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Burning with Potential: Understanding the Relationship between Biochar and Agriculture of the Northern Glaciated Plains Ecoregion

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BURNING WITH POTENTIAL:

UNDERSTANDING THE RELATIONSHIP BETWEEN

BIOCHAR AND AGRICULTURE OF THE

NORTHERN GLACIATED PLAINS ECOREGION

BY

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THESIS ACCEPTANCE PAGE

Kaitlyn Abrahamson

This thesis is approved as a creditable and independent investigation by a candidate for

the master's degree and is acceptable for meeting the thesis requirements for this degree.

Acceptance of this does not imply that the conclusions reached by the candidate are

necessarily the conclusions of the major department.

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GLOSSARY AND LIST OF ABREVIATED TERMS

Biochar	Carbon-rich charcoal biotechnology made from organic feedstock that has undergone pyrolysis and is often used as a soil amendment to improve soil productivity by providing nutrients and support systems that plants need for healthy growth (Lehmann and Joseph 2009, 1);(International Biochar Initiative 2017).
Biomass	The weight of living plant material above ground surface at any given time (Roberts et al. 1985)
Biotechnology	Biotechnologies are manipulations of living organisms or their outputs for productive use (Gaile and Willmott 1989).
EC	Electrical conductivity in soils measure salt levels, or exchangeable ions, in the soil and how well the soil conducts electricity.
NDVI	Normalized difference Vegetation index is a "ratio of the difference between the near infrared (NIR) and the red bands versus the sum of the two bands" (Zhitao et al. 2014, 64).
Northern Glaciated Plains	An EPA ecoregion within the Great Plains of the United States that is highly suitable for crop production, because of its continental climate and plentiful precipitation over a wide spatial range (EPA 2016).
Precision Agriculture	Technologies that increase agricultural productivity and financial earnings while decreasing inputs needed for agricultural production.
Remote Sensing	Data collected through images accessed remotely through spectral cameras and manipulated for analysis.
Soil Fertility	The chemical, physical, and biological properties of soil that allow nutrients to be transferred from soil to plant and determine its ability to foster plant growth.

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ABSTRACT

BURNING WITH POTENTIAL:

UNDERSTANDING THE RELATIONSHIP BETWEEN BIOCHAR AND AGRICULTURE

OF THE NORTHERN GLACIATED PLAINS ECOREGION

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Achieving global sustainable agriculture is one of the most incredible challenges of this century, yet many continue to try to solve this problem through the development of precision technologies. Biotechnologies, such as biochar, can perform like a precision technology while protecting agricultural land from soil erosion and fertility loss. The Northern Glaciated Plains ecoregion of the United States is little researched in the benefits from the use of biochar through improved soil nutrient capture and water retention, crop health improvements, and yield increases. The study plot has four sections of corn stover biochar and eight sections of control sections. This project assessed soil chemical properties by testing topsoil samples, resulting in increased soil pH and electrical conductivity in biochar-amended soils. Remotely sensed normalized difference vegetation index images created from a spectral camera measured soybean phenology through reproductive growth stages and showed the positive effect biochar has on health and associated greenness of soybean plants. Destructive, dry weight soybean biomass measurements taken at soybean maturity showed increased soybean biomass in biochar amended plot sections. The goal was to determine how biochar reacts with a haploboroll soil in Brookings County, South Dakota and if biochar application is an appropriate management strategy for this soil and soils of the greater Northern Glaciated Plains ecoregion of the United States. In this study, results conclude that biochar application may not have the significant productivity

increases necessary to make biochar a highly recommended amendment for this region through this study's soil and soybean reactions to biochar, but biochar has the potential to reduce soil productivity loss through other aspects of soil fertility improvement.

Keywords: biochar, soybean, normalized difference vegetation index, biomass, remote sensing, soil fertility, agricultural geography, precision agriculture, Northern Glaciated Plains

CHAPTER ONE: INTRODUCTION

1.1 Problem Identification and Description

Humans have vastly changed the agricultural system in the United States in the last century. Agriculture has evolved from inventions such as the plow, to high-tech engineering, advancing to a storm of improvements in precision technology that made agriculture a revolutionary field. What comes next in agriculture's surge of sustainability? The possibility of more beneficial, more sustainable, and more economical solutions exists, and just like the agricultural processes of the past, it will take another revolution to discover (Rockström et al. 2017, 14).

Farmers today always want more. They want better performing crops, additional production options, and more product for their money. With technological advancements improving so rapidly, there are many ways farmers can get the most out of the money they spend. Precision technology may help defend against land degradation, but it is only as advanced as the technology allows, merely mending gaps in agriculture that the technology is built for. Technologies which control output, track precision, and map progress can only go so far when it comes to protecting soil from erosion and fertility loss.

Natural technologies, or biotechnologies, that protect the soil while protecting or increasing yields are much rarer, yet they possess the potential to obtain higher levels of sustainability than previous precision technologies (Hazell & S. Wood 2008, 512). Biotechnologies and soil-friendly practices such as controlled burning, crop rotation, perennial polyculture, or fallow periods have been around for centuries, and humans continue to use them for their sustainable attributes (Tilman et al. 2002, 674). However, the increase in agricultural

intensity in the last century forced farmers to forfeit many of these biotechnologies and natural practices to procure increased yields (Hazell & S. Wood 2008, 512). The need for the return of natural and sustainable biotechnologies is critical because increased agricultural production has caused a loss in soil fertility globally (Turner II 2001, 271) specifically within the United States. This is especially true in areas of high production such as the Northern Glaciated Plains ecoregion in the United States, where soil fertility is very high and soil fertility usage is thrust to the maximum. Biochar is a biotechnology that originates from controlled burning that has the potential to be the key to sustained or increased yields while protecting farmers' paychecks (Sanvong and Nathewet 2014, 101). When paired with crops that benefit soil fertility, biochar has the potential to boost crop productivity and quality in higher value crops for years to come while protecting valued resources (Kimetu et al. 2008, 737). In a world of increasing population and decreasing arable land, biochar could be the biotechnology of both the past and the future.

1.2 Thesis Objectives

This study measured soybean health and phenology throughout eight reproductive growth stages, compared dry soybean biomass weights, and recorded basic soil properties in biochar-amended and control soils in Brookings County, South Dakota within the Northern Glaciated Plains ecoregion (EPA 2016). **The purpose of the study was to determine if biochar is an agriculturally beneficial and applicable biotechnology within this ecoregion that could potentially provide producers with an economically practical and more sustainable method for maintaining or improving soil quality while earning more income through increased soybean production.** The tests employed in this study aim to provide more understanding of the reaction soils in this ecoregion have to biochar in the form of soil pH and soil electrical conductivity (EC). The methodologies also sought to track soybean (*Glycine max* L.)

normalized difference vegetation index (NDVI) throughout the eight stages of reproductive growth and total soybean biomass weights. This research aimed to build research upon these questions:

a)   Will soil properties differ between the control and biochar plot sections, and if so, will levels of soil pH and EC increase or decrease with the addition of biochar?

b)   Will NDVI measurement reveal differences in soybean phenology between the treatments throughout the stages of reproductive growth, and if so, will the results be significant enough to affect crop health?

c)   Will biochar application increase soybean biomass growth rate?

d)   How will this research affect research and agricultural practices in the Northern Glaciated Plains ecoregion?

CHAPTER TWO: LITERATURE REVIEW

2.1 Agriculture in the United States

Humans are recognized for being agents of change, especially when it comes to changing landscapes. William Pattison, the creator of the four traditions of geography, recalled that one of the hardest tasks we face is finding a balance between humans and environment (1990, 205). Agricultural intensification is one area where the line between humans and environment converges. The United States is in need of a more sustainable agricultural system (Tilman et al. 2002, 671), but in order to find more sustainable options, we must evaluate the current system. Farmers in the United States produce many kinds of crops, varying in type and depending on climate. Many farmers grow most of these crops under intense conditions that often compromise soil health, making it imperative that farmers across the country care for their soil by taking precautions against soil erosion.

2.1.1 The Significance of Legumes in Crop Rotations

One of the ways farmers in the United States protect their soil from erosion and fertility loss is through crop rotation. Crop rotation is defined as "repetitive cultivation of an ordered succession of crops (or crops and fallow) on the same land," in which one variety of crop grows for several years in the same field (Francis 1989, 3). Crop rotations normally involve rotating cash or food crops with other crops, other plants such as legumes, or a fallow period in which farmers allow the soil to regenerate. Legumes are plant in the pea family that grow nodules on their roots that contain nitrogen-fixing bacteria unlike plants in different families. Lal (1989, 172) explained that crops should rotate with legumes or legume crops to prevent erosion, nutrient leaching, and fertility loss. Crop rotations benefit cropping systems by improving soil conditions

such as pH, nitrogen, and carbon that often produce larger crop yields (Kelley et al. 2003, 49). Legumes, such as soybeans, obtain nitrogen through biological nitrogen fixation using a symbiotic relationship with a soil bacterium called rhizobia (Santos et al. 2013, 17); (Wood 2015, 750). The establishment protein found in legumes absorbs nitrogen from the air and directs nitrogen nutrients into soil while preventing them from leaching (Reckling, 2016, 196). Fertile soils require ample amounts of nitrogen for organic matter creation, important to crop growth. Legumes are important to agriculture for their nitrogen fixing ability (Duchene, 2017, 149), and farmers will most likely continue to utilize legumes in crop rotations in the future.

2.1.2 Northern Glaciated Plains Ecoregion and its Characteristics

Soils in the Great Plains of the United States have undergone massive transformation in a short period. After heavy extensification and thorough intensification, this fertile region has benefitted from systems such as crop rotation to prevent mass losses of soil fertility loss. Most of the soils in this region have a high level of natural soil fertility and are highly agriculturally productive (Environmental Protection Agency 2016). Some ecoregions within the Great Plains are highly agriculturally productive because of well-suited climatic conditions and nutrient-rich glacial sediments. The Northern Glaciated Plains ecoregion is an ecoregion within the Great Plains of the United States that is highly suitable for crop production, because of its continental climate and plentiful precipitation over a wide spatial range. All soils differ in chemical properties, color, structure, and production capacity, making it difficult to determine how the biotechnology that has worked in other regions will affect crops in this Northern Glaciated Plains ecoregion (Laird et al. 2017, 53). According to the United States Environmental Protection Agency, the Northern Glaciated Plains ecoregion refers to a substantial area stretching throughout the eastern North and South Dakota and parts of the western edge of Minnesota

where large amounts of glacial deposits exist from the retreating Wisconsinan glaciation, the most recent glacial period of the North American ice sheet (2013).

The Northern Glaciated Plains ecoregion is home to the Prairie Pothole region and Coteau des Prairies. It is littered with small wetlands, river valleys, and depressions in the gently rolling landscapes. The sediments known as glacial till along the Coteau des Prairies is coarse and stratified (Rijsdijk 2004, 370), which provided the soil with a fertile mix of minerals that was excellent parent material for the development of soils that supported both tall and short grass prairies. Although nearly homogenous within the ecoregion because of similar parent material, climate, vegetation, and formation time, soil differs to some extent depending on the series of geomorphic processes after glaciation.

The region's soils, while separated by a multitude of soil series, are all under the same soil order of mollisols. Mollisols are distinguished by their dark, mollic epipedon, or mollic soil horizon at the surface. Many of the mollisols in this ecoregion supported short and tall grass prairies that added to the amount of organic matter in the soil. The growth of grassland prairie contributed to the amount of rich, naturally fertile soil within the Northern Glaciated Plains ecoregion. Since this region has naturally fertile soil and some of the best agricultural conditions within the United States, a plot within Brookings County, South Dakota was chosen for the study area.

Soil series categories within this ecoregion are divided mainly because of variations in climate, but differences in vegetation, organic matter, and parent material are also large factors in determining soil characteristics in each series. The dominant suborders found in this ecoregion are udolls, ustolls, and aquolls in which all are based upon the amount of moisture in the soil (Natural Resource Conservation Service). Udolls are made under humid climates and are

relativley well-drained. This suborder is used heavily for crop production. Ustolls are drier than udolls and support less vegetation unless irrigated. This suborder is still mainly used for cropland and rangeland. Aquolls are the least common suborder in this ecoregion and are found sparingly throughout the northeastern part of North Dakota. They are very wet and require draining in order to cultivate crops.

2.2 Biochar as a Sustainable Biotechnology

Rotating nitrogen-fixing legumes supplies the soil with direct nutrients, solving soil nutrient deficiencies between commercial crops. However, this process can be made more effective by using an additional biotechnology that better retains nutrients. Biochar is a type of carbon-rich charcoal biotechnology made from organic feedstock that has undergone pyrolysis (Lehmann and Joseph 2009, 1). It is often used as a soil amendment to improve soil productivity by providing nutrients and support systems that plants need for healthy growth (International Biochar Initiative 2017). The support that biochar provides for plant growth depends on the type of feedstock and the pyrolysis temperature at which the biochar is made. Feedstock is any organic material used for biochar production. Many kinds of feedstock are eligible and available for biochar production. Some examples are grasses such as switchgrass or straw, food waste such as nutshells or rice hulls, animal waste such as manure or litter, field waste such as corn stover, commercial waste such as pulp, or wood products such as bark, pellets, or whole logs.

2.2.1 Characteristics of Various Biochar Feedstock

The feedstock that goes into making biochar and the temperature at which the biochar was created often changes how it interacts with individual soil properties such as pH, electrical conductivity, water holding capacity, and nutrient levels. All feedstock for biochar production

differs in structure and nutrient content (Ding et al. 2016, 4); (Laird et al. 2010, 441). These differences in feedstock, and varying pyrolysis temperature, affect how the resulting biochar will affect soil chemical properties and plant growth, such as pH or carbon and nitrogen content, and biochar properties such as surface area or pore volume, yield, and moisture rates (Guo et al. 2016, 479; Ahmad et al. 2012, 536). For example, biochar made from woody feedstock has been shown to have some of the highest surface area (Ronsse et al 2013, 112), the lowest ash content (Ronsse et al 2013, 112; Kookana et al. 2011, 107), and the lowest electrical conductivity levels (Brewer et al. 2011, 318), while biochar made from plant feedstock has a higher ash content (Guo et al. 2016, 4), lower surface area, and high electrical conductivity levels. One study found that grass or plant feedstock burned at a lower pyrolysis temperature during biochar creation offers the most nutrient holding abilities in agricultural biochar use in southeastern South Carolina soils (Novak et al. 2009, 200); (Laird et al. 2010b, 449). Rajkovich et al. reported a 16 percent average increase in soybean production after applying a corn stover biochar in a New York alfisol soil, while other biochar feedstock did not show any growth (2012, 278).

2.2.2 Biochar's Impacts on Soil and Plant Growth

In many studies, biochar increased pH in acidic soils (Obia et al. 2015, 6);(Masud et al. 2014, 794);(Jien and Wang 2013, 230);(Rogovska et al. 2016, 104) depending on the type of feedstock, application rate, and temperature of pyrolysis (Randolph et al. 2017, 276), stabilizing soil for plant growth and allowing more manageable crop production. Randolph et al. found that high pyrolysis temperatures tend to increase both soil pH and soil electrical conductivity, no matter the feedstock type (2017, 279). PH change after biochar application is often reported specifically when the biochar was applied on the surface layer of agricultural soils (Sandhu 2016, 25). Soils with biochar are also likely to retain water better and have higher electrical

conductivity (EC) than soils without biochar, allowing increased crop growth and crop vitality especially in drought events or arid and semi-arid environments such as the southeastern United States (Randolph et al. 2017, 279);(Khan et al. 2017, 1151);(Mohamed et al. 2015, 69), although some reported no significant change in EC (Drake et al. 2015, 365). Increased water holding capacity is one of the major reasons that researchers have used to explain the increased crop yield in biochar-amended fields (Sohi et al. 2010, 68);(Jeffery et al. 2011, 185). Statistics have shown that soil water holding capacity is positively correlated with the amount of biochar present in the soil (Yu et al. 2013, 7);(Laird et al. 2010b, 446);(Basso et al. 2013, 139).

Soil with biochar releases nutrients at a slower pace, following crop responses for nutrients or water. Several researchers in the Amazon Basin have observed that biochar directly improved biological nitrogen fixation in legumes through increased phosphorous and nitrogen intake (Lehmann et al. 2003, 355);(Parmar et al. 2014, 1677);(Güereña 2015, 489). Laird et al. found that biochar reduces nutrient leaching in both nutrient poor and nutrient rich soils (2010, 441), with both nutrients found naturally in the soil and synthetic fertilizer. Studies in fertile soils in the Midwestern United States have shown that farmers could use biochar as a soil conditioner rather than a fertilizer, perhaps reducing the need for chemical fertilizer inputs in major crop-producing regions and possibly increasing crop production at the field level (Guo et al. 2016, 480).

Many studies have shown that biochar application can significantly promote crop production through increasing biomass or yield (Rogovska et al. 2014, 7);(Parmar et al. 2014, 1677);(Major et al. 2010, 126-127);(Arif et al. 2015, 396-397). Biochar application has been shown to increase biomass and crop production dependent on location, pyrolysis temperature, and biochar feedstock (Sigua et al. 2015, 747);(Schulz et al. 2013, 820). The combination of

high pyrolysis temperatures (Rajkovich et al. 2012, 281) and high rates of biochar application (Mia et al. 2014, 88);(Lui et al. 2013, 591) often have decreased plant growth rates than the combination of lower pyrolysis temperatures and lower biochar application rates. In a fertile Hapludoll soil in Iowa, Rogovska et al. reported a 11% to 55% increase in corn biomass when treated with biochar, but attributed the biomass increase to a higher water holding capacity (2014, 6-7).

Biochar application can promote an increase in biomass growth particularly in legumes such as clover and beans because of measured increases in either potassium or nitrogen intake (Oram et al. 2014, 96);(Rondon et al. 2007, 702). Mia et al. recorded the biochar application amount for optimum legume biomass growth is 10 t ha−1 in field experiments with red clover that also had increased levels of potassium (K) (2014, 88). In soybeans, biomass growth increases with biochar application (Reyes-Cabrera et al. 2017, 458);(Tawadchai 2012, 247); however, rates of biochar application over (20%) do not provide and increase in biomass growth (Wang et al. 2016, 1501).

The addition of biochar could improve crop production through healthier soils and result in increased biomass and increased crop yield. United States agriculture demands high crop yields, and biochar has the potential to increase crop yields in a more sustainable and natural way (Liu 2017, 22). Numerous studies of legume-based crop rotations reveal benefits from biochar additions. Few studies report negative biochar results, citing changes in soil pH (Kishimoto and Sugiura 1985) or excess calcium in alkaline soils (Mikan and Abrams 1995, 694). The majority of research suggests that biochar either has no significant influence or positively affects soil fertility, crop biomass, and crop production, yet scientists must examine biochar applications in more situations to solidify that conclusion.

2.3 Normalized Difference Vegetation Index and Plant Growth

The normalized difference vegetation index (NDVI) is defined as a "ratio of the difference between the near infrared (NIR) and the red bands versus the sum of the two bands" (Zhitao et al. 2014, 64). The purpose of NDVI is to estimate plant greenness by measuring the absorption of red light wavelengths and the reflectance of NIR wavelengths to indicate growing conditions, plant health, and areas of crop stress or vitality (USGS 2015). Areas of higher crop stress have lower reflectance values in the near infrared wavelength. NDVI is often generated using multi-spectral or hyperspectral satellite imagery that covers a large spatial scale (Esquerdo et al. 2011, 3712). Van Leeuwen et al. expressed that the ultimate goal of periodical NDVI assessments is to be able to interpret and improve systems of agricultural production and land cover on the surface of the earth for mapping growth, photosynthetic activity, and the duration of growth (2006, 68).

NDVI is often measured using satellite hyperspectral images; however, using unmanned aerial vehicles (UAV) with attached multispectral cameras is becoming more common when it comes to a small study area. In case of the field plot in this study, one of the most suitable approaches to measure NDVI is to use a hand-held spectral radiometer at the ground level. (Poças et al. 2012, 4337). Measuring at ground level, at an oblique angle allows for greater detailed measurements of the plant as it is exposed to the sun (Mistele and Schmidhalter 2008, 95) because more of the layers of the plant are exposed to the measurement. Therefore, in biochar amended study plots, NDVI derived from a spectral camera at an oblique angle could help to examine the change of the healthiness of the legume plants.

One of the applications of NDVI is measuring crop phenology, while other studies show strong linear relationships between NDVI and biomass accumulation (Goswami et al. 2015, 8).

The phenological growth curve for soybeans lasts anywhere from 4-8 months, or 75 to 210 days (Figure 1) (Board and Kahlon 2011, 6), depending on latitude and specific soybean hybrid (USDA 1997);(de Oliveira et al. 2016, 1685) and has a peak NDVI value about four months into the growing season (Esquerdo et al. 2011, 3720). Peak average canopy reflectance of soybean plants is between about 700 to 750 nm, reaching that peak later in the growing season when the canopy was at its largest (Bai et al. 2016, 186). Recording NDVI values along the reproductive growth cycle within a year can offer rapidly accessed information about soybean health and productivity, possibly forecasting amount of biomass accumulation and crop yield.

2.4 Biomass Assessment

Measuring biomass is important in studying plant and ecosystem resilience because biomass is an indicator of plant health and the health of the growing environment (Eisfelder et al. 2012, 2938). Researchers have found that biochar has positive effects on the growth of legumes biomass in many studies (Lehmann and Rondon 2006, 525) (Liu 2017, 22),. The application of biochar often increases plant biomass (Junna et. al. 2016, 630);(Laird et al. 2017, 53);(Zhang et al. 2012, 270); however, this result is highly dependent on soil and crop type (Laird et al. 2017, 53). Plant height and shape can indicate types and degrees of erosion, as well as explain how plants exchange nutrients with natural processes such as the hydrological and nitrogen cycle (Eisfelder et al. 2012, 2938). Legumes often have excellent biomass growth rates when paired with biochar, especially in crop rotations (Lui et al. 2017, 22).

$$Y = -0.0026x^3 + 0.4802x^2 - 13.3x + 96.9$$
$$R^2 = 0.99$$
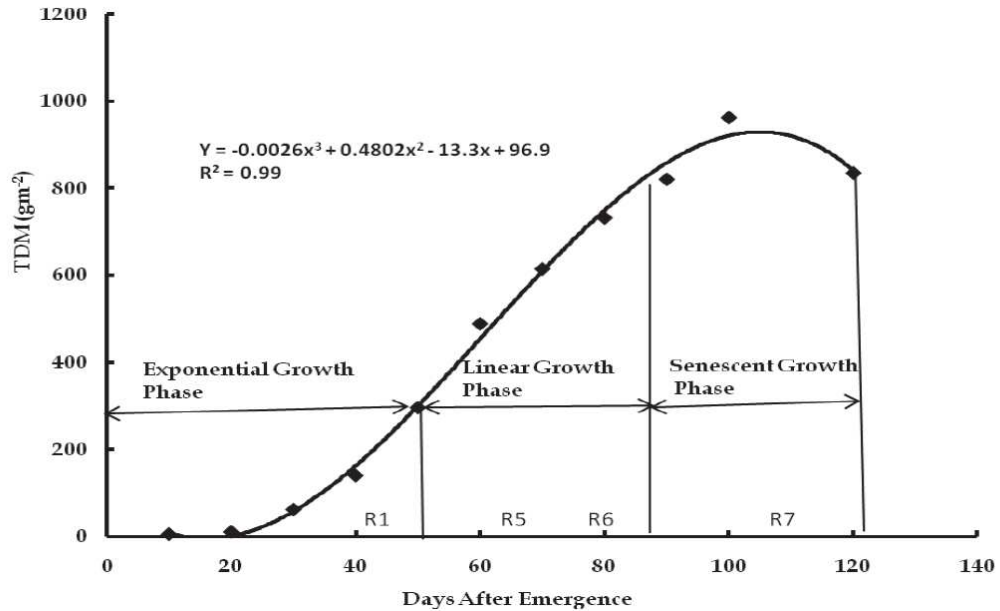
Figure 1: Phenological curve for a typical soybean crop throughout the reproductive growth phases using dry biomass accumulation per day. Data adapted from Carpenter and Board (1997).
Source: Board and Kahlon 2011.

2.4.1 Large Scale Biomass Measurement Methods

Remote sensing by satellite imagery is a way to accurately assess amounts of large

sections of biomass because it processes large amounts of data very quickly, provides a more

comprehensive view of spatial biomass distribution (Dengsheng 2006, 1298), and makes it easier

to observe temporal differences using time-series analyses (Eisfelder et al. 2012, 2939). Biomass

measurements from satellite imagery use land cover data from an observatory satellite such as

MODIS or AVHRR as well as products that separate individual land cover classes into the land

cover type to be measured (Du et al. 2014, 1268-1269);(Roy and Ravan 1996, 540). Different

coefficients are used for individual plant species along with an algorithm that converts plant

volume into biomass of each species (Du et al. 2014, 1270);(Nguyen et al. 2015,

18870)(Asekova et al. 2016, 50). However, remotely sensed satellite imagery has a large spatial extent that does not have high enough resolution for small field experiments.

2.4.2 Small Scale Biomass Measurement Methods

Small unmanned aerial systems (sUAS) are valued research tools for taking field measurements that are too small for observatory satellites. Unmanned aerial vehicles can record data more precisely than observatory satellites because they have a higher resolution, making them a beneficial research tool for small scale and on-site projects (Beloev 2016, 72);(Marcaccio et al. 2015, 255). UAVs offer more comprehensive, photogrammetric data, allowing researchers to measure data over a larger space than ground-based measurements by measuring at an aerial perspective and stitching images together (Everaerts 2008, 1190);(Beloev 2016, 72). Agricultural research has benefited from sUAS because of its more detailed data assessments, ease of operation, low cost, and rapid analysis period (Erena et al. 2016, 814);(Yun et al. 2017, 107);(Hristov et al. 2016, 38).

Field measurements often provide the most accurate data. Biomass measured in the field by hand, although more accurate, is often more time-consuming. Destructive and non-destructive are the two biomass measurement styles. Destructive measurement requires the plant to be taken from the plot, dried, and measured, while non-destructive measures rely on allometric equations that measure plant volume, diameters, and heights without harming the plant (Nordh 2004, 1-2);(Henry et al. 2012, 326);(Chave et al. 2014, 3181). Destructive measurements are regarded as the more accurate (Mannetje and Jones 2000, 159) and least biased (Bell and Fischer 1994, 2) of the two methods.

2.5 Justification of the Proposed Study

With global population rising and worldwide agricultural trade at its peak, the need for sustainable production practices is stronger than ever before. Agricultural demand is expected to rise with increasing global population, which will put pressure on each country to provide food in a world in which yield increase is decelerating and available land is disappearing (Hazell and Wood 2008, 495). Precision technologies, although exceptionally beneficial, are purely temporary and mostly provide small increases in yield, plant health, and savings for the individual farmer, whereas biotechnologies such as biochar may provide benefits that are longer lasting and more natural. Styger and Fernandes stated, "Given the fact that future food production in the world will have to be achieved with less land and water per capita, and given the expectations that poverty will be reduced, efforts for sustainable intensified agriculture should give priority to developing knowledge and skills for optimizing ecological and agricultural environmental conditions (2006, 426).

One of the hardest problems to solve is how to promote more sustainable farming solutions, while making it affordable and profitable for farmers. Many farmers in the Northern Glaciated Plains ecoregion use a corn and soybean rotation, where the soybean is the legume that renews soil nitrogen levels by procuring nitrogen and supplying it to soils. Rotating soybeans, or other nitrogen fixing plants, with other high value crops is necessary in supporting ecosystem services vital to farming systems and those under threat from agricultural intensification (Wood et al. 2015, 750). Few studies focus on biochar application in combination with soybeans in the Northern Glaciated Plains ecoregion of the United States because this region is highly agriculturally productive and very agriculturally intensive. Of those studies, very few studies record NDVI and soybean phenology in accordance with biomass measurements and biochar's

effect on soil fertility. The long-term effects of biochar on soybeans are under-researched and have the potential to promote more efficient growth based on field location and soil fertility (Sorensen and Lamb 2016, 710).

Zhang et al. acknowledged that feeding the world's growing population will require a more comprehensive knowledge of the effects of biochar on agriculturally productive areas of the world (2016, 28). Since very few studies involving biochar application have been completed in the Northern Glaciated Plains ecoregion, it is challenging to estimate the effect that biochar will have on this ecoregion's soils (Laird et al. 2016, 53); however, the results of this study could be beneficial to most every soil series within the Northern Glaciated Plains ecoregion. If farmers are able to produce healthier, and subsequently more productive soybean crops, the excess product would support local farmers and markets while providing a more sustainable and long-term option for soil fertility loss protection. This project proposes to (1) measure soybean health and phenology throughout eight reproductive growth stages, (2) compare dry soybean biomass weights, and (3) record basic soil properties in biochar-amended and control soils in Brookings County, South Dakota to determine if biochar is an agriculturally beneficial and applicable biotechnology within the ecoregion that could potentially provide producers with an economically practical and more sustainable method for maintaining or improving soil quality while earning more income through increased soybean production.

CHAPTER THREE: STUDY AREA AND METHODS

3. Region of Study

The United States possesses a large percentage of the world's arable land, along with one of the world's largest commercial farming systems. Much of the arable land in the United States is located centrally in the Great Plains region, where large-scale land conversions took place to make way for future croplands. Large-scale soil erosion is one of the damaging consequences of mass land conversions, because it involves the disturbance and transformation of prairie grasslands to croplands. Many of the conversions occurred in areas not suited for crop production, while many very suitable landscapes experienced intensified agricultural production. The Northern Glaciated Plains ecoregion produces many of the world's most important crops, and the region is highly susceptible to constant land cover change and drastic transformations.

3.1. Physical Background of Region of Study

The Northern Glaciated Plains ecoregion is located centrally, in the northern part of the United States, stretching through three different states (Figure 2). The landscape consists of rolling and flat short and tall grass prairies carved by previous glacial periods (US Environmental Protection Agency 2013). This region is highly subjected to climate fluctuations of high heat in the summers, accompanied by subzero temperatures in the winter. Annual temperatures of this ecoregion are about 35- 50 degrees F, providing an annual growing season that lasts about 120 – 160 frost-free days (Natural Resource Conservation Service 2017). Annual precipitation in this ecoregion is about 15 – 25 inches, mostly falling in the summer months between April and September (NOAA). Annual snowfall for this region is about 33-inches (2018 US Climate Data). Droughts occur in the summer months after annual precipitation peaks.
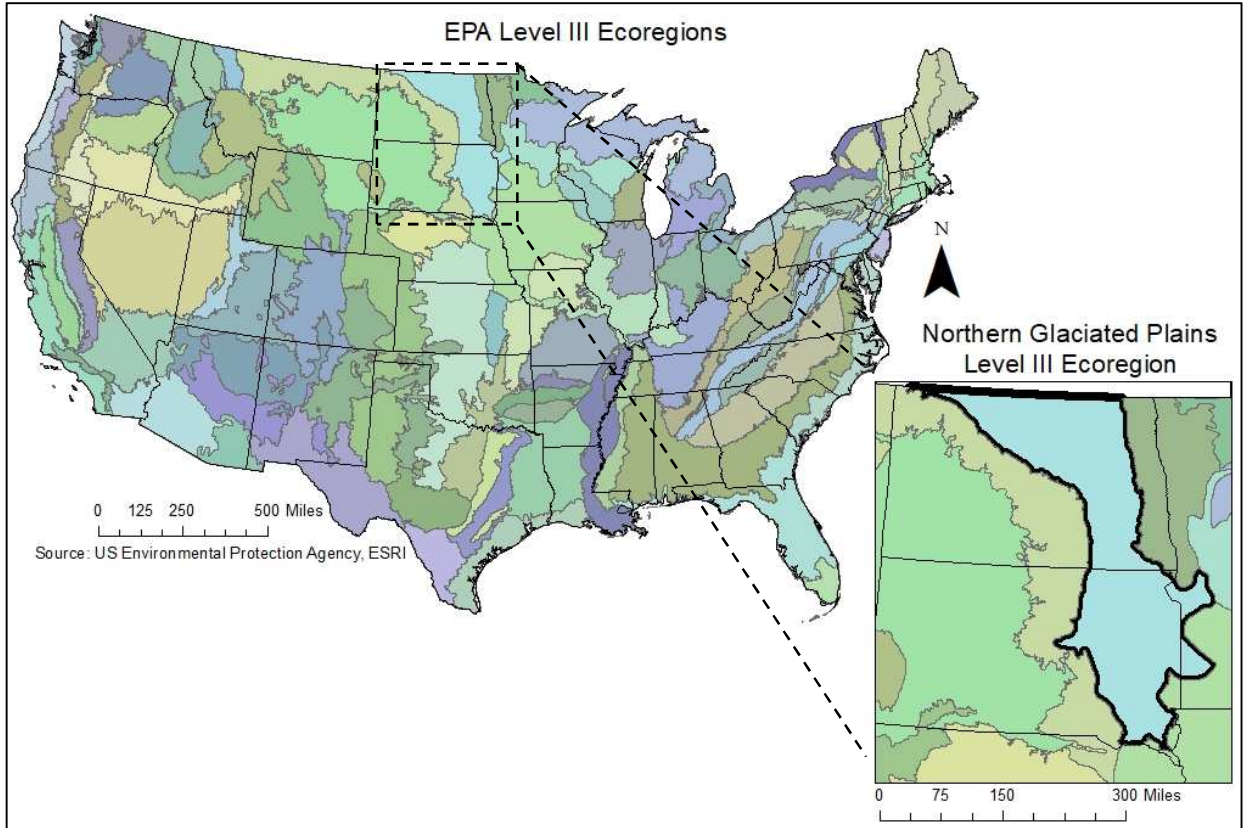
Figure 2: Left: EPA level III ecoregions. Right: The Northern Glaciated Plains ecoregion within the United States.
Source: U.S. Environmental Protection Agency 2013

Small wetlands dominate the hydrology of this ecoregion and have an important role in supporting the surrounding ecosystem. The Prairie Pothole region makes up a majority of this ecoregion, consisting of many temporary, semi-permanent, and permanent depressions that recharge with precipitation and underlying ground water. These wetlands control surface salinity by filtering salts from surface water before returning the water to the soil, protect against flooding, and provide essential habitat for migratory waterfowl (Niemuth 2010, 1053). Other major hydrologic features are rivers such as the James, Red, and Sioux rivers. These rivers bring in rich sediment that provides this ecoregion with highly productive soils. All water features

eventually drain into the Mississippi River, running from north to south throughout the ecoregion.

