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Environmental and Climatic Constraints on Large-scale Camelina Production in Eastern Arkansas

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Environmental and Climatic Constraints on Large-scale Camelina Production in Eastern Arkansas

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by

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Abstract

Camelina sativa is a cold weather crop that is typically grown in semi-arid environments in the Western United States, usually as a spring crop, but sometimes during the winter. Research analyzing climate data and soil hydrology is important to better understand the environmental and terrain conditions necessary for Camelina farming wherever it is proposed for large-scale production. This study focused on various conditions and constraints pertaining to the potential for Camelina as a crop biofuel in Eastern Arkansas. Due to interest in the economic potential of crop biofuels in this area, and in particular the low input costs for Camelina, experimental farming began as early as 2013. Farmers in Eastern Arkansas grow soybeans during the summer and fall months, leaving Camelina to be grown in the winter and spring months as a potential second rotational crop. Initial experiments have been unsuccessful, with farmers attributing this result to suboptimal climate and soil conditions. Data and research compiled from literature, along with climate and soil hydrology data in the region show significant differences in environmental conditions in Eastern Arkansas when compared to areas of successful Camelina farming. Previous research has shown that Camelina requires at most 15 inches of rainfall, with successful yields in California from just 7.5 inches of rainfall. Camelina grows best in semi-arid environments, with research and field trials indicating the crop having difficulty growing in wetter regions. Results of the study indicate that climate and terrain conditions in Eastern Arkansas are far too wet, and do not seem suitable for large-scale Camelina production. However, small-scale Camelina production may be viable in select suitable fields.

Acknowledgments

I'd like to thank the staff at the Center for Advanced Spatial Technologies (CAST), and Communities Unlimited for helping me with funding and resources throughout my research. I would also like to thank my thesis advisor Dr. Jason Tullis, and my committee members, Dr. Song Feng and Dr. Fiona Davidson.

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1 Introduction

Camelina sativa, a member of the Brassicaceae family, is a cold weather crop that is native to Northern and Eastern Europe. It was very much a neglected and forgotten crop until recently when a renewed interest has taken place; both for its high content of Omega 3, as well as for a potential use in biofuel. Currently, the market for Camelina is underdeveloped, largely attributed to limited consumer awareness of the crops benefits. However, there is significant potential considering the low level of input costs required and the useful nature of the crop, making it potentially very profitable. Camelina is predominately used as vegetable oil, as well as being used in skincare products, with a more recent interest in biofuel capabilities. Camelina is being researched globally, including here in the United States (Centre for Alternative Land Use, 2007).

Camelina is a short season crop that typically matures between 85-100 days when planted in early spring. Camelina requires very little moisture when compared to alternative crops, requiring no more than 15 inches of rainfall, with some field trials reporting success with just 7.5 inches (George et al, 2015; George et al, 2015). Camelina generally requires very few input costs as it can grow in marginal conditions, and responds well to drought conditions. Seedlings germinate in low temperatures with young plants very resistant to frost. It is documented that seedlings can withstand temperatures as low as 12 degrees Fahrenheit (Ehrensing and Guy, 2008). It is also interesting to note that successful yields have shown the importance of planting in cold temperatures and frozen grounds, with widespread 25% yield reductions reported when instead planted in warmer temperatures (McVay and Lamb, 2008).

The demand for edible oils and biofuel capabilities is increasing, with vegetable oils being an important part of the global diet. Soybeans, Sunflower, and Canola are by far the most significant; however, each of these have its limitations, requiring high input costs and adapted to a limited climate region. Camelina is being researched in many different environments due to its reduced input requirements, suitability in marginal soils, drought tolerance, and cold weather tolerance. In the United States, research began in the Pacific Northwest and Upper Midwest, especially in the states of Montana and Minnesota, where field studies have been carried out for over 50 years (Putnam et al, 1993). More recently, field trials have begun to spread southward into Nevada, eastward into the Great Plains and parts of the Northeast, and now most recently into the Deep South.

1.1 Camelina Farming in Eastern Arkansas

This study's research focused on a new initiative of Camelina trials beginning as early as 2013 located in the Delta region of Arkansas; specifically, Arkansas, Desha, Monroe and Woodruff counties, but as a winter crop, rather than typically grown in the early spring. Growing Camelina in the winter, if successful, will allow for economic development through the production of biofuel, and a valuable animal feed supplement. It will also provide farmers with an additional rotational crop for generating revenue during the off-season (DeltaBioenergy, 2016).

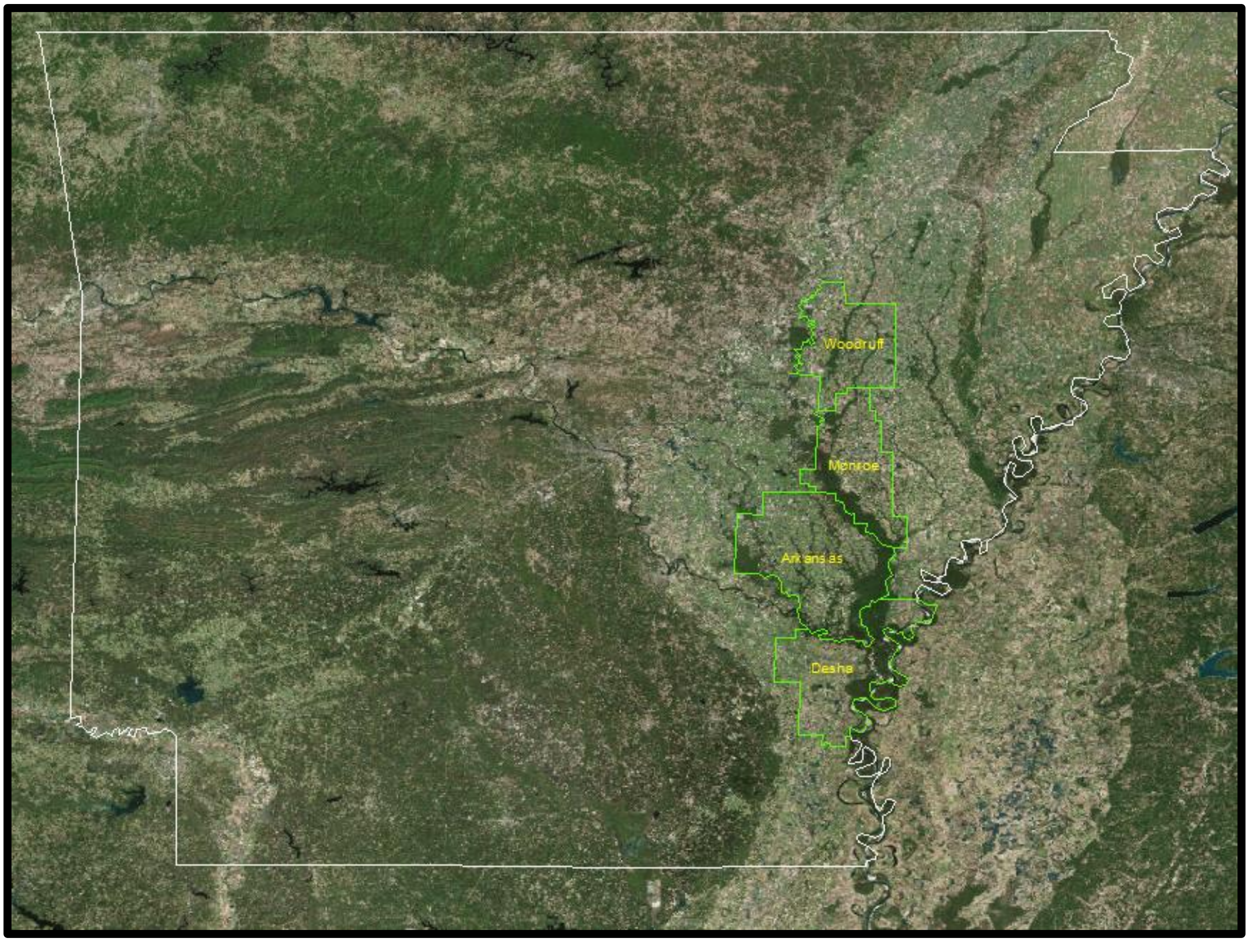

Figure 1: This image represents the four counties focusing on Camelina farming in Eastern Arkansas; Woodruff, Monroe, Arkansas and Desha counties (Data acquired through ESRI).

The first three seasons of Camelina farming in Eastern Arkansas, 2014 - 2016, were unsuccessful, with only 200 pounds of Camelina seed harvested from a small 8 acre field in 2015, and yields of 300 pounds/acre from 16 acres in 2016. In both cases, the harvested seed was planted in December, later than the rest of the failed crop, which was planted in late-October to mid-November. Failure in Camelina farming has largely been attributed to the climate and soil conditions in the area, especially the lack of adequate drainage.

Research into whether environmental and climate conditions are suitable for large-scale winter Camelina farming in Eastern Arkansas will help farmers make key investment decisions. Two key questions are addressed in this study:

1) What does the existing literature and climate data indicate regarding Camelina's optimal growing conditions?
2) How suitable are the growing conditions in Eastern Arkansas for Camelina during the winter season?

In support of the above questions, a research hypothesis was addressed in this study: climate and soil moisture conditions in Eastern Arkansas are not suitable for large-scale Camelina farming. This research is the first known research to identify Camelina suitability within the state of Arkansas.

2 Literature Review

Successful Camelina farming has occurred for many years in parts of the United States, with a major effort underway in the Northwestern states to produce Camelina in large-scale dryland conditions. Based on compiled research, it was identified that Camelina requires at most, 15 inches of rainfall, with field trials in California reporting success with just 7.5 inches (George et al; George et al, 2015). Camelina has shown to be very resistant to extreme weather prior to maturation, with reports of seedlings withstanding temperatures as low as 12 degrees Fahrenheit (Ehrensing and Guy, 2008). Field trials within the study area have shown less resilience in mature plants, especially in wet conditions. Research at the University of Wyoming supports this in a 2015 field trial that experienced a complete seed yield loss after rainfall just prior to harvesting (Sintim et al, 2015). Research indicates that Camelina grows best in semi-arid environments, with the highest yields reported in areas receiving 18-25 inches of annual precipitation (USDA, 2011). Wetter environments have shown difficulty with successful Camelina trials, both in Pennsylvania, and during initial field trials throughout the study area. The area of interest in the Mississippi Delta region of Arkansas has very poor drainage, and averages nearly 50 inches of precipitation a year (NOAA, 2016).

2.1 Camelina Farming throughout the U.S.

Camelina has been grown in a number of regions throughout the United States, with some areas having years of successful Camelina farming, while others have just recently conducted field trials. Camelina has predominately grown well in drier conditions, with some regions experiencing difficulty in summer heat and wetter environments.

2.1.1 Minnesota

Camelina has been researched at the University of Minnesota for over 50 years. When planted as a winter crop, Camelina flowers in late April into early May. Yield rates within the state have been reported to be up to 1700 pounds/acre. Research suggests breeding a winter variety could produce even higher yields (Anderson et al, 2016).

2.1.2 Montana

Recent substantial field trials have been conducted in the early 2000s at Montana State University when the Montana Agricultural Experiment Station (MAES) identified the crop as having significant potential. By 2006, a few potential producers started planting the crop for commercial production. It is estimated that up to 20,000 acres of Camelina was planted during the 2006 season. By 2007, an estimated 24,000 acres of Camelina had been planted. It was during these initial trials that the importance of planting in colder temperatures was discovered, as planting later in early spring severely decreased seed yields when compared to planting in the late winter months (McVay and Lamb, 2008). In Montana, under dryland conditions (15-18 inches of annual precipitation) Camelina is expected to yield 1500-2000 pounds/acre with harvesting taking place in late June into July. The highest yields have been reported further west in Eastern Washington, in an area of 18-25 inches of annual precipitation, where greater than 2000 pounds/acre are consistently reported (USDA, 2011).

