There is negligible rise in precipitation totals and percent of rainy days with extreme precipitation for all the three scenarios in 2030 and 2060. However, extreme precipitation will remain an issue of concern; with extreme precipitation relative to total precipitation projected to increase substantially. In the future, it is anticipated that in some instances, it will pour instead of rain posing tremendous challenge to stakeholders especially farmers. It will particularly strain irrigated agriculture which is highly dependent on ground water Eastern Arkansas.

Frost is a major risk during growing seasons, so these results indicate a potential decrease in frost risks. This also means insurance premiums for frost risk would go down, which will in turn reduce fixed costs for farmers in Arkansas. Ideally, farmers in Arkansas should be able to plant longer season cultivars in addition to having a greater variety of other crops and sowing early. Our results are consistent with general results of model simulations for late 20th century, which reveal a decrease in number of frost days in US with rise in greenhouse gases (Griggs and Noguer, 2002; Moonen et al., 2002). Therefore, fewer frost days are projected to increase the growing season length (Easterling, 2002).

Previous satellite and climatological studies agree that shifts in timing and length of the growing season are probable (Tucker et al., 2001). Increasing growing season length provides opportunities for earlier planting, ensuring maturation and possibilities of multiple cropping in Arkansas. While our results project an increase in the length of the growing season, increased warmth during growing season may cause slight decreases in yields, because higher temperatures speed development and reduce time to accumulate dry mater (Assessment, 2004; Linderholm, 2006; Stocker et al., 2013a).

3.3.1 Adaptation and policy implications

Arkansas faces key challenges for water use. Any adaptations will have to address increase in productivity verses, quantity, amount, timing and supply of water to the competing sectors of the economy in the face of climate change (Ward and Pulido-Velazquez, 2008). Rice is the most water intensive crop in irrigated agriculture in Arkansas accounting for $1.2 billion cash receipts. Studies reveal that, adaptation of multiple inlet irrigation approach could lead to increases in rice yields up to 3.4% due to water use efficiency (Vories et al., 2005). In the multiple inlet system, the operator can fill all paddies simultaneously; flood fields quicker, leading to reduced pumping times and increased irrigation efficiency (Chen and Liu, 2002; Watkins et al., 2012).

Construction of reservoirs with tail water recovery has been shown to improve farm net returns by 15% and decreased aquifer depletion by 39%. It also improved water quality, reduced pollutant loadings and enhanced conservation (Kovacs et al., 2013b). Studies by Kovacs et al. (2013) showed that technology adoption should be the main focus of conservation groups as opposed to advocacy of environmental values. Tax on ground water was more effective in increasing water table; subsidy for reservoir construction was cost effective but insufficient in maintain aquifer levels (Kovacs et al., 2013a; Young et al., 2003).

Other strategies proposed include, cost sharing for efficient irrigation technologies, incentives for change of irrigated to dry land crop production, tradable quotas for groundwater stock and switching to less water intensive bioenergy crops. More weight could be given to; site productivity maintenance, insect pest management, soil water conservation together with climate change mitigation and socio-economic values (Ding and Peterson, 2012; Kovacs et al., 2013a; Wheeler et al., 2012; Zhang et al., 2007a). Ultra-short season cultivars for cereals like corn; with maturity dates of 75 to 90 days is worth consideration. These could evade weather related problems affecting quality like Aflatoxin while giving consistent desirable yields (Keisling et al., 1999).

In Arkansas, an integrated approach will be key to policy formulations incorporating both hard infrastructures (Reservoirs, efficient irrigation, bio system engineering for soil and water conservation, tail water recovery systems) and softer measures (insurance schemes, water buyouts, subsidies and taxes). These could also take the form of pure technological (infrastructure) or behavioral (altered ground water use). There is no fit answer for all situations and effectiveness of various options to fully reduce risks and vulnerabilities due to climate change is still unknown.

3.4 Summary and Conclusion

The goal of this project was to examine projected changes in agro-meteorological indices due to climate change and how these changes impact agriculture within the eleven counties of Eastern Arkansas. The following objectives were met: 1) To project future climate scenarios within eleven counties of Eastern Arkansas; 2) To assess the impacts of future climate scenarios on agriculture within eleven counties of Eastern Arkansas and 3) To assess temporal and spatial change of agro-meteorological indicators within the eleven counties of Eastern Arkansas. To fulfill the above objectives, a set of hypotheses were tested:

(H_{o4}) There was no relationship between temperature driven indicators and future climate change projections within eleven counties in eastern Arkansas.

Results revealed that GDDs, GSL, first fall frost day, last spring frost day and growing season length all changed with severity of RCP projections in each of the three scenarios in 2030 and 2060. Therefore, the null hypothesis was rejected, confirming that there was strong relationship between temperature driven indicators and future climate projections within the study area.

(H_{o5}) There was no relationship between precipitation driven indicators and future climate change projections within eleven counties in eastern Arkansas.

Total precipitation, percent of rainy days with extreme precipitation and percent of extreme precipitation relative to total precipitation all yielded marginal changes under all RCP scenarios in 2030 and 2060. Given the mixed results from precipitation analysis, we failed to reject the null hypothesis.

(H_{o6}) There was no spatial change in temperature and precipitation driven indicators within eleven counties in eastern Arkansas.

All spatial analysis for temperature and precipitation driven indicators clearly show distinct spatial change on our geographic information systems maps for the study area. Therefore, the null hypothesis was rejected, confirming that spatial change was apparent in our study area for both temperature and precipitation indicators analyzed.

This study examined impact of climate change on irrigated agriculture in Arkansas through assessment of agro-meteorological indicators, including precipitation changes, frost days, growing season length and growing degree days. Results show only modest increases in total precipitation. There is negligible rise in percent number of days with extreme precipitation. Analysis of extreme rainfall events carried out for all periods (baseline, 2030 and 2060) have shown a shift towards more intense precipitation which accounts for 1.25% rise in extreme precipitation in 2060. Farmers will have to invest more in crop insurance to offset the risks of extreme weather.

Frost days per year have been decreasing in the baseline period and are still projected to decrease thereby reducing frost risks to crops. Under RCP 8.5, the last frost day is projected to come at least two weeks earlier in 2060. This could be a positive as it allows for stable prediction of planting season. Results show an increasing trend of delayed first frost period. Ideally, farmers should be able to plant long season cultivars, sow earlier in addition to having a greater variety of other crops. The association of frost days with growing season is very strong confirming that temperature is a key factor of influence. Results reveal lengthening of growing season under all scenarios of climate change for 2030 and 2060. By 2030, the growing season is projected to increase by 10 days on average; while for 2060 there would be an increase of about 19 days.

Growing Degree Days are projected to rise for all crops studied under all scenarios of climate change with cotton showing an increase of up to 37%. It is anticipated that these changes in GDDs for crops will interact with other crop limiting factors such as temperature, precipitation, diseases and weeds to affect crop productivity. These results indicate that farmers will have to plant the right crop varieties at the right time. They will also have to weigh the planting decisions against inherent risks as frostbite and diseases. Excessive precipitation might lead to delayed harvest in summer crops because of wet soils; which also delays planting season. In the future, climate forecasts will be a key determinant factor of planting dates and variety selection for farmers.