Much of the vegetation in this area is highly dependent on the hydrology of this ecoregion. The dominant vegetation is short and tall grasses, along with hydric grasses, sedges, and forbs that surround and inundate the many wetlands across the ecoregion. Some of the dominant grass species within this temperate grassland biome include Big Bluestem (Andropogon gerardii), Little Bluestem (Schizachyrium scoparium), Switchgrass (Panicum virgatum), Western Wheatgrass (Pascopyrum), and Buffalograss (Bouteloua dactyloides). Examples of common aquatic grass species include Bulrush (Scirpus), Cattails (Typha), and Slough Sedge (Carex obnupta). Much of the native grassland ecosystem has been converted to cropland, altering ecosystem balance and introducing invasive species.

3.2. Physical Background of Study Site

Brookings County, South Dakota is located in an area of prime farmland within the Northern Glaciated Plains ecoregion (Figure 3), with an average growing season of 120 to 160 days annually. The climate of Brookings County has a mean annual precipitation of about 18 to 30 inches and the mean annual air temperature is about 39 to 45 ˚F. The specific study plot is located on a non-cultivated soil and has been used in research and data collection prior to this study. Previous research on this plot began in 2013 with the application of biochar to certain plot sections. Sandhu et al. found that biochar in this soil and landscape position had no significant effect on soil pH throughout the study, while the application of corn stover biochar drastically reduced electrical conductivity (EC) before harvest the first year with no significant change the second year after biochar application (2015, 25-27). Although soil pH and EC have been

recorded in plots with and without the addition of biochar, soybean phenology through NDVI

and biomass assessments have never been calculated.
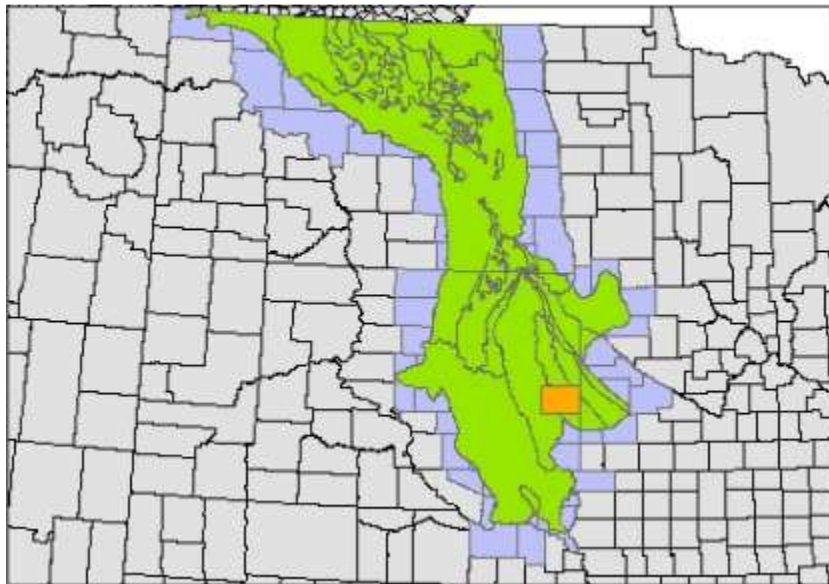
*Figure 3: Brookings County, South Dakota within Northern Glaciated Plains
ecoregion in which the study plot is located.
Source: U.S. Environmental Protection Agency 2013*

3.3. Field Preparation

The study location is privately owned land in southern Brookings County, South Dakota

(Figure 4). The plot sits on a Barnes clay loam (BbB) soil and is classified as a fine-loamy,

mixed, frigid udic hapludoll located at 44˚13'03.81''N, 96˚44'39.46''W. The soil was formed in

loamy till parent material, is very well drained, and has a crop productivity rating of 82 out of

100 (Soil Survey Staff). The size of the study plot is 80 feet by 90 feet. The plot was divided
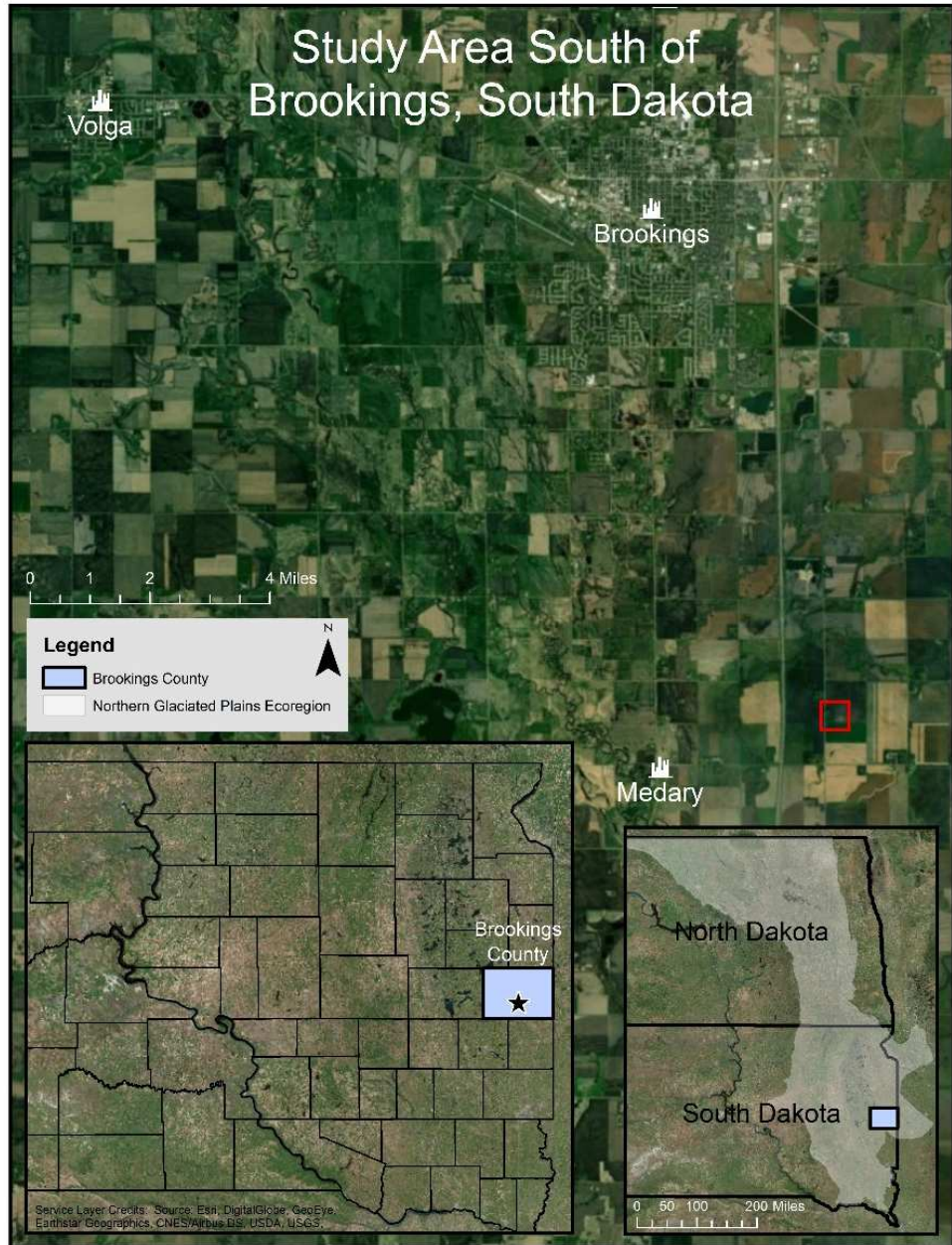
Figure 4: Research site location in Brookings County, South Dakota. Site is located south of the city of Brookings, and in the southernmost part of Brookings County.

into 24 sections measured at 15 feet by 20 feet, treated separately in 2013 in a randomized

complete block design. A randomized complete block design is a design that is most commonly

used in agricultural research in which treatments to each plot section are randomly assigned with

each treatment occurring once per block with the number of blocks matching the number of

treatments. The plot was treated with six treatments; three treatments consisted of three different

feedstocks of biochar, two treatments were different manures, and the last treatment was a

control plot section (Figure 5).
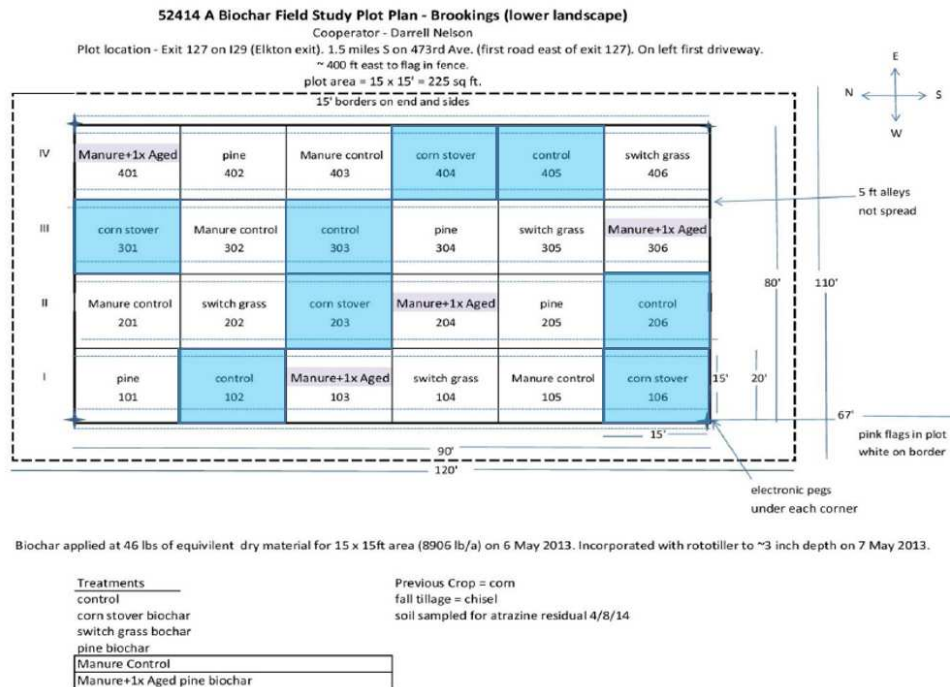
Figure 5: Study plot design. Outlined plot sections were the corn stover biochar and control
plot sections used in this research.
Source: Sandhu 2015).

This research project solely utilizes highlighted plot sections of corn stover (*Zea mays* L.)

biochar and all control plot sections, which had no treatment applied. The biochar was applied at

a rate of 10 Mg ha^{-1} in 2013 and tilled into the topsoil at a depth of 3 inches or less with a

rototiller (Sandhu 2015, 22). Overall, the study site includes eight selected plot sections in total ,

which are biochar plot sections 106, 203, 404, and 301 and control plot sections 102, 206, 303,

and 405. The research team planted Acceleron AG17X7 treated soybeans using a four-row

planter pulled by a tractor on May 9, 2017 in a non-cultivated cropping system with 30 inch

spacing between rows and a 1-2 inch seed depth.

3.4. Data Collection

Data collection was conducted from three perspectives: soil fertility, soybean biomass,

and soybean health. Data collection in the plot field began in May of 2017 and commenced

October of 2017 with soybean harvest after its maturity. Other data collection and testing was

completed using a professional soil laboratory or biomass storage facility. During July of 2017,

weed growth was becoming hard to control, so the research team applied an herbicide to the

entire plot. This herbicide did not affect the soybeans, but was very effective in killing the

surrounding weeds. When in the field, I took photos to document changes in soybean plant

physical appearance with a Nikon 5100 DSLR camera throughout the soybean planting,

reproductive growth stages of the soybeans, and soybean harvest.

3.4.1. Soil Characteristic Data

Soil samples were collected throughout the eight biochar and control plot sections. The

purpose of sampling the surface of the soil was to observe only the soil, which was affected by

the biochar since application in 2013. After the sampling was completed, the samples were to be

tested for levels of pH and electrical conductivity (EC). The level of pH in the soil is an

indicator of the acidity of the soil and can be an important parameter for soil health and the

management of the soil. Just like pH, EC is also important in evaluating a soil's health because

it measures salt levels, or exchangeable ions, in the soil and how well the soil conducts

electricity. Both tests are used in research to gain information on the nutrient availability of the

soil as well as the soil's potential for crop growth. Soybeans grow most productively in slightly acidic pH levels around 6.8 (NRCS 2014a, 2) and EC levels around 280 to 360 µS/cm (NRCS 2014b, 5).

This study's soil sampling took place after soybeans were planted, but before they emerged. The collection was taken using a coring method 10 inches deep to test only the topsoil in each plot section. The sampling method is a systematic sampling approach consisting of five spatially equidistant soil samples from each plot with a one inch diameter stainless steel soil core probe. The sampling method consisted of five sample locations, four from the corners and one from the center (Figure 6).
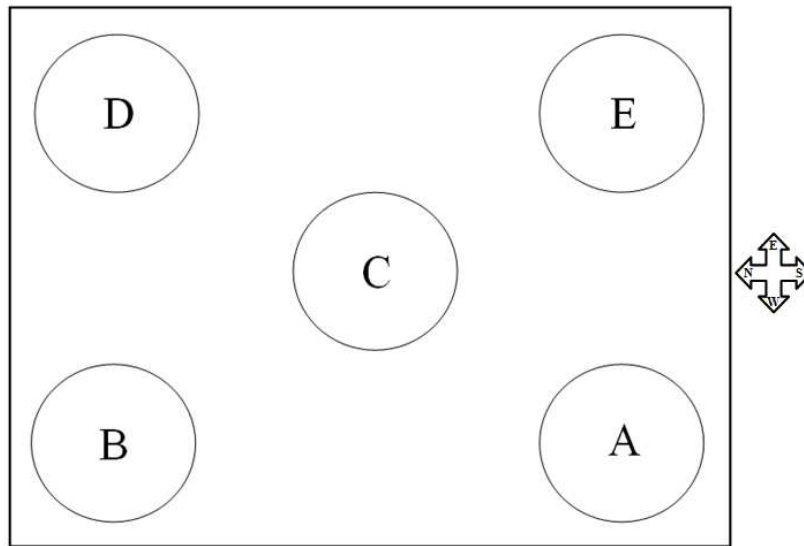
Figure 6: Soil sampling design from each plot section.

The soil samples were stored in labeled plastic bags and air dried in a soil storage facility for one week. Laboratory soil testing began after the samples were completely dry and ground with a mortar and pestle. The total number of soil samples equaled 40. After the dried samples were ground to less than two millimeters, they were taken to a lab and tested for levels of pH and EC.

The soil tests were performed by hand in a professional soil laboratory with an Orion Star A215 pH and conductivity meter.

3.4.2. Soybean NDVI Collection

Remotely sensed imagery was used to determine the health of the soybeans over the eight stages of reproductive growth (Figure 7). This was measured by creating normalized difference vegetation (NDVI) images throughout the soybean growing season of 2017. NDVI measures the greenness, or plant health on a scale from -1 to 1, where healthy vegetation is near one and stressed vegetation is nearer to 0 or even negative. The purpose of using NDVI was to measure the health of the soybeans and track any differences in reflectance between the two soil treatments.
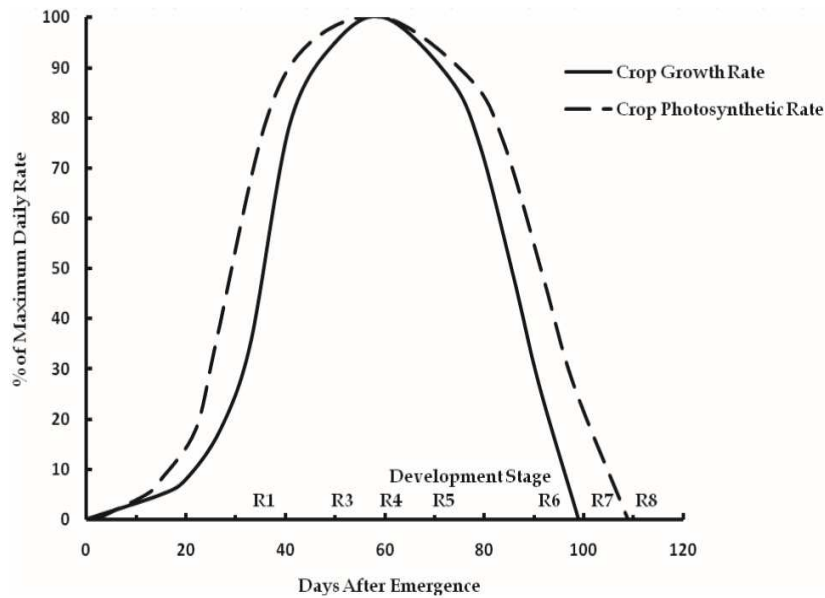
Figure 7: Reproductive growth stages of soybean growth by day of emergence.
Source: Board and Kahlon 2011

The images were taken using a Survey 2 MAPIR red and near infrared (NIR) camera to measure the red and near infrared (NIR) reflectance of the soybeans throughout their growth.

Before taking photos of each plot section at each reproductive growing stage, an image of a MAPIR camera reflectance calibration ground target was captured. This ensured that each image taken throughout the entire growing season was not only accurate, but also uniform with all the other images throughout the growing season no matter the amount of solar radiation each time a photo was taken. The multispectral camera was mounted on a monopod at a fixed distance of four feet above the ground (Christenson et al. 2016, 628) throughout the surveying period, and the camera was oriented at a 44-degree angle to the ground to capture oblique images facing the center of each plot section. The oblique images were taken from the eastern edge of each plot section, on the center of each plot section boundary facing west (Figure 8).
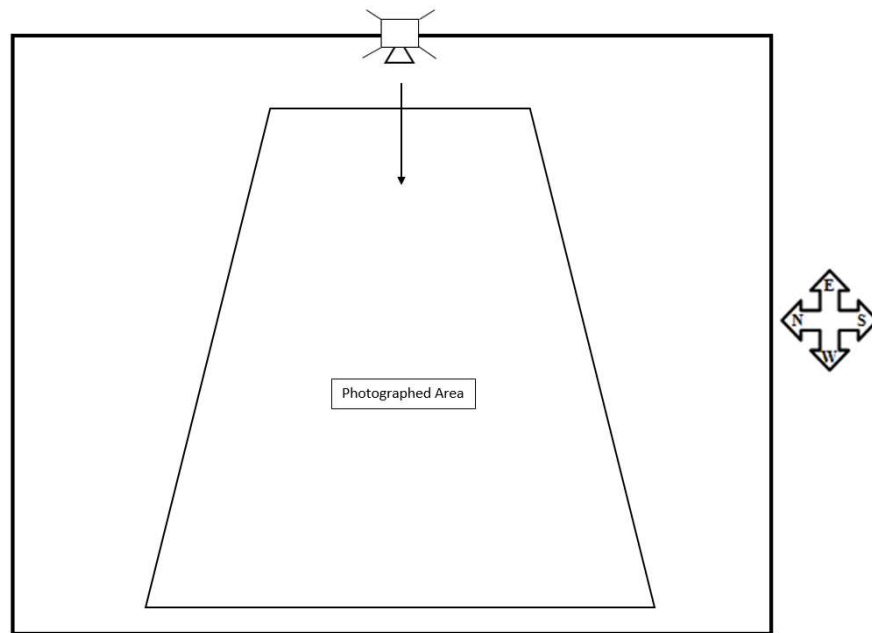
Figure 8: NDVI image orientation located in the center of the eastern plot section border.

Two photos were taken at each reproductive stage within 10 days of the start of each soybean reproductive growth stage (Board and Kahlon 2011, 5);(Fehr and Caviness 1971, 930);(Ma et al. 2001, 1228) and within 2 hours of solar noon (Christenson et al. 2016, 628). The

photos began with the soybean reproductive stage R1 (first bloom), and finished with the final

stage before harvest, or the R8 stage (Ma et al. 2001, 1228);(Christenson et al. 2016, 628). The

purpose of taking two images at each reproductive growth stage was to reduce the possibility of

any noise such as wind bursts or gaps in solar radiation. The least noisy, or clearest, photo was

chosen for creating an NDVI (Tucker et al. 1979, 241);(Ma et al. 2001, 1228).

3.4.3. Soybean Biomass Sampling

Soybean biomass sampling was completed at the end of the growing season. The

soybean harvest took place on October 13, 2017, after the last stage of the growth process (R8),

or full maturity (Fehr and Caviness 1971, 930). The conventional destructive approach was

applied here to cut the soybeans at two inches above the soil surface. The soybeans were cut

from the center of each plot section with hand held sickles within a four by four feet quadrant to

eliminate the possibility of cross-contamination between plot sections (Rotundo et al. 2012,

59);(Van Roekel and Purcell 2015, 1191);(Nelson and Renner 1998, 139);(Edwards et al. 2005,

1779). After cutting the soybean plants, they were placed in labeled bags and brought to a

storage facility to dry. Once the plants were completely dry, total weight of the soybean plant

including the crop was recorded in grams.

3.5. Data Analysis

I used several programs and methods to test the differences in soybean biomass, soybean

health, and soil properties between the control treatment and the corn stover biochar-amended

treatment. To test the differences in soil pH and EC and soybean biomass weight between both

treatments, I performed two-tailed t-tests using a 95% confidence level (Sheng and Zhu 2018,

1394);(Partey et al. 2016, 204);(Obia 2015, 8). I compared the two plot section treatments by

creating a frequency histogram of soil pH and EC to show the distribution of the data throughout

plot field.

The NDVI images were uploaded into QGIS for calibration using the image of the

calibration target captured before taking the plot section images. After calibration, the images

represent a reflectance percentage for the entire photographed area and are ready to create the

NDVI. NDVI images were created using the QGIS raster calculator and the NDVI equation for

every plot section in each reproductive growth stage. The equation subtracts the reflectance

from the red band from the reflectance of the NIR band and divides the difference by the sum of

the NIR reflectance and red band reflectance (Formula 1).

Formula 1: Normalized Difference Vegetation Index,

$$NDVI = \frac{\rho NIR - \rho red}{\rho NIR + \rho red}$$

With: **ρNIR** = NIR reflectance
       ρred = red reflectance

Each NDVI shows the amount of live vegetation within the targeted image on a scale from 0-1,

with 0 representing no vegetation and 1 representing live and very healthy vegetation.

The NDVI images were reclassified to represent only positive values using the raster

calculator and setnull function in ArcGIS. The reclassification was necessary to represent only

live vegetation without giving value to any soil or water that may be in the image. It also made

the images easier to distinguish the differences between the two plot treatments of corn stover

biochar and control. The final images were recolored and clipped to show soybean greenness in

the center of each plot section. The clipped images ensured that there were no values from other

plot sections interfering with the reflectance in each image. Histograms were made to quantify

the data to show the frequency and distribution of reflectance throughout each NDVI raster image. This process was done using the raster and rgdal packages in the statistics program R. The total number of maps and histograms made was 64; there were eight plot sections photographed through eight stages of reproductive growth. To analyze the NDVI images, the mean was calculated for each of the 64 images and compared to a corresponding image of an adjacent plot section with the opposite treatment. For example, biochar plot section 106 was photographed during reproductive growth stages R1-R8. The images and histograms for the plot section 106 were compared with adjacent control plot section 102 during reproductive growth stages R1-R8. The plot section pairs are 106 (biochar) and 206 (control), 405 (biochar) and 404 (control), 203 (biochar) and 303 (control), and 301 (biochar) and 102 (control) (Figure 9).
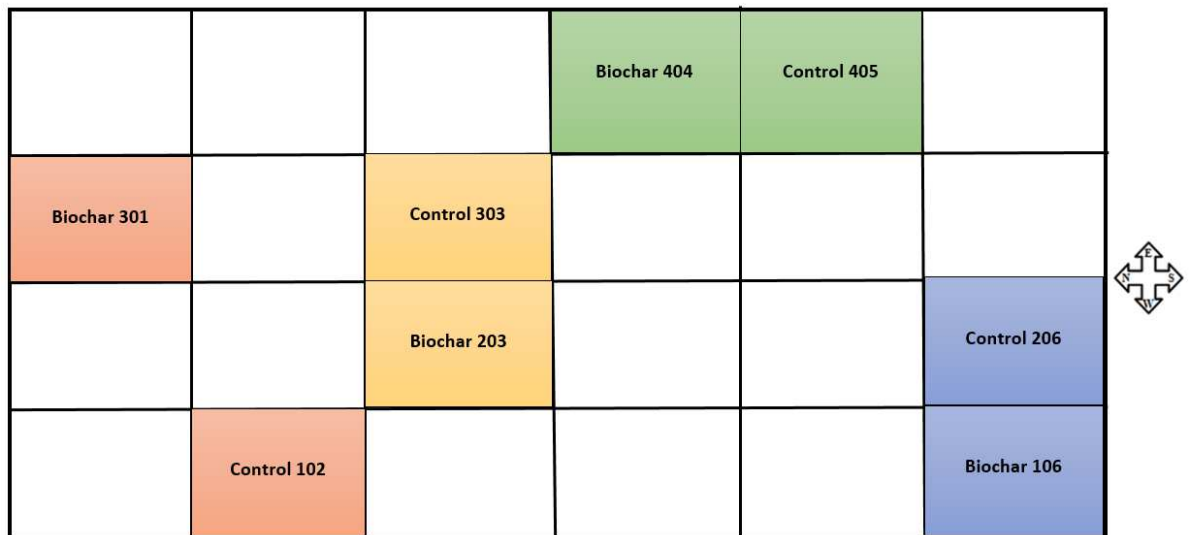
Figure 9: Plot section pairs for comparing NDVI data.

The pairing of the plot sections reduced the possibility of error due to weed disturbance and soil variability. After the mean was calculated, four two-tailed t-tests were completed to

analyze the treatments against their adjacent and opposite counterpart plot section using a 95% confidence level.

3.6 Adapted Methodology

This methodology was developed using research designs from other biochar studies located in similar and differing locations. Many of the methodologies used in this study have been adapted to fit this study and have resulted in significant changes to soil and crop characteristics. Adaptability of other biochar research methodology was important in creating a diverse array of methodology appropriate for this study. When used in combination, these methodologies provide a better understanding of the complexities of the study and the power of the potential results.

CHAPTER FOUR: RESULTS

4. Study Results

This study was successfully completed in September 2017. The growing season lasted from May 2017 until August and was officially completed when the soybeans were harvested. The three sets of analysis included soil testing, soybean NDVI measurement, and soybean biomass assessment. The following results demonstrated the effectiveness biochar has in this soil and provides more understanding of this amendment in the Northern Glaciated Plains ecoregion.

4.1 Soil Analysis

Basic soil health parameters of soil pH and soil electric conductivity (EC) were tested to determine the acidity and salinity of the soil within the plot field during the study. Upon testing, no significant differences were found in the biochar or control plot sections in either soil pH or soil EC. Generally, the majority of pH values are within the range of 5 to 7 in both plot section treatments and locational distribution showed an increase in pH in a northern direction. EC values were mostly within the range of 150 µS/cm to 250 µS/cm with a faint pattern in locational distribution. Although statistically there were no differences between either treatment, biochar plot sections had higher means in soil pH and lower means in soil EC.

4.1.1. Soil pH

Soil pH within the plot field differed only slightly between plot sections. The pH values ranged from acidic to neutral, with the lowest pH value at 4.94 in control plot section 206 and the highest pH value reaching 7.13 in biochar plot section 301. Biochar amended plot sections

showed slightly higher pH values but were not statistically significantly higher than the control plot section pH values. The two-tailed t value representing the difference between the biochar and control plot section pH values was 0.44, which was not statistically significant when tested at a 95% confidence level.

Soil pH values of each biochar plot section soil sample were very similar within each plot section throughout the five sample locations yet showed distinct differences in pH between biochar plot sections (Figure 10). The pH values in the biochar plot sections ranged from 4.96 found in biochar plot section 106, to the highest value in the dataset, 7.13 found in 301. The mean pH for biochar plot section soil samples was 6.22, while the most productive pH for growing soybeans is about 6.8. One of the biochar plot sections, biochar plot section 106, had significantly lower pH values at an average of 5.13, making that plot section not ideal for growing soybeans.

The lowest pH value in the dataset, 4.94, was recorded in the control plot section 106, while the highest value within the control plot sections was 6.98, recorded in the control plot section 405 (Figure 11). Soil pH values were consistent throughout each plot section except for plot section 405. One sample from the control plot section 405 was an outlier at a pH of 6.98, while the surrounding samples were much lower at a pH of about 5.9. The mean pH for the control plot sections was 6.05, which is slightly lower and more acidic than the mean biochar plot section pH. The lower pH values within the control plot sections make them less ideal for soybean production than the biochar plot sections.

Figure 10: pH values within biochar plot sections. The different colors distinguish samples within each plot section.

Figure 11: pH values within control plot sections. The different colors distinguish samples within each plot section.

The spatial distribution of pH values showed interesting and definite patterns, although they did not show a pattern of difference between the two plot treatments. The highest mean pH values in both plot section treatments were found in samples from biochar plot section 301, found on the northern edge of the plot field (Figure 12).
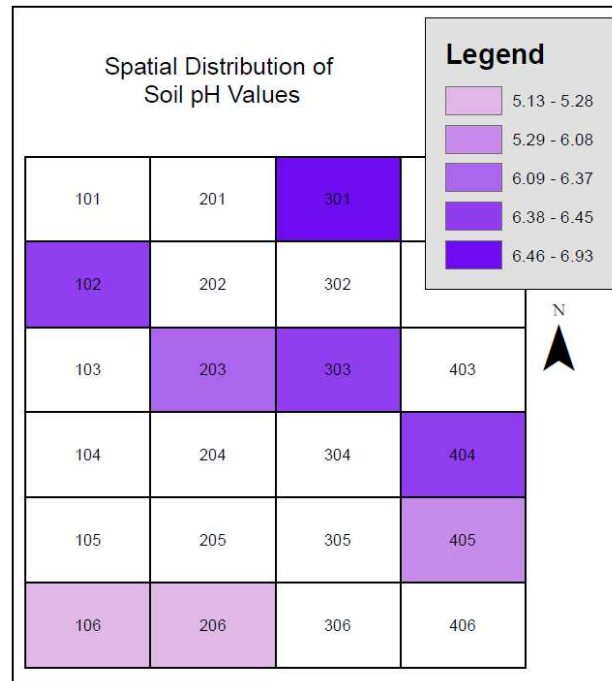
Figure 12: Spatial distribution of soil pH within plot field.

The lowest mean pH values in both plot section treatments were found in samples from biochar plot section 106, found on the southwest corner of the plot field. Biochar plot section 301 had the highest pH value in the dataset, which was on the northern edge of the plot field. The highest consistent pH values in the control plot sections were found in samples from control plot section 102, found on the western edge of the plot field, near the northwestern corner. The lowest pH values in the biochar plot sections were found in samples in from plot section 206, found on the southern edge of the plot field, near the southwestern corner. Soil pH values

increase across the plot field from south to north and don't show statistically significantly different values within the plot sections.

The pH values of both treatments had roughly normal distributions, representing the similarity of pH values of all plot sections across the plot field. (Figure 13). Overall, biochar plot sections had a higher soil pH values, but a lower frequency of soil pH values in the near-neutral range, at 7 than control plot sections. Three of the four biochar plot sections had pH values at or above 6, with only one plot section, 106 at a pH of about 5. Control plot sections had the highest frequency of near-neutral soil pH values, while having a lower mean pH value. Control plot sections had more consistent pH values, while biochar plot sections varied more.
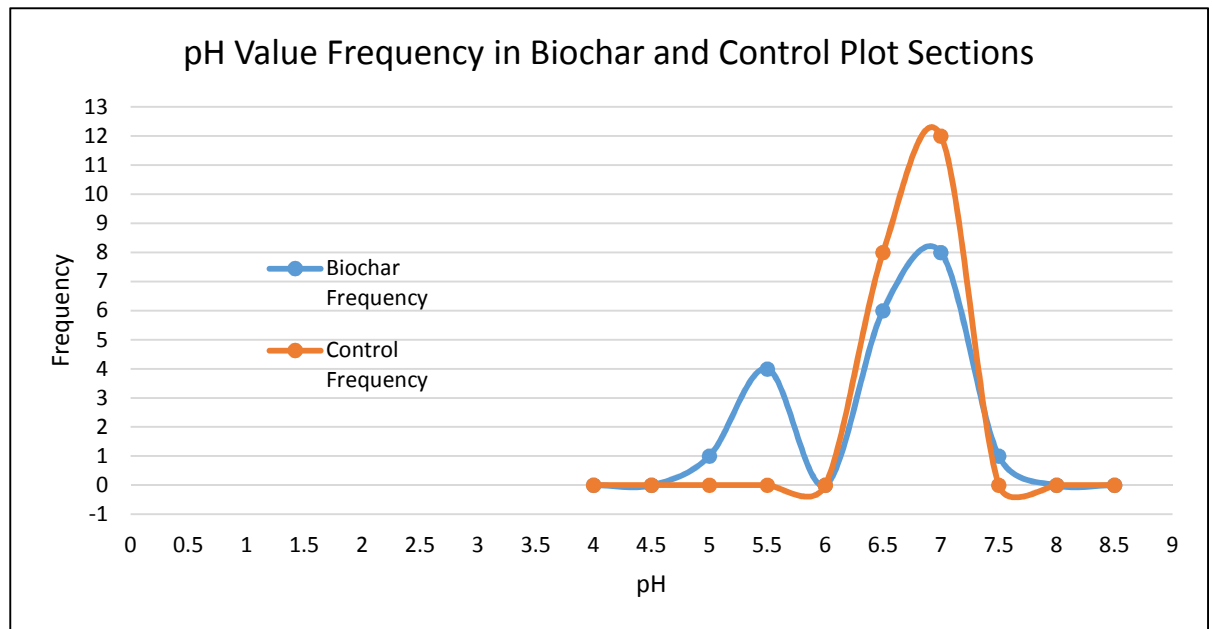
Figure 13: Distribution of pH values within biochar and control plot sections.