2.1.3 Washington

From 2008 to 2011, crop trials were conducted during the winter season and were successful in the state of Washington. Based on climate conditions in the region, it was found that the best yields occurred when planting in late winter, in the months of February and March. It was also identified that planting Camelina directly after harvesting cereal crops produced higher yields than when planted on fallow fields. The research in the area was specifically conducted for potential fuel production purposes (Hulbert et al, 2012).

2.1.4 North and South Dakota

From 2005 to 2007, Camelina was used in field trials to identify crops that are adapted to semi-arid environments of the central and northern Great Plains. It was quickly discovered that Camelina is very resilient to the cold and dry conditions during the early spring. It was concluded that Camelina would be suitable for production in the northern High Plains with irrigation required in some cases. It was also discovered that pod shattering during harvesting had a significant effect on yield losses, and that Camelina seed oil content was greatest at mid-harvest, when roughly 75% of the Camelina pods were ripe (Sintim et al, 2015).

2.1.5 Kansas

In 2013, research at Kansas State University Agricultural Research Center, in Hays, KS showed dramatic differences in seed yields based on planting dates in the spring. Research concluded that early seeding allowed the Camelina to flower before the summer heat, as well as seedlings to sprout in the colder soil temperatures, ultimately producing significantly higher seed yields (Obour et al, 2015).

2.1.6 Nevada

In 2012, an article in the Countryside & Small Stock Journal detailed the success of Camelina by a farmer in central Nevada, at an elevation of 6000'. The farmer himself explains how successful the crop has been in a drought prone environment, and that the cooler temperatures as well as the lack of significant moisture allows for high yields of Camelina oil. The farmer explains how truly adaptable Camelina is due to its low fertility requirements, drought tolerance, and resilience to very cold temperatures; having success planting in both the spring and winter months (Hoard and Hoard, 2012).

2.1.7 Pennsylvania

The first documented research of Camelina trials in the United States outside of the Western states and the Central High Plains was in Pennsylvania. In 2007, the Penn State Cooperative Extension purchased 1,000 pounds of Camelina seed for farmers to grow (Mulhollem, 2008). In the limited amount of experience, it failed as a winter crop due to heavy snowfall in the Northwestern part of the state, and was instead planted as a spring crop. It was discovered in initial Pennsylvania trials that Camelina does not perform well in wet and poorly drained soils, having performed well in the drier conditions out west. Camelina success was dependent on the year, and ultimately trials were stopped due to climate and economic factors (Hunter and Roth, 2010).

2.2 Suitability Modeling

Due to the significant differences in climate, a suitability model assessing drainage capabilities was conducted to compare the study area to an area with successful Camelina farming in Montana. There are significant differences in precipitation patterns when comparing Eastern Arkansas to areas that successfully farm Camelina. Camelina traditionally is planted in semi-arid environments where water logged soils from precipitation is normally not an issue. Suitability models have been used in a number of research projects to identify crop suitability based on environmental and climate factors.

2.2.1 Crop suitability modeling in Illinois

In Illinois, a suitability model was created to determine the state's suitability for various crops. Several different variables were used, including crop soil requirements (soil texture, soil pH, and soil drainage), and climate variables (daily maximum and minimum temperatures, precipitation, extreme minimum winter temperature, and growing days) to identify suitable regions in Illinois for 414 different crops. Crop requirements were compared with soil and climate conditions on a regional basis to determine suitability within the state (Bowen and Hollinger, 2004).

2.2.2 Crop suitability modeling in Hawaii

In Hawaii, a graduate student conducted a suitability model to assess the suitability of macadamia nuts and coffee throughout the Big Island. Environmental datasets including rainfall, temperature and soil properties were compared to the ecological ranges of coffee and macadamia. Crop requirements and environmental data were then assessed to identify compatibility for a given site (Gross, 2014).

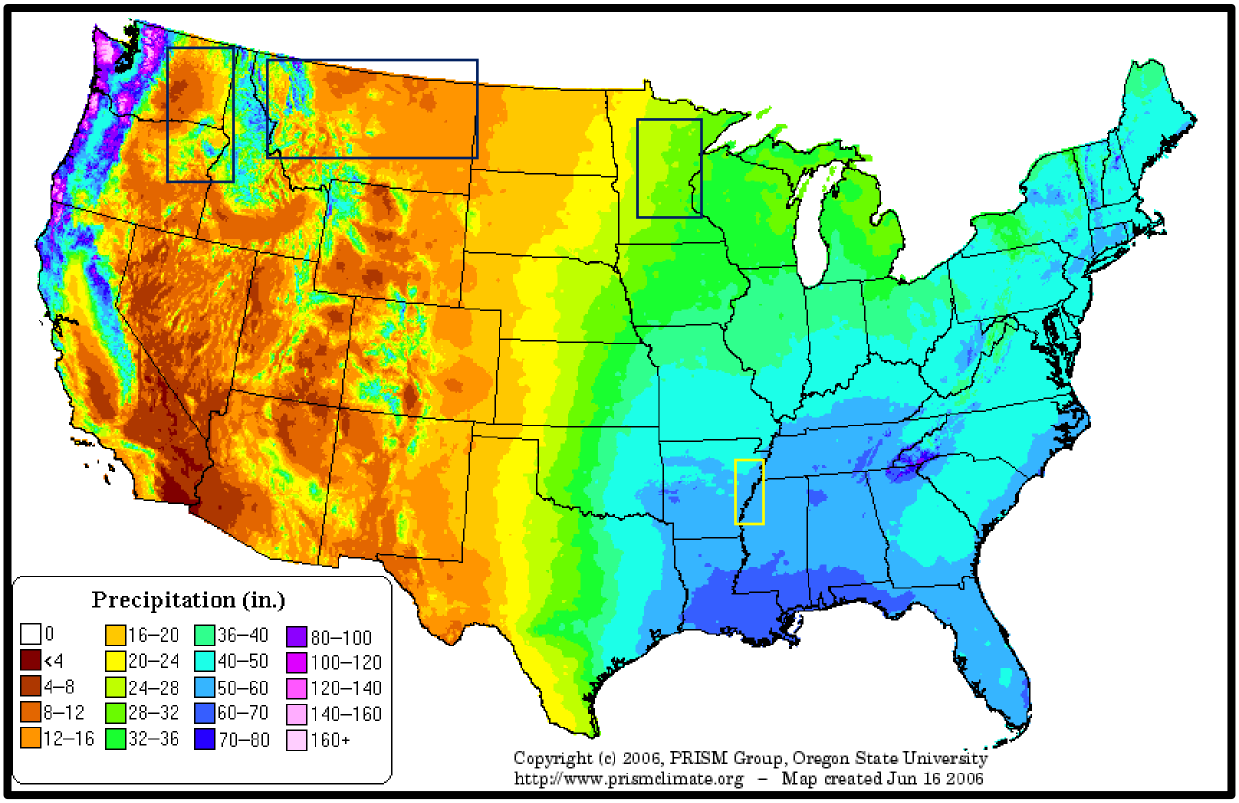

Figure 2: This US annual precipitation map shows significant differences when comparing areas of current large scale Camelina farming to the study area. Camelina is farmed mostly in areas that receive between 12-25 inches of annual precipitation. The study area receives nearly 50 inches.

3 Materials and Methods

3.1 Study Area

The study area is comprised of four counties within the Arkansas Delta; Arkansas, Monroe, Woodruff and Desha counties (Figure 3). The Arkansas Delta is comprised of a series of river basins that empty into the Mississippi River; these rivers include the St. Francis, White, and Arkansas rivers. Eastern Arkansas was initially settled in the early 1800's, and was covered in heavy forests and swamps. Today a very different landscape exists, comprised of predominately agricultural fields and small farming communities (Bowden, 2012)

According to the 2012 US census tract, the area of interest has a population of just under 50,000, with an annual median household income of just over $30,000. The economy is predominately agricultural, with most farmers farming rice and soybeans. This area of Arkansas is known as the "rice capital of the world", largely attributed to very fertile soils, and an abundance of precipitation. In 2013, select farmers volunteered to plant Camelina as a potential rotational crop during the winter season due to a local demand in biofuels. Initial trials have been unsuccessful, largely attributed to the wet climate in the region. The study area receives nearly 50 inches of annual precipitation, with an average of 29 inches during the current growing season. (NOAA, 2016).

An area in Flat Head County, Montana, near Creston, was used to compare Camelina suitability to the study area, due to its success in large scale Camelina farming. Creston averages just shy of 20 inches of annual precipitation, with an average of just 8 inches during the Camelina growing season (NOAA, 2016).

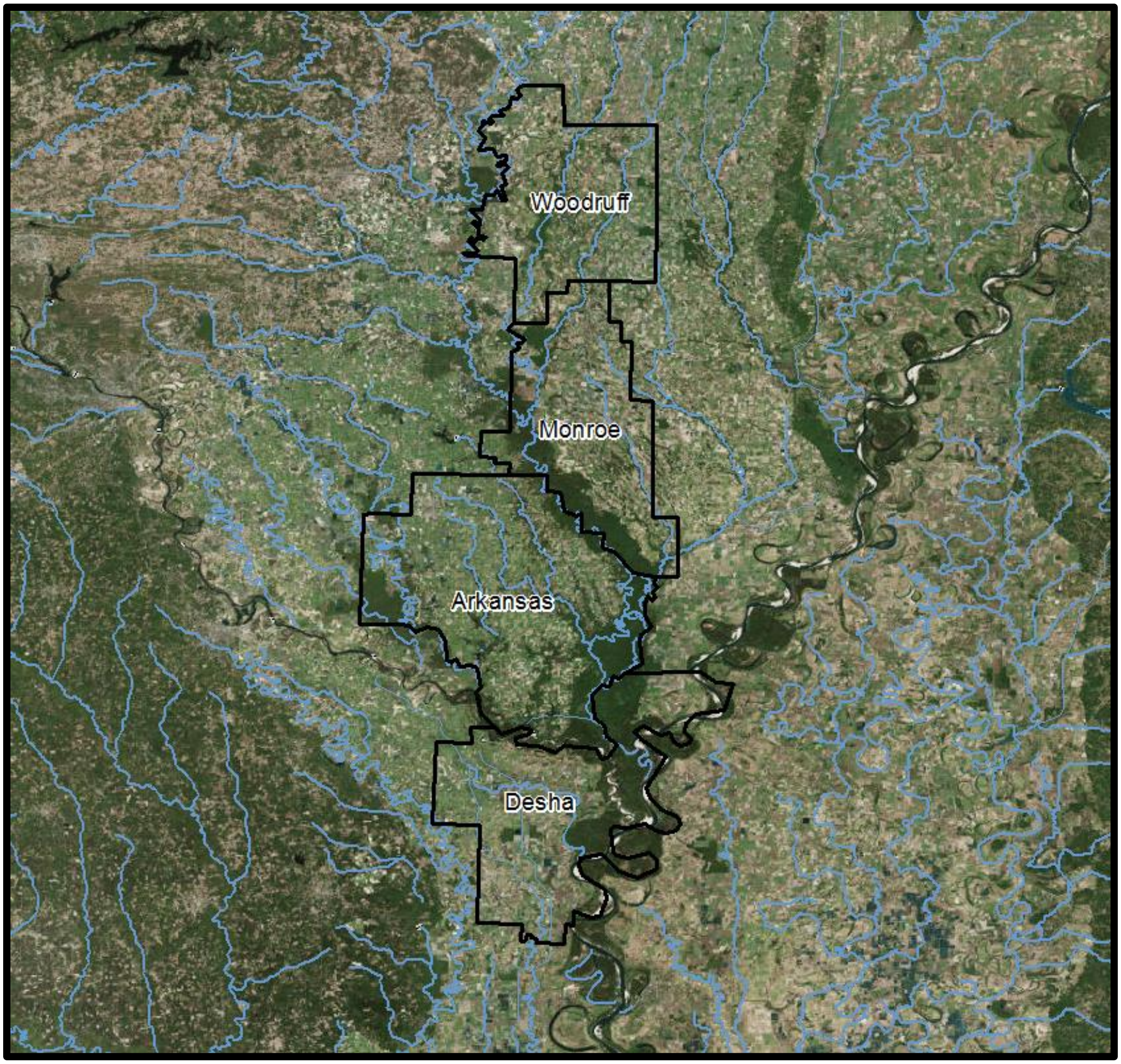

Figure 3. This image shows the study area in Eastern Arkansas. Many streams and rivers can be found throughout the region (Data acquired through ESRI).