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CHAPTER 4: SOCIO-ECONOMIC FACTORS AFFECTING AGRO-FORESTRY (AFR) TECHNOLOGY ADOPTION IN NYANDO KENYA

Abstract

Agro-forestry (AFR) technologies are perceived to improve livelihoods and natural resource sustainability of rural households. Despite their promotion, the adoption of AFR technologies has been minimal in Kenya. This study conducted a survey to examine the socio-economic factors that affect the adoption process in Nyando, Kenya. Results revealed that farmers with bigger farms and higher education were more likely to adopt the new technology. Additionally, farmers were quicker to adopt technology if they had an increase in crop yields and had stayed longer in the study area. Generally, wealthier famers tended to adopt more AFR technology than those with less income. Access to information was the only factor strongly correlated with the rest of the independent variables. The results suggest that, adoption would be more enhanced with a clear focus on extension activities, income enhancing AFR practices and soil amelioration technologies. This study can be replicated in other parts of Kenya and East Africa to improve the level of AFR technology adoption for sustainable rural development.

Keywords: Agro-forestry technology, adoption, income, farmers.

4.0 Introduction

Agroforestry(AFR) is the intentional mixing of trees and shrubs into crop and animal production systems to create economic, environmental, and social benefits (Erdmann, 2005). Agroforestry practices creates a more diverse landscape to achieve multiple goals and create proper microclimatic conditions for high value specialty crops (Workman and Allen, 2011). At the landscape scale, agroforestry leads to the generation or enhancement of the desired ecological processes essential for sustainable land use (Alemu, 2012). It is also believed that AFR can provide reliable framework for soil and water conservation at much lower cost than the traditional methods such as terraces, banks and ditches (Jackson et al., 2000).

The need for detailed research on AFR systems has never been more urgent in Africa. According to Reyes (2008), agroforestry is one of the fundamental disciplines for sustainable development in Africa especially for livelihood improvement and sustainable land management. Since most of these smallholder farm parcels are over exploited, declining productivity is pushing farmers to seek more fertile lands. Compounded with unsustainability of traditional farming systems, and land use pressure, the land is rapidly degraded (Clay et al., 1998; Pender et al., 2006). Many AFR technologies like improved fallows have been in trial to help replenish the degraded soils because poor farmers cannot afford to buy inorganic fertilizers (Franzel, 1999; Kang and Wilson, 1987). Recent adoption studies indicate that both trialing and adoption of these technologies are low (Kwesiga et al., 2003).

After Kenya's independence in 1963, there was little public farm forestry activity until early 1980s. Most of the AFR work was pioneered by CARE international and government of Kenya setting up AFR extension project (AEP) in western Kenya. Other NGOs followed up borrowing from AEP technology and philosophy (Scherr, 1995). Soil fertility decline, fuel wood decline, scarcity of building materials, wind damage and dry season fodder shortage were the main issues to be addressed (Scherr, 1995). In these areas, most farmers were smallholder with 82% cultivating less than 2 hectares of cropland. They also protected and established fruit and medicinal species like Mangoes. At the time, the most economically important trees were species for pod and leaf fodder, construction and shade (Scherr, 1995). By the end of British colonial period (1963), Kenya's agriculture stagnated; fallow periods shortened due to land use intensification and declining soil fertility and crop yields. Due to population increase, farm sizes declined such that by 1989 most AEP participants had less than a hectare of cropland (Scherr, 1995). Shrinking land sizes has made intercropping, boundary plantings and field boarders among the most common AFR practices in Western Kenya (Scherr, 1995).

A survey of low resource endowed households in western indicated that farm revenue made up a paltry 7% of total household income. Even in the most optimistic scenario where farm revenues were increased 400%, these farmers would have to supplement their income through off-farm activities. In contrast, high resource endowed farmers earned 63% of total household income from the farms. Furthermore, medium resource endowed farmers had four times as much land therefore earning revenues seven times higher than their low resource endowed counterparts (Shepherd and Soule, 1998). An evaluation of farm returns showed that low resource endowed farmers were barely breaking even when family labor was valued at market wage. High resource endowed farmers had more success due to use of inorganic fertilizers and intensive dairy cattle enterprises (Shepherd and Soule, 1998). In another study of improved fallows and biomass transfer by first generation farmers in western Kenya, various reasons were given for poor technology uptake or abandonment. Small farm size was the highest (63%), no noticeable increase in crop yields (18%), lack of market for seed (18%), improved fallows did not provide edible products (3%), lack of labor (3%) and lack of knowledge (2%) (Kiptot et al., 2006).

Almost 70% of Kenya's population consists of rural based subsistence families whose sole source of energy is fuel wood and charcoal (Mwangi, 2013). The Kenyan smallholder farmer is bedeviled with many challenges, including low productivity, extreme reliance on rain fed agriculture, floods, drought and poor technology (Alila and Atieno, 2006; Muchena and Hilhorst, 2000). Downsizing by Kenya government has left a shortage of extension officers who are demoralized with limited resources to carry out extension. High corruption and mismanagement of donor funds in government has led to a major shift in donor support to non-governmental organizations (NGOs) whose work has been patchy and not comprehensive (Davis et al., 2004; Kiptot et al., 2006). There is increased encroachment into protected forest lands with population increase, causing catastrophic deforestation (Bleher et al., 2006; Lambrechts et al., 2003; Reyes, 2008). Land fragmentation is common with population increase but farmers are always reluctant to adopt technologies on agriculturally productive land (Current et al., 1995; Kabwe et al., 2009). AFR technologies give an alternative solution to poor smallholder farmers who would otherwise have a reduction in crop yields (Sanchez et al., 1997). However, unless farmers widely adopt these technologies, the potential benefits of AFR for livelihood improvement and sustainable environmental management will not be realized (Rule et al., 2000).

The best measure of the social success of new or improved AFR technology is the readiness with which farmers accept the technologies to improve their lives. If innovations do not take into account the social context in which these farmers operate, then the adoption rates will be reduced (Kabwe et al., 2009). The factors affecting AFR adoption are increasingly variant, hence the need to understand the specific factors influencing AFR technology adoption

(Ajayi et al., 2007). Once these factors affecting AFR adoption are identified, policies may be tailored to promote technology transfer and improve acceptance of AFR practices among target populations.

High population pressure, land fragmentation, easy access to labor, complex land tenure systems and poor market infrastructure are the key issues making AFR a subject of study in Africa. This study conducted a survey to examine the socio-economic factors that affect the AFR technology adoption process in Nyando, Kenya. Farmers in Nyando Kenya face many challenges in a light of global climate change, population expansion, and deforestation. AFR technologies have the potential to alleviate some of these problems, especially in long-term development scenarios by allowing farmers to use fewer resources, mitigate biotic and abiotic crop stress, and provide a more stable income over time. Thus, this preliminary study on AFR adoption in Kenya is critical to understanding AFR technology transfer and AFR as a sustainable land use solution for smallholder farmers. The next section will discuss the experimental setup, variables and general methodology adopted. The major results are discussed in section 3, evaluation is done on the independent variables to assess their impact and establish whether they met the threshold of significance. A critical discussion of the findings from results is also provided. The study concludes by highlighting the lessons learned and giving recommendations.