4.1.2 Soil Electrical Conductivity

The distribution of EC values across the plot field differed greatly between the biochar and control treatments. EC values also fluctuated between the five samples within each plot

section. Both the lowest and highest EC values were in control plots. Soil EC is measured in

conductivity (μS/cm), otherwise known as the resistance between two electrodes. The lowest EC

value was 161.5 μS/cm in the control plot section 303, and the highest EC value was 300.2

μS/cm in control plot section 206. Control plot sections had a slightly higher mean EC value

than biochar plot sections, but were not statistically significantly higher than mean biochar plot

section EC. Two-tailed t-test results showed that the difference between the biochar and control

plot section EC values was 0.62, which was not statistically significant when tested at a 95%

confidence level.

Biochar plot sections showed a smaller range of EC values, yet EC values between the

five samples within each plot section differed slightly in three of the four plot sections. The

biochar plot sections had EC values that ranged from a minimum of 165.4 μS/cm to a maximum

of 251.4 μS/cm (Figure 14). The mean EC value of the biochar plot sections was 202.07 μS/cm,

which is slightly lower than the ideal EC range for soybean production at 280-360 μS/cm.

Biochar plot sections had fewer outlying EC values than the control plot sections that affected

the mean.

EC values within control plot sections varied greatly, both across the plot field and

between the five samples taken within each control plot section. Control plot sections had a

minimum of 161.5 μS/cm in the control plot section 303 and a maximum of 300.2 μS/cm in

control plot section 206 (Figure 15). The maximum EC value in this control plot section is

drastically higher than the EC values of the rest of the soil samples within that plot section, with

a mean of 203.30 μS/cm. Many of the plot sections have outlying EC values in one of the

samples from each plot section that increases the overall mean of the control plot sections. The

mean EC for the control plot sections was 207.11 µS/cm, which is slightly more suitable for

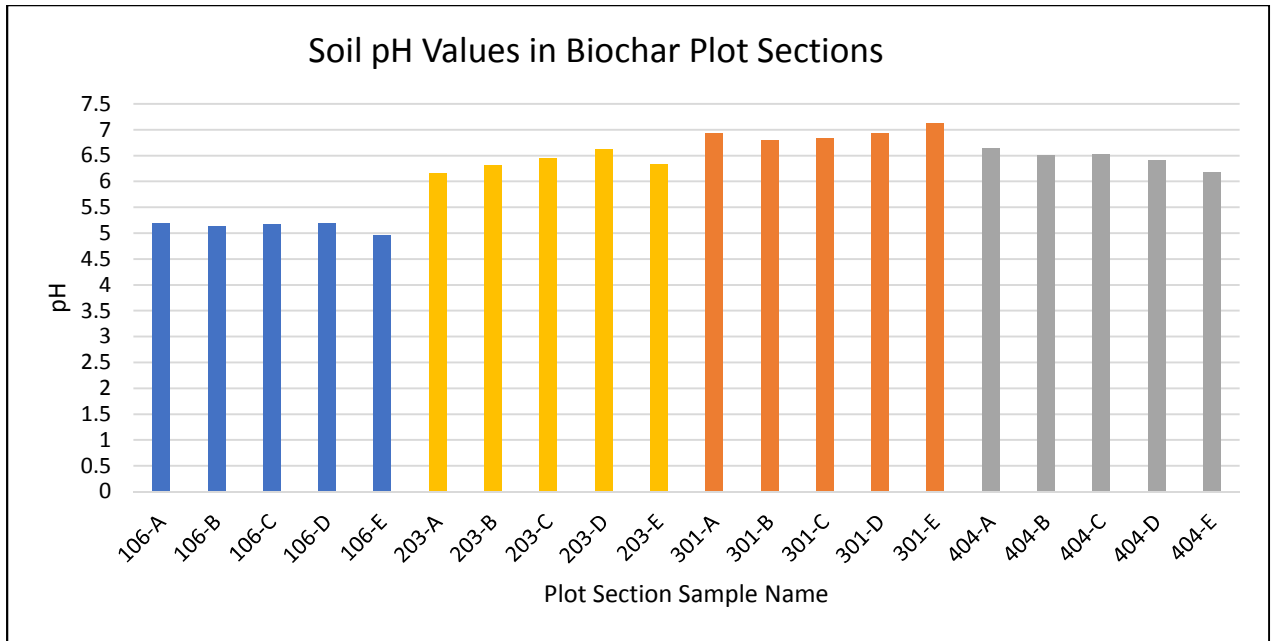soybean production than the biochar plot sections.
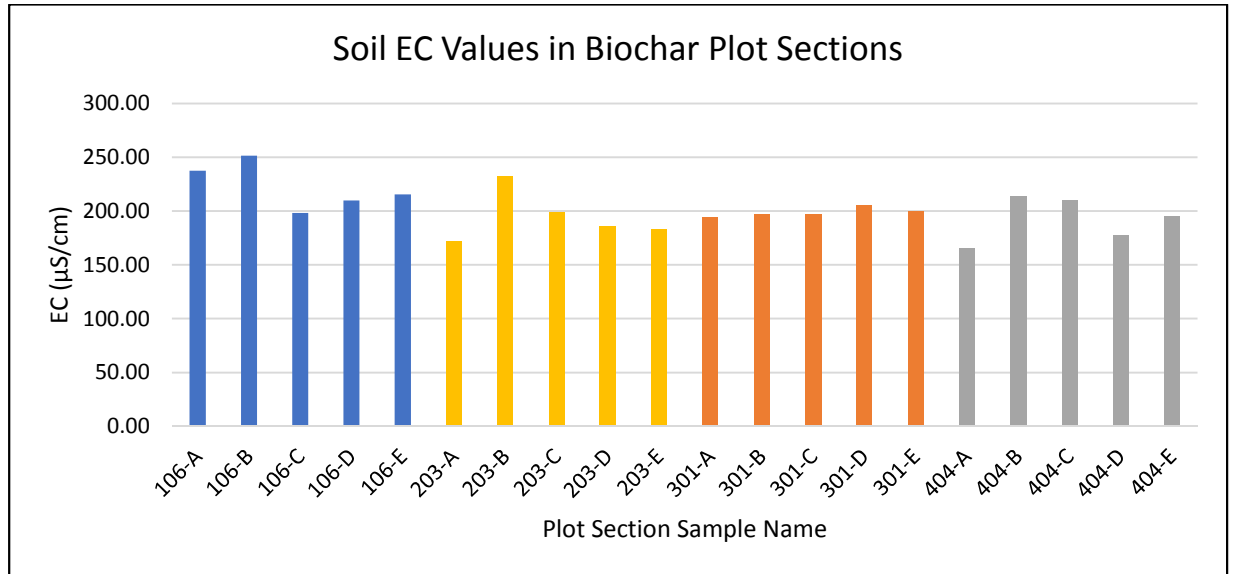
Figure 14: EC values within biochar plot sections. The different colors distinguish samples within each plot section.
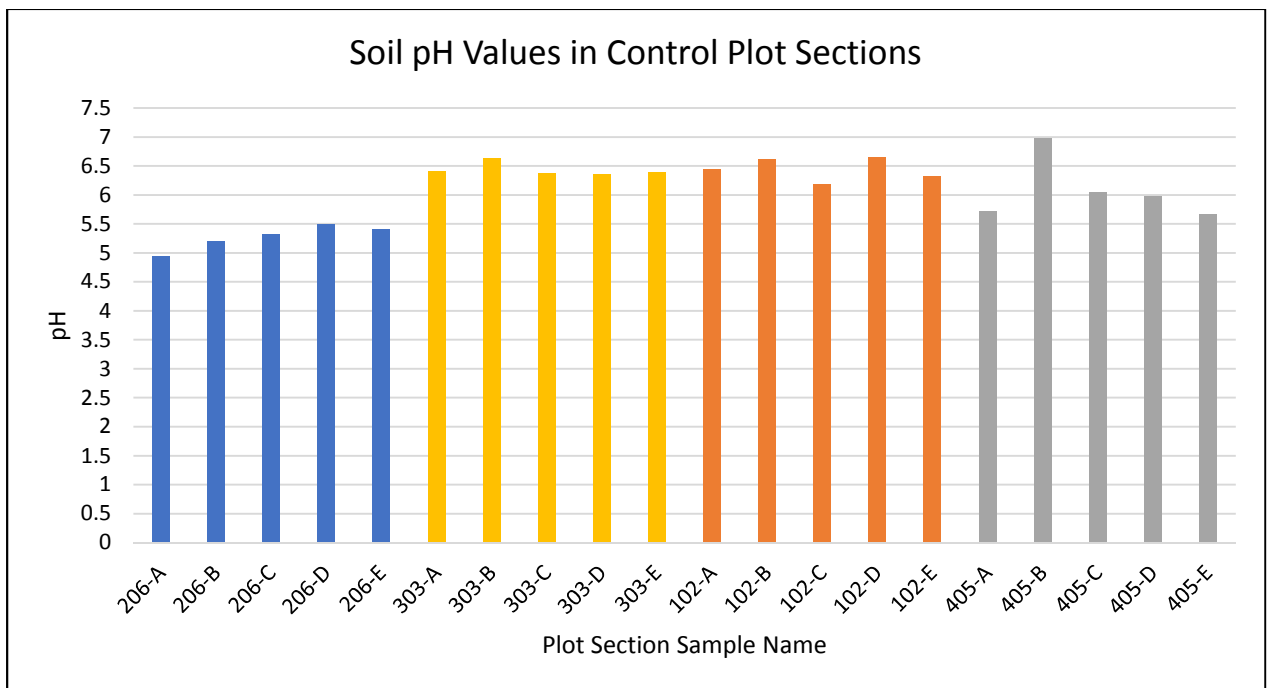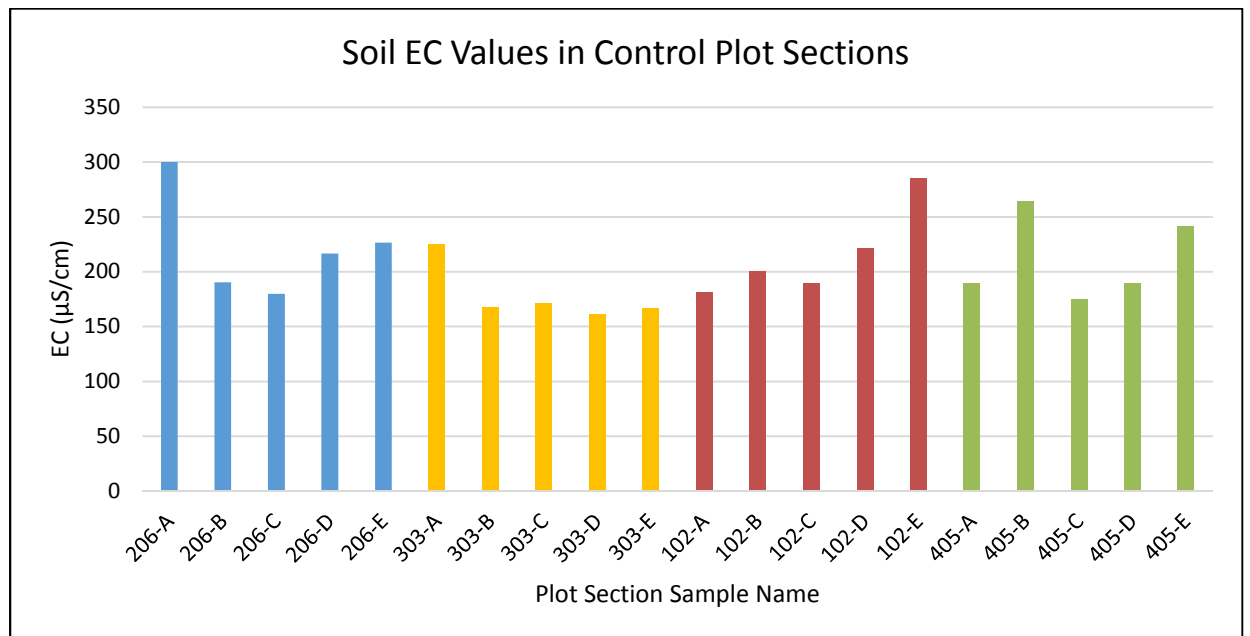

Figure 15: EC values within control plot sections. The different colors distinguish samples within each plot section.

The spatial distribution of soil EC values showed a loose pattern of control plot sections having higher mean values than biochar plot sections. The highest mean EC values in both plot section treatments were in control plot section 206, found on the southwest edge of the plot field (Figure 16). The lowest mean EC values in both plot section treatments came from samples taken from control plot section 303, which is in the center of the plot field. Within the biochar plot sections, EC level was consistent and stayed at a mean level when compared to the control plot sections. Only one of the biochar plot sections, biochar plot section 106, had high soil EC values. Three of the four control plot sections had one EC value higher than the rest within the plot section samples. Only one of the control plot sections had a consistently low soil EC value, found in control plot section 303. Likewise, only one of the biochar plot sections, biochar plot section 106, had high EC values. Although control plot sections had a slightly higher soil EC mean than biochar plot sections, it was not statistically significantly different.
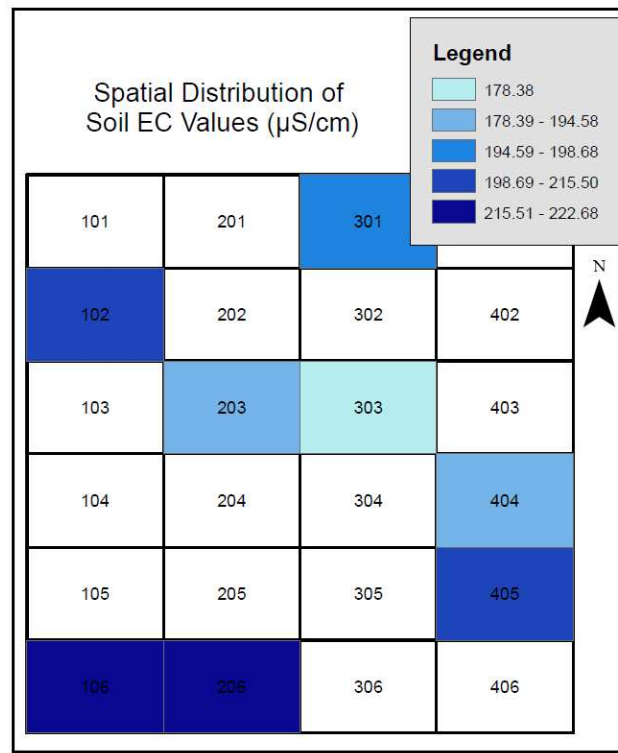
Figure 16: Spatial distribution of soil EC within plot field.

The EC values within the biochar plot sections were normally distributed because of the small range in EC values within this dataset (Figure 17). However, control plot sections displayed a different distribution in soil EC frequency with two peaks. Control plot section EC peaked the highest at about 180 µS/cm and again at about 245 µS/cm. Although biochar plot section EC was more normally distributed, the peak frequency was about 200 µS/cm. Overall, biochar plot sections had higher frequencies at about 200 µS/cm, but lower levels of soil EC than the control plot sections.
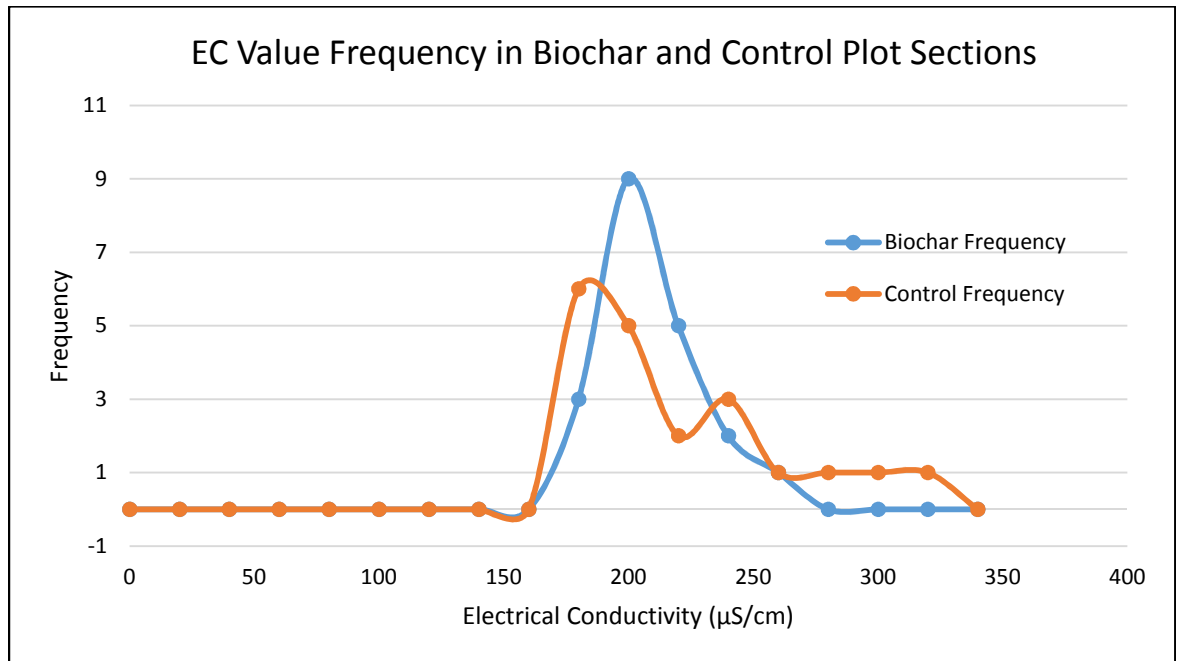
Figure 17: Distribution of EC values within biochar and control plot sections.

4.2 Soybean NDVI

NDVI was measured throughout all eight plot sections throughout all eight stages of soybean reproductive growth. Those growth stages include: R1 is the stage in which the first flower appears (Figure 18). R2 is the stage in which the whole plant is flowering (Figure 19). R3 is the stage in which the soybean pods begin development (Figure 20). R4 is the stage in

which the soybean pods are completely developed (Figure 21). R5 is the stage in which the

seeds begin development (Figure 22). R6 is the stage in which the seeds reach full development

(Figure 23). R7 is the stage in which the soybean plants are beginning maturity (Figure 24). R8

is the stage in which the soybean is completely mature (Figure 25).

Figure 18: Soybean in reproductive stage 1, first flower.

Figure 19: Soybean in reproductive stage 2, full flowering.

Figure 20: Soybean in reproductive stage 3, beginning pod development.

Figure 21: Soybean in reproductive stage 4, complete pod development.

Figure 22: Soybean in reproductive stage 5, beginning seed development.

Figure 23: Soybean in reproductive stage 6, full seed development.

Figure 24: Soybean in reproductive stage 7, beginning maturity.

Figure 25: Soybean in reproductive stage 8, complete maturity.

NDVI was measured over eight stages of growth in eight different plot sections. Each plot section had an adjacent plot section of the opposite treatment in which it was compared to. Those pairs were biochar plot section 106 and control plot section 206, biochar plot section 203 and control plot section 303, biochar plot section 301 and control plot section 102, and biochar plot section 404 and control plot section 405. The mean NDVI for all biochar plots from all reproductive growth stages (R1-R8) was 0.536 and the mean NDVI for all control plot sections was 0.526. Biochar plot sections had a slightly higher NDVI value than control plot sections throughout the growing season. The data within each reproductive growth stage shows that none of the NDVI means were statistically significantly different than their adjacent plot sections of the other treatment.

The spatial distribution of soybean NDVI values throughout the growing period showed that biochar plot sections had higher mean values than biochar plot sections. There was no

discernable spatial pattern in NDVI values. The highest mean soybean NDVI values in both plot

section treatments at 0.6892 were in control plot section 102, found on the north western corner

of the plot field (Figure 26). The lowest mean soil NDVI value in both plot section treatments at

0.6106 came from samples taken from control plot section 405, adjacent to the plot section with

the highest soil NDVI value on the eastern edge of the plot field. Most NDVI means fluctuated

from 0.68 to 0.70. Although biochar plot sections had higher soybean NDVI means than control

plot sections throughout the growing season, it was not statistically significantly different.
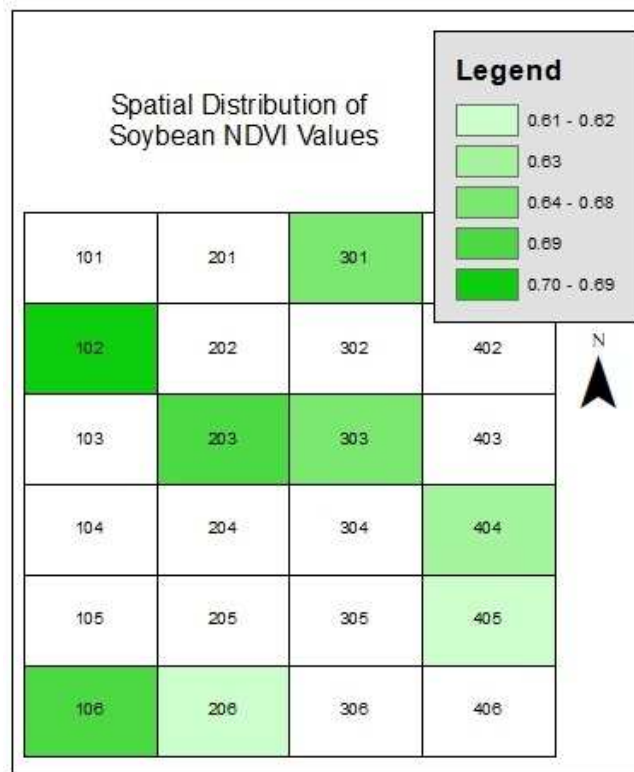
Figure 26: Spatial distribution of soil pH within plot field.

4.2.1. Soybean NDVI in Biochar Plot Section 106 and Control Plot Section 206

Biochar plot section 106 and control plot section 206 are in the southwest corner of the

plot field (Figure 27). Both plots experienced very little weed pressure throughout the growth

period of the soybeans and a very high rate of soybean germination. Throughout the growing season, biochar plot section 106 had a mean NDVI of 0.688 and control plot 206 had a mean NDVI of 0.707. Although the mean NDVI for biochar plot section 106 was lower than control plot section 206, it was not statistically significantly different. When tested using a t-test at a 95% confidence level, the t-score was 0.832. The data for these two plot sections had one anomaly in the maximum NDVI for control plot section 206 in growth stage R1, which was not used to calculate the NDVI mean over the growing season or the t-test.

Figure 27: Study plot design. Corn stover biochar was incorporated in 15 ft by 15 ft areas (225 sq. ft.) within biochar plot sections in May 2013 (Sandhu 2015).

Soybeans in biochar plot section 106 had a higher minimum NDVI than control plot section 206 during reproductive growth stage one (R1) (Figure 28). However, control plot section 206 had a much higher maximum NDVI that was outside the normal range, so it was considered an outlier in the data and not included in any statistical calculations. This shows in the NDVI image for control plot section 206, as it has very few values within the normal NDVI range and appears to have very little coloring in the image. The reason for the abnormalities could be an error in camera calibration or image corruption during image or NDVI processing. These two plot sections were incomparable during this stage of growth because of abnormal NDVI value in the control plot section 206. Frequency histograms of NDVI value during growth stage R1 showed that the highest frequency was an NDVI value of about 0.75 in biochar plot section 106 and about a 0.70 in control plot section 206. Biochar plot section 106 had frequencies of NDVI values over a larger range (Figure 36). Control plot section 206 had higher NDVI frequencies over a smaller range.

Growth stage R2 showed more comparable differences than growth stage R1 because the NDVI values were in an acceptable range of 0 to 1. Biochar plot section 106 had both a lower minimum NDVI and a higher maximum NDVI than control plot section 206 and mean NDVI was higher in control plot section 206 than in biochar plot section 106 (Figure 29). NDVI images showed similar results with both plot section treatments. Frequency histograms of growth stage R2 show higher frequencies of 0.6 NDVI in biochar plot section 106 than in control plot section 206, but showed no other visual differences in value frequency (Figure 36). The highest frequency NDVI value was recorded in control plot section 206 at about 0.8.

Soybeans during growth stage R3 began to display higher NDVI minimums in both treatments as soybean plants got larger; therefore, the images became noisier, or less detailed

(Figure 30). The NDVI images remained similar in value in both plot treatments. Biochar plot section 106 had a lower minimum NDVI value than control plot section 206. Both plot sections had the same maximum NDVI value for growth stage R3 at 1. Mean NDVI was lower in biochar plot section 106 than in control plot section 206. NDVI histograms show differences in the distribution of higher NDVI frequencies in the two section treatments during growth stage R3 (Figure 36). Biochar plot section 106 had a very large frequency of NDVI values at 0.9 while control plot section 206 had a lower frequency of 0.9 NDVI, but a larger variety of high frequency values between 0.8 and 1.0 NDVI.

NDVI images in growth stage R4 were similar in value between both treatments (Figure 31). Biochar plot section 106 had a higher minimum NDVI, while control plot section 206 had a lower minimum NDVI. Both plot sections had maximum NDVI values at 1. The mean for biochar plot section 106 during growth stage R4 was slightly lower than the mean value for control plot section 206. NDVI frequency histograms showed little change between the NDVI frequencies in plot sections 106 and 206, with the highest frequency at about 0.9 NDVI for both treatments during growth stage R4 (Figure 36).

Soybeans during growth stage R5 were very similar, both in NDVI image and value (Figure 32). The NDVI images recorded only positive values. This allowed the NDVI images to have areas of missing data. Biochar plot section 106 had a minimum NDVI value of 0, which was lower than the NDVI minimum of control plot section 206. Biochar plot section 106 had a slightly higher maximum NDVI value than control plot section 206. The mean for biochar plot section 106 was lower than control plot section 206 during growth stage R5. NDVI frequencies during growth stage R5 were very similar between plot treatments (Figure 37). NDVI

frequencies gradually increased with increasing NDVI value and peaked at 0.85 for both biochar plot section 106 and control plot section 206.

Growth stage R6 was the first growth stage in plot sections 106 and 206 that showed visual differences in NDVI images (Figure 33). The NDVI image for biochar plot section 106 showed faster maturing soybeans, while the NDVI image for control plot section 206 showed soybeans that did not mature as quickly. This may have happened because of the locations of the plot sections being on the edge of the plot field. Biochar plot section 106 had a lower minimum NDVI and the same maximum NDVI as control plot section 206. The mean for biochar plot section 106 was lower than control plot section 206 during growth stage R6. The NDVI frequency histograms in growth stage R6 were similar to the histograms in growth stage R3 (Figure 37). Control plot section 206 had more frequencies of NDVI values between 0.6 and 1.0. Biochar plot section 106 had a much larger frequency of NDVI values at 0.8 while control plot section 206 had a much lower frequency of 0.8 NDVI.

The NDVI images for plot sections 106 and 206 during growth stage R7 were very similar in value (Figure 34). Biochar plot section 106 had a slightly lower minimum and maximum NDVI value. The mean for biochar plot section 106 was higher than control plot section 206. Frequency histograms for NDVI in growth stage R7 were different from other growth stages because the soybeans have been maturing and the highest frequencies were about 0.65 in biochar plot section 106 and 0.6 in control plot section 206 (Figure 37).

The plot sections 106 and 206 in the last growth stage, R8, had the most similar NDVI values throughout the entire growing period (Figure 35). Both biochar plot section 106 and control plot section 206 had minimum NDVI values at 0 and nearly the same maximum NDVI value with biochar plot section 106 having a slightly lower maximum NDVI value. Biochar plot

section 106 had a slightly higher mean NDVI than control plot section 206 in growth stage R8.

NDVI frequencies in growth stage R8 are similar between the two treatments. Both plot sections

showed higher frequencies in lower NDVI values because soybeans were at full maturity during

this stage (Figure 37). Biochar plot section 106 had slightly higher frequencies from 0.65 to 0.8

than control plot section 206. Overall, an NDVI of 0.55 had the highest frequency in both plot

section treatments during growth stage R8.

NDVI of Biochar Plot Section 106 in Soybean Growth Stage R1

NDVI of Control Plot Section 206 in Soybean Growth Stage R1

Legend
High : 1
Low : 0.000208011

Legend
High : 65504
Low : 0
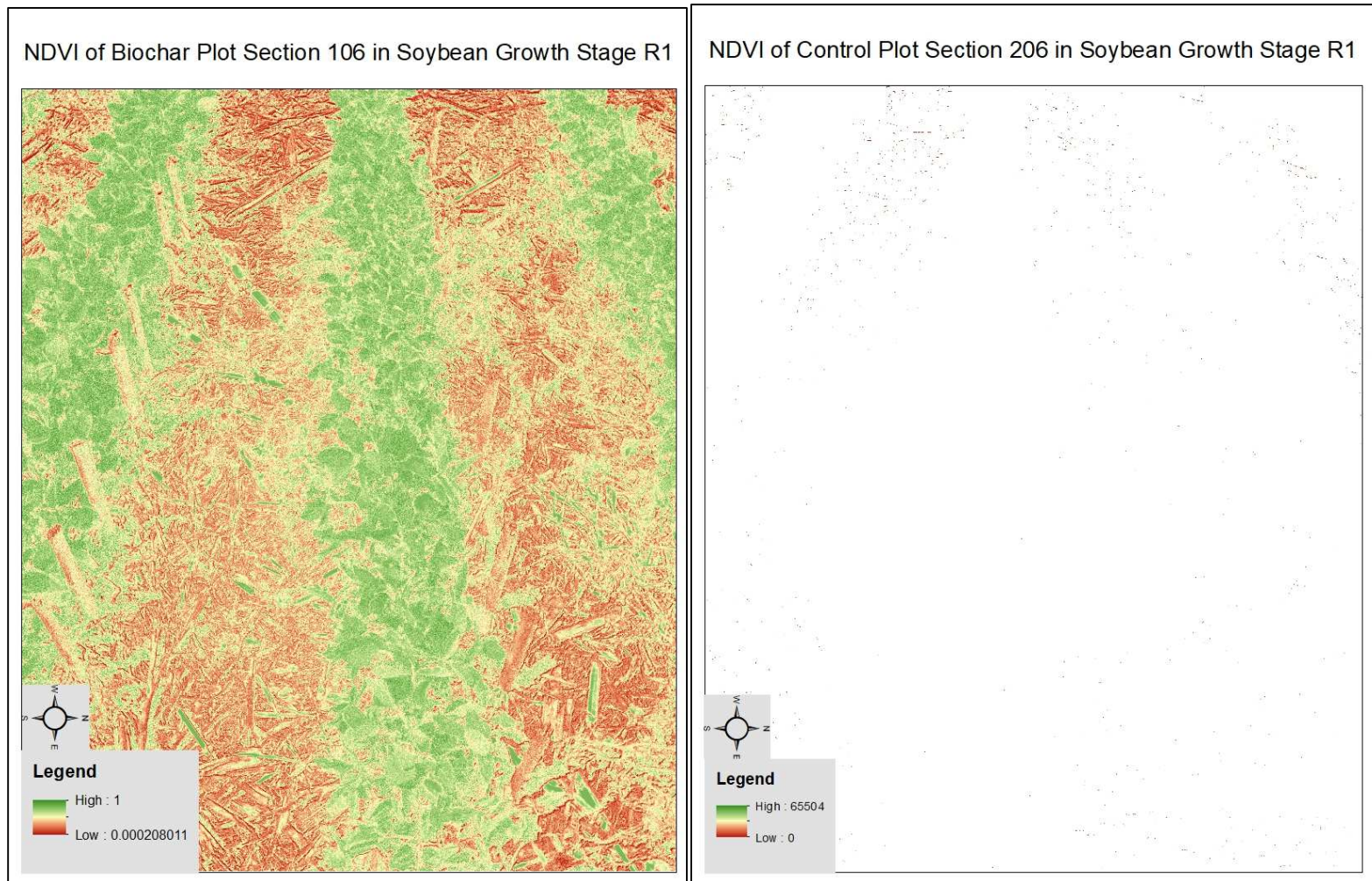
Figure 28: NDVI of biochar plot section 106 and control plot section 206 in soybean reproductive stage one.

Figure 29: NDVI of biochar plot section 106 and control plot section 206 in soybean reproductive stage two.

Figure 30: NDVI of biochar plot section 106 and control plot section 206 in soybean reproductive stage three.

Figure 31: NDVI of biochar plot section 106 and control plot section 206 in soybean reproductive stage four.

Figure 32: NDVI of biochar plot section 106 and control plot section 206 in soybean reproductive stage five.

Figure 33: NDVI of biochar plot section 106 and control plot section 206 in soybean reproductive stage six.

Figure 34: NDVI of biochar plot section 106 and control plot section 206 in soybean reproductive stage seven.

Figure 35: NDVI of biochar plot section 106 and control plot section 206 in soybean reproductive stage eight.