3.1.1 Recent Camelina Trials

Camelina has proven to grow without problems in Eastern Arkansas during dry conditions. Camelina has successfully survived through harsh winter temperatures within the study area, suggesting that temperatures are not the main factor in failed Camelina trials. For the past three seasons, the majority of the planted Camelina died after heavy rains, specifically crops that were more mature, and in areas prone to ponding. The surviving crops were the least mature and were in slightly higher ground, providing for better drainage. Photographic evidence shows this in Figures 4-6 taken during the 2015-2016 season.

Figure 4: This image was taken shortly prior to heavy March rainfall and shows healthy growing Camelina on February 29, 2016. Photo courtesy of Communities Unlimited, Inc.

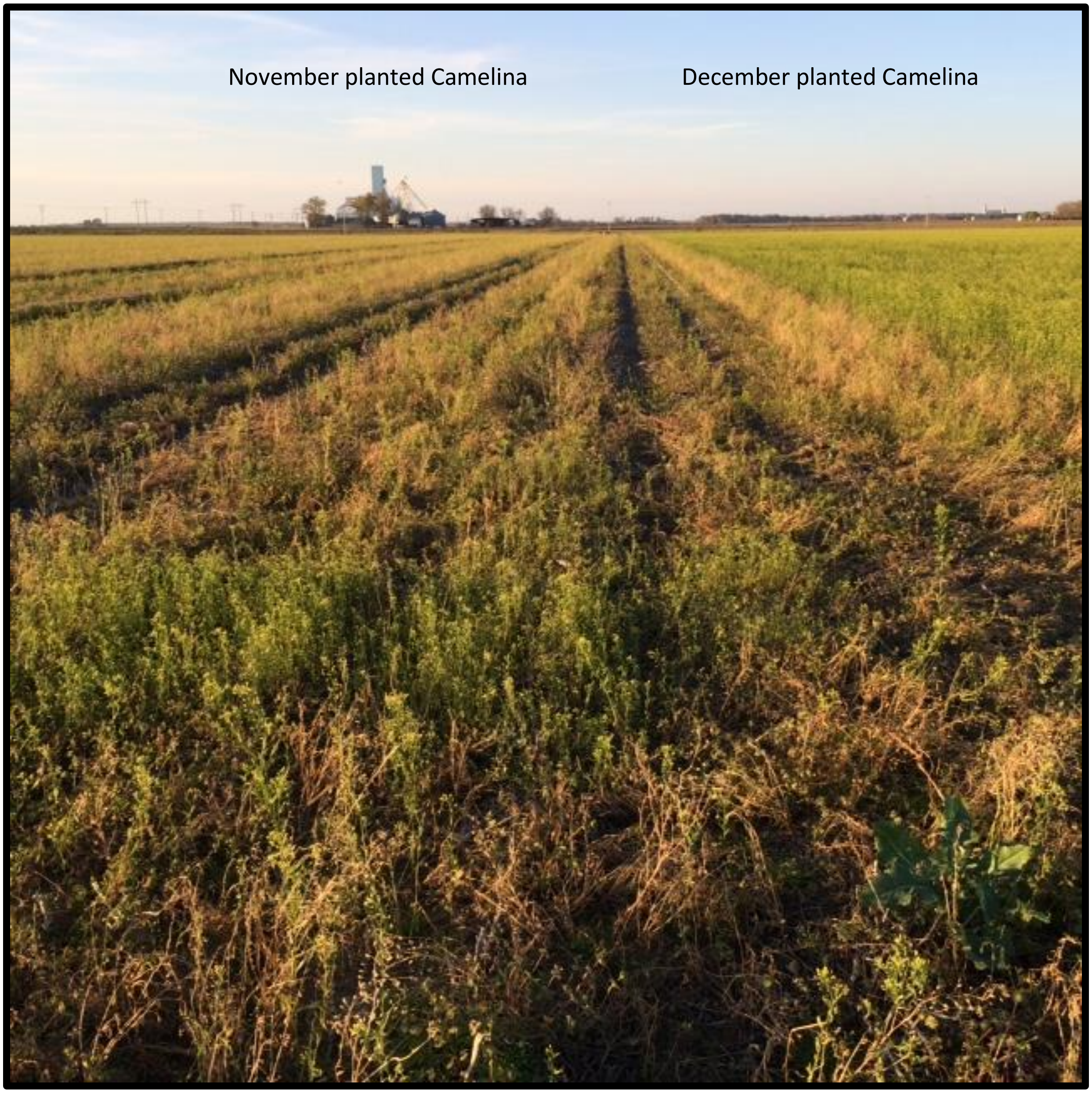

Figure 5: This image was taken shortly after March heavy rainfall. The majority of the Camelina planted in November was destroyed, whereas the December planted crop survived the heavy rains. Research and field trials indicate that as the crop matures, it may lose its resiliency to colder and wetter conditions. Photo courtesy of Communities Unlimited, Inc.

Figure 6: This image was taken shortly after heavy rains in March, and shows a large area of Camelina destroyed from ponding due to the lack of drainage. Photo courtesy of Communities Unlimited, Inc.

3.2 Field Data Collection

In May of 2015, and June of 2016, a variety of data was gathered by Communities Unlimited, Inc. within the study area, including crop field polygon boundaries, and planting, growing, and harvesting dates from each of eight farmers who volunteered to plant this experimental crop. Field boundaries were collected using a handheld mapping grade GPS, and farmers were asked to submit farming information. It was identified that farmers were farming on the same soil conditions (Silt Loam), and on flat terrain, with many of the fields located on flood plains. The majority of the farmers were also using the same herbicide and pesticide; with the only noticeable difference being the planting date.

	Date Planted	Number of days grown until February Winter Storm	Outcome
Farmer 1	12/10/2014	67	25 lbs/acre
Farmer 2	11/25/2014	82	Fail
Farmer 3	11/20/2014	87	Fail
Farmer 4	11/3/2014	104	Fail
Farmer 5	11/3/2014	104	Fail
Farmer 6	11/3/2014	104	Fail
Farmer 7	11/3/2014	104	Fail
Farmer 8	10/28/2014	110	Fail

Table 1: The table shows planting dates from the 2014-2015 season, along with the total growing days up to a very wet and cold late winter storm that affected the majority of the eastern part of state between 15 and 17 February, as well as the crops outcome.

Camelina was growing very well during the start of the 2015 season, with a successful harvest looking promising. This quickly changed after a mid-February winter storm affected the region, bringing below freezing temperatures, snow and freezing rain. Nearly all of the Camelina was destroyed.

Table 1 shows all but one Farmer's crop survived a late winter storm, producing yields of just 25 pounds/acre. This was partially attributed to a very late harvest date. Farmer 1 planted in a small 8-acre field on slightly higher ground, possibly providing better drainage. The surviving crop was planted in December, unlike the rest of the crop having been planted in either late October or November. Camelina typically takes 85-100 days to fully mature as a spring crop, taking longer as a winter crop. It is thought by some that even though Camelina is very resistant to extreme winter temperatures and precipitation as a young crop, it quickly loses its resiliency when it reaches a certain stage of maturity. The December planted crop may have been slightly more resistant to the colder temperatures and precipitation amounts, allowing it to survive, unlike the earlier planted crops.

Date Planted	Number of days grown before heavy March rainfall event	Outcome
11/5/2015	121	Fail
11/11/2015	115	Fail
12/11/2015	85	300lbs/acre

Table 2: The table shows the planting dates from the 2015-2016 season, along with the total growing days up to a 5-day heavy rainfall event in March that affected the majority of the eastern part of state, dumping up to 10 inches of rainfall between 9 and 14 March, as well as the crops outcome.

The 2015-2016 Camelina season was an even bigger disappointment. Crops were beginning to bolt, and were just weeks away from harvesting before a heavy rain event affected the region for a five-day period in mid-March. Up to 10 inches of rainfall fell within the study area.

During the 2015-2016 season, 48.2 acres of Camelina was planted on three different planting dates; November 5, November 11, and December 11. Even though cold temperatures did not play a factor in this year's crop, heavy rainfall in the late winter season destroyed the majority of the crop due to poor drainage conditions. Only 16 acres successfully made it to harvest; which was roughly sixty percent of the crop that was planted in early December. It is possible that the crop had not yet fully matured, and was still resilient to the harsh weather conditions. The surviving 60% was planted on slightly higher ground, unlike the rest of the crop, which potentially provided better drainage. Even with the surviving crop, only 4700 pounds of Camelina seed made it to harvest, a yield of roughly 300 pounds/acre, well below what is considered viable. Camelina seeds are very small and fragile (Figures 7-8), leading to considerable loss during harvesting. Identifying a harvesting technique that is better suited for Camelina seeds may allow for higher overall yields.

Figure 7: This image shows Camelina just prior to harvesting in May of 2016. Photo courtesy of Communities Unlimited, Inc.

Figure 8: This image shows Camelina pods just prior to harvesting in May of 2016. Photo courtesy of Communities Unlimited, Inc.

3.3 Overall Workflow

Large scale winter Camelina farming is dependent on a number of environmental conditions and constraints. Analyzing terrain conditions such as soil hydrology and drainage is essential in determining suitable areas for Camelina farming. Analyzing climate data is essential in identifying when to plant, and ultimately determining a growing season. Research has indicated that Camelina is sensitive to water logged soils, and may be sensitive to colder temperatures when mature. Analyzing average monthly precipitation and low temperature data, as well as growing degree day data (GDD) will determine whether climate conditions are suitable for Camelina farming, and when.