4.1 Methodology

4.1.2 Study area

The study area was Nyando in Kisumu County on the shores of Lake Victoria in Kenya East Africa (Figure 1). The district lies within latitudes 0˚ (equator) 0.42˚ South and longitudes 34.07˚ and 35.35˚ East. The terrain is flat with the highest population density of 469 persons per km^2 according Ministry of planning Kenya gazette 2010. Settlement is determined by the physical geography of the district and relative agricultural potential. Large scale plantation farming is done on the sugar belt. The highlands have high agricultural potential but farm sizes are increasingly becoming smaller with increased fragmentation of land. On the other hand, lowlands are bedeviled by perennial flooding. Nyando area represents a typical area in Africa; therefore the study can be used as a benchmark for other areas with similar challenges.

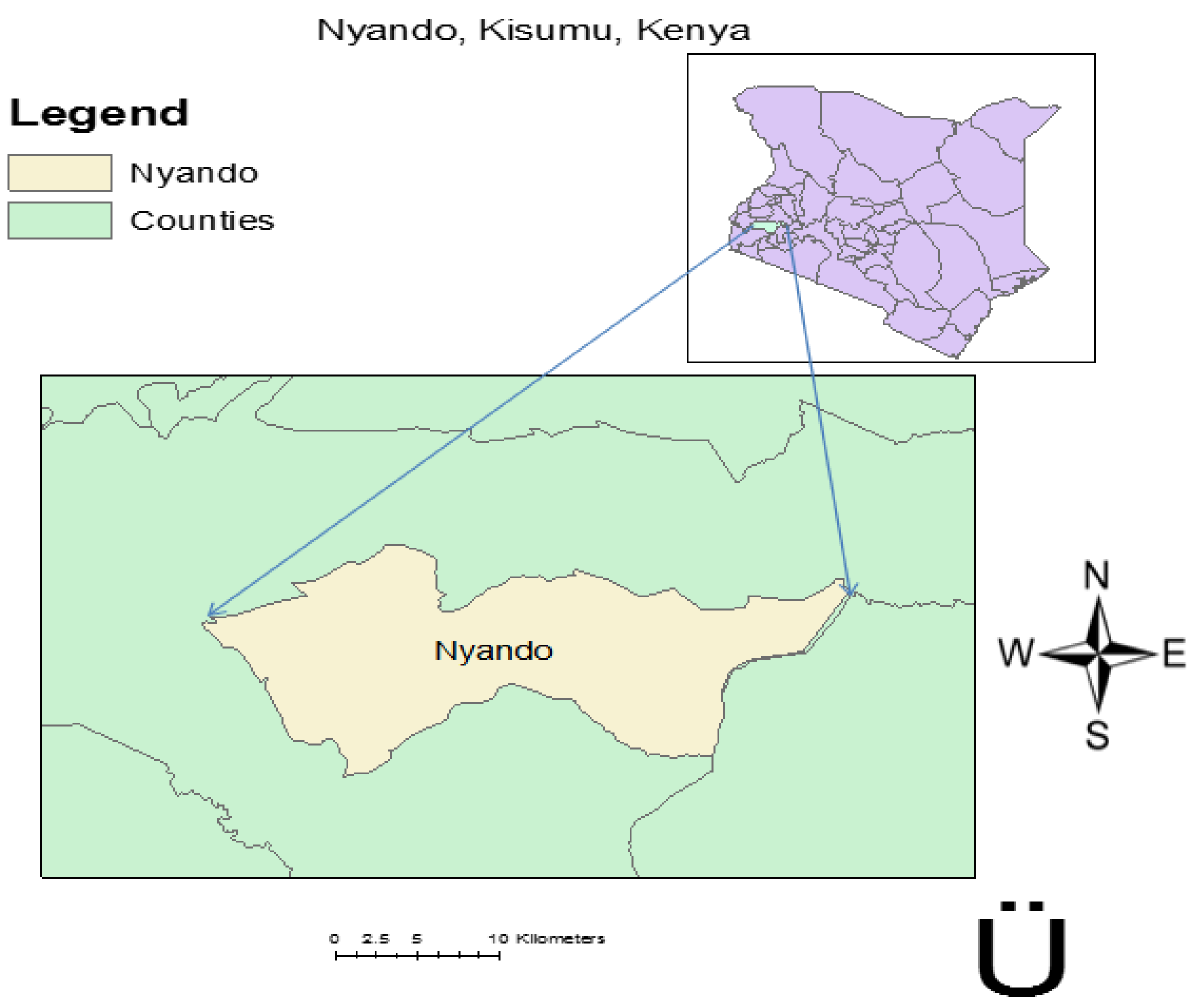

Figure1: Map of study area

4.1.3 Survey design

Probability sampling was used in this study. Personal interest of the farmer to engage in the study was also a key consideration. The study considered only farmers practicing AFR to ensure that the participants were involved in the study as of January 2010. The sample size was determined using Fishers formula *(Mugenda, 1999)*:-

$$n = \frac{Z^2pqD}{d^2(N-1)+Z^2pq}$$

Where,

n = the desired sample size

Z = the standard normal deviate (1.96), which corresponds to 95% confidence interval

D = proportion in target population that has characteristic being measured =1400

p = 0.5

q = (1-p)

d = level of statistical significance set (0.05)

N = Target population

$n = (1.96)^2 \text{ x } 0.5 \text{ x } (1-0.5) \text{ x } 1400/ (0.05)^2 (1400-1) + (1.96)^2 (0.5 \text{ x } 0.5) = 301$

n=301

Due to fieldwork logistics, remoteness and costs, 10% of the target population was randomly taken as a representative sample. The sample was 59.4% male and 40.6% females. Farmers were selected for their exposure to AFR based on a list of contact farmers held by International Centre for Research in Agro-forestry (ICRAF), also known as World Agro-forestry Centre. Appointments were made through the contact farmers, for the farmers to be present at households during the administration of questionnaires. Personal interviews in local language were conducted and responses recorded on the questionnaires. The chief representative of the contact farmers assisted with clarifications and translations as necessary. On each farm visit, an initial survey of the property was conducted to assess which of the most common technologies had been adopted. These technologies included: trees for shade, boundary trees, trees for fodder, windbreaks/shelterbelts, and trees for soil amelioration.

4.1.4 Analysis

Data variables were organized into sets for easy interpretation. Technology adopters were labeled 1 and non-adopters 0 in binary fashion. Age of farmers is divided into 6 categories where 1 for 20 years and below, 2 for 21-30 years, 3 for 31-40 years, 4 for 41-50 years, 5 for 51-60 years, and finally 6 for those above 70 years. For farm sizes, 1 represented farm sizes less than 1 acre, 2 for between 1-2 acres, 3 for 2-5 acres, 4 represented 5-10 acres and finally the largest land holders were category 5 with more than 10 acres. The education levels of farmers were classified as illiterate 1, primary educated 2, secondary educated 3 and finally tertiary educated 4. The household incomes were classified into poor (less than 1 $ a day) and high income (more than 1 $ a day). Household sizes were classified as 1 for (2-5), 2 for (5-10) and 3 for more than 10 people in a household. Farmers' years of residence were classified as 1 for less than 10 years, 2 for 10-20 years and 3 for more than 20 years 3. Finally, farmers' access to information was categorized as rare 1, moderate 2 and frequent 3.