Figure 36: NDVI frequency histograms for reproductive growth stages R1-R4 in biochar plot section 106 (top) and control plot section 206 (bottom).
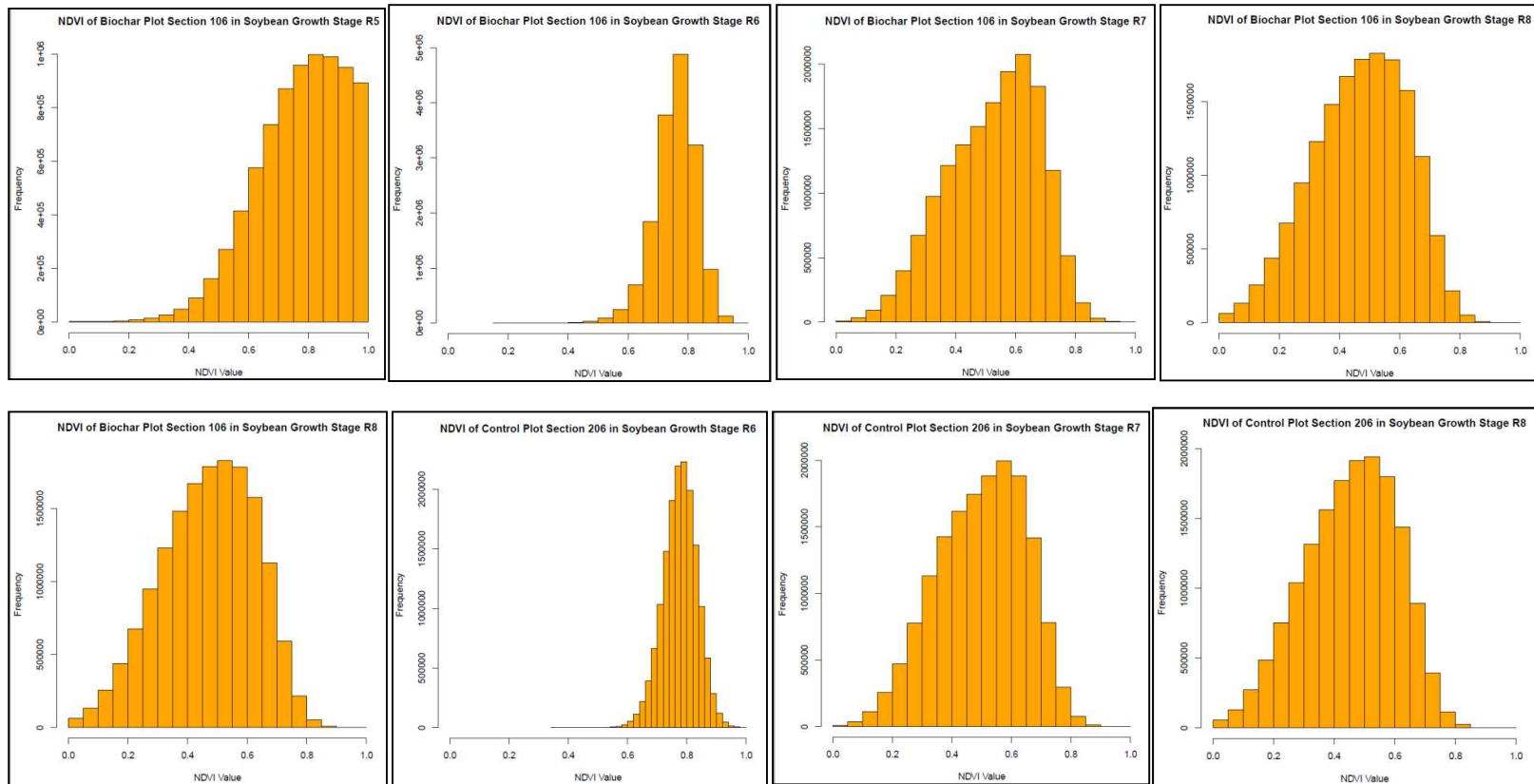
Figure 37: NDVI frequency histograms for reproductive growth stages R5-R8 in biochar plot section 106 (top) and control plot section 206 (bottom).

4.2.2. Soybean NDVI in Biochar Plot Section 203 and Control Plot Section 303

Biochar plot section 203 and control plot section 303 are located near the center of the plot field (Figure 27). Weeds were more prevalent in these two plot sections than anywhere else in the plot field, resulting in a lower soybean germination rate within these two plot sections. Throughout the growing season, biochar plot section 203 had a mean NDVI of 0.688 and control plot 206 had a mean NDVI of 0.681. Although the mean NDVI for biochar plot section 203 was higher than control plot section 303, it was not statistically significantly different. When tested using a t-test at a 95% confidence level, the t-score was 0.919.

Biochar plot section 203 soybeans had a higher minimum NDVI than control plot section 303 during reproductive growth stage one (R1) (Figure 38). Both plot section treatments had a maximum NDVI at 1, most likely because of the weed growth within the plot. The mean NDVI for biochar plot section 203 was higher than control plot section 303. Frequency histograms of NDVI value during growth stage R1 showed that the highest frequency was an NDVI value of about 0.7 in biochar plot section 203 and about a 0.65 in control plot section 303. Biochar plot section 203 had higher NDVI frequencies overall and higher frequencies from 0.75 to 1.0 NDVI than control plot section 303 (Figure 46).

NDVI images in growth stage R2 were very similar visually and in NDVI value. Biochar plot section 203 had both a higher minimum NDVI and the same maximum NDVI as control plot section 303. Mean NDVI was higher in control plot section 303 than in biochar plot section 203 (Figure 39). NDVI images showed similar results with both plot section treatments. NDVI frequency histograms showed little change between the NDVI frequencies in plot sections 203 and 303, with the highest frequency at about 0.9 NDVI for both treatments during growth stage

R2. The highest frequency NDVI value was recorded at about 0.75 for both plot sections 203 and 303 during growth stage R2 (Figure 46).

Soybeans during growth stage R3 began to display higher NDVI minimums in both treatments as soybean plants got larger; therefore, the images became noisier, or less detailed (Figure 40) The NDVI images were similar in value in both plot treatments; however, there were more weeds in control plot section 303. Biochar plot section 203 had a higher minimum NDVI value than control plot section 303. Both plot sections had the same maximum NDVI value for growth stage R3 at 1. Mean NDVI was lower in biochar plot section 203 than in control plot section 303. Both plot section 203 and 303 have almost identical NDVI histograms. Both plot treatments have a peak frequency of 0.9 NDVI in growth stage R3 (Figure 46).

NDVI images in growth stage R4 were similar in value between both treatments, but once again show more weed pressure in control plot section 303 (Figure 41). Biochar plot section 203 had a higher minimum NDVI, while control plot section 303 had a lower minimum NDVI. Both plot sections had maximum NDVI values at 1. The mean for biochar plot section 203 during growth stage R4 was slightly lower than the mean value for control plot section 303. NDVI frequency histograms showed little change between the NDVI frequencies in plot sections 203 and 303, with the highest frequency about 0.85 NDVI for both treatments during growth stage R4 (Figure 46).

Soybeans during growth stage R5 were very similar, both in NDVI image and value (Figure 42). Both biochar plot section 203 and control plot section 303 had a minimum NDVI value of 0. Biochar plot section 203 had a slightly higher maximum NDVI value than control plot section 303. The mean for biochar plot section 203 was lower than control plot section 303 during growth stage R5. NDVI frequencies during growth stage R5 were very similar between

plot treatments (Figure 47). NDVI frequencies gradually increased with increasing NDVI value and peaked at 0.8 in biochar plot section 203 and peaked at 0.85 in control plot section 303.

Plot sections 203 and 303 had very similar NDVI images for growth stage R6 (Figure 43). Biochar plot section 203 had a higher minimum NDVI and the same maximum NDVI as control plot section 303. The mean for biochar plot section 203 was lower than control plot section 303 during growth stage R6. The NDVI frequency histograms showed differences between the two treatments. Biochar plot section 203 had more frequencies of NDVI values between 0.6 and 1.0 (Figure 47). Control plot section 303 had a much larger frequency of NDVI values at 0.8 while biochar plot section 203 had a much lower NDVI frequency of 0.8.

The NDVI images for plot sections 203 and 303 during growth stage R7 were very similar in value (Figure 44). Biochar plot section 203 had the same minimum and maximum NDVI value than control plot section 303. The mean for biochar plot section 203 was higher than control plot section 206. Frequency histograms for NDVI in growth stage R7 were different from other growth stages because the soybeans have been maturing and the highest frequencies were about 0.65 in both biochar plot section 203 and control plot section 303 (Figure 47).

The plot sections 203 and 303 in the last growth stage, R8, were very visually similar (Figure 45). Both biochar plot section 203 and control plot section 303 had minimum NDVI values at 0 and maximum NDVI values at 1. Biochar plot section 203 had a higher mean NDVI than control plot section 303 in growth stage R8. NDVI frequencies in growth stage R8 are similar between the two treatments (Figure 47). Both plot sections showed higher frequencies in lower NDVI values because soybeans were at full maturity during this stage. Biochar plot section 203 had slightly higher frequencies from 0.65 to 0.8 than control plot section 303. One difference between the two NDVI histograms was a large increase in NDVI frequency in the 0.0

to 0.2 range in control plot section 303. The cause for this could be an error in NDVI processing or a corrupt image. Overall, an NDVI of 0.6 had the highest frequency in both plot section treatments during growth stage R8.
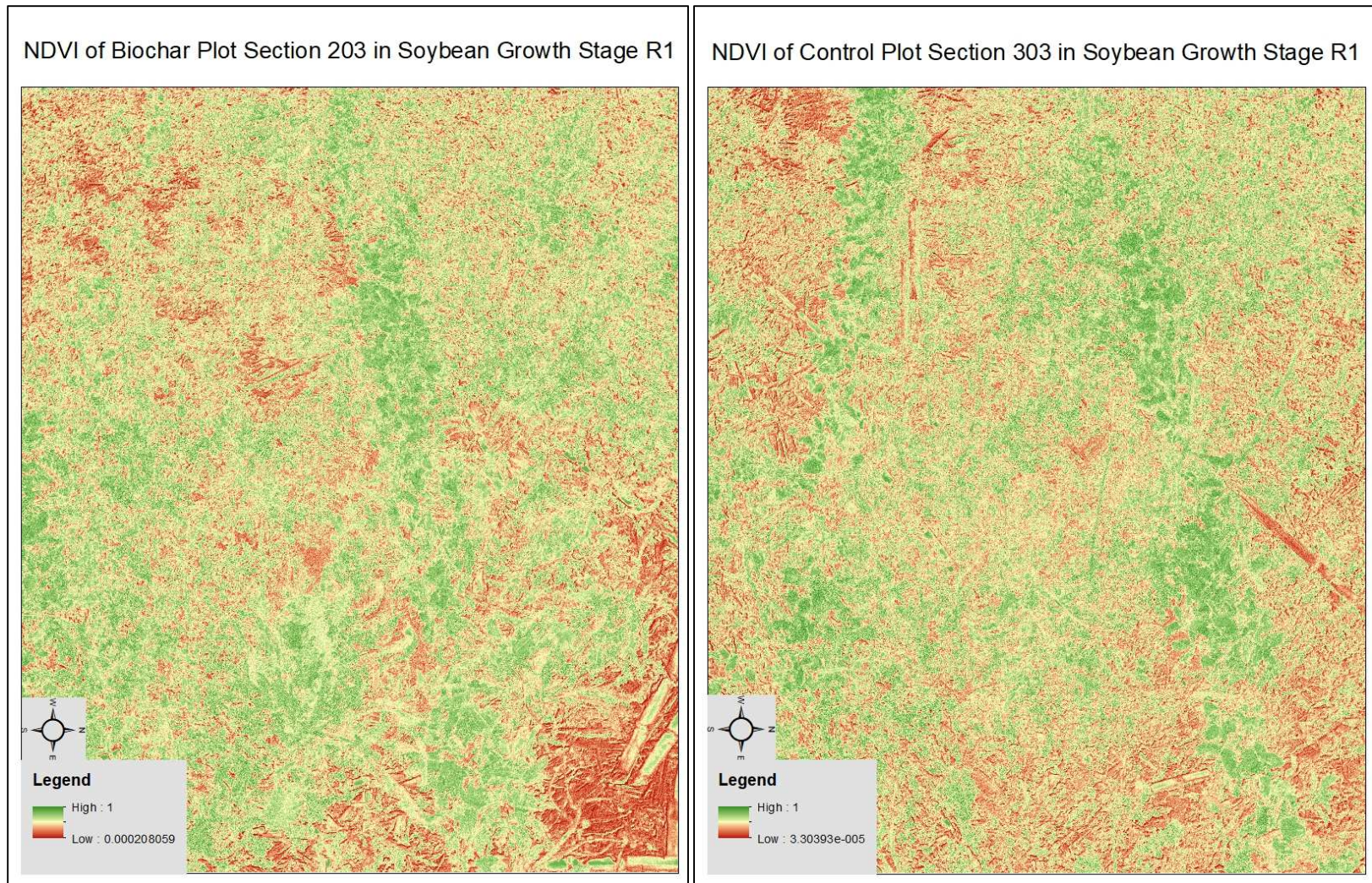
Figure 38: NDVI of biochar plot section 203 and control plot section 303 in soybean reproductive stage one.
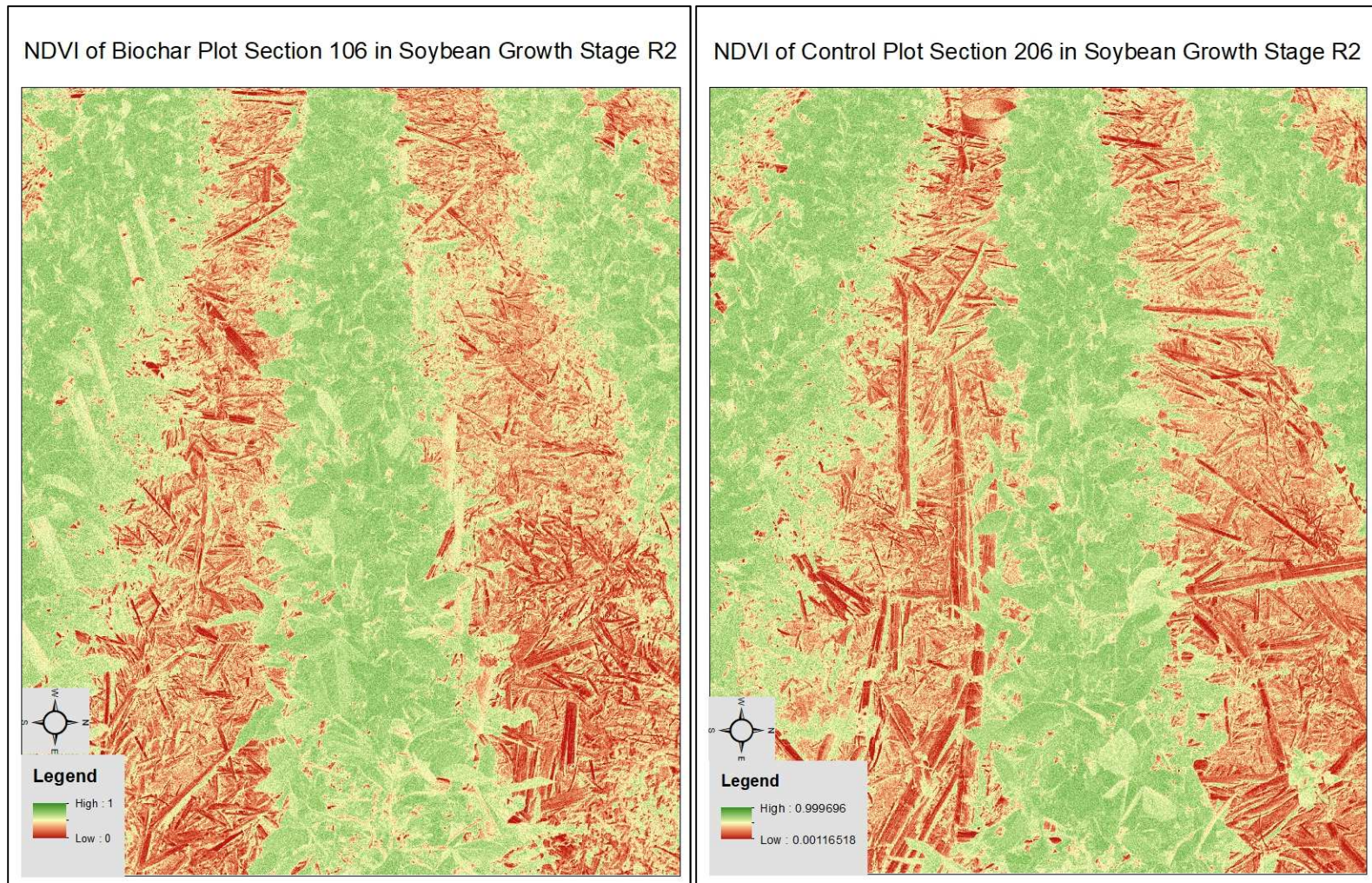
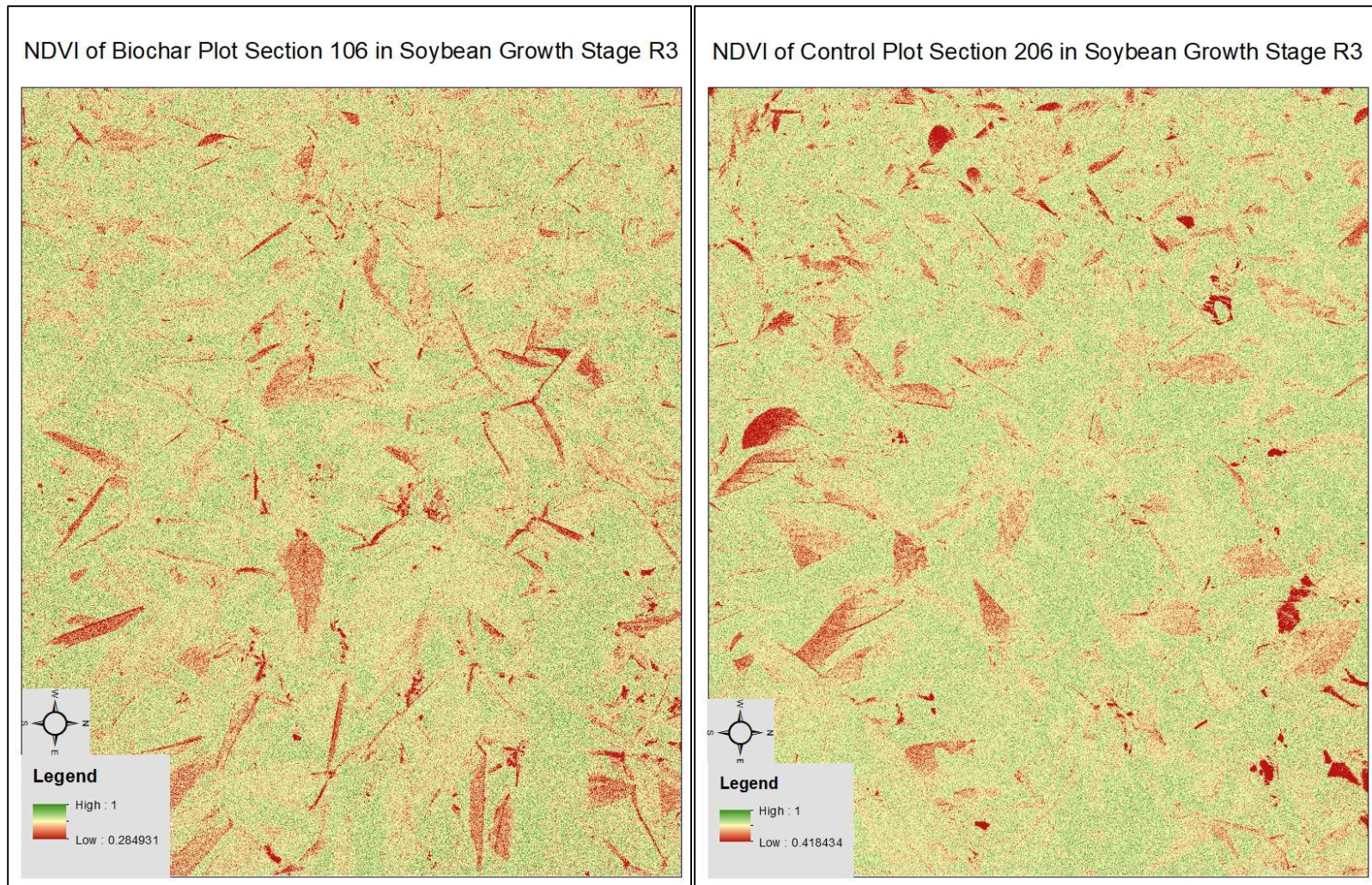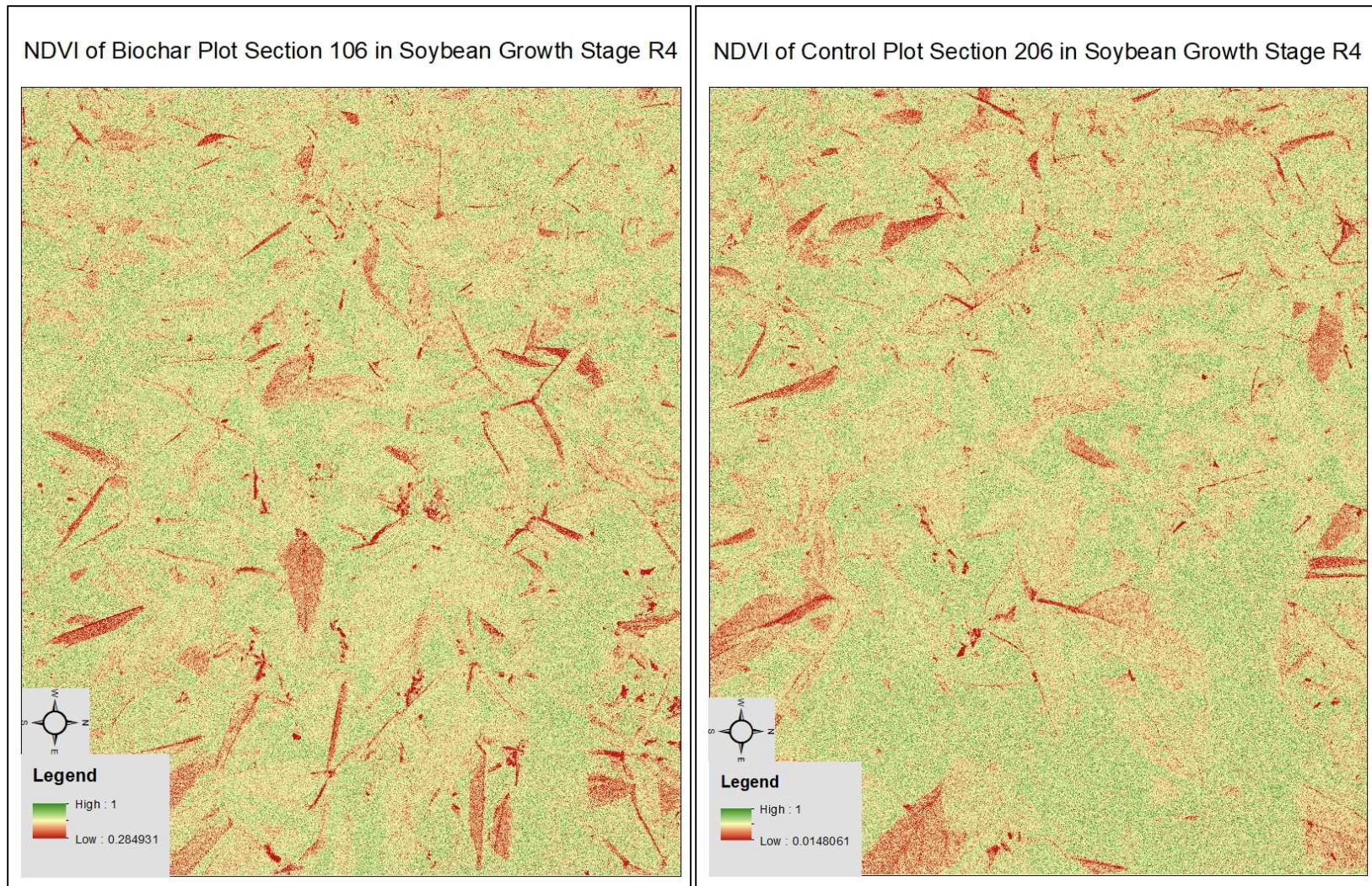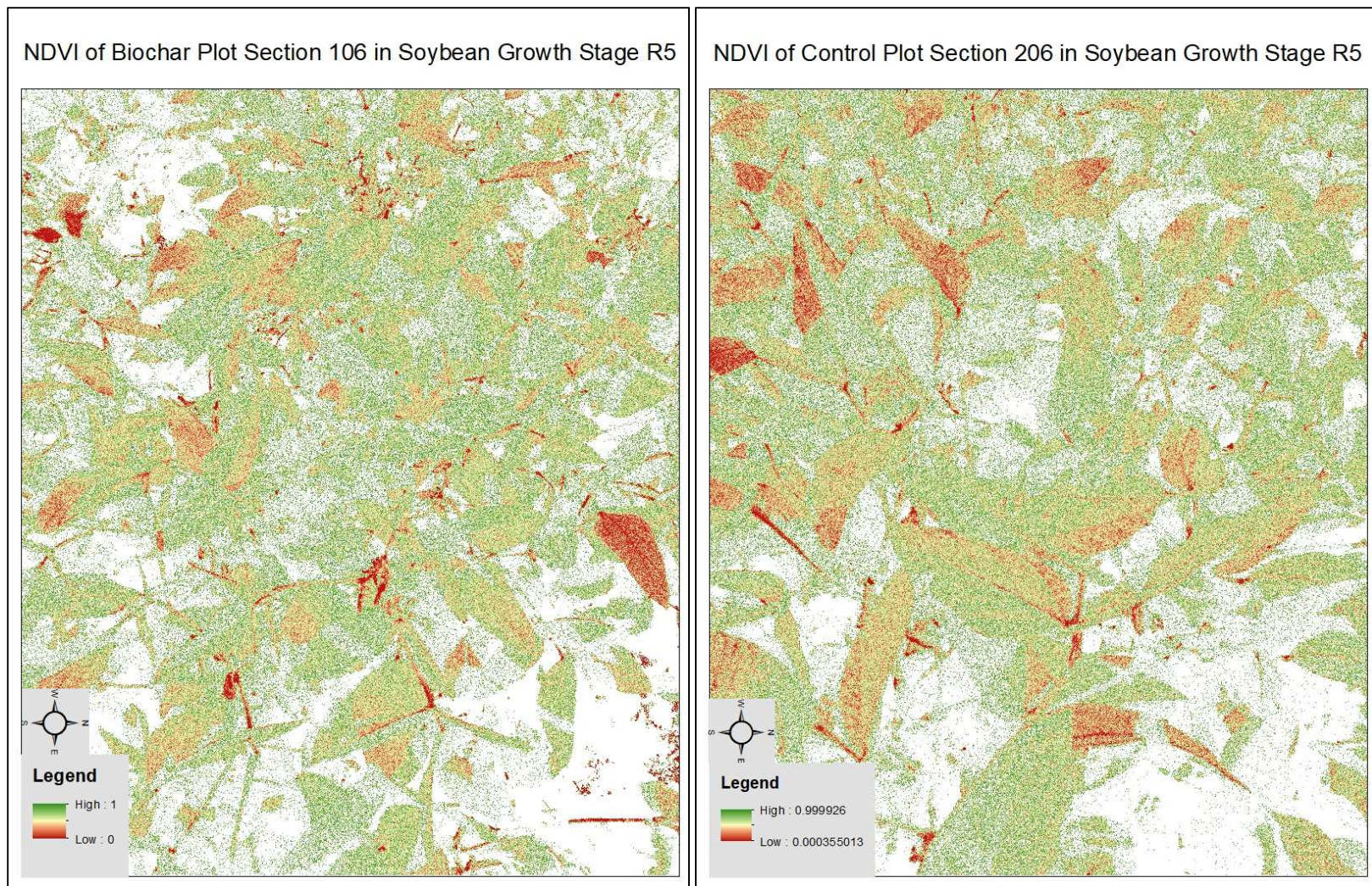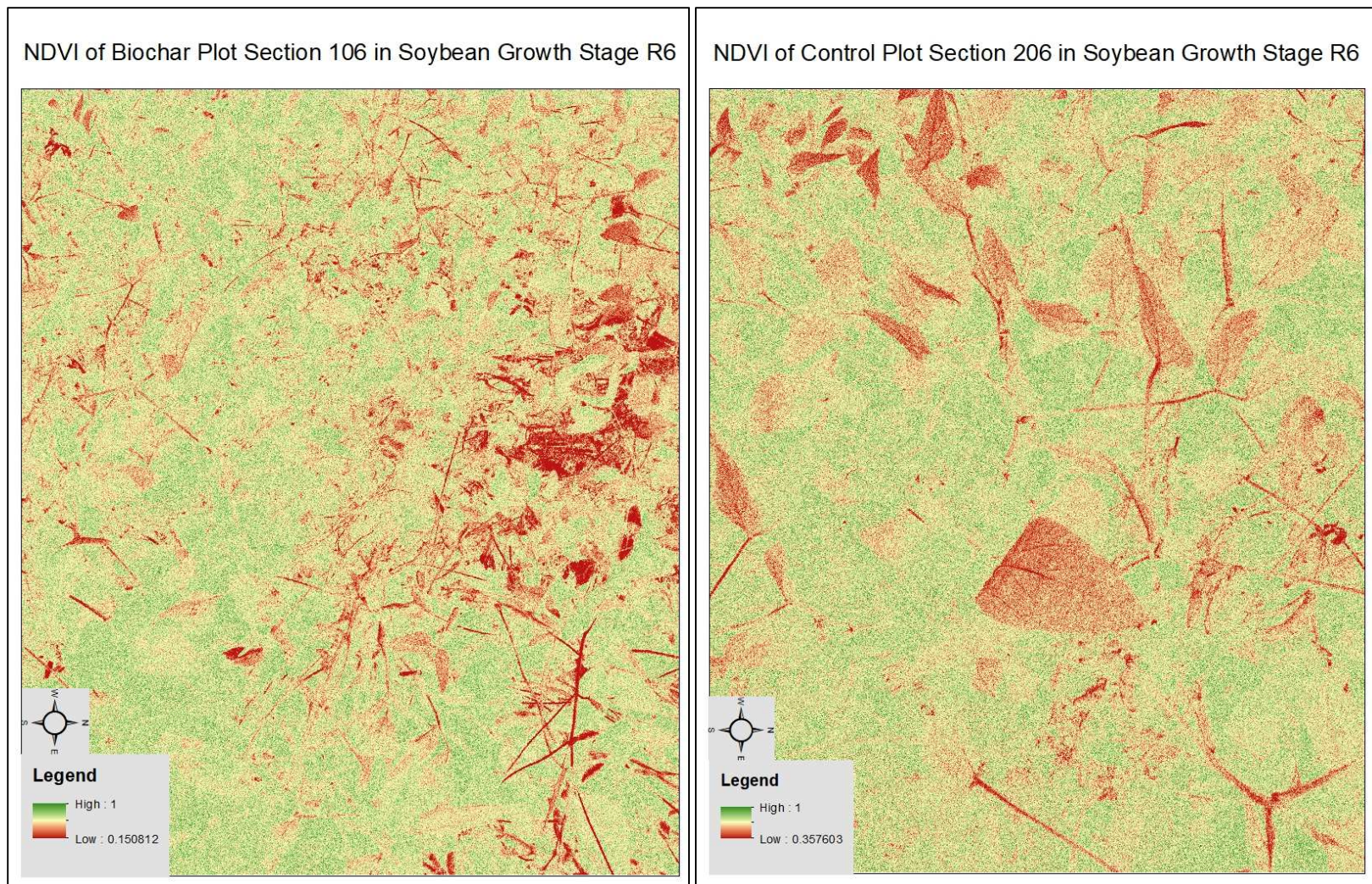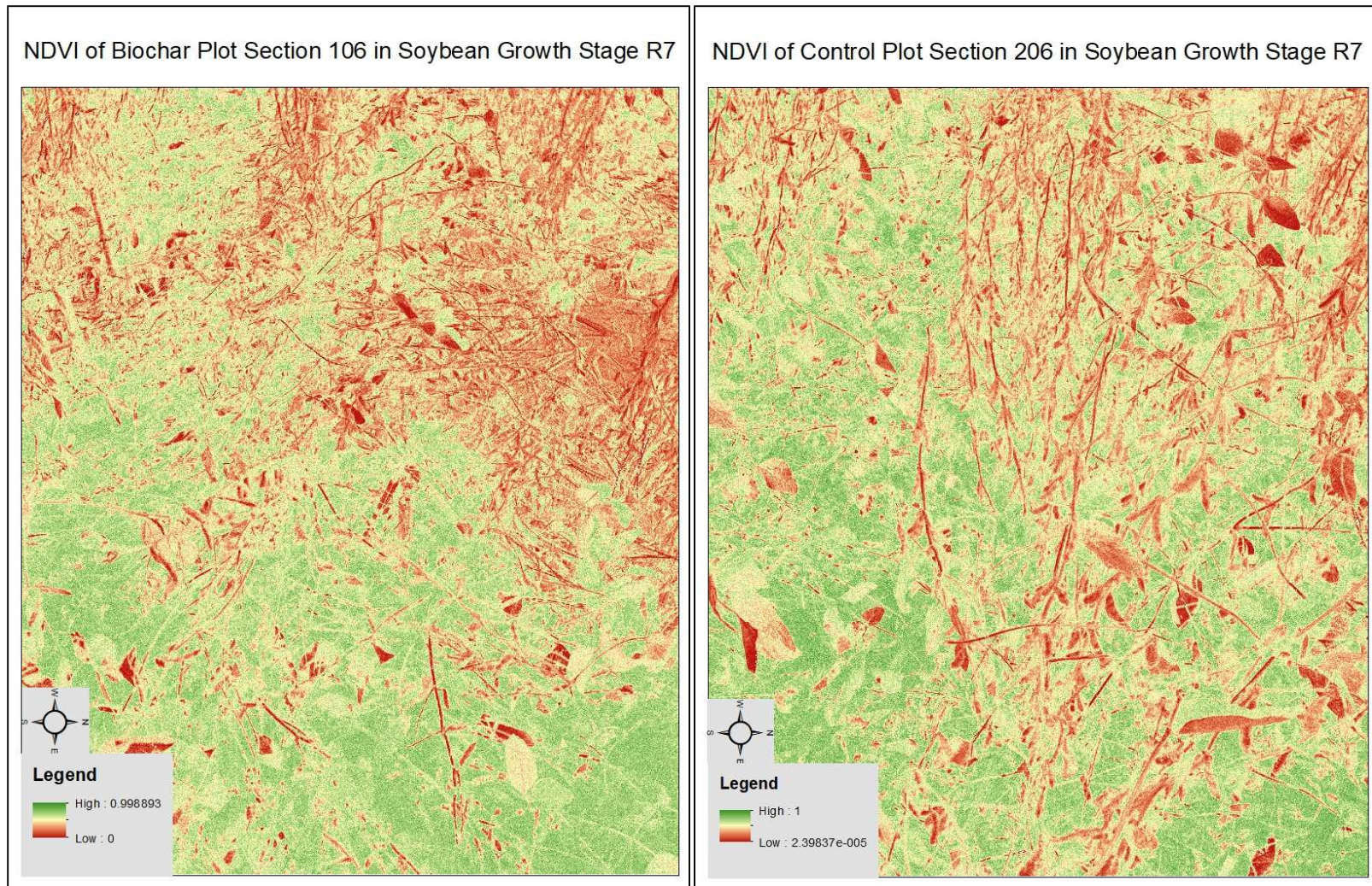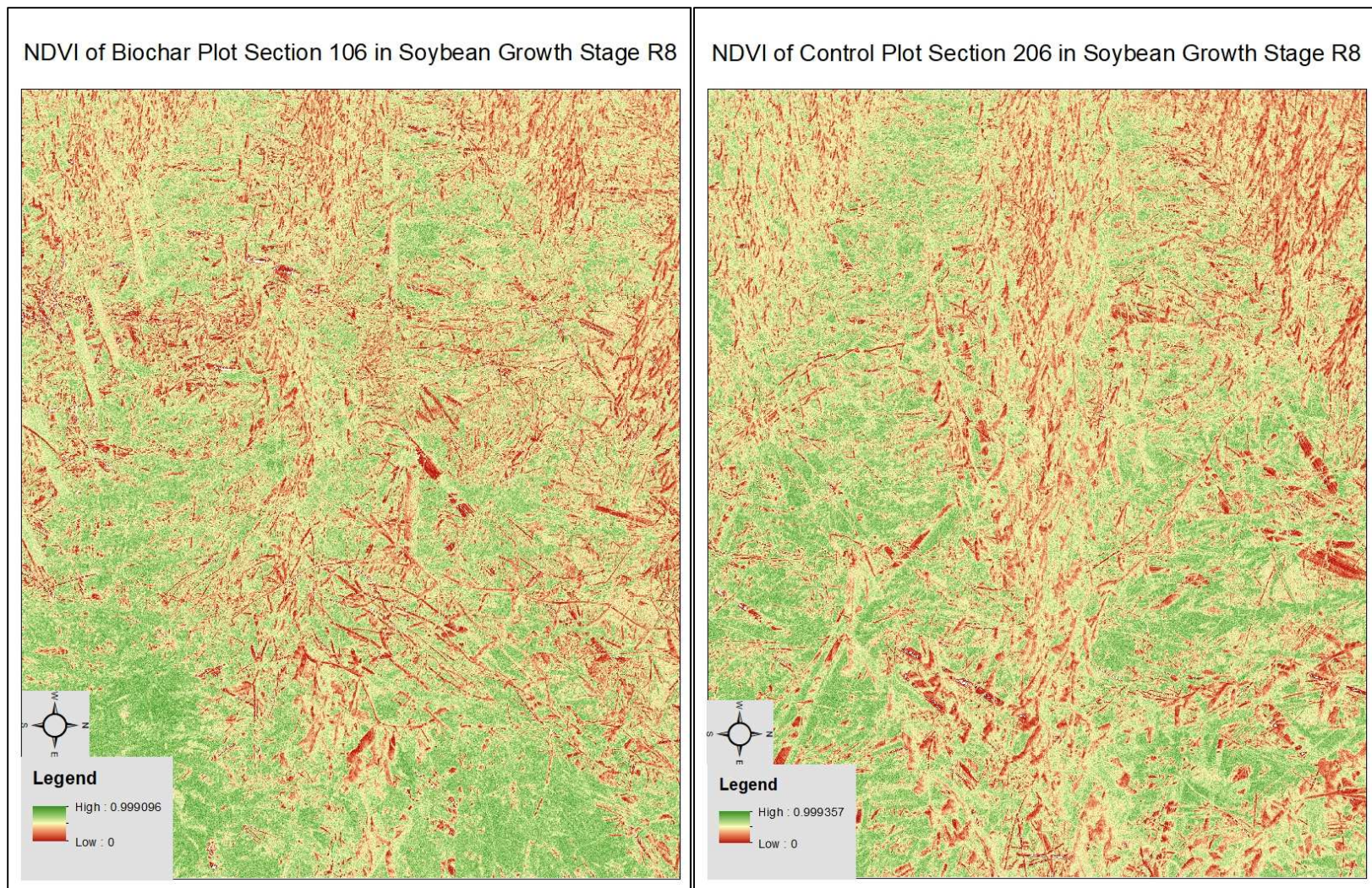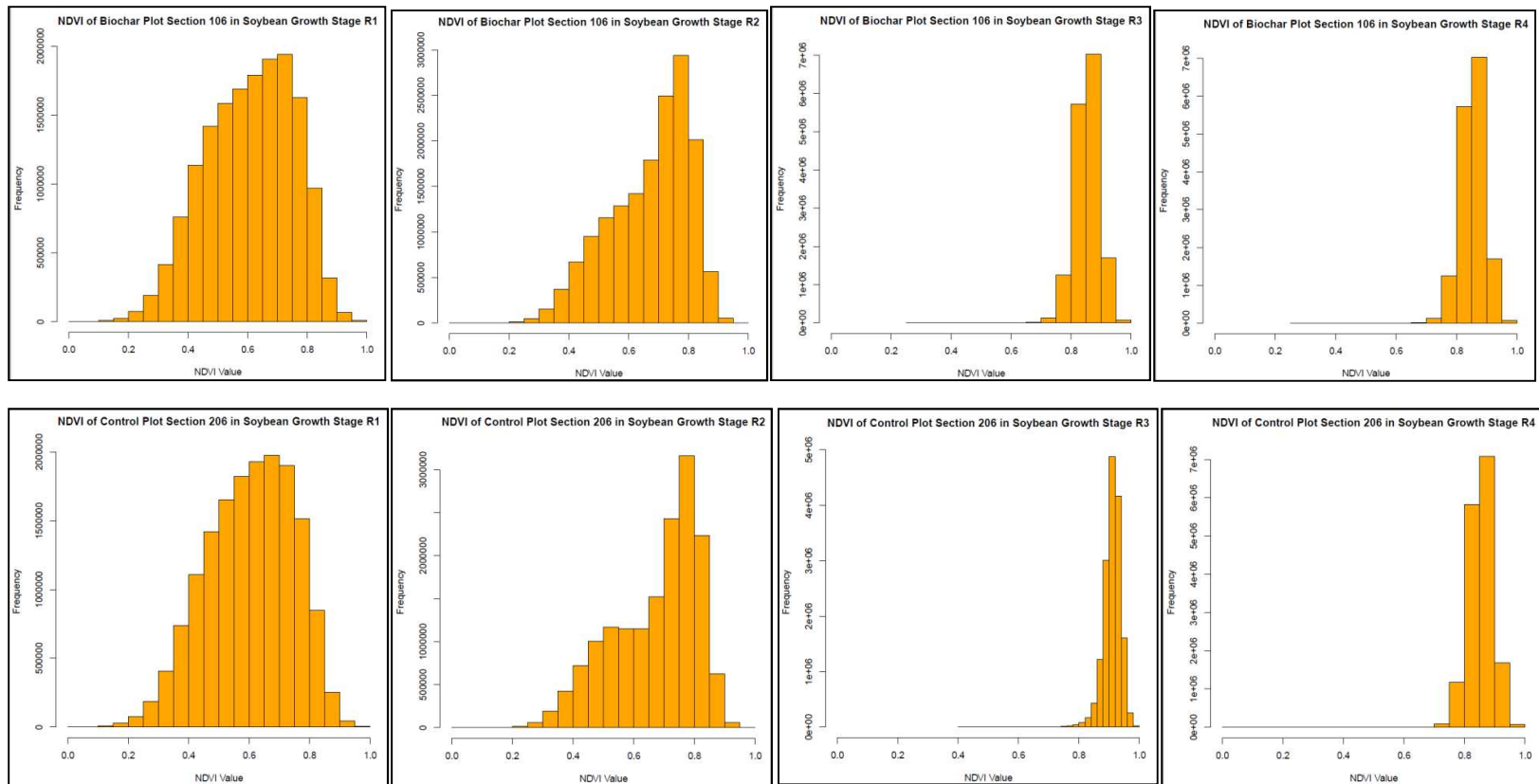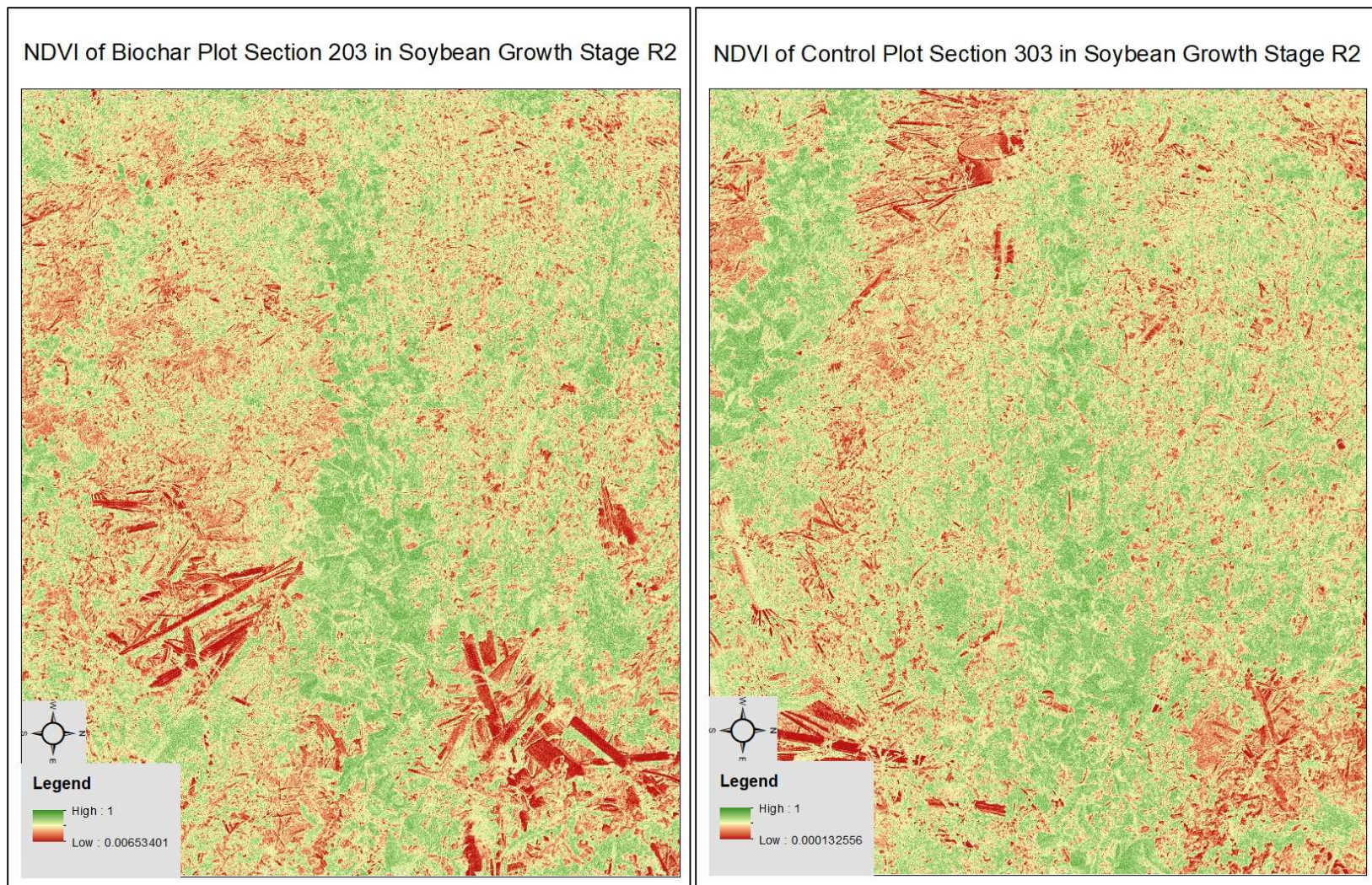*Figure 39: NDVI of biochar plot section 203 and control plot section 303 in soybean reproductive stage two.*
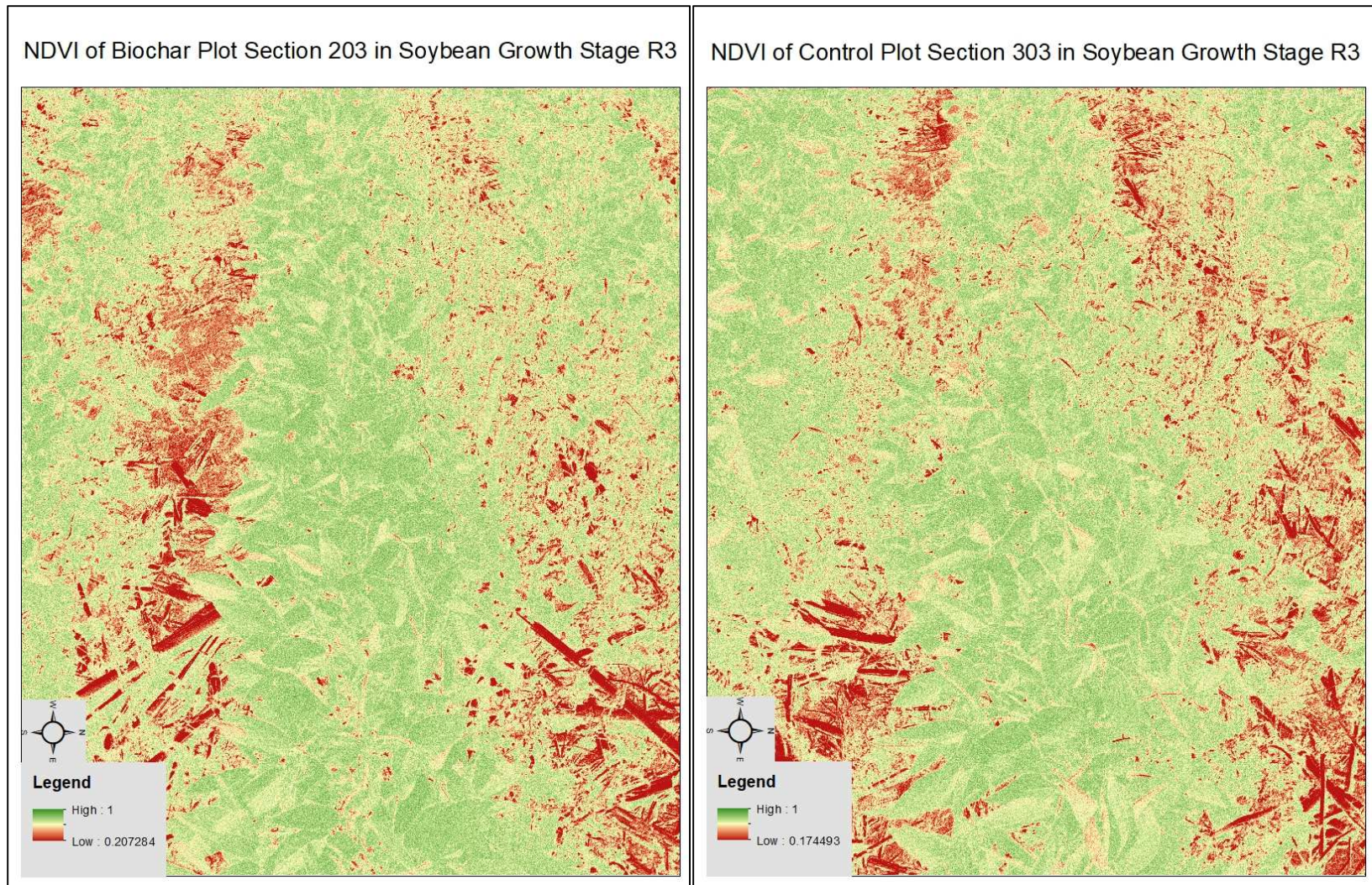
Figure 40: NDVI of biochar plot section 203 and control plot section 303 in soybean reproductive stage three.
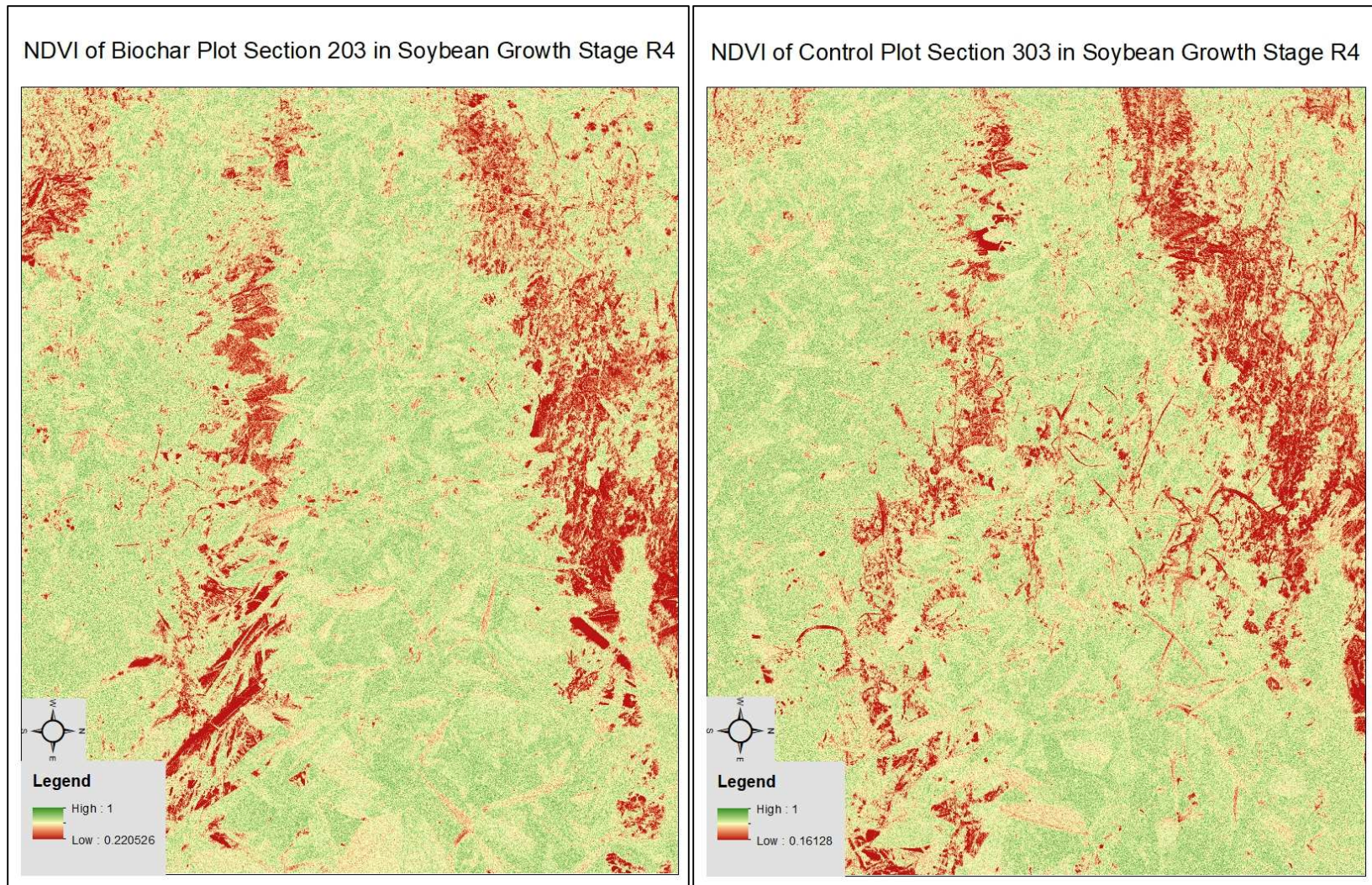
Figure 41: NDVI of biochar plot section 203 and control plot section 303 in soybean reproductive stage four.
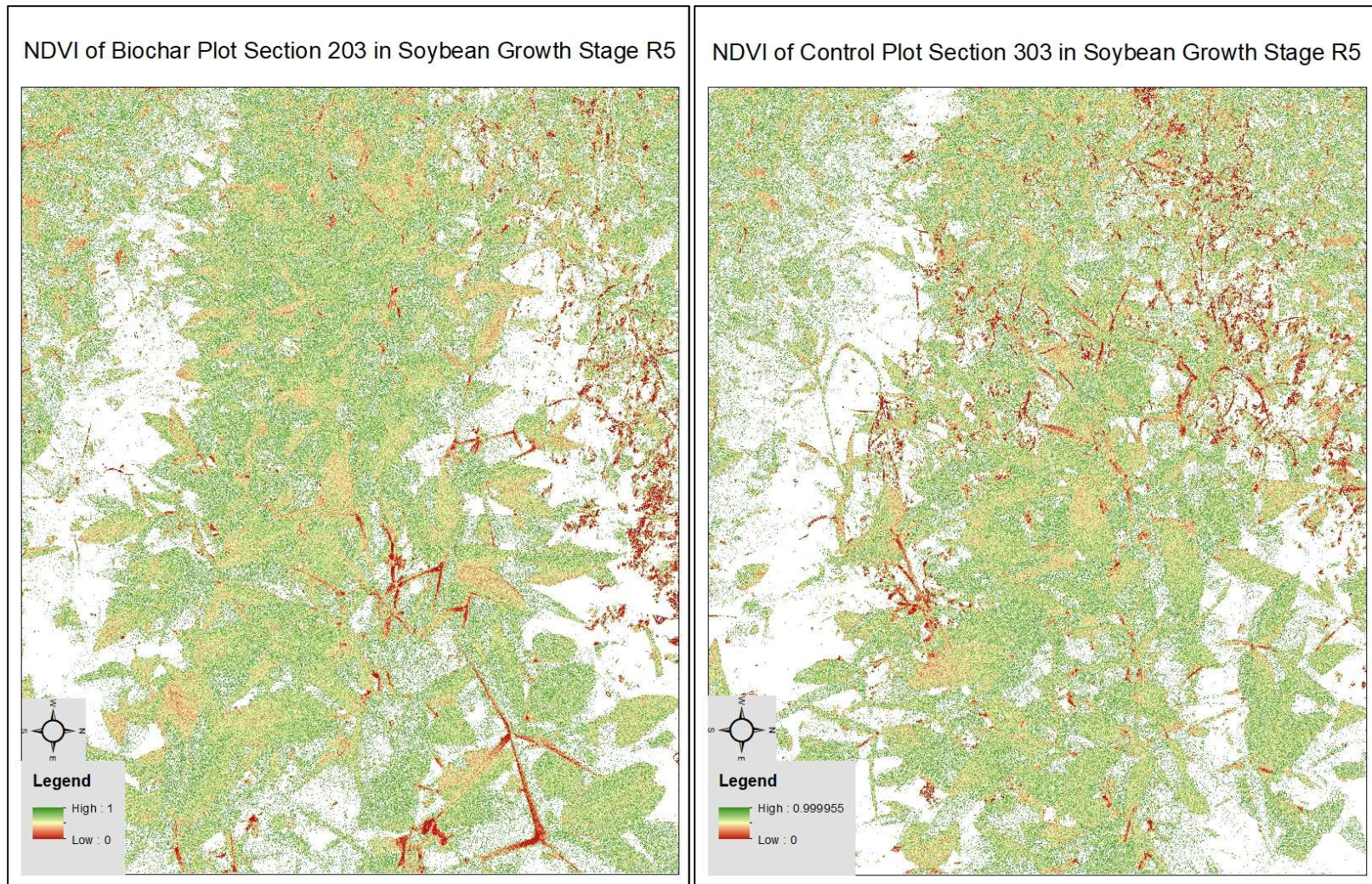
Figure 42: NDVI of biochar plot section 203 and control plot section 303 in soybean reproductive stage five.