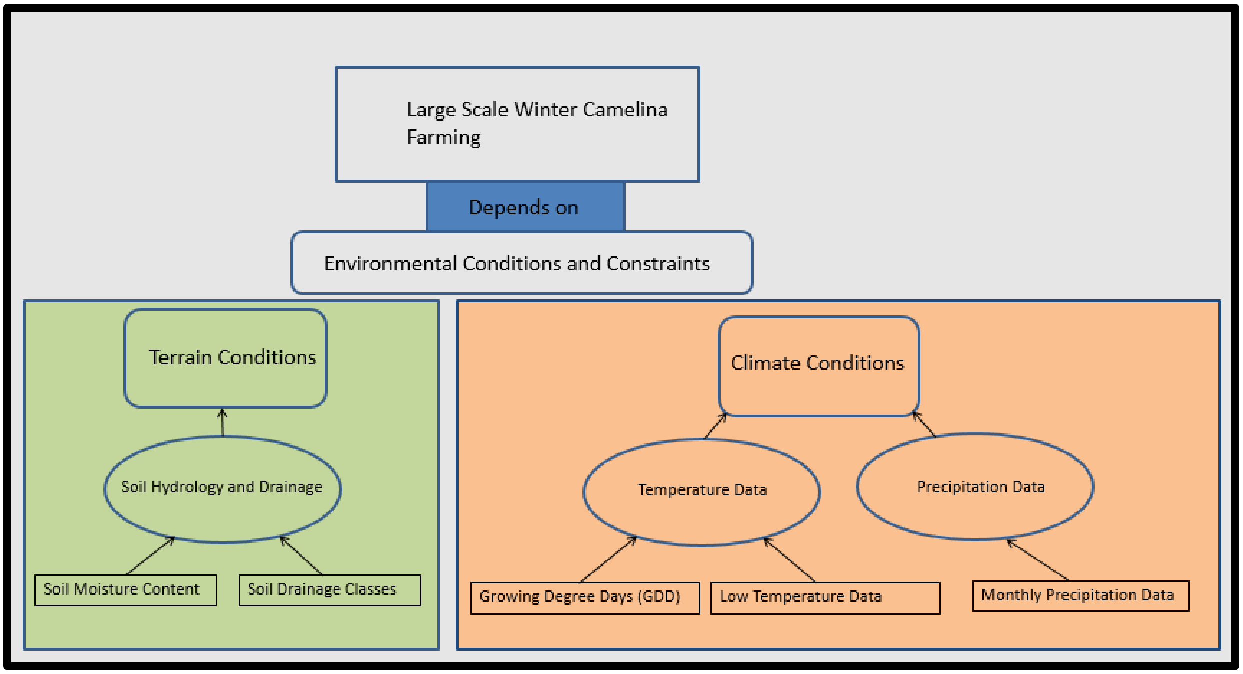

Figure 9: The work flow above shows that analyzing both terrain and climate conditions are essential in determining winter Camelina suitability.

3.4 Software

ArcMap 10 was used for creating the maps throughout this research paper. A work flow was created using Model Builder for a suitability model in determining land parcels that are most suitable for Camelina farming. RStudio was used to create a box plot which can be used to visually identify average low temperatures throughout the growing season. Microsoft Excel was used for converting daily climate data into monthly averages, and for creating all climate graphs.

3.5 Climate data

Assessing climate data is necessary to determine the conditions that exist within the study area, and based on research determine whether these conditions are suitable for Camelina farming. Temperature data was assessed to determine the ideal planting season so that Camelina can endure the cold winter temperatures as seedlings, which has proven to provide higher yields, and mature when temperatures are warmer. Analyzing mean low temperatures and average daily temperatures were used for this process. Graphs were created from daily temperature data gathered from NOAA's national dataset on climate. The data was acquired from a weather station in Des Arc, Arkansas (NOAA, 2016)

Identifying the length of the growing season for the region was identified using cumulative growing degree days (GDD). GDD is the measure of heat accumulation used to predict when a plant will reach maturity for harvesting. Research has shown that Camelina requires cumulative Growing Degree Days (GDD) of around 1300 degrees Celsius, allowing the crop to fully mature for harvest between 85-100 days as a spring crop (Hunsaker, 2012). GDD was also calculated to identify the cumulative measurement of heat during the 2015-2016 season, and identify whether the crop had overgrown. This possibly was a contributing factor to the low yields in the surviving crop.

GDD is determined using the following formula:

$$GDD = \frac{T_{max} + T_{min}}{2} - T_{base} \qquad (1)$$

Where T_{max} is the maximum daily temperature, T_{min} is the minimum daily temperature, and T_{base} is a constant of 40° Fahrenheit representing the base temperature for Camelina, or the temperature at which Camelina successfully grows (Hunsaker, 2012).

Precipitation data was acquired from the same weather station in Des Arc, AR, and was used to assess moisture patterns within the study area, specifically average precipitation amounts during the winter growing season. Daily precipitation data was used to create graphs representing monthly averages. Precipitation data was also acquired from two locations that have had years of successful Camelina farming, St. Paul, MN, and Creston, MT, as well as a Meadville, PN, which has had minimal success with Camelina farming. This data was used to compare and identify the differences in average precipitation within the study area to other locations that have had years of successful Camelina farming, as well as an area that has had similar challenges in successfully farming Camelina.

3.6 Soil Moisture and Hydrology Data

Soil moisture data was analyzed using daily soil moisture content values from an automated weather station in DeWitt, AR, part of the Soil Climate Analysis Network (SCAN). This is a network of automated weather stations across the country that monitors real-time soil and weather conditions. Data was used to create a graph that identifies soil moisture content from 2014-2016. This data was used to identify soil moisture values throughout the year, but more importantly during the growing seasons. Research has identified Camelina being sensitive to waterlogged soils, which is thought to be a major factor in preventing successful Camelina farming throughout the region (NRCS and National Water Climate Center, 2016).

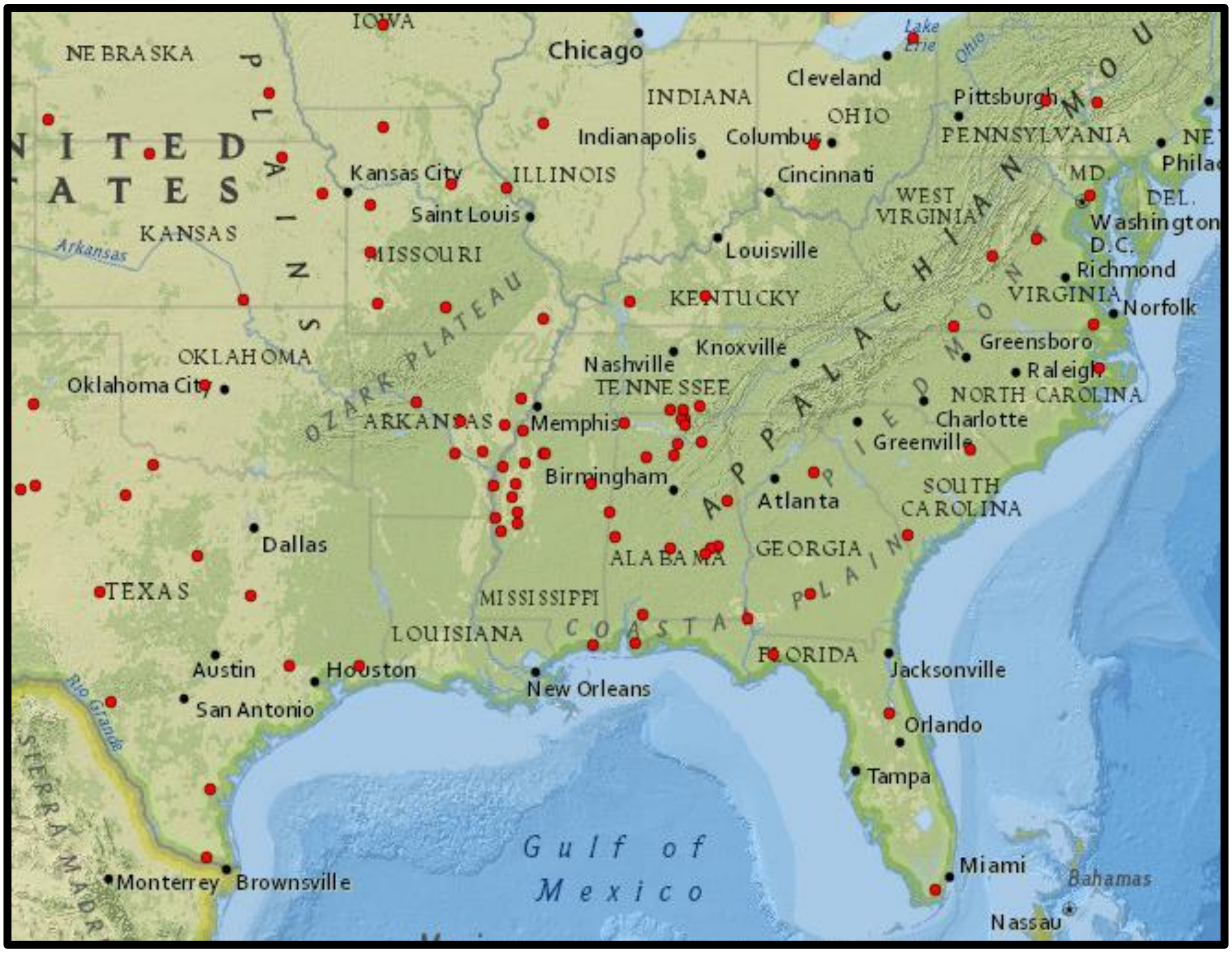

Figure 10: This image shows the placement of weather stations that are part of the SCAN network across the Southeastern U.S.

3.7 Geodata Sources and Access

A workflow and maps were created for part of the study area near DeWitt, AR as well as an area near Creston, Montana to identify and compare land parcels that contain at least 10 acres of Camelina suitability based on three variables; soil drainage classes, slope and land classification. Soil drainage class data was acquired through ESRI which was created from soil types and porosity values identified by USDA NRCS (Dangermond, 2012). Slope data was acquired through 5-meter resolution digital elevation models from USGS National Elevation Dataset (USGS, 2015). The study area's land classification and parcel data was acquired through the Arkansas GIS Office, with land classification data published in 2007 from the Center for

Advanced Spatial Technologies (Arkansas GIS Office, 2016; Center for Advanced Spatial Technologies (CAST), 2007). Land classification and parcel data from Creston, Montana was acquired through the Montana State Library and was published by Flathead County GIS in 2016 (Flathead County GIS, 2016).

3.8 Geospatial Processing

A workflow was created using Model Builder in ArcMap 10.4, to identify land parcels that contain at least 10 acre fields that are suitable for Camelina farming. The model identifies drainage capabilities and uses three variables; soil drainage classes, land classification and slope. The model can be run for any specified location. Slope should be reclassified as suitable from 0.5 – 3 degrees for areas that receive an average of 15 inches or more precipitation during the growing season, and 0 – 3 degrees for areas that average less than 15 inches of precipitation during the growing season.