The responses to the individual questionnaires were processed and analyzed using Statistical Package for the Social Sciences/ SPSS (Bryman and Cramer, 2004; Pallant, 2010). Descriptive statistics were used to characterize households and the chi-square test of independence was used to compare various factors with adoption of various AFR technologies. Dependent variable was the outcome (adoption or non-adoption) while the independent variables were, farm size, education status, decision maker (husband or wife), total income, % of income from crops, access to information and years of residence. Logistic regression was applied to identify the relationship between "outcome" (dependent variable) and the seven independent variables

4.2 Results

4.2.1 Preliminary household data

As shown in table 1, *Euphorbia tirucalli* emerges as the most common species for boundary (56%) while *Lantana camara* is the least at 3%. *Sesbania sesban* is the most important species for fodder (34%) but *Leucaena leucocephala* is the least common at 3%. Acacias remain the most important species for shade 18% while *Moringa oleifera* is the preferred species for soil amelioration at 28%. The most highly ranked species for windbreaks by respondents are *Grevillea robusta* and *Casuarina equisetifolia* species but blue gum is the least popular at 29%, 26% and 13% respectively

Table 1: Multipurpose tree species and their uses by respondents in Nyando

Tree species	% of respondents using the species for boundary	% of respondents using the species for fodder	% of respondents using the species for shade	% of respondents using the species for soil amelioration	% of respondents using the species for windbreaks
Acacia species	3.1	6.3	18	6.3	
Grevillea species	12.5	-	9.4	15.6	29
Calliandra species	3.1	31.3	3.1	-	

Lantana species	3.1	-	-	-	
Casuarina species	6.3	12.4	-	-	26
Theveta peruviana	6.3	-	-	11	
Euphorbia species	56.3	3.1	-	-	14.4
Sisal species	6.3	-	-	-	
Terminalia brownie	3.1	-	-	-	
Leucaena species	-	3.1	-	-	
Sesbania species	-	34.4	3.1	15.6	
Mangoes	-	-	8.4	-	
Markhamia species	-	-	11.2	-	15.6
Croton species	-	-	21.1	-	
Sena siamea	-	-	16.3	-	
Terminalia mentalies	-	-	9.4	-	
Moringa oleifera	-	-	-	28.8	
Gliricidia species	-	9.4	-	9.1	
Dolchos lablab	-	-	-	13.1	
Blue gum					13

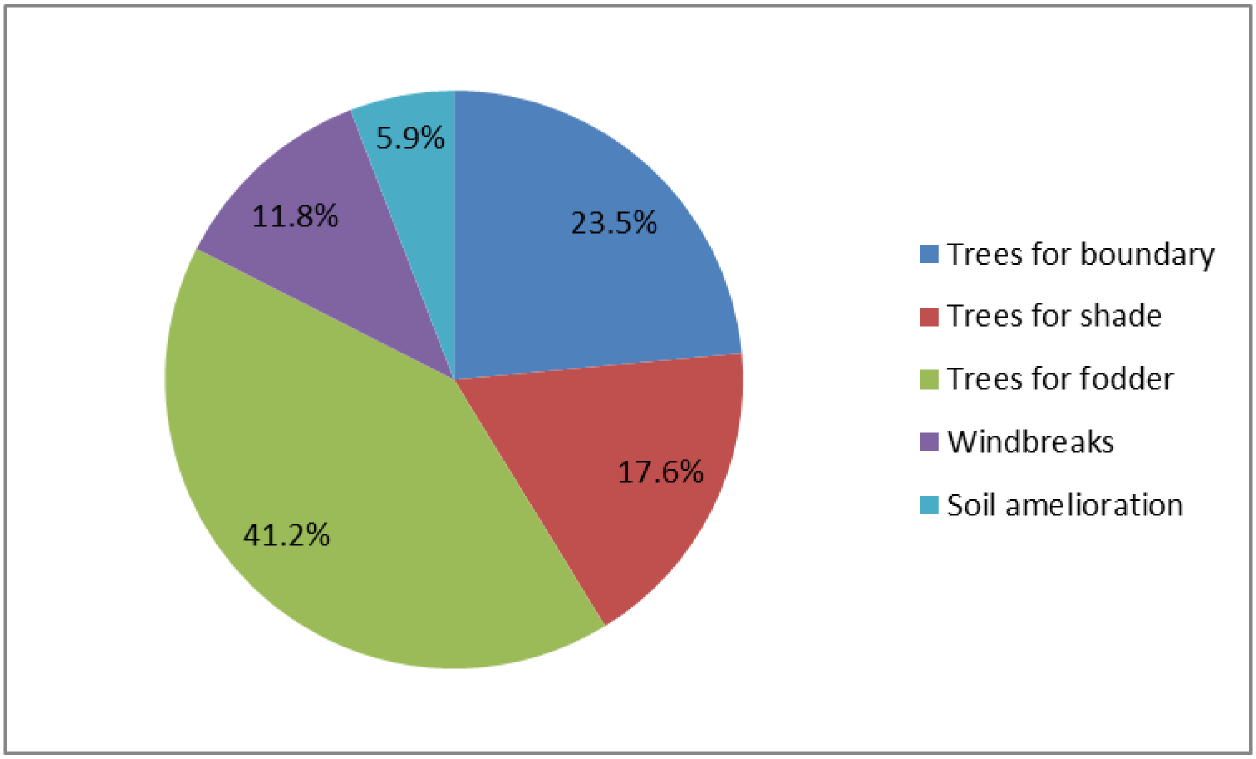

Figure 2: Agroforestry technologies adopted among respondents in Nyando

As shown in figure 2, trees for fodder was the most critical practice at 41.2%, boundary plantings at 23.5%, trees for shade at 17.6%, windbreaks at 11.8% while trees for soil amelioration close the list at 5.9%. Various constraints and strategies to land, labor, income and off-farm tree resources led to different agroforestry- choices. Farmers were practicing an agroforestry technology in one way or another depending on their circumstances. Findings by Scherr, (1995) also found that farmers tended to adopt specific tree species for priority uses in given specific sites. In most cases, farmers modified AFR systems to meet their own needs, whether particular spacing or to obtain various products and services. Economic logic was at center stage in selecting low cost sites for tree growing. Farmers tended to plant trees on more marginal or degraded land to preserve better land for crop production (Scherr, 1995).

Table 2: Farm sizes among respondents in Nyando

Farm sizes (acres)	Proportion of respondents (%)
<1	25
1-2	43.75
3-4	15.63
5-6	6.25
7-8	0
9-10	6.25
>10	3.12
Total	100

Table 2 shows land parcel sizes among respondents in Nyando, about 44% of respondents own 1-2 acres, 25% less than an acre, 15% 3-4 acres, 6.25% own 5-6 acres while only 3.12% of the respondents own more than 10 acres. Nearly 60% of respondents own less than 4 acres of land, yet farm size is a critical determinant of AFR technology adoption because poor farmers are reluctant to take risk in changing traditional land uses. On the other hand, richer farmers tend to have bigger parcels for diverse technology trials (Scherr, 1995). Managing AFR on smaller parcels is extremely labor intensive; including removing canopies before crop is planted to reduce tree crop competition (Jackson et al., 2000). Therefore, scarcity of land hampers AFR adoption the most (Scherr, 1995).