NDVI of Biochar Plot Section 203 in Soybean Growth Stage R6

NDVI of Control Plot Section 303 in Soybean Growth Stage R6

Legend
High : 1
Low : 0.306629

Legend
High : 1
Low : 0.280211
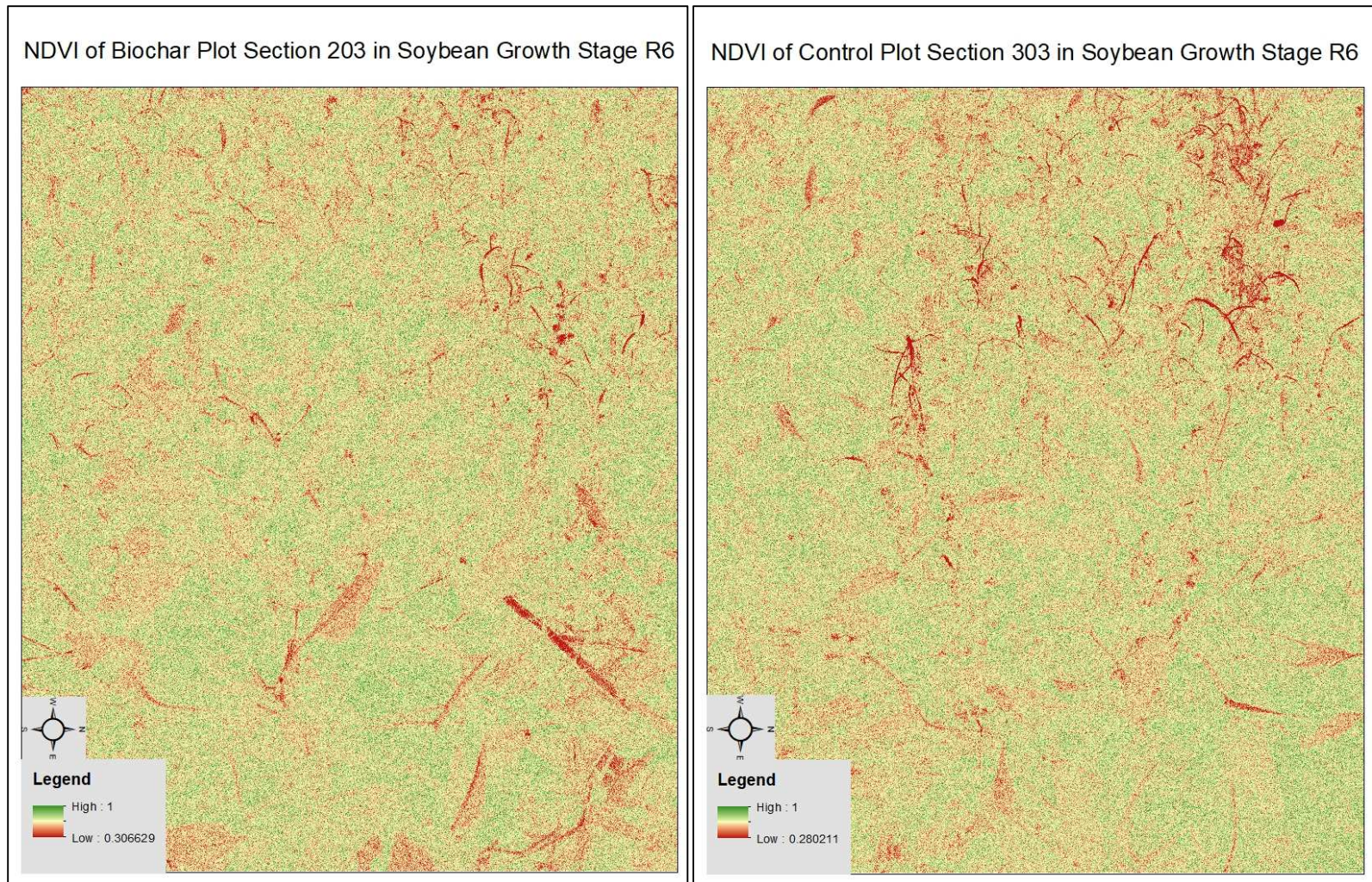
Figure 43: NDVI of biochar plot section 203 and control plot section 303 in soybean reproductive stage six.

Figure 44: NDVI of biochar plot section 203 and control plot section 303 in soybean reproductive stage seven.

Figure 45: NDVI of biochar plot section 203 and control plot section 303 in soybean reproductive stage eight.

Figure 46: NDVI frequency histograms for reproductive growth stages R1-R4 in biochar plot section 203 (top) and control plot section 303 (bottom).
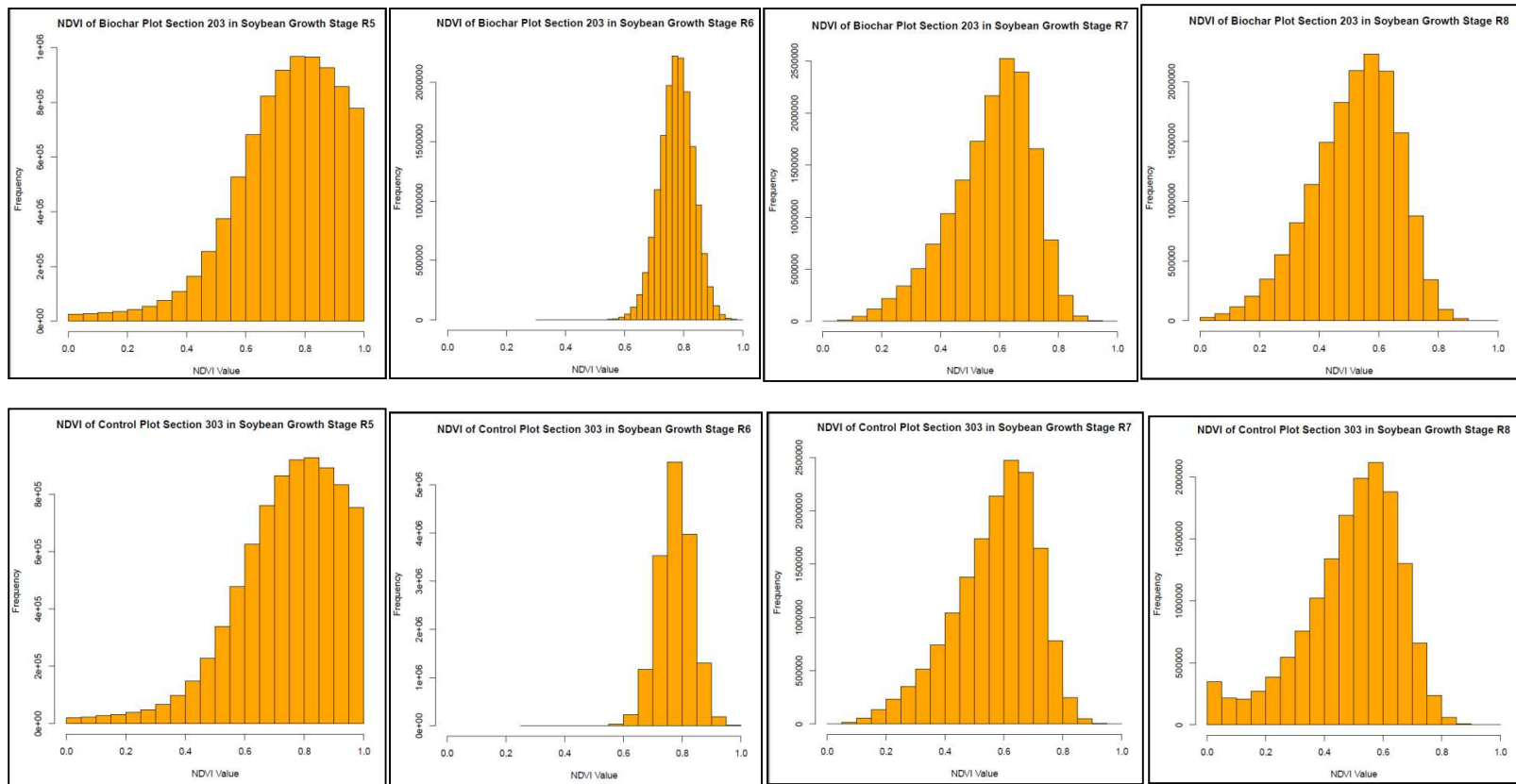
Figure 47: NDVI frequency histograms for reproductive growth stages R5-R8 in biochar plot section 203 (top) and control plot section 303 (bottom).

4.2.3. Soybean NDVI in Biochar Plot Section 301 and Control Plot Section 102

Biochar plot section 301 is located on the northern edge of the plot field and control plot section 102 is located on the northwestern edge of the plot field (Figure 27). Weeds were not as prevalent in control plot section 102, but biochar plot section 301 had a significant amount of weeds. As a result, soybean germination was much higher in control plot section 102 than biochar plot section 301. Throughout the growing season, biochar plot section 301 had a mean NDVI of 0.684 and control plot 102 had a mean NDVI of 0.689. Although the mean NDVI for biochar plot section 301 was lower than control plot section 102, it was not statistically significantly different. When tested using a t-test at a 95% confidence level, the t-score was 0.939.

Weed pressure is evident in the NDVI image for growth stage R1 in both treatments. Biochar plot section 301 soybeans had a lower minimum NDVI than control plot section 102 during reproductive growth stage one (R1) (Figure 48). Both plot section treatments had a maximum NDVI at 1, most likely because of the weed growth within each plot at this stage of growth. The mean NDVI for biochar plot section 301 was lower than control plot section 102. Frequency histograms of NDVI value during growth stage R1 showed that the highest frequency was an NDVI value of about 0.7 in both biochar plot section 301 and control plot section 303 (Figure 56).

NDVI images in growth stage R2 were very similar in NDVI value, even when biochar plot section 301 had more weed pressure than control plot section 102. Biochar plot section 301 had both a lower minimum NDVI and lower maximum NDVI than control plot section 102. Mean NDVI was higher in biochar plot section 301 than in control plot section 102 (Figure 49). The NDVI frequency histograms showed differences between the two treatments. Biochar plot

section 301 had much higher frequencies of NDVI values between 0.2 and 0.85, while having

much lower NDVI frequencies in higher NDVI values than control plot section 102 (Figure 56).

Control plot section 102 had a much larger frequency of NDVI values from 0.85 to 1.0. Control

plot section 102 had the highest NDVI frequency numbers for an NDVI of about 0.92.

Soybeans during growth stage R3 began to display higher NDVI minimums in both

treatments, signifying the soybean plants got larger (Figure 50). The NDVI images were similar

in value in both plot treatments; however, there were still more weeds in biochar plot section

301. Biochar plot section 301 had a lower minimum NDVI value than control plot section 102.

Both plot sections had the same maximum NDVI value for growth stage R3 at 1. Mean NDVI

was lower in biochar plot section 301 than in control plot section 102. The NDVI frequency

histograms showed differences between the two treatments. Biochar plot section 301 had the

largest peak in frequency at an NDVI of 0.9. Control plot section 102 had a many smaller

frequencies between 0.8 and 1.0 (Figure 56).

NDVI images in growth stage R4 show that soybeans did not get as large as quickly in

biochar plot section 301 as they did in control plot section 102 (Figure 51). This could be

because of a planting error or a decrease in soybean germination because of weed pressure.