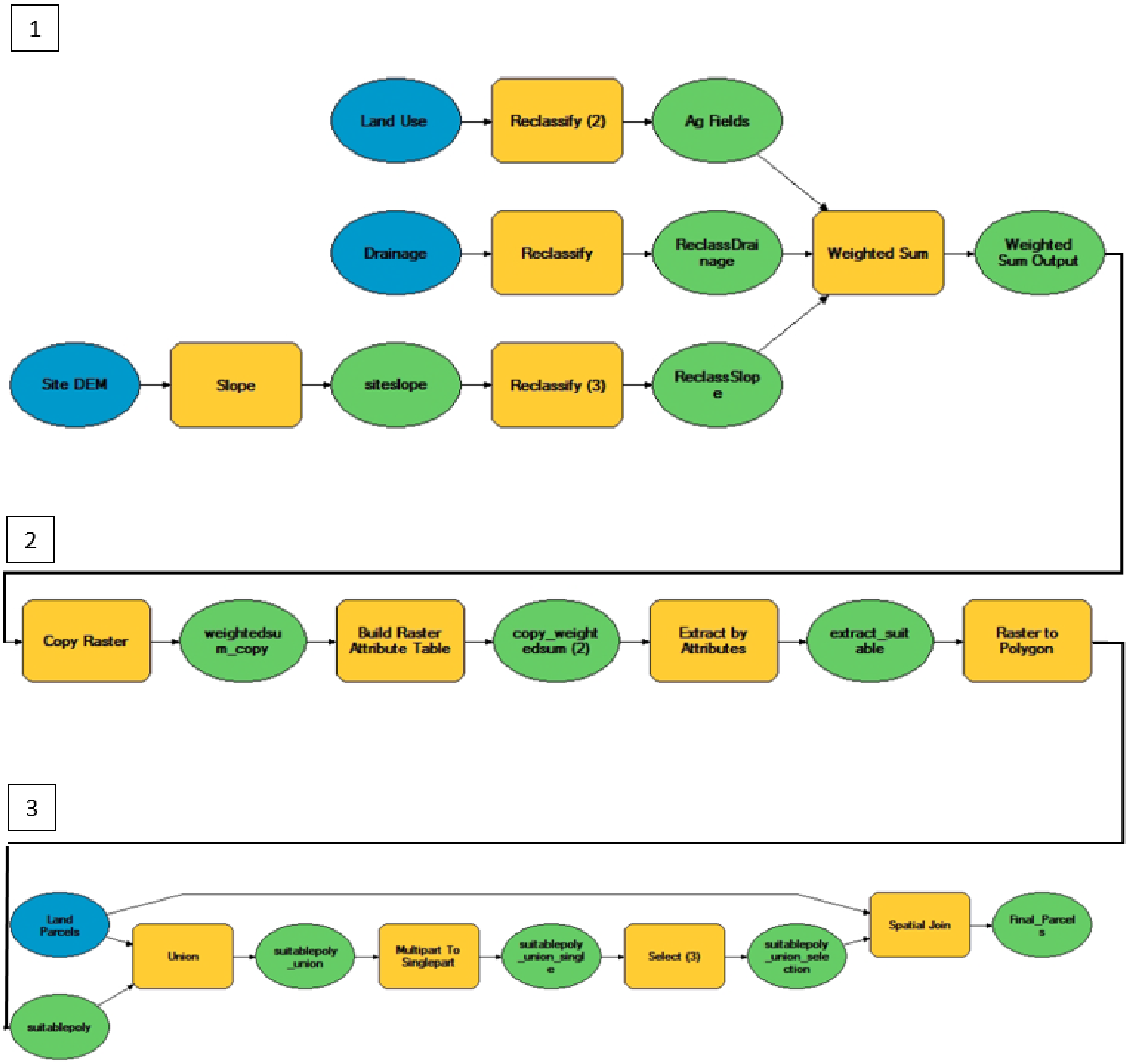

Figure 11: The workflow above was created using Model Builder and identifies land parcels that are most suited for Camelina farming using the variables: Land Use, Soil Drainage Classes and Slope, with Slope being derived from a 5-meter resolution Digital Elevation Model.

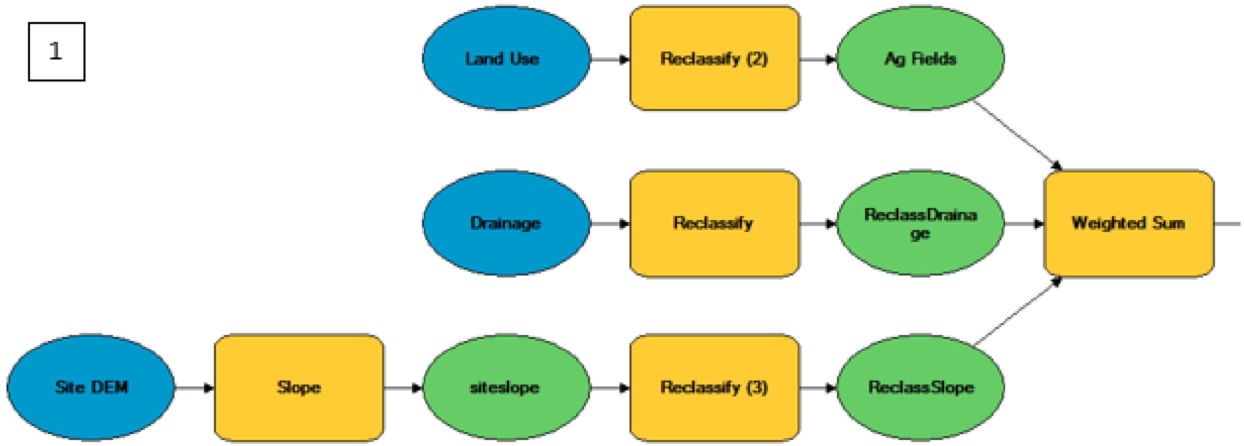

Figure 12: Step 1 shows a Slope model being created from a Digital Elevation Model. The Slope, Land Use and Drainage Class variables are then reclassified and input into a Weighted Sum. Land Use is reclassified to only identify agricultural fields, Drainage Classes are reclassified to identify well-drained soils, and the Slope model is reclassified to identify slopes from 0.5 – 3 degrees.

In Step 1, a land use layer is reclassified to only identify agricultural fields, drainage classes are reclassified to only identify areas with well drained soils, and a slope model is created using a 5-meter resolution DEM. The slope model is then reclassified to identify locations with 0.5 – 3 degree slope to exclude areas prone to ponding, and identify areas with adequate drainage. After reclassification, the three layers are then used in a weighted sum, which identify areas from 0 – 3, with 3 being areas that are the most suitable for Camelina farming.

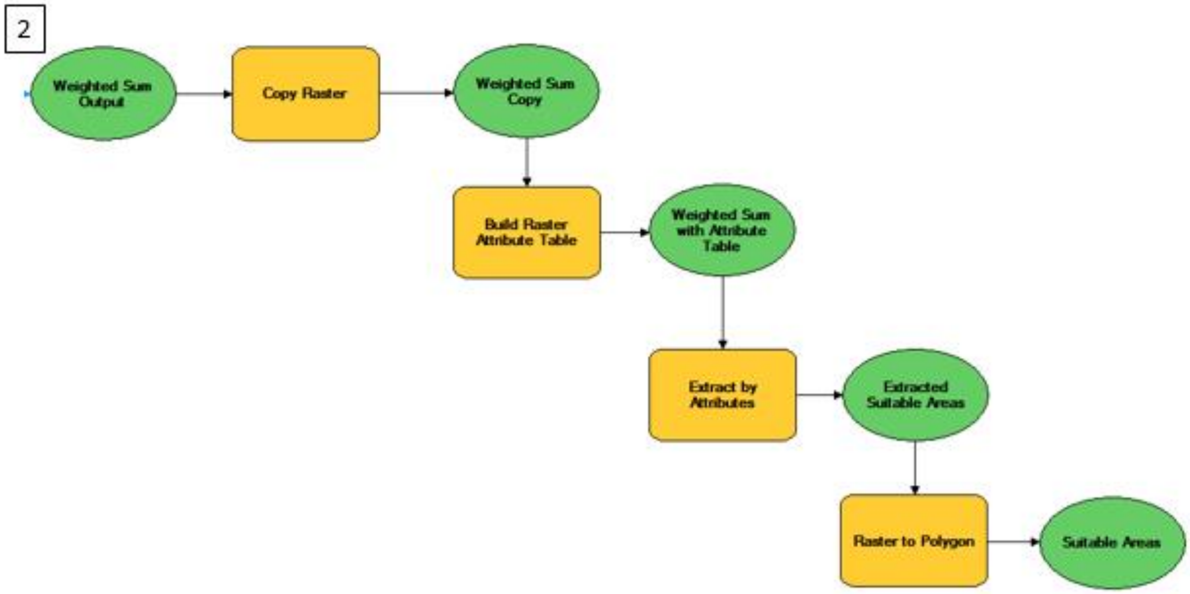

Figure 13: Step 2 shows the steps needed to convert the weighted sum dataset from raster to vector format. A copy of the dataset is needed to build a raster attribute table before extracting the most suitable data, before finally converting to polygons.

In Step 2, the output weighted sum is then copied to allow for the creation of an attribute table. The weighted sum now has attributes and all areas with a Value of 3 are then extracted, leaving only areas that are the most suitable for Camelina farming. The raster dataset is then converted to vector data using the tool, Raster to Polygon.

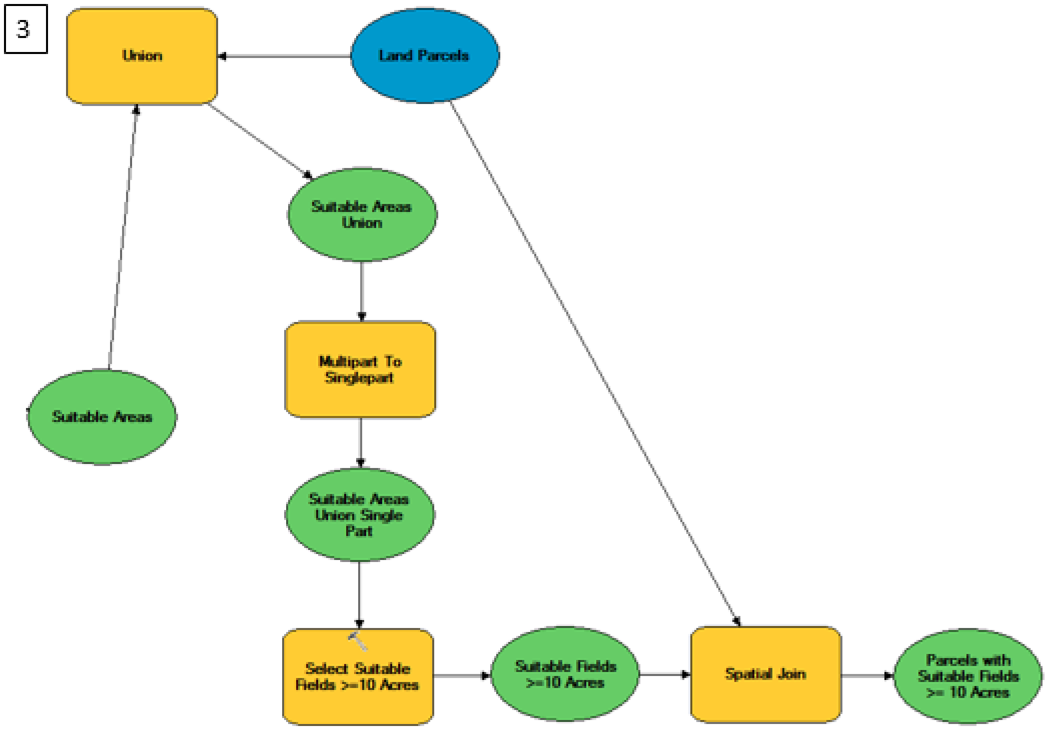

Figure 14: The final step of the workflow shows the steps needed to identify land parcels that contain at least 10 acres of suitable Camelina fields. After performing a union between the suitable polygons and land parcels, the multipart feature is converted to single part features before a selection is made to identify suitable polygons that are at least 10 acres in area. A spatial join is then performed to identify the land parcels that contain the most suitable fields.

The final step creates a union between the extracted most suitable polygons and land parcels within the target area. This output multipart feature is then converted to single part features that contain the attributes of both datasets. A selection is made to only identify suitable polygons that are at least 10 acres in area. A spatial join is then performed to identify the land parcels that contain the selected suitable fields.