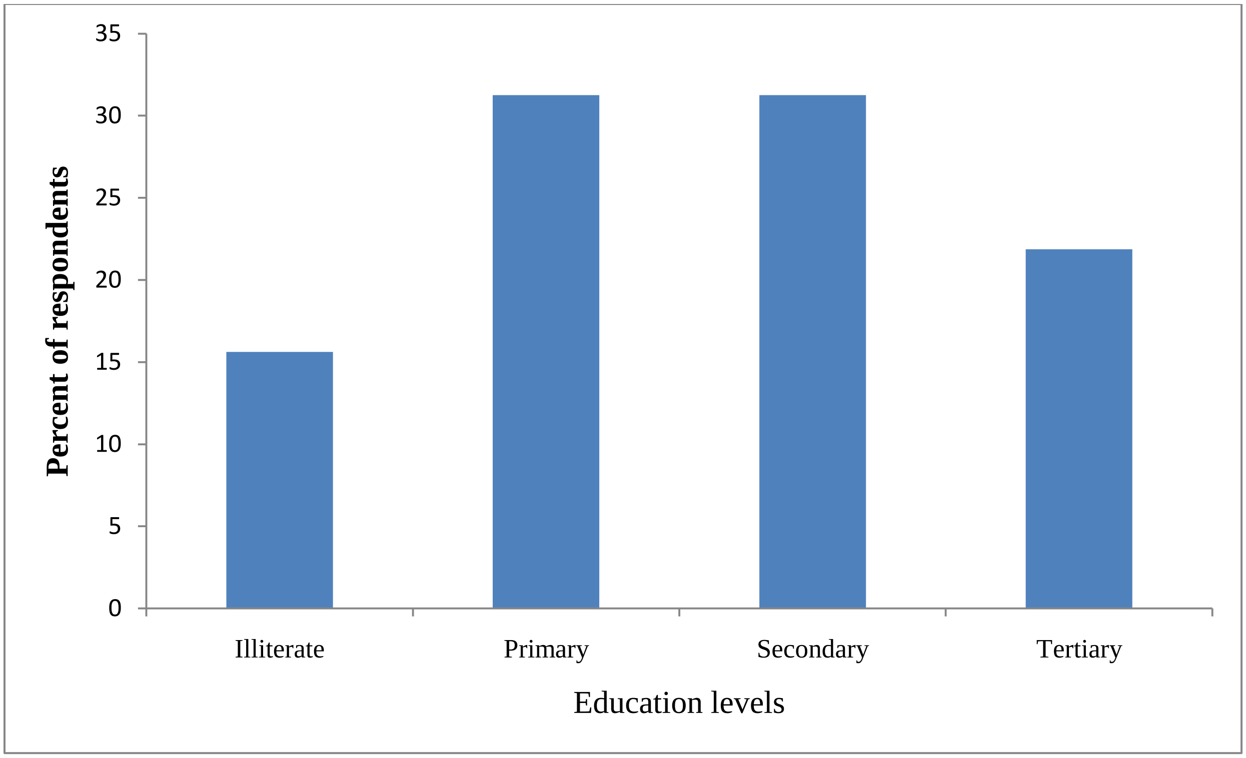

Figure 3: Education levels of respondent in Nyando

Figure 3 shows education status among sampled residents of Nyando. About 15% of respondents are illiterate, 30% have primary education, and 22% have tertiary education while about 30% have secondary education. These results reveal that almost 80% of sampled residents have attained primary education.

Table 3: House hold decision makers in Nyando

Decision Maker	% of respondents
Husband	56.25
wife	25
Both	18.75
Total	100

Table 3 shows the decision making criteria in Nyando among sampled residents. Results reveal that, in most households, husbands (56%) are the main decision makers. Wives account for 25% of decision makers while both wife and husbands make decisions in about 19%

of the sampled households. Similar AFR studies in western Kenya revealed that land and labor decision making authority was thought to hamper females from adopting AFR technology (Bonnard and Scherr, 1994; Scherr, 1995).

Table 4: Livestock income among respondents in Nyando

Animals income	Mean Ksh
cattle income	16,789.47
Poultry income	15,330
Goats income	4,566.667
Sheep income	3,640
Total livestock income	21,207.41

Table 4 shows mean household incomes accrued from livestock enterprises. Results reveal that poultry and livestock incomes are the highest. Farmers would therefore increase their income through fodder banks and mixed feed poultry enterprises.

Table 5: Income from Tree products among respondents Nyando

Income from Tree products (ksh)	% of respondents
10,000-20,000	3.1
50,000-80,000	6.2
None	90.6
Total	100

Table 5 results reveal that up to 90% of households do not accrue any income from tree products. Of the 6.2% that are the highest earners, the returns on investment are very high, even higher than those from livestock enterprises in the study area. In fact, in most of the households sampled, tree species planted were still young for cash enterprises like poles and timber. Similar studies in western Kenya by Scherr, (1995), established that poorer farmers could not wait long enough to allow trees to grow to timber size, despite the high returns. Under such circumstances, profitability was an important but not sufficient incentive for AFR technology adoption.

Table 6: Income from crops among respondents in Nyando

Income from crop (Ksh)	% of respondents
1,000-10,000	2
10,000-20,000	3.9
20,000-30,000	5.1
None	89
Total	100

Table 6 shows crop income among residents in Nyando. About 89% of respondent do not accrue any income from crop enterprises they are engaged in, they mainly do so for their livelihoods. In total, about 10% of respondents produce surplus food to sell from their crop enterprise earning more revenue. This is not surprising, because these farmers tended to value land for crop production in cases where parcels are very small like the study area. They only planted trees in exposed or degraded lands (Scherr, 1995). In other studies in western Kenya, results revealed that a better knowledge of below ground interactions between trees and crops was needed before real benefits of AFR practices are fully incorporated by farmers (Odhiambo et al., 2001; Rao et al., 1998).

Table 7: Years of residence in Nyando

Years of residence	Proportion of respondents (%)
2-5 years	6.25
6-10 years	12.5
11-15 years	12.5
16-20 years	6.25
>20 years	62.5
Total	100

From table 7, at least 62.5% of the respondents have lived in the area for more than 20years, 12.5% between 11-15 years and 6-10 years. 6.25% of respondents have lived in the area for between 2-5 years and 16-20 years respectively. Longer years of residence are associated with land tenure security because farmers want to plant trees only if they are assured of benefits. Studies by Scherr, (1995), in western Kenya revealed that legal and regulatory constraints such as land tenure insecurities remain part of the impediments to AFR technology adoption among new residents.

4.2.2 Household characteristics

Table 8 shows household characteristics of the farmers in the study area. Perennial flooding along the flood plain has led to increased landslides and land dereliction, thereby causing land fragmentation and reduction in the average family parcel sizes. Average farm size in the region is 5.5 acres. Most farmers in the study area have been residents for approximately 21 years and have attained at least primary education. A large portion of the sampled farmers who had frequent access to information adopted AFR technology and earned at least 10% of their income from crops. Of all the households sampled, most decisions were made by husbands and the mean household income was approximately $288 annually.

Table 8: Characteristics of farmers in the study area

	Mean	Median	Standard deviation	Minimum	Maximum
Farm Size (acres)	**5.54**	4.1	5.45	0.1	23
Dummy, = 1 if has primary or above education	**0.84**	1	0.37	0	1
Dummy, = 1 if decision maker is husband	**0.59**	1	0.5	0	1
Total Income (US $)	**288.4**	147.5	354.46	0	1414.75
Years of residence	**21.44**	23.5	9.73	4	40
Dummy, =1 if has frequent access to information	**0.63**	1	0.49	0	1
Percent income from crop	**10.25**	5	24.71	0	97

4.2.3 Correlation analysis

Table 9 shows the correlations between independent variables and outcome. Farm size was positively correlated with farmers' decisions on agroforestry technology adoption, likely due to the ability of these farmers to conduct trials on small portions of land without sacrificing a large percentage of the overall farm returns (Current et al., 1995; Neupane et al., 2002; Scherr, 1995). There was a strong connection between wealth and AFR technology adoption, because farmer's needs and objectives were influenced by capital asset endowments (Iiyama et al., 2008; Liniger et al., 2011; Reed et al., 2013).