Biochar plot section 301 had a lower minimum NDVI, while control plot section 102 had a

higher minimum NDVI. Both plot sections had maximum NDVI values at 1. The mean for

biochar plot section 301 during growth stage R4 was lower than the mean value for control plot

section 102. NDVI frequency histograms showed slight change between the NDVI frequencies

in plot sections 301 and 102, with the highest NDVI frequency at about 0.85 for both treatments

during growth stage R4, with control plot section 102 having a slightly higher frequency (Figure

56).

Soybeans during growth stage R5 were visibly smaller in biochar plot section 301, but NDVI value within the two NDVI images was similar (Figure 52). Both biochar plot section 301 and control plot section 102 had a minimum NDVI value of 0. Biochar plot section 301 had a slightly higher maximum NDVI value than control plot section 102. The mean for biochar plot section 301 was lower than control plot section 102 during growth stage R5. NDVI frequencies during growth stage R5 were slightly different between plot treatments (Figure 57). NDVI frequencies gradually increased with increasing NDVI value and peaked at 0.8 in biochar plot section 301. Control plot section 102 peaked at 0.9, with a majority of the NDVI values distributed within higher NDVI values.

Plot sections 301 and 102 had very similar NDVI images for growth stage R6 (Figure 53). Biochar plot section 301 had a slightly lower minimum NDVI and the same maximum NDVI as control plot section 303. The mean for biochar plot section 301 was slightly lower than control plot section 102 during growth stage R6. NDVI frequency histograms showed little change between the NDVI frequencies in plot sections 301 and 102, with the highest NDVI frequency at about 7.8 for both treatments during growth stage R6 (Figure 57).The highest frequency NDVI value was recorded at about 0.75 for biochar plot section 301 and 0.8 for control plot section 102 during growth stage R6.

The NDVI images for plot sections 301 and 102 during growth stage R7 were very similar in value (Figure 54). Biochar plot section 301 had the same minimum and nearly the same maximum NDVI value as control plot section 102. The mean for biochar plot section 301 was higher than control plot section 206. Frequency histograms for NDVI in growth stage R7 were nearly identical between the two treatments (Figure 57). The highest frequencies was about

0.65 in biochar plot section 301, with control plot section 102 having a lower NDVI frequency at 0.65.

The plot sections 301 and 102 in the last growth stage, R8, were very visually similar (Figure 55). Both biochar plot section 301 and control plot section 102 had minimum NDVI values at 0. Maximum NDVI values were higher in biochar plot section 301 than control plot section 102. Biochar plot section 301 had a higher mean NDVI than control plot section 102 in growth stage R8. NDVI frequencies in growth stage R8 are similar between the two treatments (Figure 57). Both plot sections showed higher frequencies in lower NDVI values because soybeans were at full maturity during this stage. Peak NDVI frequency was 0.6 for biochar plot section 301 and 0.55 for control plot section 102.
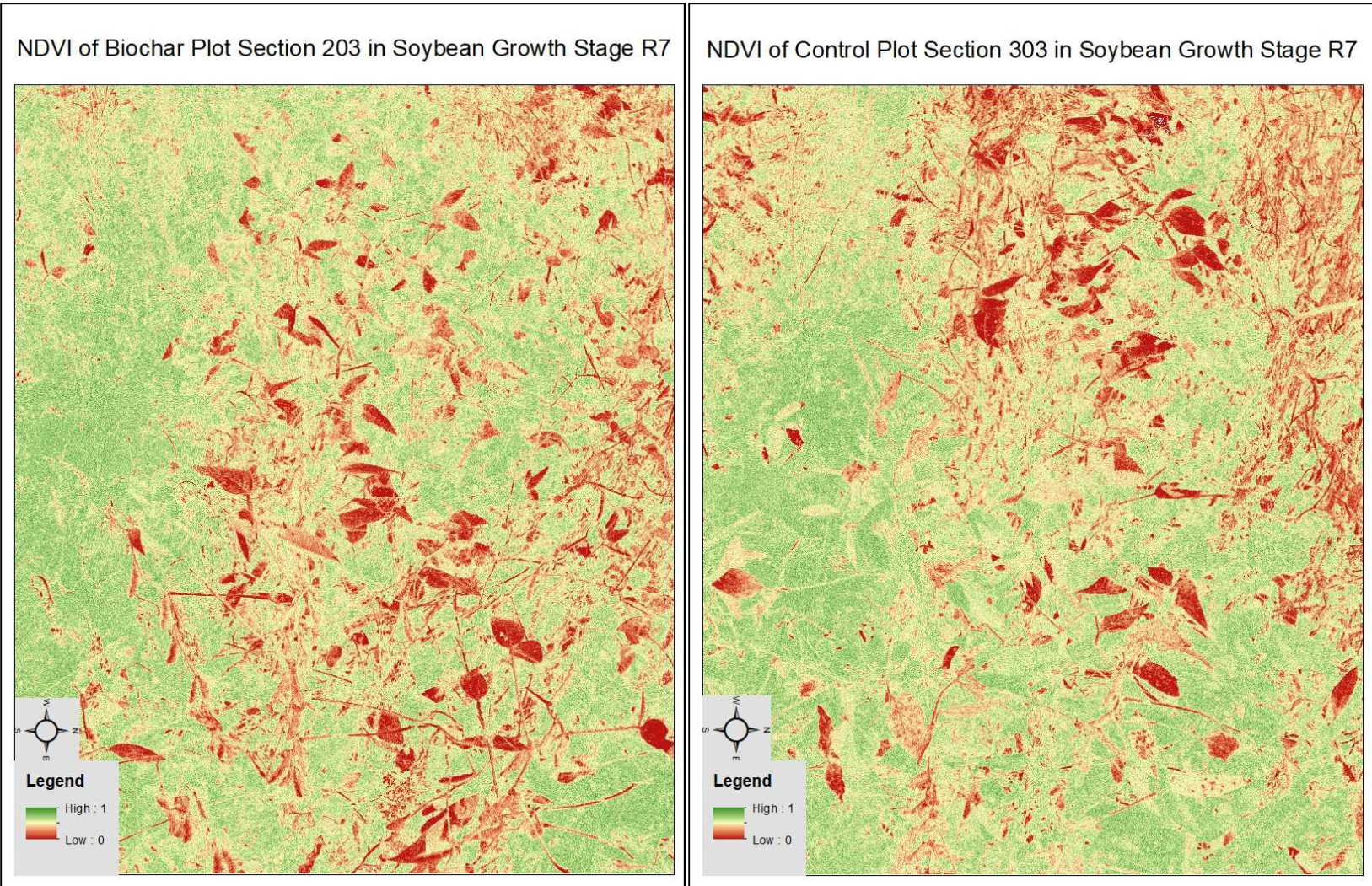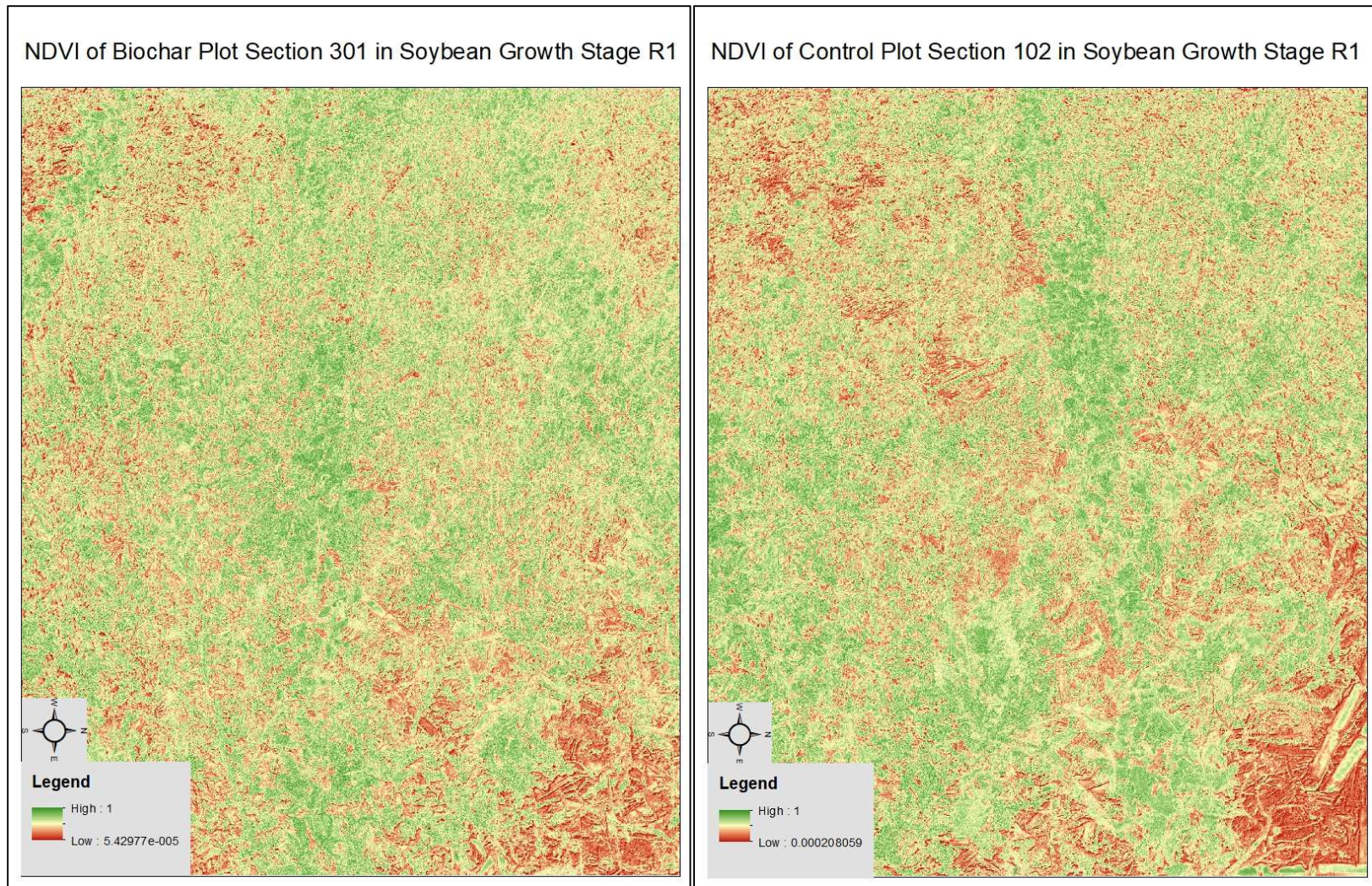
Figure 48: NDVI of biochar plot section 301 and control plot section 102 in soybean reproductive stage one.
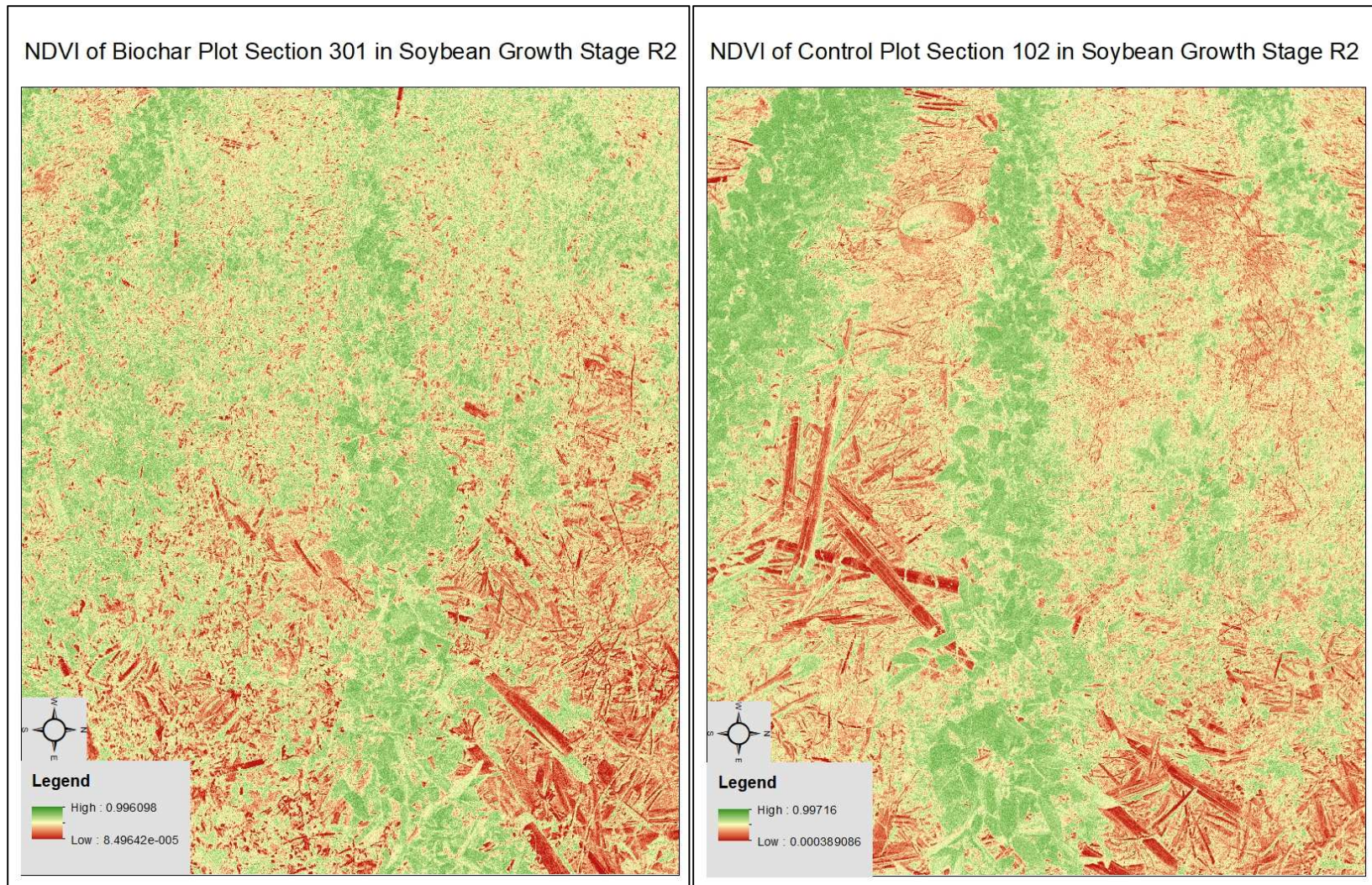
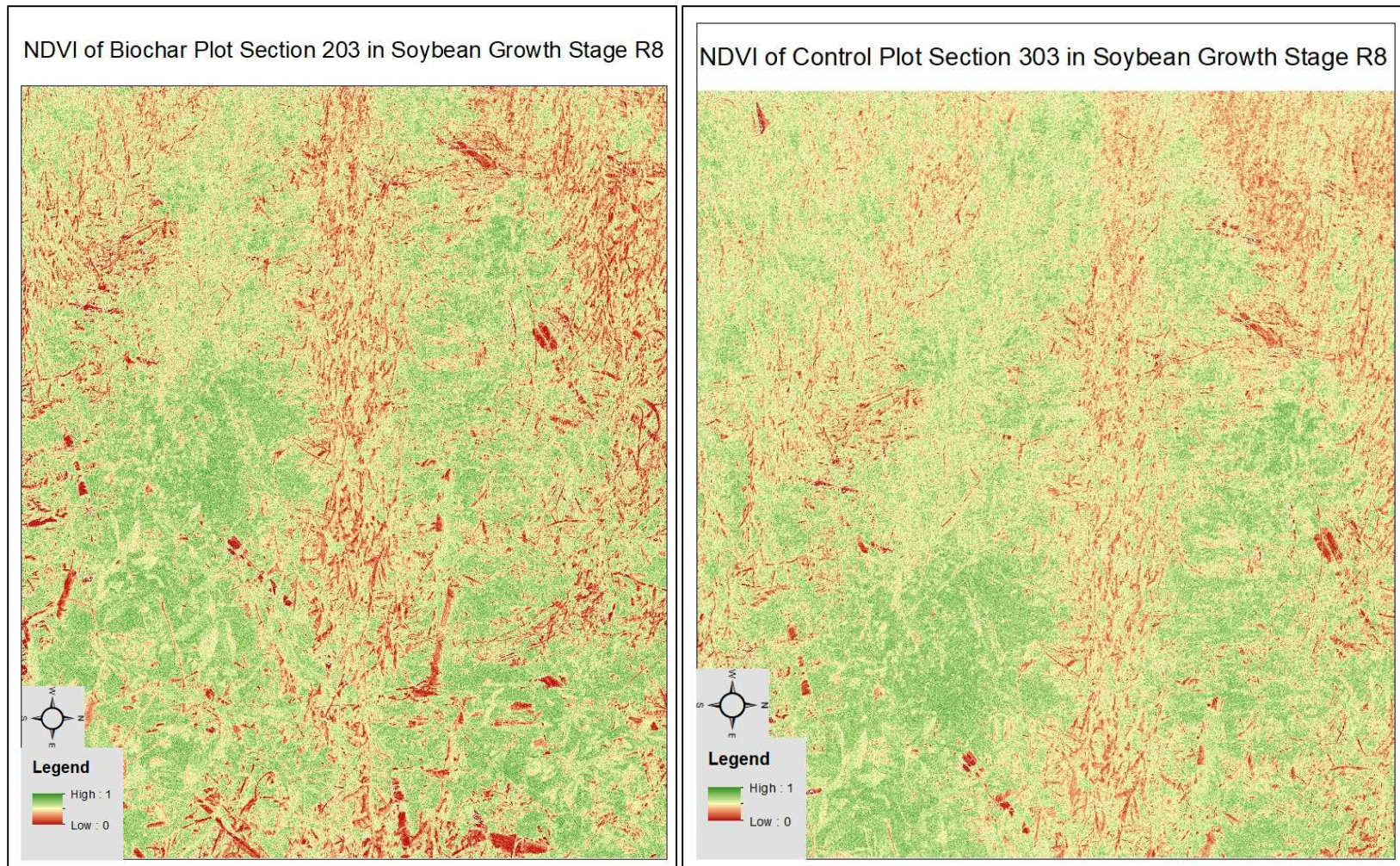*Figure 49: NDVI of biochar plot section 301 and control plot section 102 in soybean reproductive stage two.*
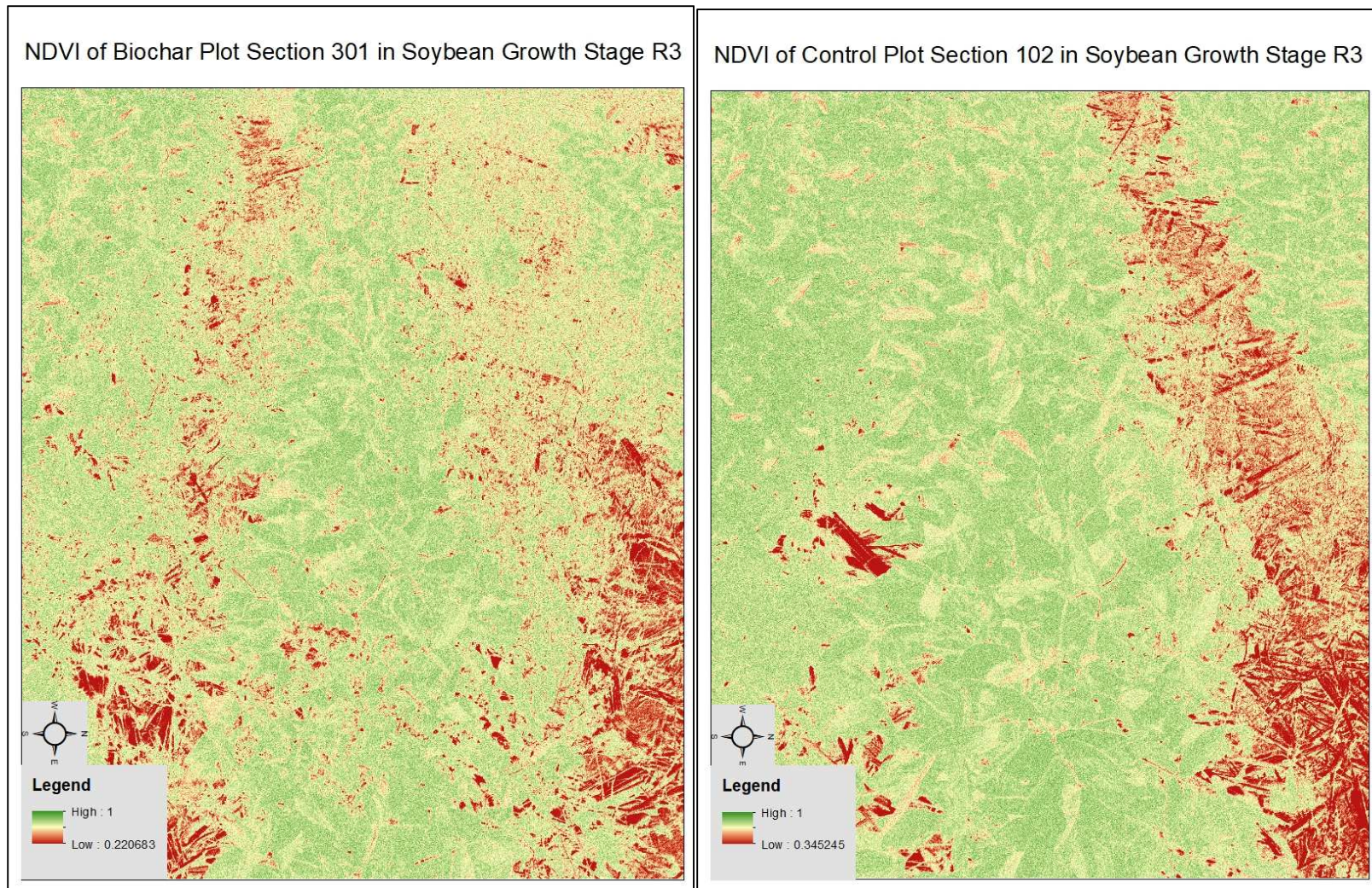
Figure 50: NDVI of biochar plot section 301 and control plot section 102 in soybean reproductive stage three.
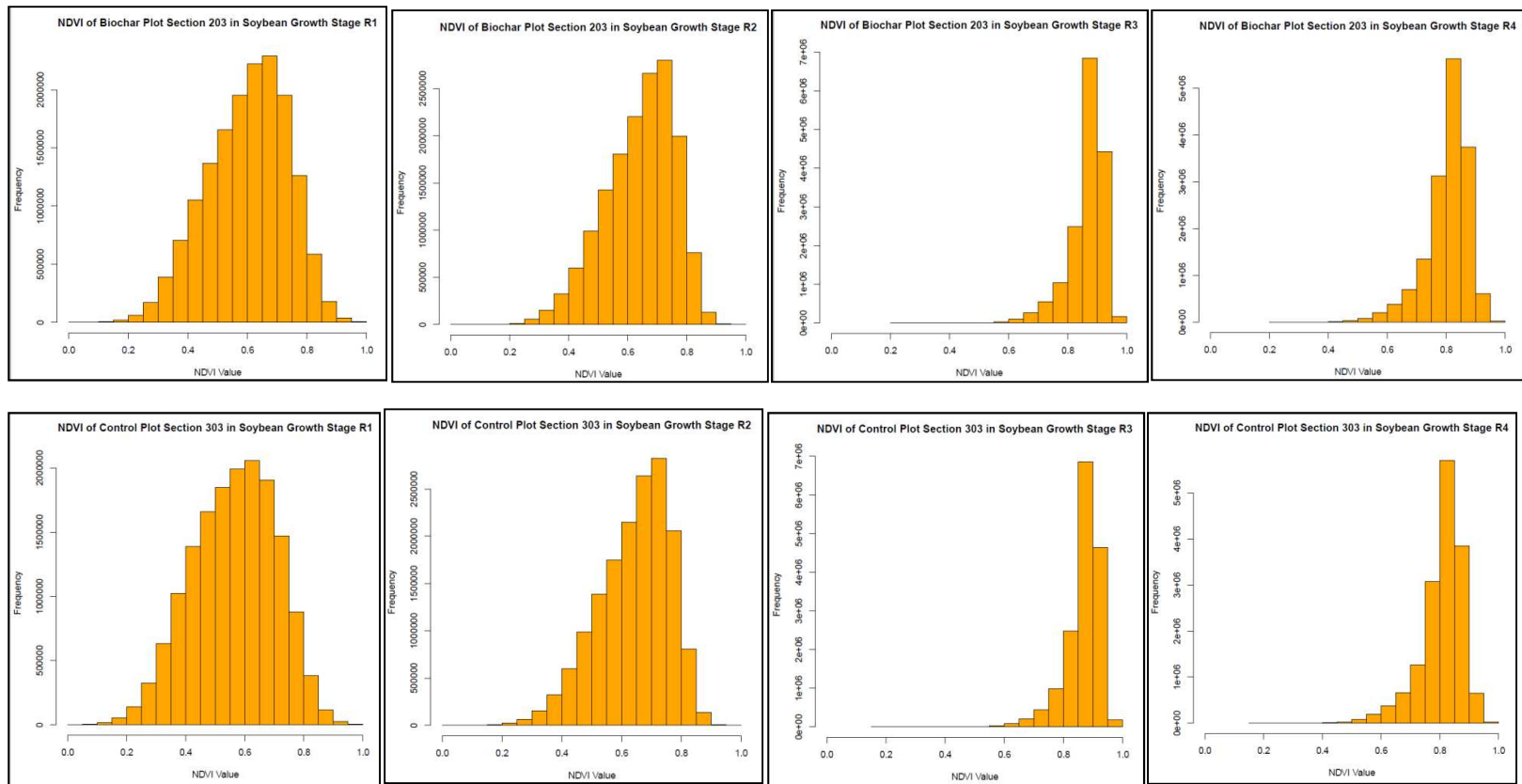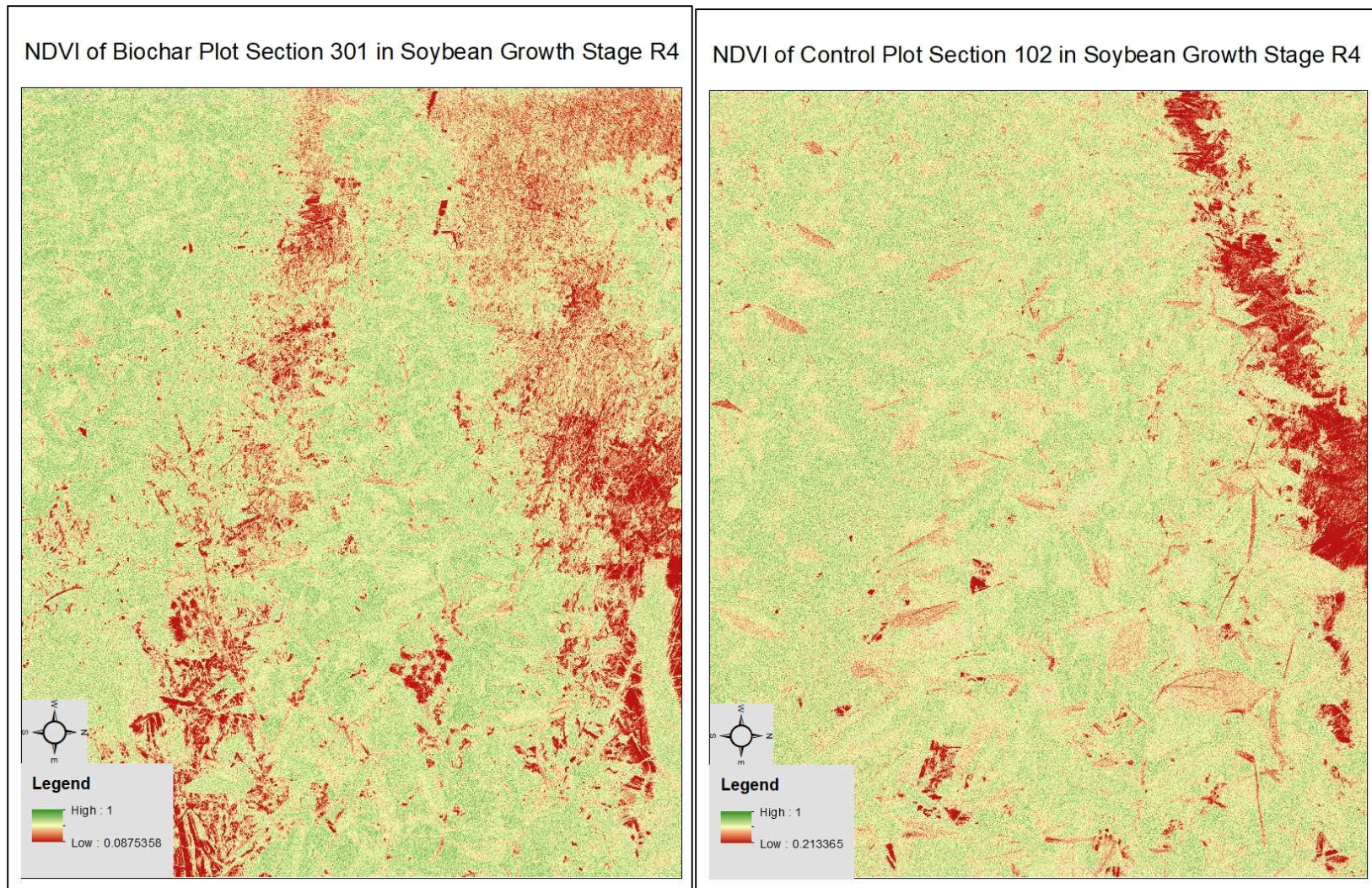
Figure 51: NDVI of biochar plot section 301 and control plot section 102 in soybean reproductive stage four.

Figure 52: NDVI of biochar plot section 301 and control plot section 102 in soybean reproductive stage five.

Figure 53: NDVI of biochar plot section 301 and control plot section 102 in soybean reproductive stage six.

Figure 54: NDVI of biochar plot section 301 and control plot section 102 in soybean reproductive stage seven.

Figure 55: NDVI of biochar plot section 301 and control plot section 102 in soybean reproductive stage eight.

Figure 56: NDVI frequency histograms for reproductive growth stages R1-R4 in biochar plot section 301 (top) and control plot section 102 (bottom).
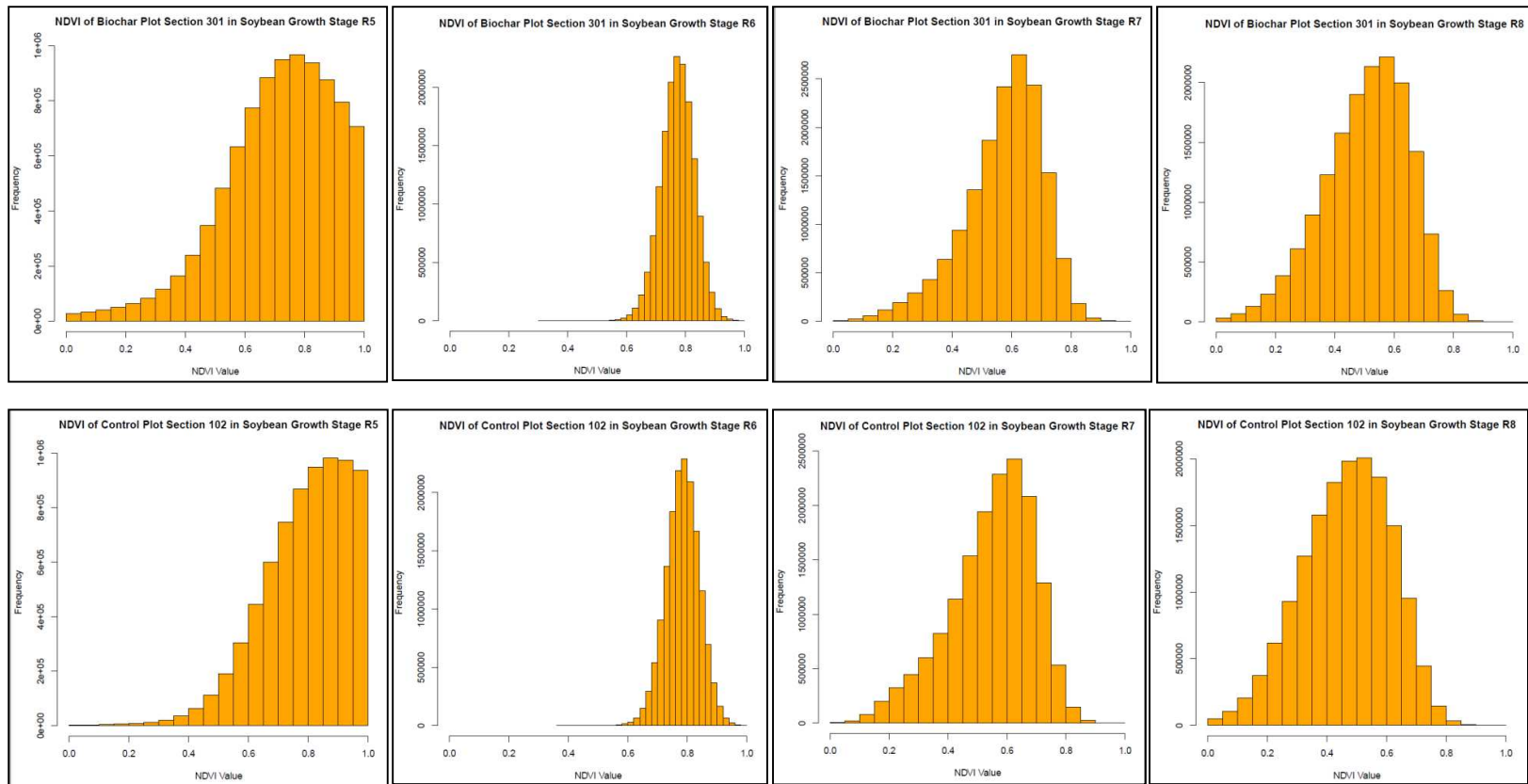
Figure 57: NDVI frequency histograms for reproductive growth stages R5-R8 in biochar plot section 301 (top) and control plot section 102 (bottom).