4 Results and Discussion

4.1 Temperature Data

Assessing temperature data is critical in determining a growing season. The results provide data on identifying when to plant Camelina so that seedlings grow in colder temperatures, and when mature and most vulnerable, they no longer experience the harsh winter temperatures.

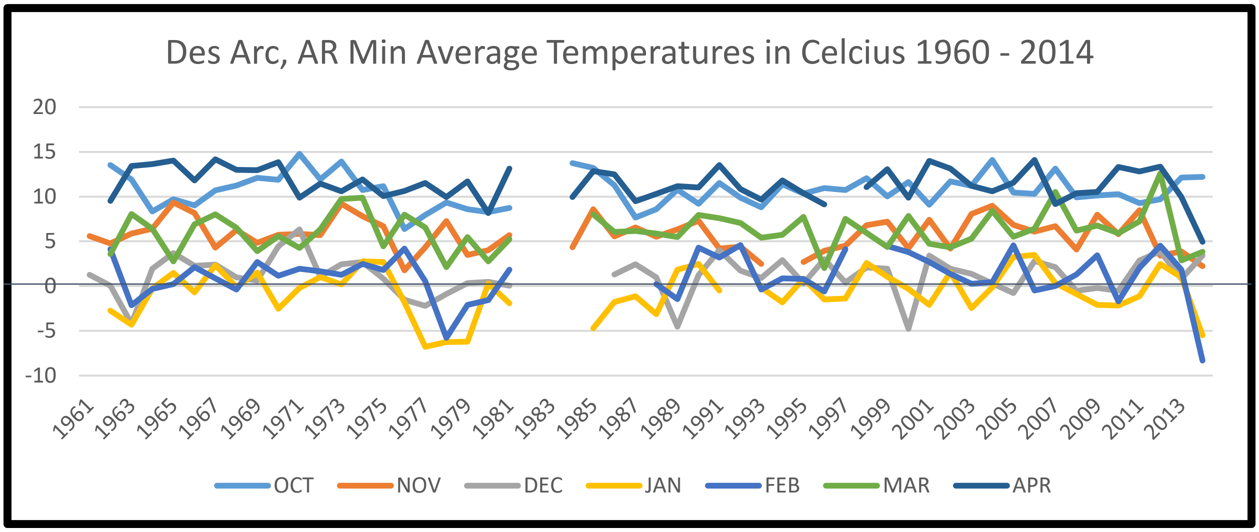

Figure 15: The graph shows temperature data from 1960-2014 from NOAA's national dataset on climate gathered from Des Arc, Arkansas in north central Prairie County.

Figures 15 and 16 show the average minimum temperatures from the past 55 years within the study area, and uses a threshold of 0 degrees Celsius (a freeze). Identifying which months the crop will endure colder temperatures, and when temperatures begin to warm up, allows us to come up with a growing season for farmers. The data shows below 0 degree Celsius minimum temperatures common throughout the months of January and February, with milder temperatures averaging 5 degrees Celsius beginning in March.

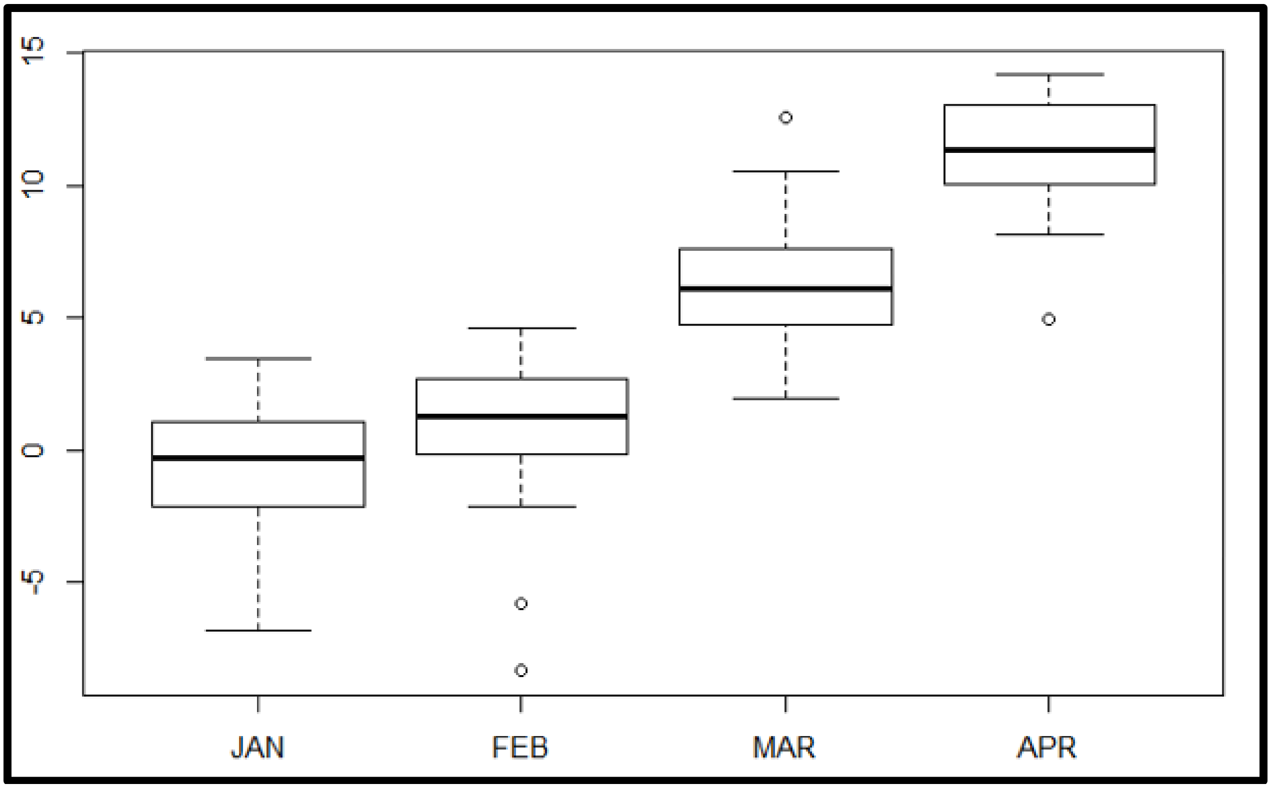

Figure 16: The boxplot above is a great visual representation showing that mean daily low temperatures below the threshold of 0c occur in both January and February, with significant warming evident in March; showing no occurrences of a mean low temperature below 0c.

Year	Month	Cumulative GGD
2015	Dec 10	125
2016	Jan	157
	Feb	228
	Mar	468
	Apr	699
	May 20	599
2015-2016	Sum	2276

Table 3: The table above shows the sum of the 30-year average daily growing degree-days (GGD) during the 2015-2016 growing season for the study area.

Based on the data in Table 3, crop maturity should occur in mid to late April, rather than in May. The current growing season of Dec 10 to May 20th shows a cumulative GDD of 2276 degrees Celsius. Research has shown that the highest yields occur when 75% of the crop is mature, and that yield rates quickly decrease as pod shattering occurs after maturation (Sintim et al, 2015). The high GDD may have been a factor for this seasons low yield rates from the harvested crop. An earlier harvest date may have provided higher seed yields.

4.2 Precipitation Data

Field trials and research have indicated that precipitation and its direct and indirect effects are a significant factor in growing Camelina. Research has indicated that Camelina is tolerant of dry conditions, with field trials suggesting far less resiliency to water logged soils. Camelina requires just 15 inches of rainfall, and based on research grows best in areas that receive around 25 inches of annual rainfall (George et al; USDA, 2011). The study area averages 29 inches of precipitation during the current growing season of December through mid-May, with an annual average of nearly 50 inches, much of which falls in the late winter and spring months. (NOAA, 2016)

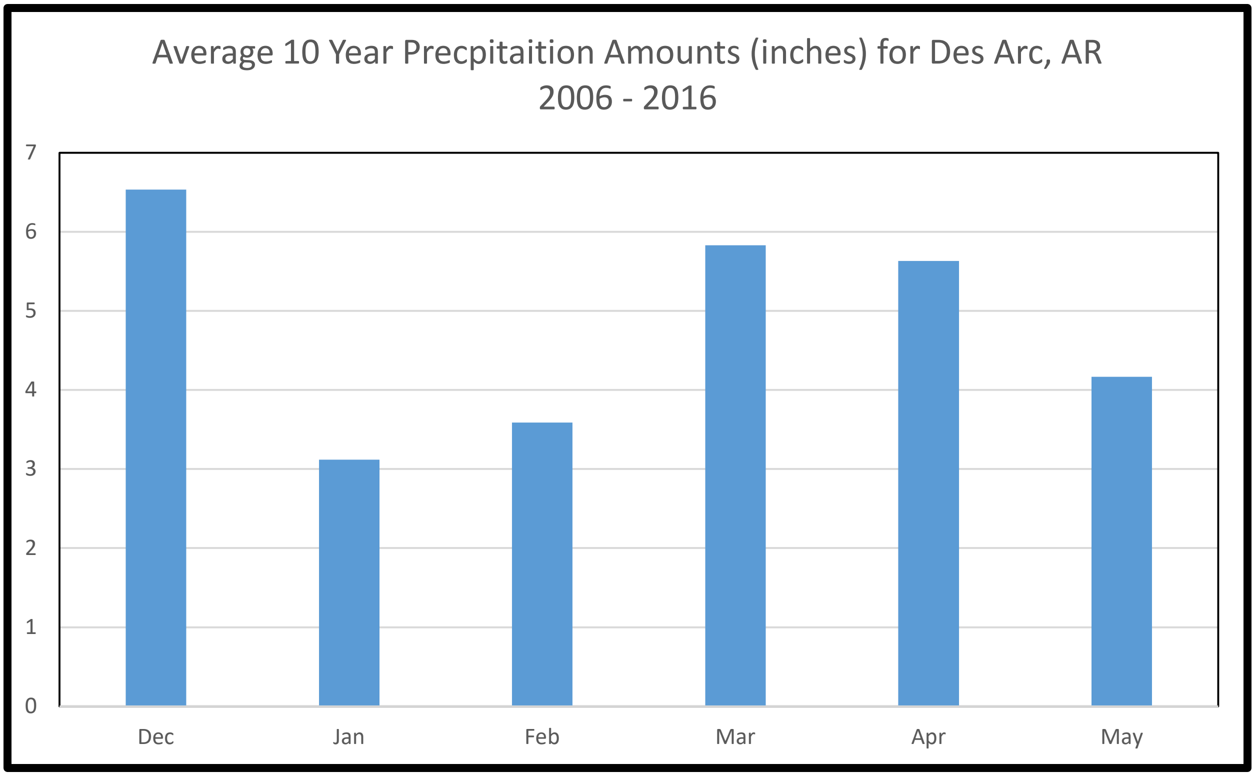

Figure 17: The graph shows average precipitation amounts during the current winter growing season of December to mid-May. Heavy rainfall is common throughout the late winter and spring months.

Figure 17 shows that precipitation within the study area averages 29 inches during the current growing season, with heavy rainfall common during the later stages of crop maturation. The study area receives significantly higher precipitation amounts when compared to locations successfully farming Camelina.