Years of residence had a strong positive correlation with AFR technology adoption. Longer years of residence could be associated with strong land tenure security leading to AFR adoption. Similar findings by Liniger et al, (2011), emphasized the need for land tenure security for AFR technology adoption. Correlation between AFR adoption and education status was also strong. Education was an influential factor because more education was associated with better information management (Liu and Huang, 2013; Traore et al., 1998).

According to Liu and Huang, (2013), cost and benefits that accrue from adoption of conservation technologies strongly influenced farmers' decisions to adopt them. Similarly in this study, crop yields were very critical for decision making on whether to adopt AFR technologies. Moreover, household incomes had the highest correlation with farm size which also had the strongest correlation with AFR technology adoption. This was ironical because AFR technologies are designed for poor households to uplift their agricultural and economic productivity (Scherr, 1995; Scherr, 1999).

Access to information was another key factor which had significant positive correlation with AFR technology adoption. In fact, access to information was the only independent variable positively correlated to all the other factors affecting AFR adoption. Similar studies on farmers in Nile Basin of Ethiopia revealed lack of information as the main reason for failure to adopt soil conservation practices (Bekele and Drake, 2003; Liu and Huang, 2013). Unfortunately, household decision makers did not have significant correlation with AFR technology adoption.

Table 9: Correlation among factors that affect AFR technology adoption

	Farm Size	Dummy, = 1 if has primary or above education	Dummy, = 1 if decision maker is husband	Total Income	Years of residence	Dummy, =1 if has frequent access to information	% income from crop
Farm Size	1.000						
Dummy, = 1 if has primary or above education	0.148	1.000					
Dummy, = 1 if decision maker is husband	0.139	0.005	1.000				
Total Income	**0.447**	0.096	0.010	1.000			
Years of residence	0.143	0.128	0.224	0.388	1.000		
Dummy, =1 if has frequent access to information	**0.293**	**0.378**	**0.542**	**0.384**	**0.271**	1.000	
% income from crop	0.006	0.187	0.108	0.052	-0.061	-0.037	1.000
Adopted AFR technology	**0.518**	**0.206**	0.040	**0.653**	**0.402**	**0.228**	**0.219**

4.2.4 Regression analysis

Results from regression analysis show the socio-economic factors that were most significant for AFR technology adoption (Table 10). Farmers with smaller parcels were reluctant to risk changing land use for new technology trials which was consistent with correlation analysis in table 9. Similar studies by Current et al. (1995) also showed significance of farm sizes in AFR technology adoption in the Caribbean and Central America. Part of these findings are contrary to those by Kabwe et al (2009), who found that land limitation was associated with trialing of improved fallows among small holder farmers in Zambia.

Table 10: Socio-economic factors that affect AFR technology adoption in Nyando, Kenya

Dependent Variable: Adopted AFR technology	
Farm Size	0.513***
	(2.21)
Dummy, = 1 if has primary or above education	5.148**
	(1.83)
Dummy, = 1 if decision maker is husband	-1.306
	(-0.94)
Total income	0.213*
	(2.12)
Years of residence	0.250**
	(1.92)
Dummy, =1 if has frequent access to information	0.426*
	(1.51)
% income from crop	0.0848**
	(1.84)

t statistics are reported in parentheses. *s indicates significance levels. * means p-value <0.15, ** means p-value<0.10, *** means p-value<0.05.

If farmers have stayed in the area longer, households were more likely to adopt AFR technology because they felt safer control of land. According to Liniger et al. (2011), long term land use strategies without a secure land tenure system were associated with lower AFR adoption among farmers. Studies by Kabwe et al. (2009), also found that lack of land tenure security hampered female farmers from participating in adopting improved fallows in Kenya.

Results reveal that, adoption rates were higher when farmers had increased income from crop yields. This is consistent with the findings from Franzel, (1999) and Muchena and Hilhorst, (2000); who found that triability of AFR technologies increased when farmers perceived low fertility of soil as their immediate problem, because fertility was strongly associated with crop yields. Furthermore, households with more income tended to adopt agro-forestry technologies due to more disposable income to offset costs like labor, seeds and implements, unlike households with less income. Rural households with more oxen often considered wealthier, had higher AFR adoption rates due to their reduced labor requirements (Kabwe et al., 2009; Oino and Mugure, 2013; Phiri et al., 2004).

Micro-level factors were also key to technology adoption (McDonald and Glynn, 1994). For instance, more literate farmers were more likely to adopt AFR technology in Nyando than illiterate farmers. Study findings also reveal that the decision maker (wife or husband) had insignificant effect on the level of AFR technology adoption; that farmers who were frequently exposed to AFR technology were more inclined to adoption; and that successful adoption of AFR technologies was dependent upon favorable convergence of social, economic, technical, institutional and policy factors, consistent with (Rogers, 2004).

4.3 Discussion

4.3.1 Adoption process and policy implications

Adoption occurs when one has decided to make full use of the new technology as the best cause of action for addressing a need (Boz and Akbay, 2005; Steele and Murray, 2004). The adoption process will be influenced by perceived attributes of innovation, social system, channel of communication and agent promotion efforts (Denning, 2001; Kabwe et al., 2009; Rogers, 2010). In Nyando, farmers have a need to increase income from crops. Our results suggested that more AFR technology adoption could be achieved by focusing on technologies that increase soil amelioration to increase crop productivity. Extension activities should therefore be tailored to emphasize soil amelioration as a key to increasing yields to address the farmers' needs.

The adoption process is generally described by a five-step process that is; 1) knowledge, where the farmer is exposed to the idea but lack information about it; 2) persuasion, where there is interest in the innovation and attempts made to seek more information; 3) decision-making, where the farmer weighs advantages and disadvantages to see whether to adopt or rejects the innovation; 4) implementation, where the farmer tries the innovation to determine its usefulness; and 5) confirmation, where the decision to use the innovation is finalized (Mattila et al., 2003; Raintree, 1983; Rogers, 2002). Studies in western Kenya by Scherr, (1995), indicated that the best strategies for technology adoption were; initial testing of the said technologies, building on familiar practices and economic returns with AFR. Where systems are based on existing agroforestry practices, adoption proceeds quickly due to farmers familiarity with management or components of the AFR system shorting famers learning curve or " testing and evaluation" period (Raintree, 1991; Scherr, 1995).

In Nyando, Policy formulators should therefore target new residents (farmers with less years of residence) to boost adoption. Additionally, land tenure insecurities faced by farmers with less years of residence should be addressed through support systems and synergies to revise disincentives to AFR adoption by new residents (Scherr, 1995). From the results, income increases likelihood of AFR technology adoption because farmers have credit constraints. Therefore, financial aid is a key policy tool for increasing adoption. Farmers with smaller parcels of land should be the key target of extension agents to boost AFR technology adoption through robust income enhancing technologies. Shepherd and Soule, (1998), also recommended that AFR interventions must be targeted to farmers with low and medium resource endowments to increase productivity and sustainability of poor rural households. They however noted that the chief challenge would be increasing farm output and or decreasing cost of inputs.