4.2.4. Soybean NDVI in Biochar Plot Section 404 and Control Plot Section 405

Biochar plot section 404 and control plot section 405 are located on the center of the eastern edge of the plot field (Figure 27). Biochar plot section 404 experienced heavy weed pressure, while control plot section 405 experienced much less weed pressure throughout the growth period of the soybeans. The rate of soybean germination was quite high for both plot sections. Throughout the growing season, biochar plot section 404 had a mean NDVI of 0.715 and control plot 405 had a mean NDVI of 0.611. Although the mean NDVI for biochar plot section 404 was higher than control plot section 405, it was not statistically significantly different. When tested using a t-test at a 95% confidence level, the t-score was 0.351. The t-score for these two plot sections was the closest to being statistically significantly different; however, this could have been a result of the weed pressure in biochar plot section 404. The data for these two plot sections had one anomaly in the maximum NDVI for biochar plot section 404 in growth stage R1, which was not used to calculate the NDVI mean over the growing season or the t-test.

Biochar plot section 404 soybeans had a lower minimum NDVI than control plot section 405 during reproductive growth stage one (R1) (Figure 58). However, biochar plot section 404 had a much higher maximum NDVI that was outside the normal range, so it was considered an outlier in the data and not included in any statistical calculations.   This shows in the NDVI image for biochar plot section 404, as it has very few values within the normal NDVI range and appears to have very little coloring in the image. The reason for the abnormalities could be an error in camera calibration or image corruption during image or NDVI processing. These two plot sections were incomparable during this stage of growth because of abnormal NDVI value in the biochar plot section 404.   Frequency histograms of NDVI value during growth stage R1

were also incomparable because of during this stage of growth because of abnormal NDVI value in the biochar plot section 404 (Figure 66).

NDVI images in growth stage R2 were drastically different in NDVI value, since control plot section 405 also had a very high, out of range NDVI for the maximum value (Figure 59). Biochar plot section 404 had both a higher minimum NDVI and higher maximum NDVI than control plot section 405. Control plot section 405 had a very low maximum and was not comparable to biochar plot section 404 by NDVI mean or NDVI image. The NDVI frequency histograms showed extreme differences between the two treatments because of the abnormally low NDVI maximum in control plot section 405 (Figure 66).

NDVI images of soybeans during growth stage R3 were comparable, although there were more weeds in biochar plot section 404 (Figure 60). Biochar plot section 404 had a lower minimum NDVI value than control plot section 405. Both plot sections had the same maximum NDVI value for growth stage R3 at 1. Mean NDVI was higher in biochar plot section 404 than in control plot section 405. The NDVI frequency histograms showed differences between the two treatments. Biochar plot section 404 had much higher frequencies of NDVI values between at 0.9 than control plot section 405 (Figure 66). Control plot section 405 many more individual NDVI frequencies than biochar plot section 404, with the peak NDVI being about 0.92. Both plot treatments had the highest NDVI frequencies from 0.8 to 1.0.

NDVI images in growth stage R4 show heavy weed pressure in biochar plot section 404, with very little in control plot section 405 (Figure 61). Biochar plot section 404 had a lower minimum NDVI, while control plot section 405 had a higher minimum NDVI. Both plot sections had maximum NDVI values at 1. The mean for biochar plot section 404 during growth stage R4 was higher than the mean value for control plot section 405. NDVI frequency

histograms showed slight change between the NDVI frequencies in plot sections 404 and 405, with the highest NDVI frequency at about 0.85 for both treatments during growth stage R4, with control plot section 405 having a slightly lower frequency (Figure 66).

Weed pressure during growth stage R5 was much less than the prior four growth stages, allowing two comparable NDVI images (Figure 62). Both biochar plot section 404 and control plot section 405 had a minimum NDVI value of 0 and a maximum NDVI of 1. The mean for biochar plot section 404 was higher than control plot section 405 during growth stage R5. NDVI frequencies during growth stage R5 were slightly different between plot treatments (Figure 67). NDVI frequencies gradually increased with increasing NDVI value and peaked at 0.85 in biochar plot section 404. Control plot section 405 peaked at 0.8, with higher frequencies than biochar plot section 404 in the 0.2 to 0.8 NDVI range.

Plot sections 404 and 405 had very similar NDVI images for growth stage R6 (Figure 63). Biochar plot section 404 had a higher minimum NDVI and the same maximum NDVI of 1 as control plot section 405. The mean for biochar plot section 404 was slightly lower than control plot section 405 during growth stage R6. The NDVI frequency histograms showed few differences between the two treatments. Most of the highest frequencies were in the 0.7 to 0.85 NDVI range, with the highest NDVI frequency at about 7.8 for both treatments (Figure 67). The highest frequency NDVI value was recorded at about 0.8 for both biochar plot section 404 and for control plot section 405 during growth stage R6.

The NDVI images for plot sections 404 and 405 during growth stage R7 were very similar in value (Figure 64). Biochar plot section 404 had a lower minimum and the same maximum NDVI value as control plot section 405. The mean for biochar plot section 405 was lower than control plot section 405. Frequency histograms for NDVI in growth stage R7 were

nearly identical between the two treatments (Figure 67). The highest frequency NDVI value was recorded at about 0.85 for biochar plot section 404 and 0.7 for control plot section 405, with slightly higher frequencies in control plot section 405 than biochar plot section 404.