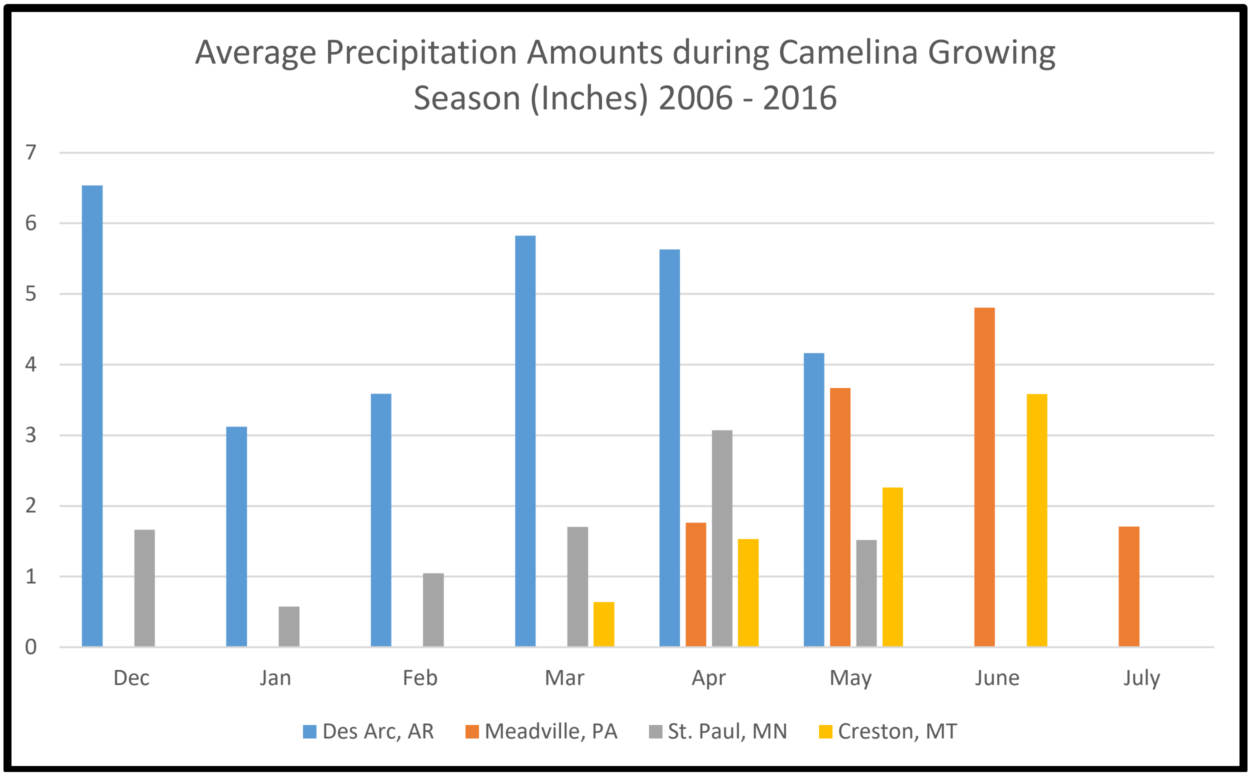

Figure 18: The graph shows significantly more rainfall within the Des Arc, AR study area when comparing average precipitation amounts during the Camelina growing season to other locations farming Camelina.

St. Paul, Minnesota has the same growing season as the study area, but averages just 9.5 inches of precipitation. Minnesota has had tremendous success in Camelina farming, with yields as high as 1700 pounds/acre reported (Anderson et al., 2016). In other states, Camelina is planted in late winter or early spring, usually March or April, and is harvested in June or July. In Creston, Montana, Camelina is planted in mid to late March and harvested in late June. Yields consistently average in excess of 1000 pounds/acre (McVay and Lamb, 2008).

Further east in Pennsylvania, moderate success has been documented. Initially planted as a winter crop, Camelina failed due to the harsh winter conditions. Researchers decided to conduct field tests as a spring crop and experienced moderate success. Some years produced better yields than others, with often times poor drainage and heavy precipitation significantly reducing yields, especially to Camelina that was farmed on flood plains. Unfortunately, after several years of trials, Camelina farming did not prove viable and was abandoned due to both economic and environmental factors (Hunter and Roth, 2010).

4.3 Soil Moisture and Hydrology Data

With heavy precipitation common throughout the study area, and with very little drainage, largely attributed to the very flat terrain, the soil becomes easily saturated during precipitation events.

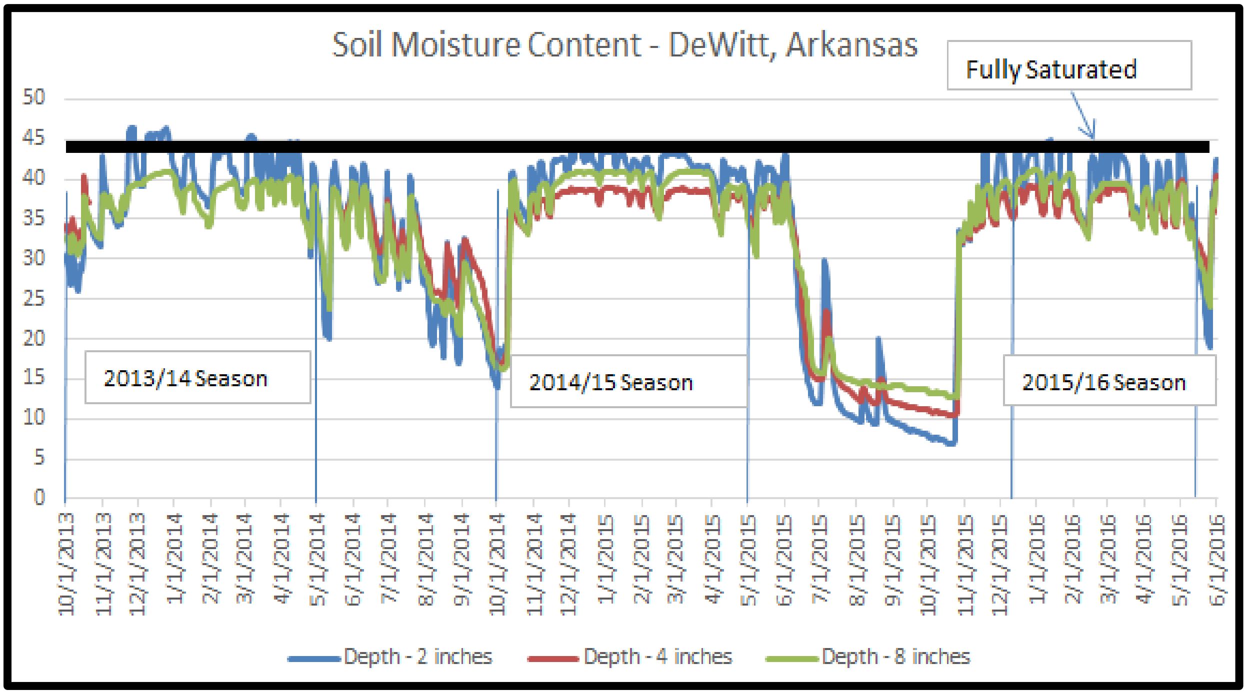

Figure 19: The graph was created using data from NCRS USDA and shows soil moisture content from a weather station in DeWitt, Arkansas. The soil type has a porosity value of .43-.45 and is fully saturated for long periods during the growing season. (Higher values are possibly caused my instrumental error).

Figure 19 shows fully saturated soils common throughout the growing season. Research suggests that Camelina is sensitive to water logged soils. This is supported by research done in the state of Pennsylvania where Camelina failed during wet years, especially in fields that were lacking sufficient drainage (Hunter and Roth, 2010). Preliminary data from the study area over the past three years also supports this, with the majority of Camelina dying after persistent rainfall events. The lack of sufficient drainage and the given soil conditions often time's produces fully saturated soils for long periods. Excess soil moisture and the lack of drainage is likely a significant factor preventing the success for Camelina farming within the study area.

Heavy rainfall events and poor drainage leads to ponding and waterlogged soils. Identifying soil hydrology, specifically drainage capabilities, is essential in determining areas that are better suited for Camelina farming. Analyzing the drainage classes based on the natural, undisturbed drainage condition of the soil gives us a representation of drainage capabilities within the area. The study area is predominately made up of poorly drained soils, which often leads to ponding for long periods of time (Figure 20). The very flat terrain and the soil type does not allow for adequate drainage, so instead the soil is wet at shallow depths for significant periods of the year. This can significantly restrict the growth, and destroy crops unless artificial drainage can be provided.

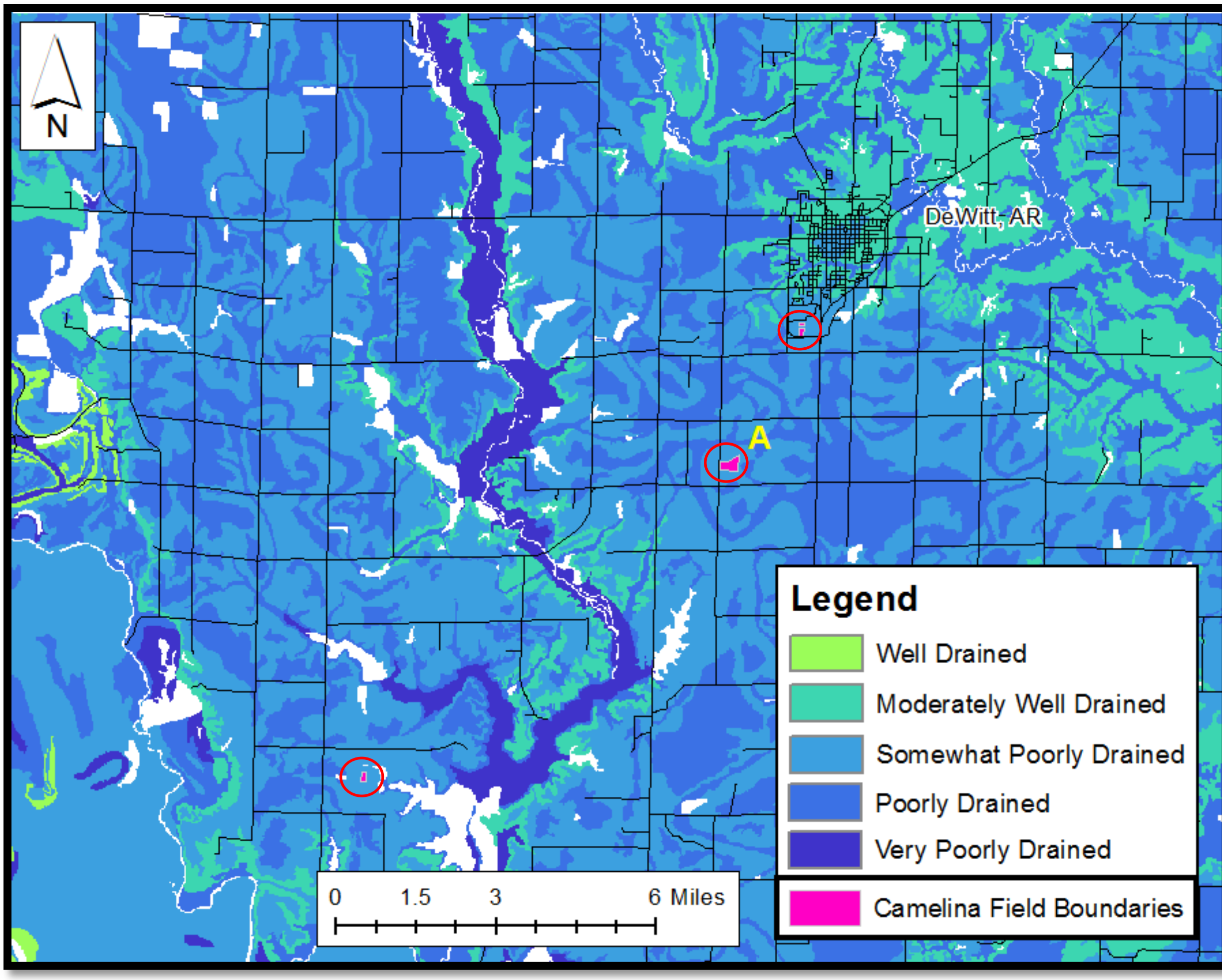

Figure 20: The hydrology map, created from soil drainage class data, identifies an area of Camelina farming near the town of DeWitt, AR. (A) represents a field that has had consistent Camelina farming. It is clearly identifiable that a large portion of the study area is in at least somewhat poorly drained soils, meaning Camelina is planted in an environment which experiences wet soils during a large portion of the year. (Data acquired from Dangermond, 2012)

4.4 Camelina Suitability

The results from the suitability model show drastic differences in land suitability for Camelina farming when comparing an area that has been farmed near DeWitt, AR to an area that has had years of large scale Camelina farming in Creston, MT. Figure 21 identifies land parcels near DeWitt that contain suitable fields of at least 10 acres. The lack of suitability is largely attributed to 0 degree slopes, and poorly drained soils. Farming in the identified land parcels should be tested to see whether terrain conditions in the area are the main factors in preventing successful Camelina farming. If Camelina is successfully grown in identified plots, then the model could potentially be used to locate other suitable fields within the surrounding area.