During the above process, farmers evaluate AFR technologies using up to six criteria related to innovation characteristics which include; 1) relative advantage, 2) trialability, 3) compatibility, 4) adaptability, 5) observability and 6) complexity (Raintree, 1985; Reed, 2007). These innovation characteristics are then considered in turn, to examine the factors affecting the likelihood of adoption of new AFR technologies (Stupples, 1988). Observability is a key factor that extension agents must emphasize, probably through trial plots and farmer field days. These events provide opportunities where semi-literate and illiterate farmers get a chance to see and experience typical outcomes of AFR technologies (seeing is believing). Similar AFR studies in western Kenya affirmed that, farmers adopted technology in incremental steps. First was small scale experimentation on lower quality land, maintenance and management of operational plots and finally, renewal of original plots or establishment new ones after production cycle (Scherr, 1995).

AFR can meet the diverse needs and objectives of farmers', but effectively communicating the benefits of using such technologies is the key to their success (Reed, 2007). Studies by Jackson et al, (2000), emphasized that adoption of AFR as a preferred system of land use would only be achieved by showing that it is either more productive (i.e. higher cumulative returns on tree and crop products) and or more sustainable than individual tree and crop enterprises. If AFR technology is explained effectively, its perceived complexity may be reduced; hence observability and adaptability may increase (Reed et al., 2013). Depending on the outcome of the evaluation, AFR technology or innovation will be adopted and implemented or rejected.

To address their diverse needs, trial farmers should be segregated according to their greatest immediate need, such as, soil amelioration, food security, environmental protection or increased financial benefits. By targeting each group individually through specific AFR technology proposals, extension agents will reduce the chance of imposing their ideas on unwilling farmers and increase the likelihood of adoption (user specificity). Extension agents will appreciate that participatory learning is shifting their role of extension officers to facilitators to enable them to make impacts on small scale farmers in Kenya (Kiptot et al., 2006). Knowledge is dynamic and is being transformed by actors to suit their circumstances. Research and extension staff should keep in touch with trial farmers to capture this knowledge and create a feedback loop to solve problems for the farmers (Kiptot et al., 2006).

Despite the fact that AFR adoption is still minimal, sustainable land use and natural resource management in these areas will benefit from structurally and functionally more complex systems like agroforestry (Ramachandran Nair et al., 2009). Most experts agree that reforestation, sustainable agricultural practices, avoided deforestation are among the most feasible remedies to climate change adaptation; all of which could be achieved through AFR (Niles et al., 2002). Education, extension, land tenure and other factors that farmers have no control over like farm size, researchers' performance and gender should be studied farmer to improve technology adaptation in Nyando.

4.7 Conclusion

The purpose of this study was to determine the socio-economic factors that influence adoption of AFR technologies in Nyando, Kenya. Preliminary results show that farm size was the most significant factor for AFR technology adoption. The remaining factors included education status, access to information, percent of income from crop, total income and years of residence. There was a clear relationship between technology adoption and livelihood improvement. For instance, farmers were growing pepper, raising individual tree nurseries and generating more income. Access to information remains the most critical factor affecting AFR technology adoption significant to policy formulators.

Farmers' circumstances also affected which technologies they chose to adopt. If farmers' circumstances were favorable, some technologies were selected over others. Adoption of some technologies was based on the organization sponsoring the project initiative and the extent of collaborative efforts between the organizations involved. However, sustainability of such projects depended upon the coordinators' ability to hang on even after the exit of the project through extension activities.

Future projects should involve both farmers and extension officers from the onset and have inbuilt ways of disseminating the project findings to enhance adoption. Analysis of extension factors could shed light on challenges met during technology trials by farmers; while correlation between researchers' performance and adoption of technology could highlight farmers' perceptions. This study can be replicated in other parts of Kenya and East Africa to improve the level of AFR technology adoption for sustainable rural development.

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Appendix

Study of the socio-economic factors affecting agro-forestry technology adoption in lower Nyando.

1. General information

   Consent Yes ( ) No ( )

   Name of respondent ………………………………………………………………

   Date of interview ……………………………………………………………..

   Age ……………………………………………………………..

   Sex ……………………………………………………………...

   Occupation ……………………………………………………………..

   Division ……………………………………………………………..

   Location …………………… Sub location ………………………………………

   Name of the person filling the form ………………………………………………..

2. Education Status

   a) Primary …………. b) Secondary ……………..

   c) Tertiary …………. d) Others …………………

3. For how many years have you been residing in the area?

   - < 2 years ( )
   - 2-5 years ( )
   - 6-10 years ( )
   - 11-15 years ( )
   - 16-20 years ( )
   - > 20 years ( )

4. What is the size of your household

   Wife (ves)………………

   Children ……………….

Age class	No. at home	No. employed elsewhere	Job description
< 5			
5-18			
19-35			
36-55			
>55			

5. What is the size of your farm in acres?..

6. Costs incurred in household farm

Management practices	Labor costs
Land preparation	
Planting	
Weeding	
harvesting	
Transportation	
Others (specify)	

7. What crops did you grow on your farm last season? Please indicate units e.g. kg

Crop	Acreage	Yield	Qty sold	Qty consumed	Price in Ksh	Storage Facility

8. Who decides on the crop quantities for sale and consumption?

   Consumption …………………………………….

   Sale ………………………………………………

9. Labor

Crop	No. of Workers	Period e.g. month	Wages (Ksh)

10. What other foodstuffs do you purchase for domestic consumption?

Foodstuff	Quantity purchased	Cost (Ksh)

11. Do you receive food from other sources? e.g. donor aid, women groups, etc

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12. Do you own livestock? Yes…………….No……………….

13. If yes, please list and indicate the number and income from each category of livestock.

Livestock	Number	Income per month/year

14. What is your total household income?..

15. Do you know about agro-forestry? If so how did you get to know about it?

………………………………………………………………………………………………

………………………………………………………………………………………………

16. How frequent are you exposed to agro-forestry information

a) Frequently ( )

b) Rarely ( )

17. Have you planted trees in your farm? If yes, list species

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18. Where do you obtain your seedlings

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Price ………………………………………………………………………..

19. For the above species, list the end products you expect to harvest from the trees?

Product	Tick as appropriate	Species
Firewood		
Charcoal		
Pole/ building materials		
Timber		
Boundary		
Shade		
Fodder		
Windbreaks		
Carbon Sequestration		
Soil amelioration		
Education and research		
Others		

20. Is there any form of value addition on the products? If yes, in what form?

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21. Where do you market /sell your products?

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22. Who are your customers?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

23. What products do you sell in the market?

Products e.g. poles, timber, firewood etc.	Quantity	Price

24. Are you satisfied with prices you receive for your products?

Yes ( ) No ( )

25. Is the market for your products adequate?

Yes ( ) No ( )

26. What problems do you encounter in marketing your products?

Problem	Tick
Low prices	
Transportation availability and cost	
Lack of market	
Others (specify)	

27. Do you perceive a welfare change in your household since you started practicing agro-forestry? If so how?

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28. Is the farmer a true adopter of agro-forestry technology?

Yes ( ) No ( )

29. Which Agro-forestry technologies have been adopted by this household?

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30. Comments and observations?

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Name ……………………………………………………………………………………….

Signature ……………………

UNIVERSITY OF ARKANSAS

June 6, 2016

MEMORANDUM

TO:	John Westley Magugu Qiuqiong Huang
FROM:	Ro Windwalker IRB Coordinator
RE:	New Protocol Submission
IRB Protocol #:	16-06-788
Protocol Title:	*Socio-economic Factors Affecting Agroforestry Technology Adoption in Nyando Kenya*

In reference to the request for IRB approval of your project titled *Socio-economic Factors Affecting Agroforestry Technology Adoption in Nyando Kenya*, the IRB is not authorized to oversee and approve such research. This protocol does not meet the definition of research involving human subjects in the federal regulations. (See the citation below.) You are free to conduct your research without IRB approval.

45 CFR 46.102 (f)

(f) Human subject means a living individual about whom an investigator (whether professional or student) conducting research obtains

(1) Data through intervention or interaction with the individual, or
(2) Identifiable private information.

If you have any questions do not hesitate to contact this office.

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CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The overall goal of this research was to have a comprehensive look at climate change from a local perspective and give a holistic view of the scenarios for policy formulators. In the study, local climate change was defined by agro-climatic indices. A key component of the study was the changes in GDDs, FDs, GSL, drought indices and their relationship with crop yield changes in current climate, 2030, and 2060. The studies gave scenario analyses for foresight into the challenges we might be facing in the future. We used climate data analysis, geographic information science, correlation analysis and regression analysis to address specific objectives.

The main objectives of this dissertation were: 1) To develop a set of agro-meteorological indicators; 2) To examine the relationship between agro-meteorological indicators and crop yields in eastern Arkansas; 3) To project future climate scenarios in eastern Arkansas; 4) To assess the impacts of future climate scenarios on agriculture in eastern Arkansas and 5) To identify the socio-economic factors affecting the Agro-forestry (AFR) technology adoption in Kenya.

A set of hypotheses were constructed to study the impact of local climate change on agriculture and to assess the relationship between various agro-meteorological indicators and crop production within the eleven counties of Eastern Arkansas. The following hypotheses were tested in this study:

> (H_{o1}) Temperature has no relationship with soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha > 0.1$).

After correlation and regression analysis, results revealed that GDDs were negatively correlated to yields. In fact, most counties of the study area produced p values ($\alpha <0.1$). Therefore, the null hypothesis was rejected, confirming that temperature was strongly associated with soybean yields within the study area.

(H_{o2}) was that precipitation has no relationship with soybean yields within eleven counties in eastern Arkansas, and that correlation and regression results will yield p values ($\alpha >0.1$).

Although total precipitation yielded mixed results after correlation and regression analysis, results revealed that dry spells were negatively correlated to yields. Some counties of the study area produced p values ($\alpha >0.1$). Given the mixed results from precipitation analysis, we failed to reject the null hypothesis.

(H_{o3}) was that there is no correlation between the three drought indices and soybean yields within eleven counties in eastern Arkansas, and that correlation results will yield p values ($\alpha >0.1$).

After correlation analysis, results revealed that PDSI, SPEI and SPI were positively correlated to yields. In fact, most counties of the study area produced p values ($\alpha <0.1$). Therefore, the null hypothesis was rejected.

(H_{o4}) There was no relationship between temperature driven indicators and future climate change projections within eleven counties in eastern Arkansas.

Results revealed that GDDs, GSL, first fall frost day, last spring frost day and growing season length all changed with severity of RCP projections in each of the three scenarios in 2030 and 2060. Therefore, the null hypothesis was rejected, confirming that there was strong relationship between temperature driven indicators and future climate projections within the study area.

(H_{o5}) There was no relationship between precipitation driven indicators and future climate change projections within eleven counties in eastern Arkansas.

Total precipitation, percent of rainy days with extreme precipitation and percent of extreme precipitation relative to total precipitation all yielded marginal changes under all RCP scenarios in 2030 and 2060. Given the mixed results from precipitation analysis, we failed to reject the null hypothesis.

(H_{o6}) There was no spatial change in temperature and precipitation driven indicators within eleven counties in eastern Arkansas.

All spatial analysis for temperature and precipitation driven indicators clearly show distinct spatial change on our geographic information systems maps for the study area. Therefore, the null hypothesis was rejected, confirming that spatial change was apparent in our study area for both temperature and precipitation indicators analyzed.

Even though agriculture in eastern Arkansas is highly irrigated, crop production is still not completely sheltered from fluctuations in weather. Research in Chapter 2 established the relationship between Ag-indicators, drought indices and soybean yields in Eastern Arkansas. Temperature, precipitation and drought indices were used to test relationship between rain-fed soybean yields between 1960 and 2014. Both correlation and regression analysis was used. Results revealed a positive correlation between precipitation and yields. Both GDDs and dry spells revealed a negative correlation. One month drought indices, especially SPEI-1 was best suited to explain yield departures of Soybean in the growing seasons. In cases where temperatures are relatively uniform, precipitation alone can be used to compute drought indices as revealed by the results.

Chapter 3 evaluated the impact of future climate scenarios on agriculture in eastern Arkansas. Daily weather data was used to construct precipitation and temperature indicators for individual grid cells in the study area for trend analysis; three scenario analyses was then done for 2030 and 2060 in tandem with Intergovernmental Panel on Climate Change (IPCC) projections. Results reveal a lengthening GSL, increasing GDDs and tendency of extreme precipitation in future years beyond 2060. Arkansas is however more vulnerable to extreme precipitation and droughts. Crops will be negatively affected by increases in temperature. Even though this study only focused in eastern Arkansas, local differences emerged; the southern region was more negatively impacted than the north. Rainfall and temperature effects were more intense in the south of the study area.

Chapter 4 identified the socio-economic factors affecting AFR technology adoption in Kenya (East Africa). Probability sampling was used in the study; logistic regression was then applied to identify the relationship between the outcome (dependent variable) and the seven independent variables. Results reveal that the farm size was the most significant factor affecting AFR technology adoption. Additionally, access to information remained the most critical factor for stakeholders and policy formulators because it had the highest correlation with all the remaining independent variables.

Findings in Kenya can shed light on possible behavioral characteristics of farmers in Arkansas. For instance, previous studies have shown that farmers are willing to implement climate change strategies if the adoption will increase net benefits (Bryan et al., 2009; Di Falco et al., 2011). Farmers' behaviors regarding climate change are more shaped by their perceptions of climate change and climate risk than actual climate patterns and expert findings (Osbahr et al., 2008). Risk perceptions and socio-cognitive processes of decision makers are also important for adaption decisions (Bryan et al., 2013; Frank et al., 2011). In addition, farmers were willing to change crop variety, planting dates, crop types, planting trees and irrigation to combat climate change (Bryan et al., 2009). Therefore, stakeholders in Arkansas should do preliminary studies on farmers' perceptions before embarking on policy formulation.

5.1 Further research

1. This study did not account for crop modeling under the various scenarios of climate change. Crop modeling is particularly insightful because it gives quantitative feedback that could be further subjected to econometric analysis of the potential cost of climate change to stakeholders.
2. The study did not survey Arkansas' farmers' perspectives on climate change; their potential preparedness and responses to climate change adaptation and resilience. These findings could be very useful for government agencies interested in water conservation in the Arkansas delta to help government limit its funds to groups with the largest bang for the buck.
3. If data becomes available, similar climate analysis, development of agro-meteorological indicators and their relationship with crop production should be done for Kenya.

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