Figure 22 identifies land parcels and suitable fields in an area near Creston, MT, verifying that conditions are suitable for Camelina farming. The same input variables were used in the model except for slope. Creston, MT has dry conditions during its growing season allowing for slope values of 0-3 degrees, compared to .5-3 degrees in the study area to allow for proper drainage.

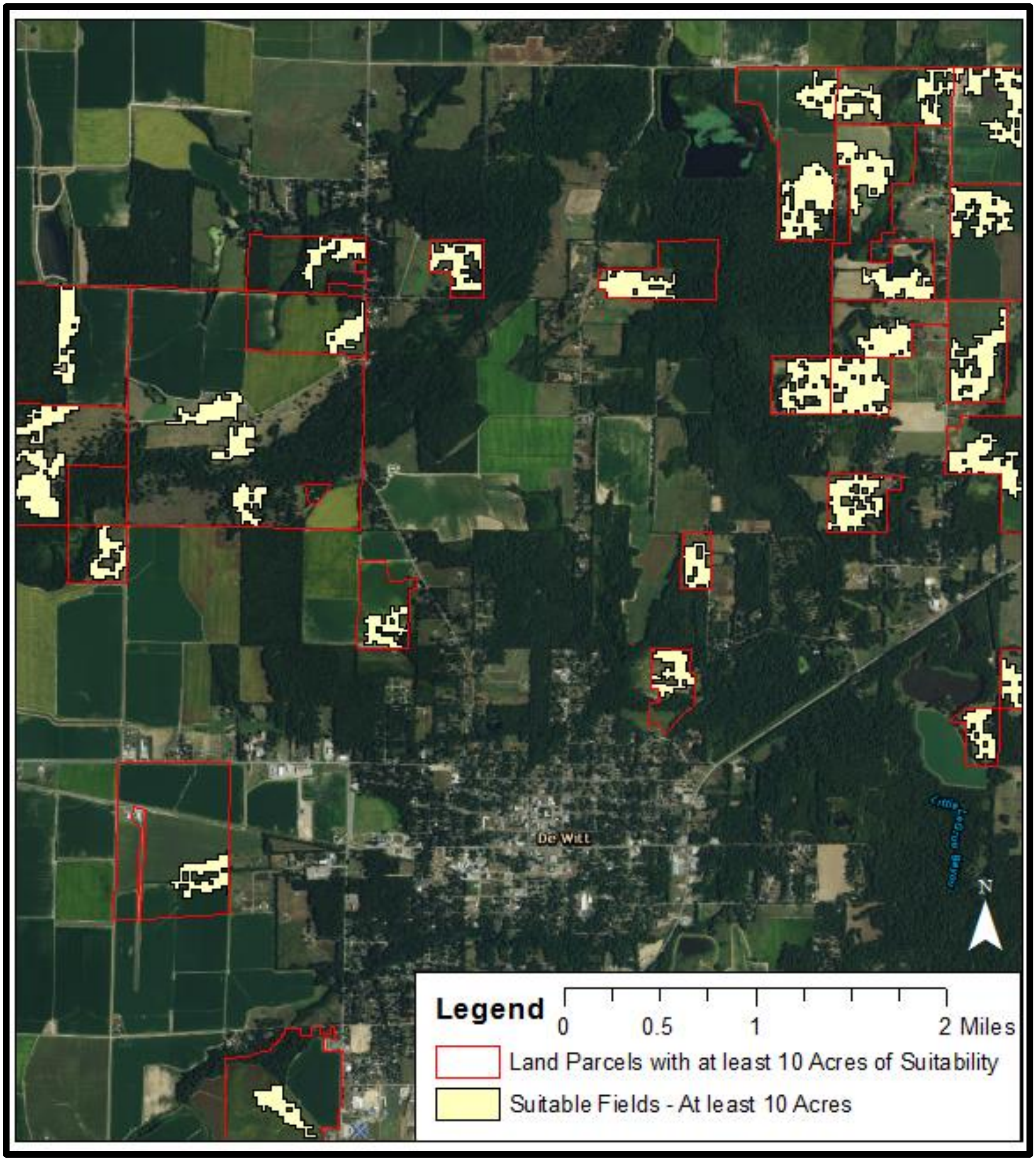

Figure 21: The map identifies land parcels near the town of DeWitt, AR, identifying scattered areas of at least 10 acres of suitablilty for Camelina farming.

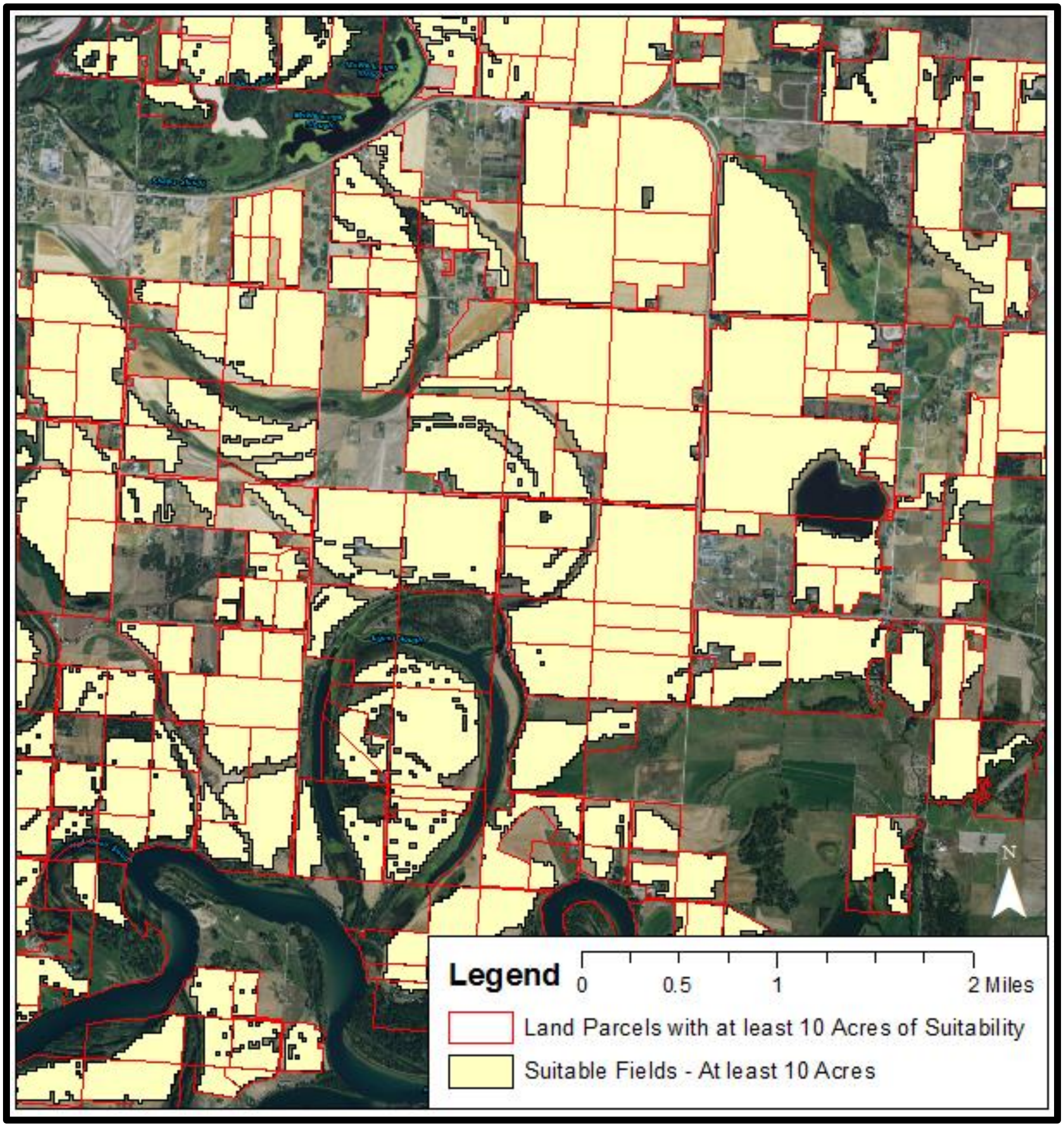

Figure 22: The map identifies land parcels near the town of Creston, MT, identifying large areas of land suitablilty for Camelina farming.

5 Future work

The current suitability model shows significant potential as it has proven that areas in Montana are well suited for Camelina farming, with much less suitability within the study area in Eastern Arkansas. The current model uses strictly terrain variables, looking specifically at drainage capabilities, which based on research is a significant factor in Camelina farming. The model can potentially be expanded to include additional variables such as climate data. It can also be tested further by successfully verifying additional locations that have had successful Camelina farming. Testing identified suitable fields within the study area would be beneficial in verifying that the model works under conditions within the area. If successful, the model can be used to locate additional suitable fields for future small-scale Camelina farming.

6 Conclusion

Compiled research indicates that Camelina grows best in semi-arid environments, with little success in wetter regions. Successful Camelina farming is currently ongoing in the Northwestern states with research indicating the potential for successful Camelina farming in the Upper Midwest. Camelina requires very little moisture when compared to alternative crops, requiring at most 15 inches of rainfall. Research and field trials within the study area indicate that water logged soils have a significant effect on Camelina, with many instances of complete crop loss.

Research and preliminary data suggests that climate conditions are better suited for winter Camelina in Eastern Arkansas during late winter into spring months. Planting Camelina in January or February, will allow for warmer temperatures during crop maturation. This would ultimately allow for a harvest date in May. The more resilient seedlings would experience colder temperatures in January and February, with warmer temperatures beginning in March. However, the abundance of precipitation and soil moisture content during the growing season in Eastern Arkansas, specifically in the months of March and April, does not seem suitable for Camelina farming. Precipitation amounts within the study area are much higher than in areas with current successful Camelina farming. Precipitation and saturated soil conditions seem to be the main factors preventing the success of Camelina farming within the study area.

The suitability model clearly shows that conditions within the study area are not ideal for Camelina farming as it is in parts of Montana. However, the model does have the ability to help farmers identify fields that are more suitable for Camelina farming based on drainage conditions, which may allow for small-scale Camelina farming.

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