The plot sections 301 and 102 in the last growth stage, R8, were very visually similar (Figure 65). Both biochar plot section 404 and control plot section 405 had minimum NDVI values at 0. Maximum NDVI values were higher in biochar plot section 404 than control plot section 405. Biochar plot section 404 had a higher mean NDVI than control plot section 405. NDVI frequencies in growth stage R8 are similar between the two treatments (Figure 67). Both plot sections showed higher frequencies in lower NDVI values because soybeans were at full maturity during this stage. Peak NDVI frequency was 0.65 for biochar plot section 404 and 0.6 for control plot section 405, with higher frequencies than biochar plot section 404 in the 0.2 to 0.6 NDVI range.
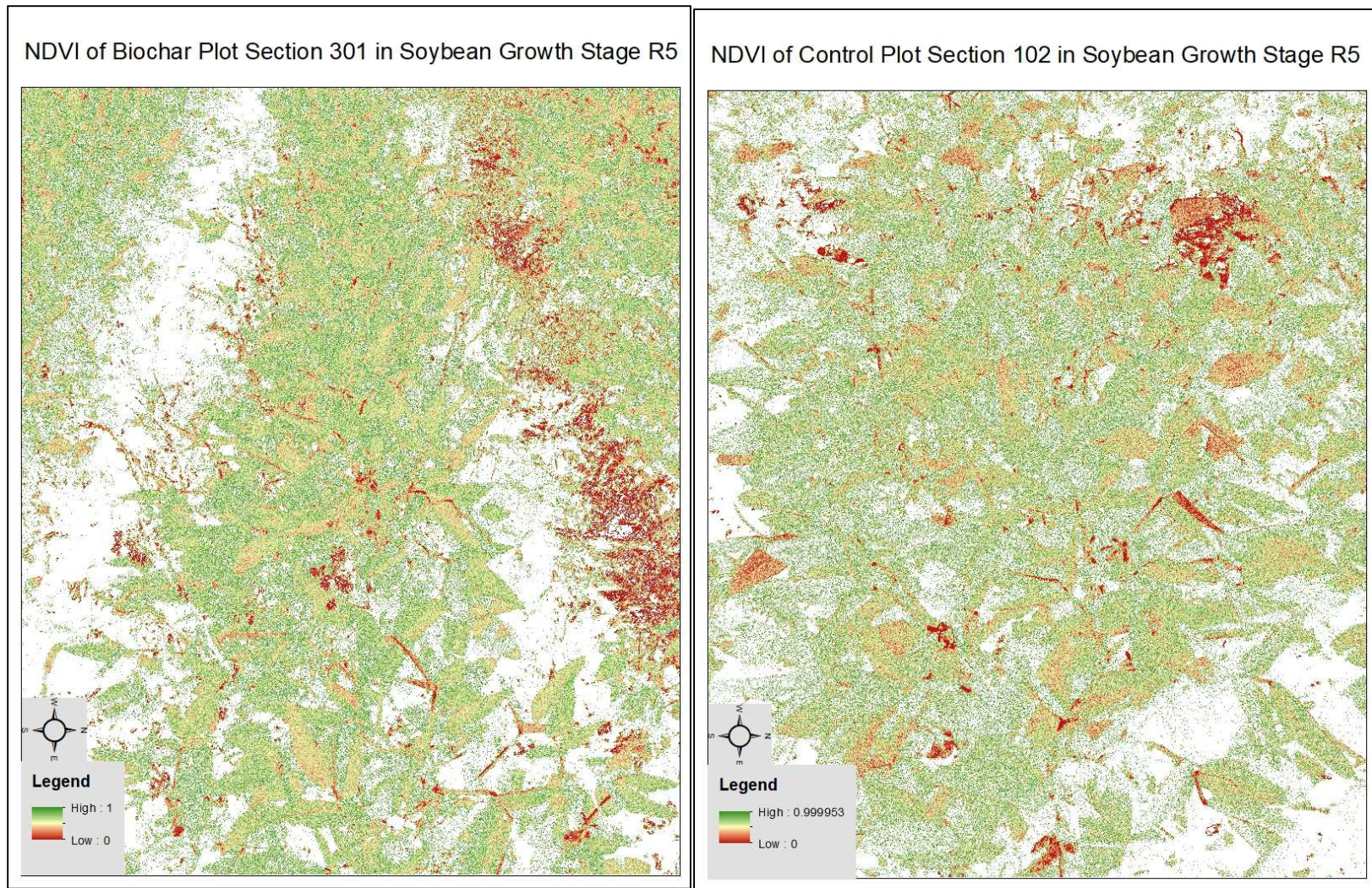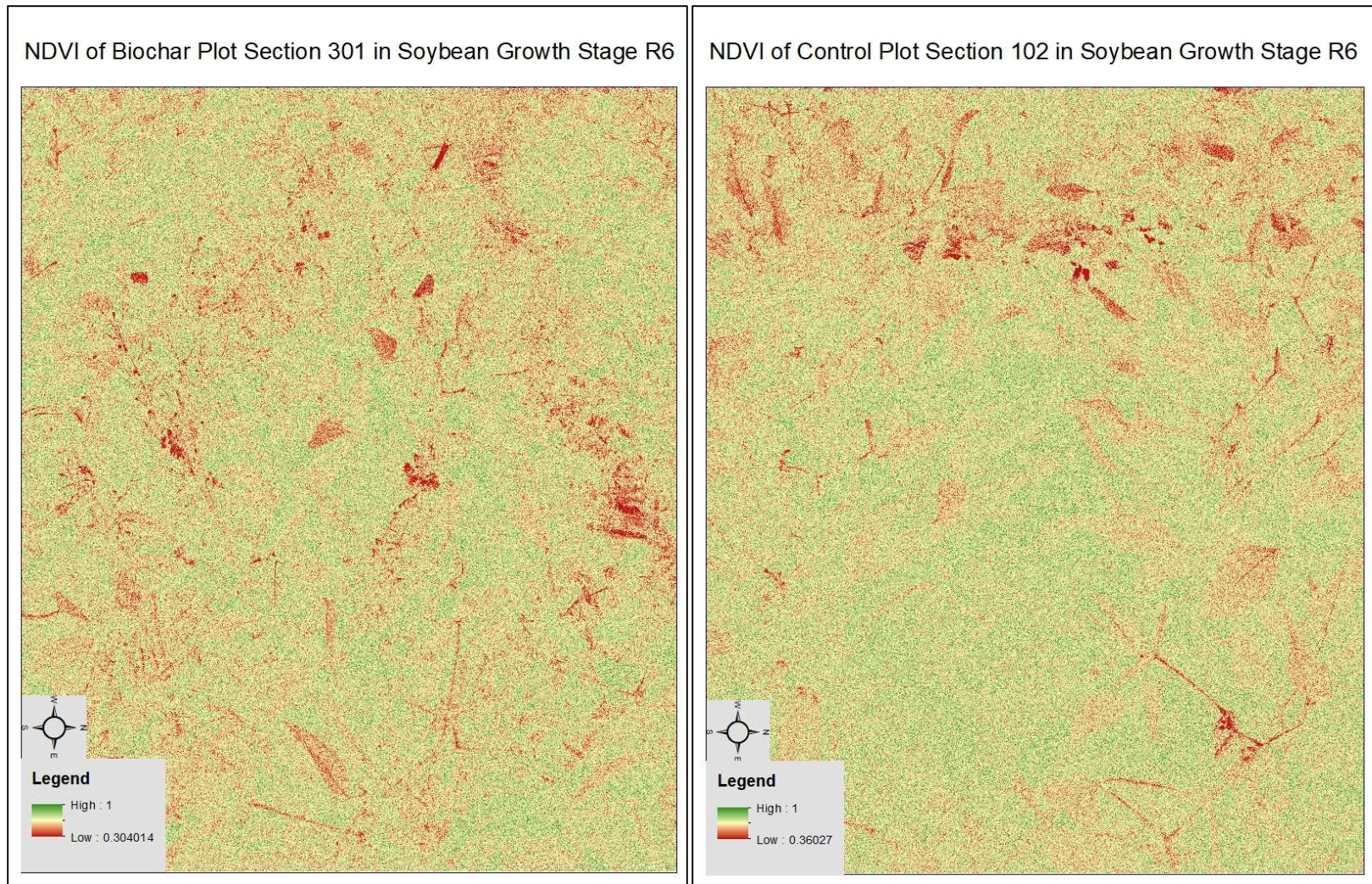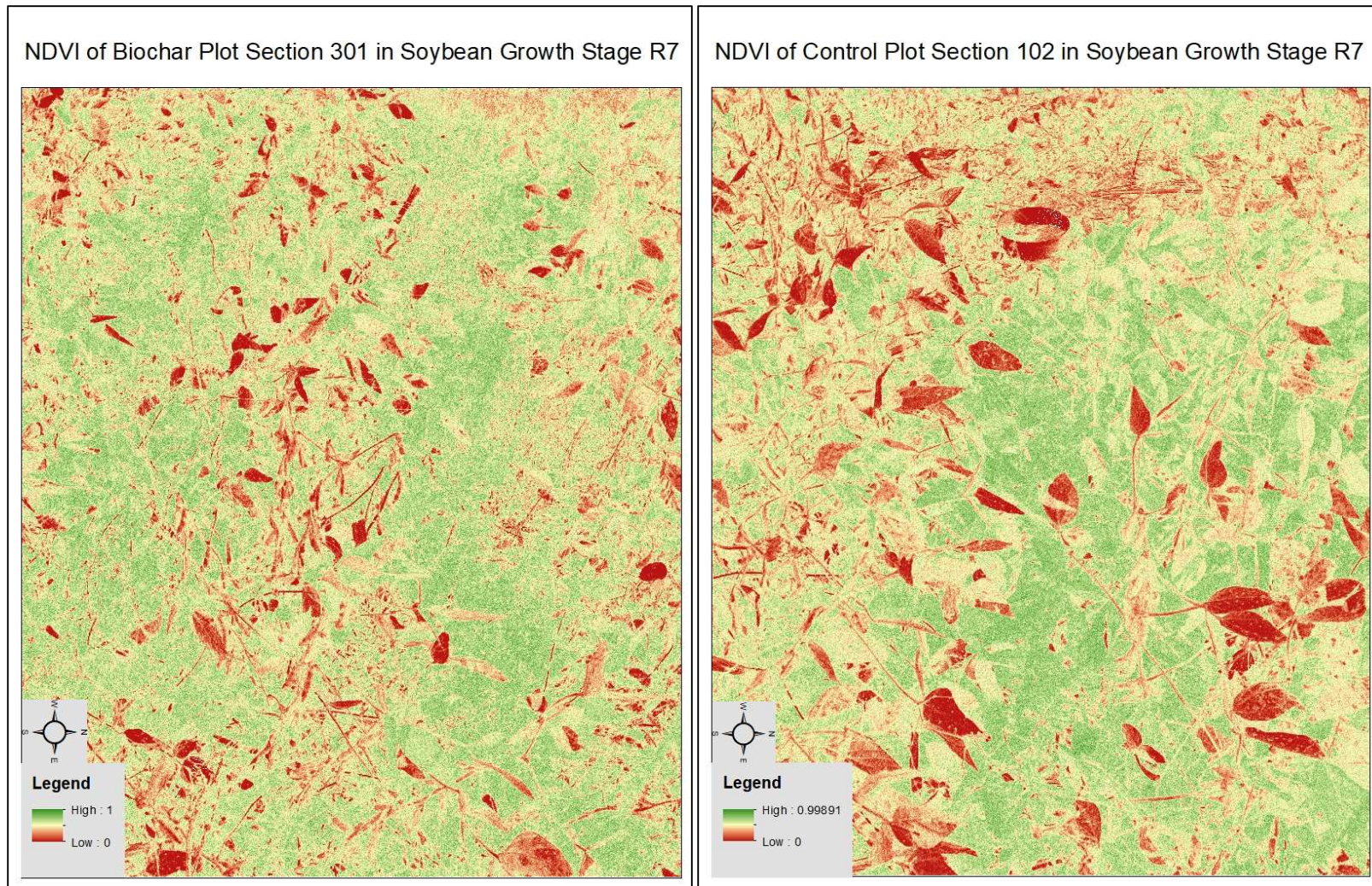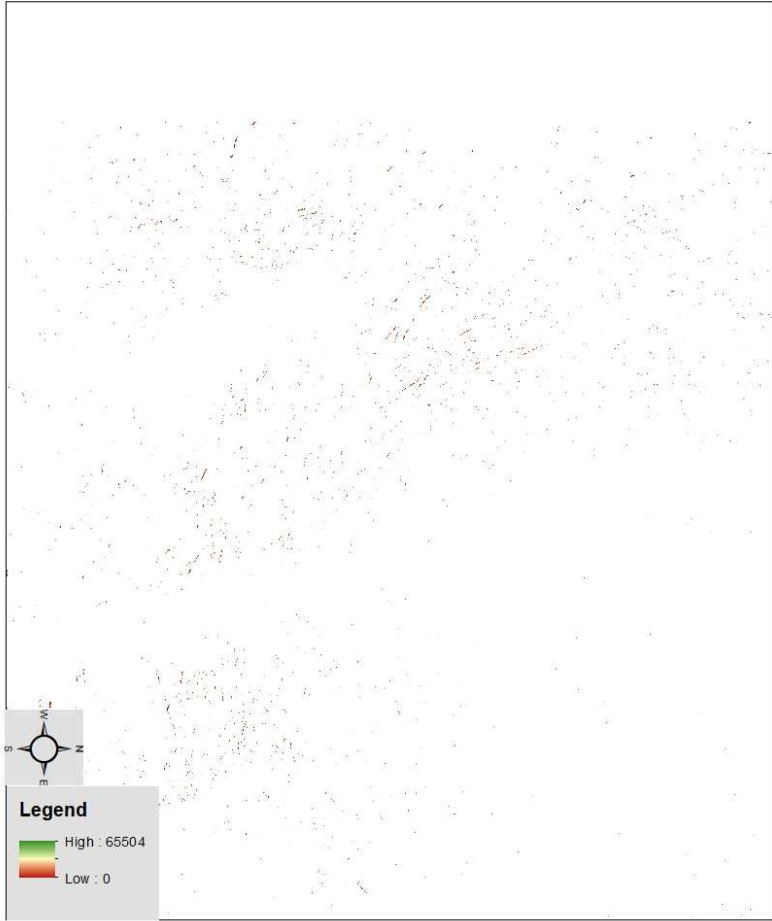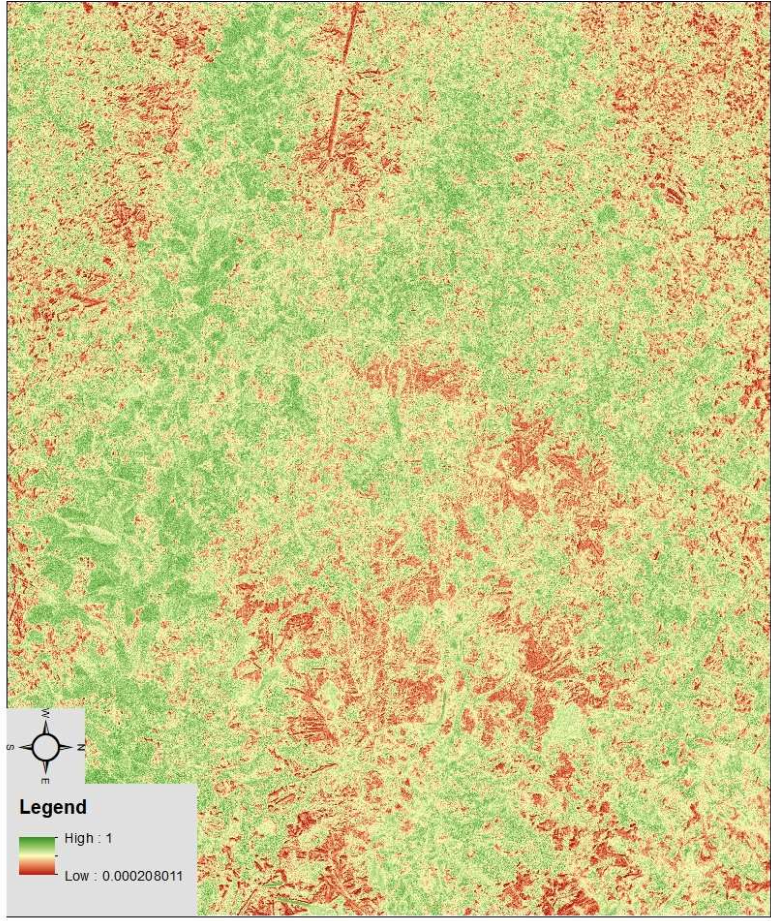
Figure 58: NDVI of biochar plot section 404 and control plot section 405 in soybean reproductive stage one.
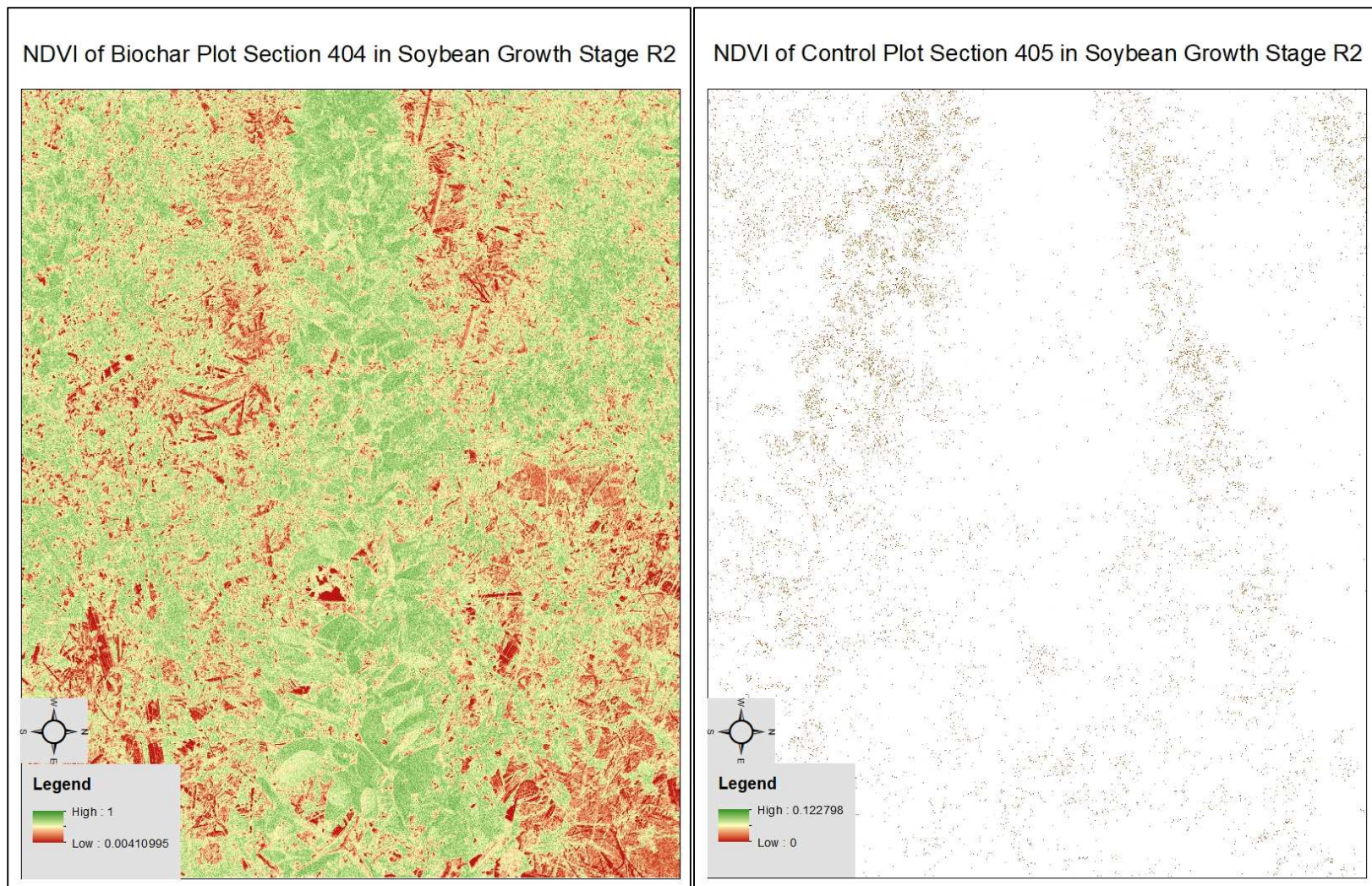
Figure 59: NDVI of biochar plot section 404 and control plot section 405 in soybean reproductive stage two.
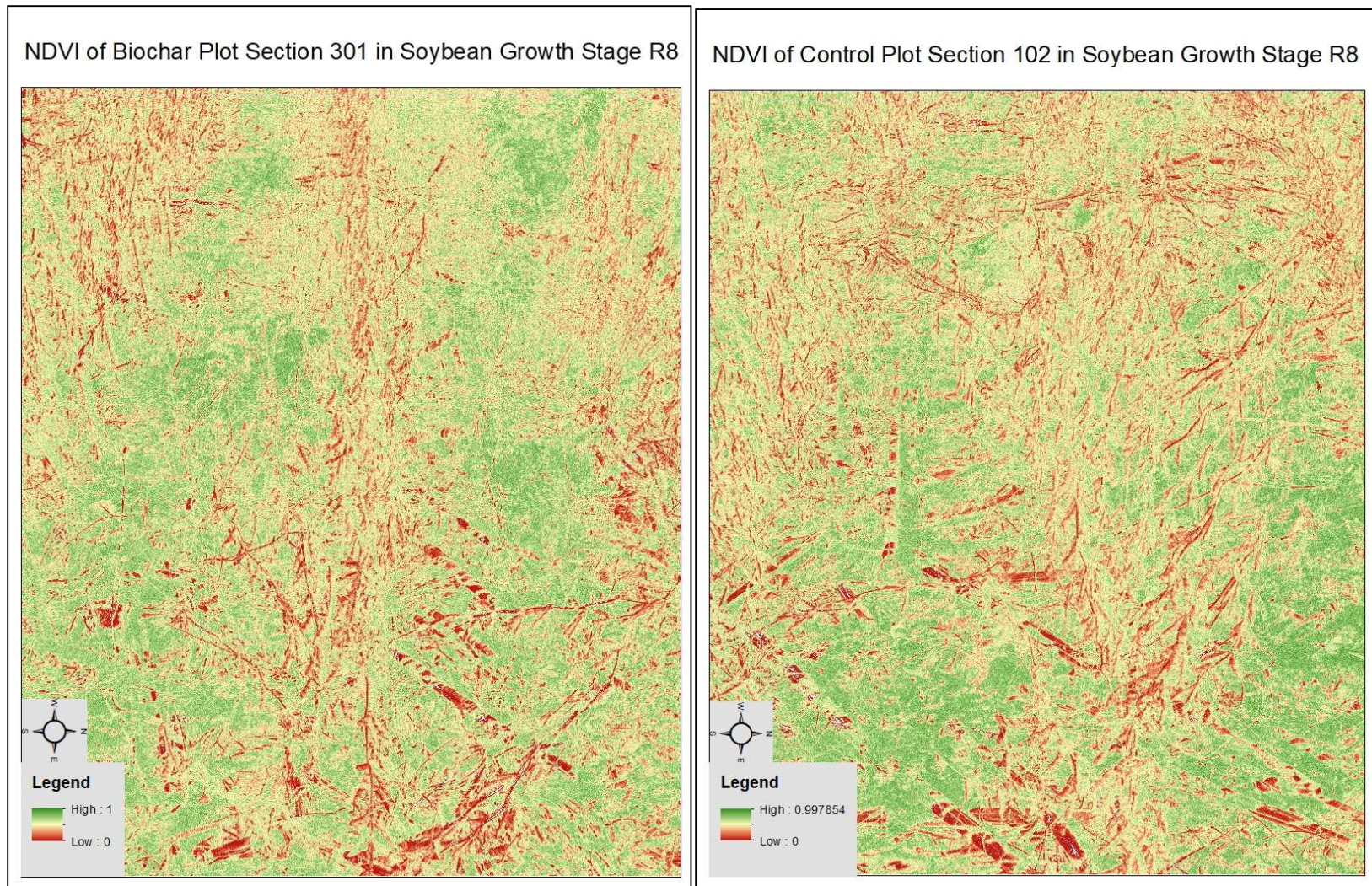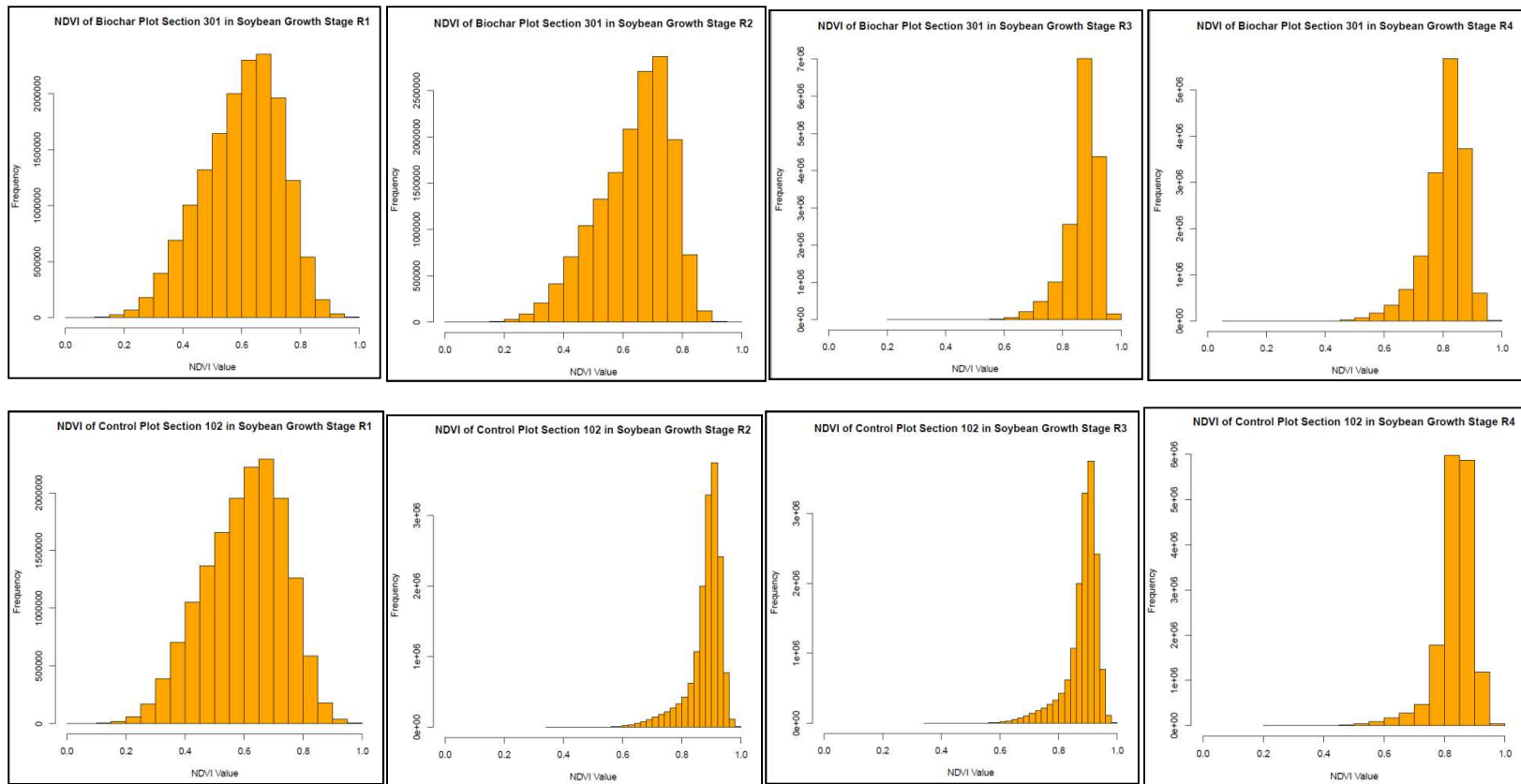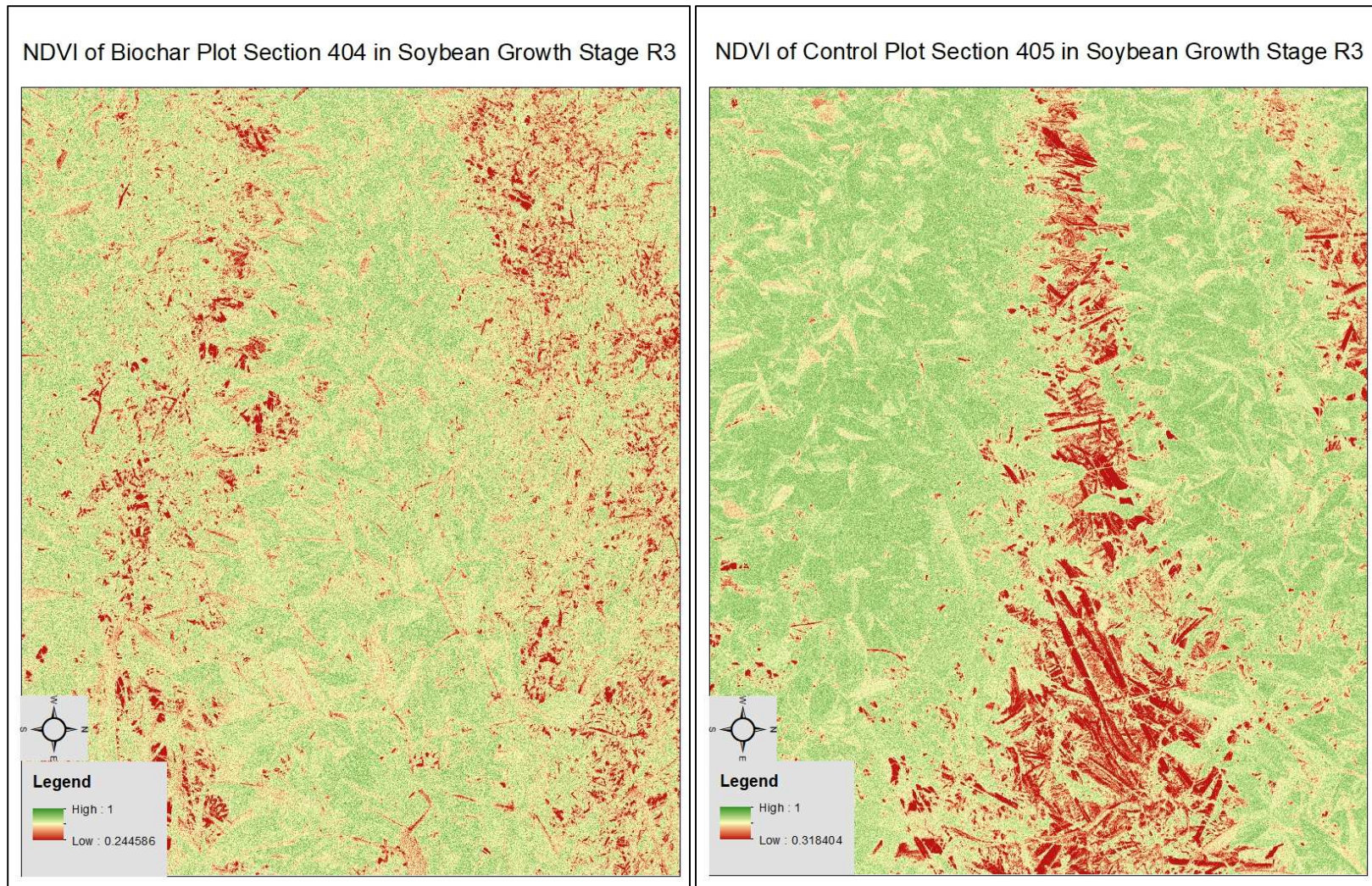
Figure 60: NDVI of biochar plot section 404 and control plot section 405 in soybean reproductive stage three.
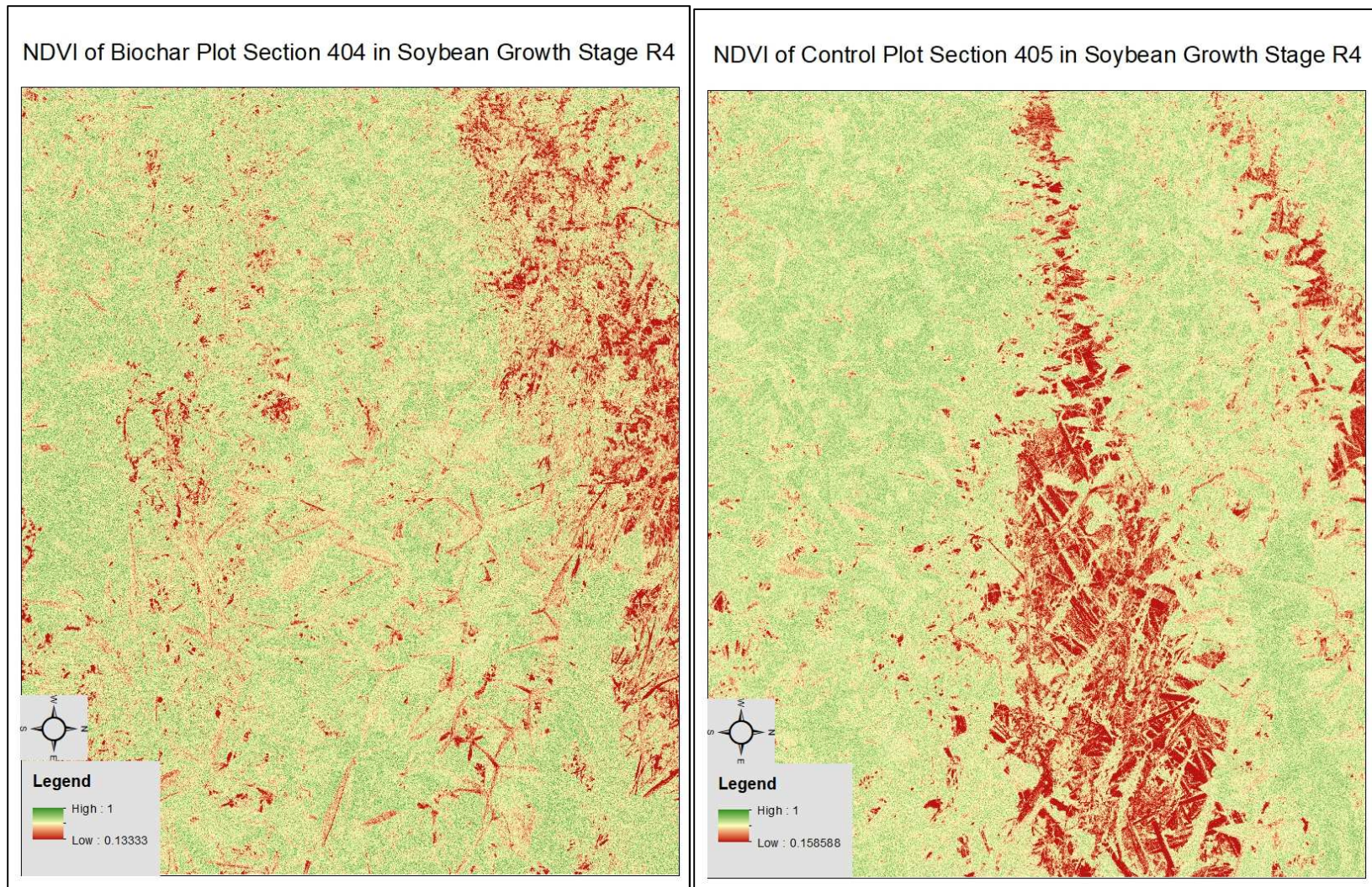
Figure 61: NDVI of biochar plot section 404 and control plot section 405 in soybean reproductive stage four.
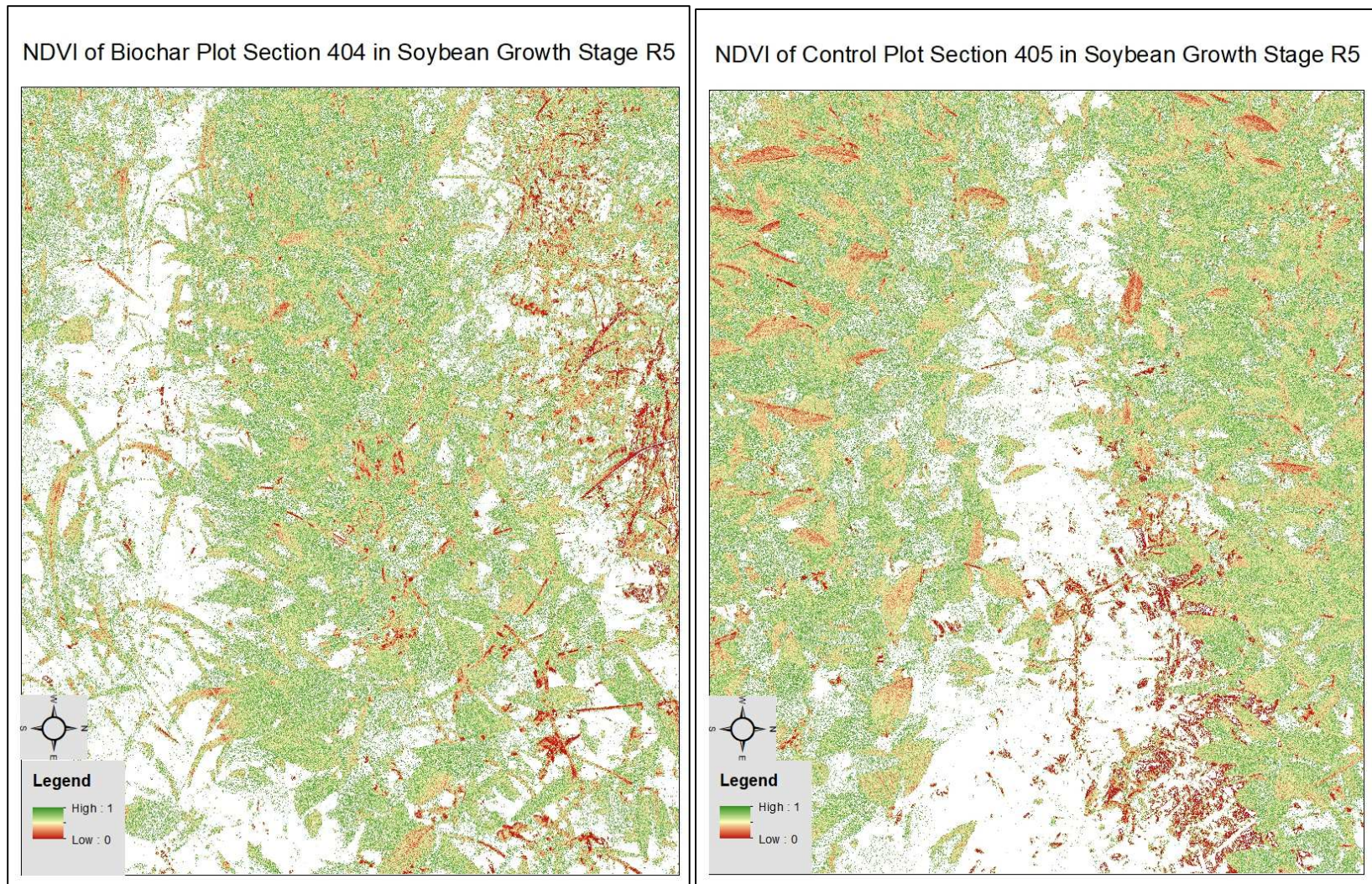
Figure 62: NDVI of biochar plot section 404 and control plot section 405 in soybean reproductive stage five.
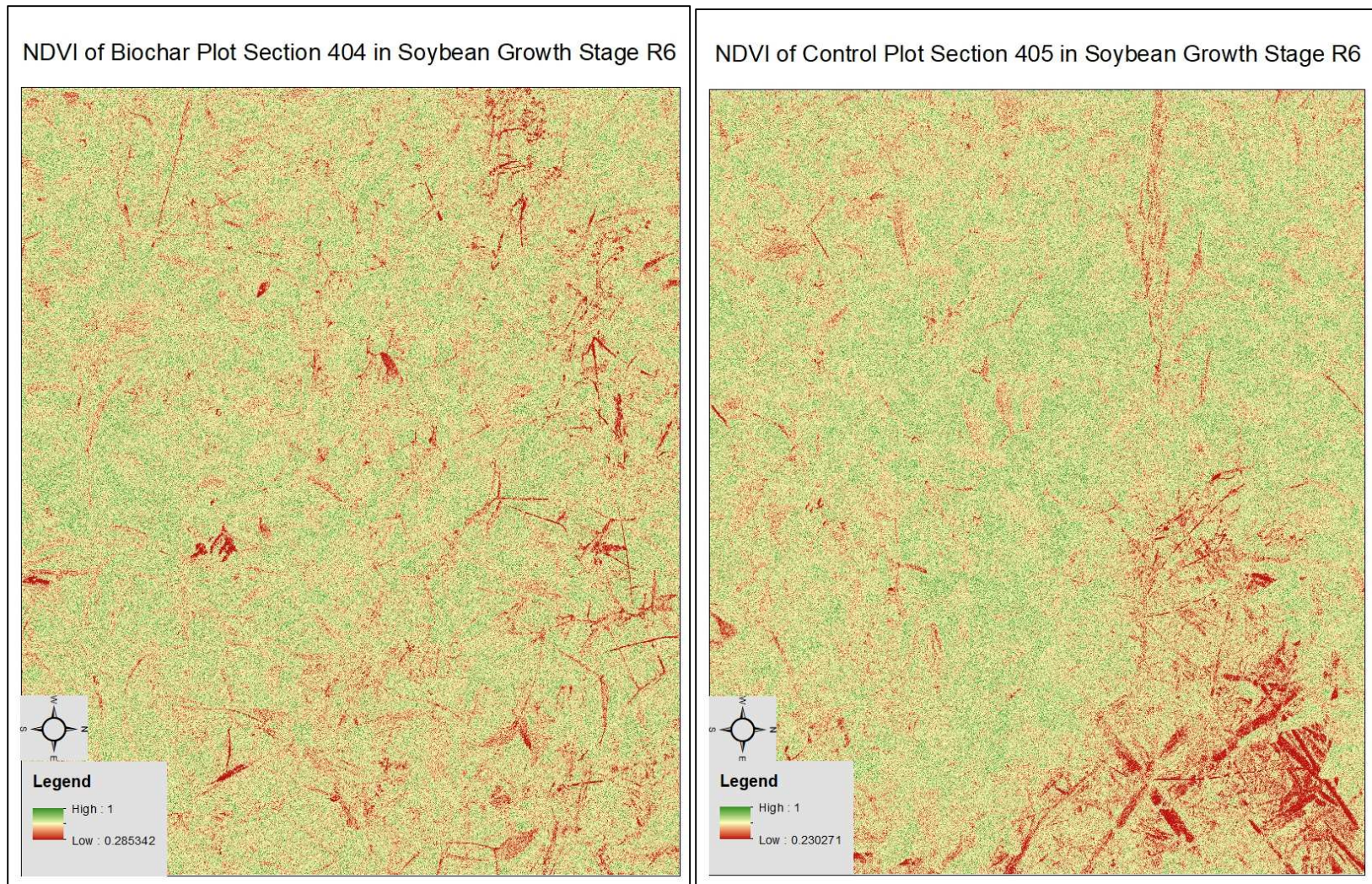
Figure 63: NDVI of biochar plot section 404 and control plot section 405 in soybean reproductive stage six.
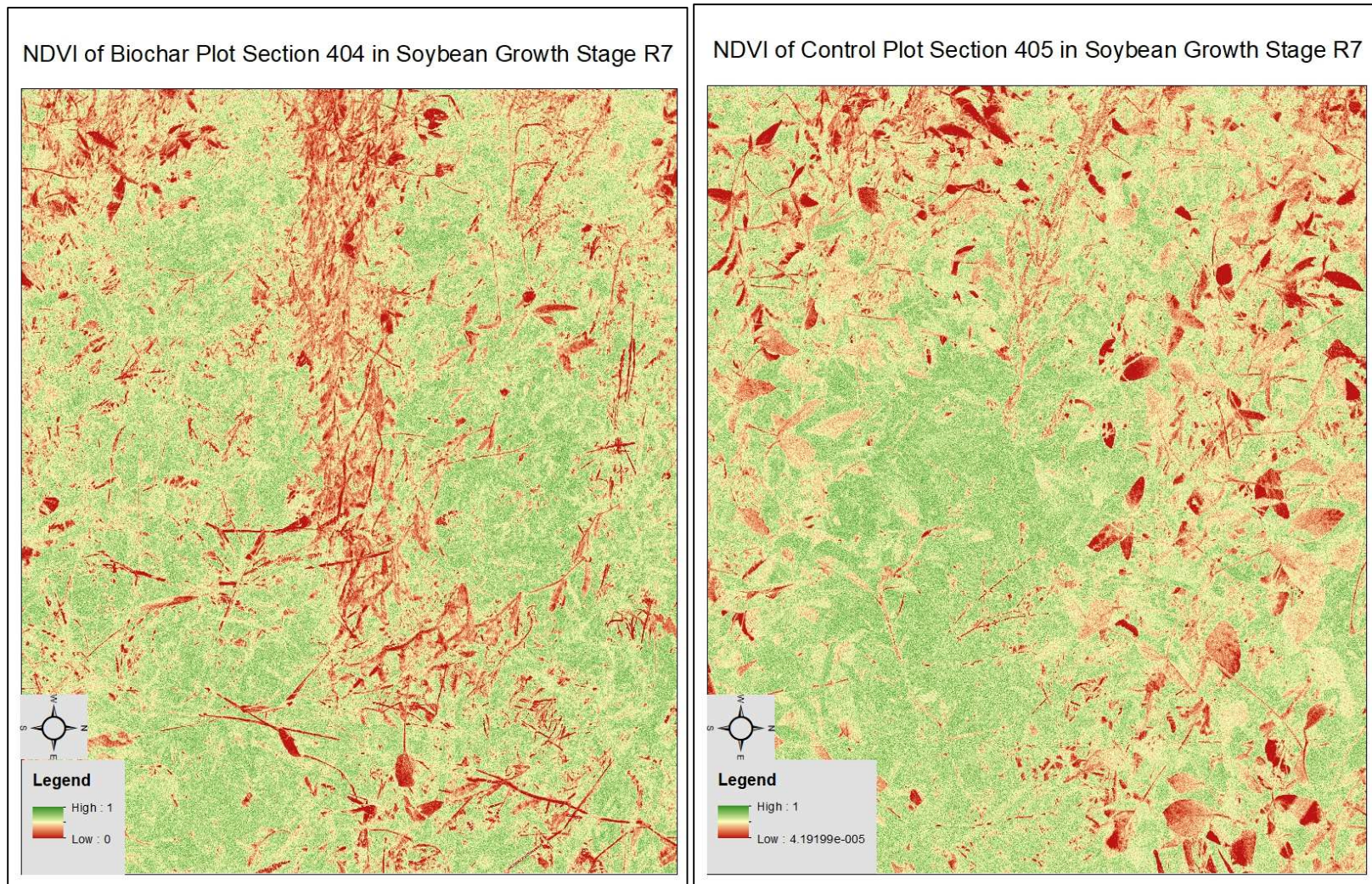
Figure 64: NDVI of biochar plot section 404 and control plot section 405 in soybean reproductive stage seven.
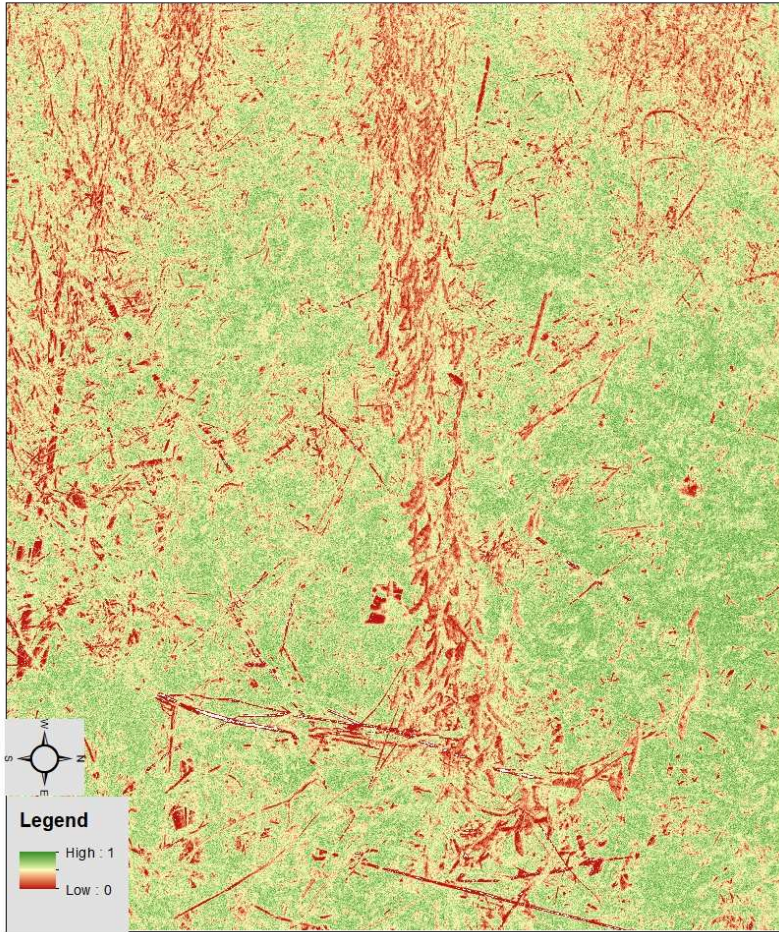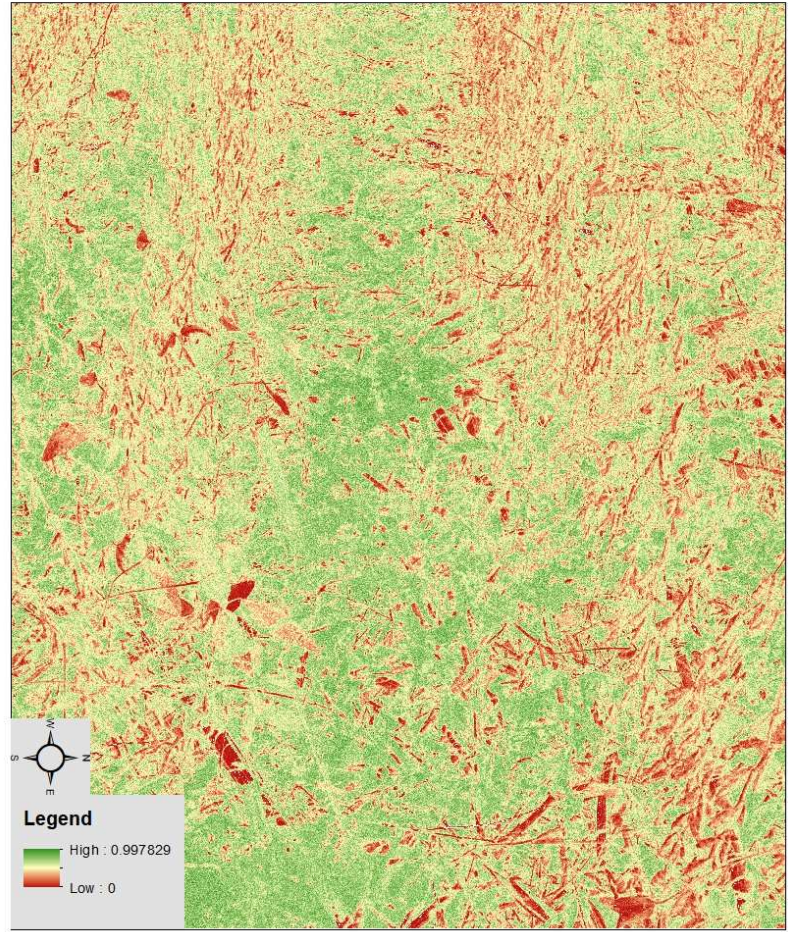
Figure 65: NDVI of biochar plot section 404 and control plot section 405 in soybean reproductive stage eight.
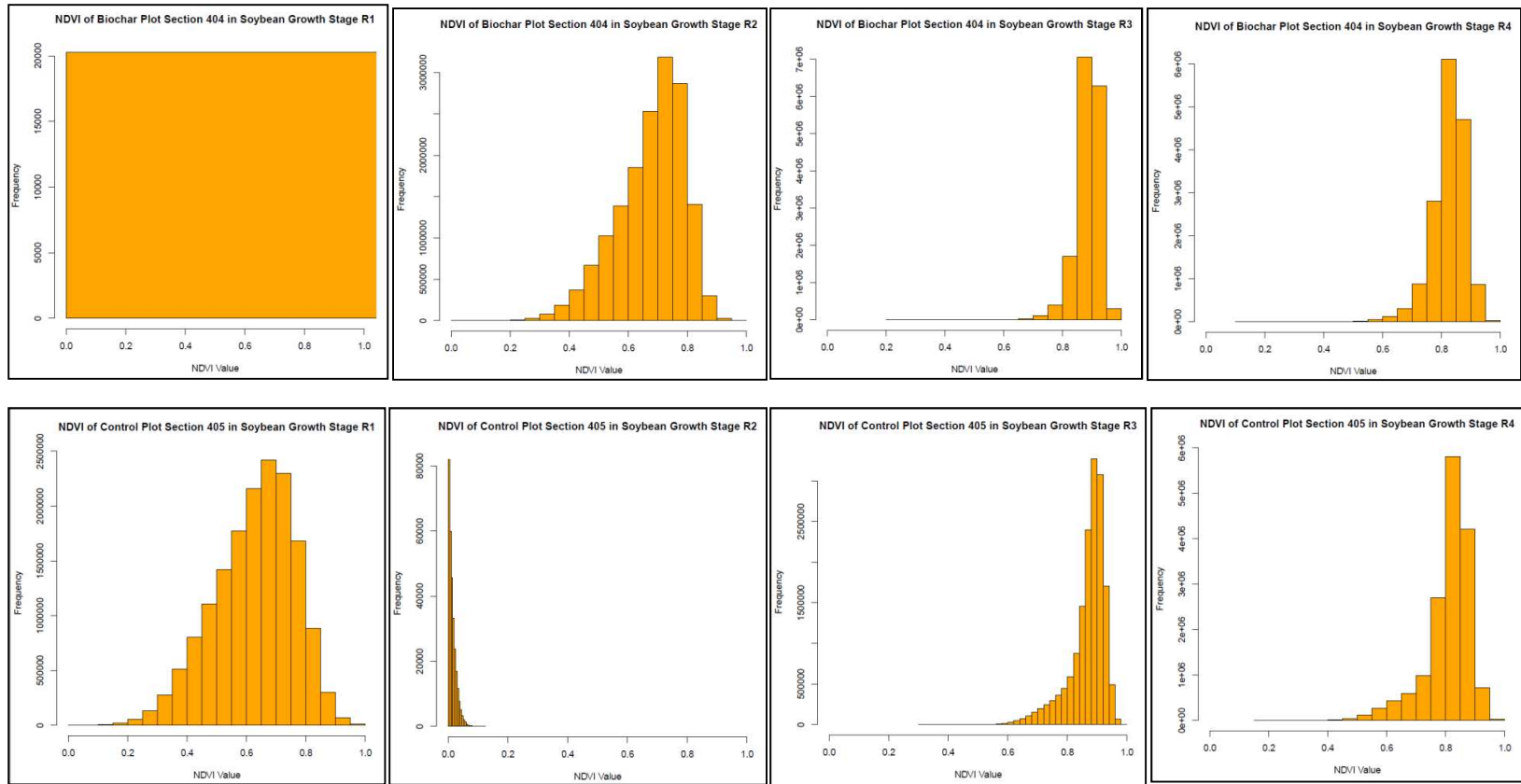
Figure 66: NDVI frequency histograms for reproductive growth stages R1-R4 in biochar plot section 404 (top) and control plot section 405 (bottom).
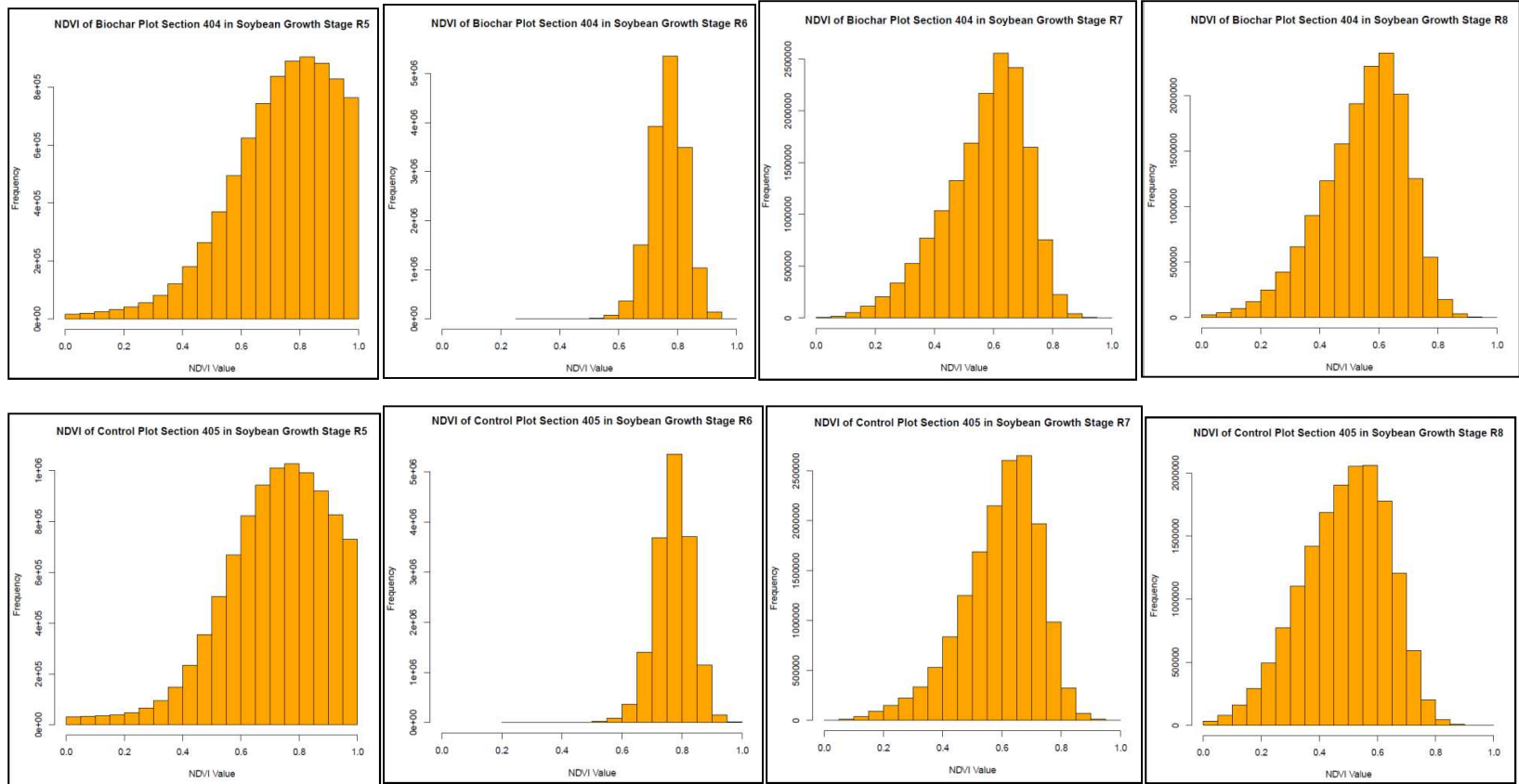
Figure 67: NDVI frequency histograms for reproductive growth stages R5-R8 in biochar plot section 404 (top) and control plot section 405 (bottom).

4.3 Soybean Biomass Measurements

Spatial location of plot sections was a crucial determinant of soybean biomass weight. The highest biomass weight was 1911.10 g located in biochar plot section 106 and the lowest biomass weight was 460.30 g located in plot section 203 (Figure 68). The two highest biomass weights were in paired sections biochar 106 and control 206, although the biomass weight for the biochar plot section was over 700 g higher than the control plot section. The biomass weights of the other three pairs were lower, with a mean at about 780 g. Plot sections 203, 303, 301, 102, 404, and 405 are much closer in soybean biomass weight with their respective pairs, as well as have lower biomass weights than plot sections 106 and 206. A two-tailed t-test showed that although biochar plot sections had a higher soybean biomass mean, it was not statistically significantly higher than the control plot sections at a t score of 0.76 and a 95% confidence level.
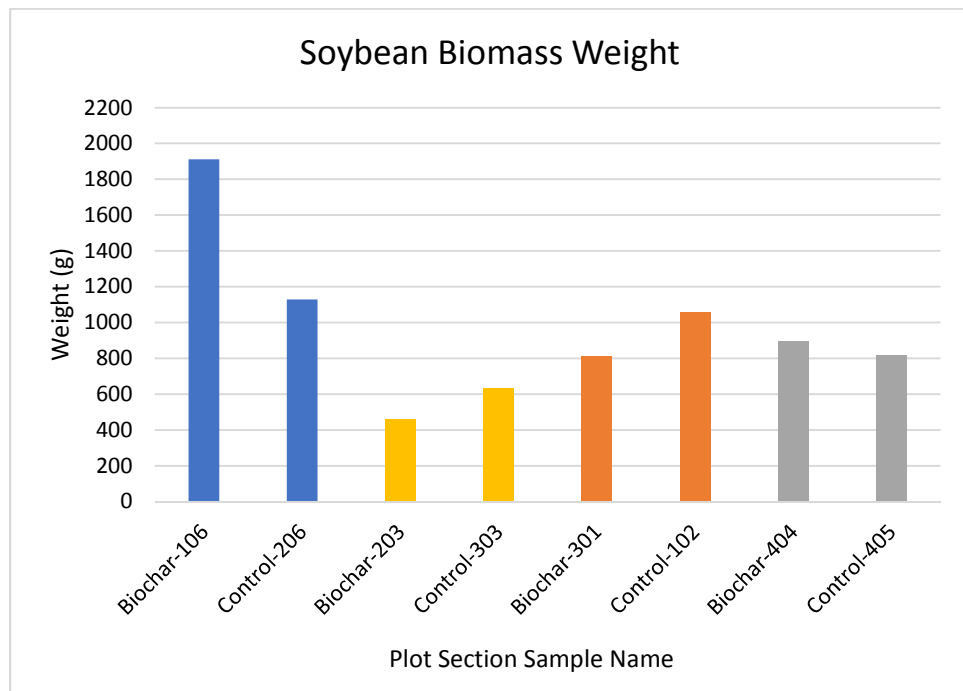
Figure 68: Soybean biomass weight by color. The varying colors distinguish samples within each plot section.

Soybean biomass weights did not show a specific spatial pattern. The highest biomass weight was 1911.10 from biochar plot section 106. This plot section is located on the southwestern corner of the plot field, adjacent to the second highest biomass weight at 1129.60 g in control plot section 206 (Figure 69). The lowest soybean biomass weight was 460.30 g in biochar plot section 203, located in the center of the plot field. Although a distinct pattern of soybean biomass weights is not distinguishable, many of the lower biomass weights were caused by weed invasion and competition. Plot section pairs of 106 and 206, 203 and 303, 102 and 301, and 404 and 405 had similar weed pressure and similar soybean biomass weights, therefore normalizing the data.
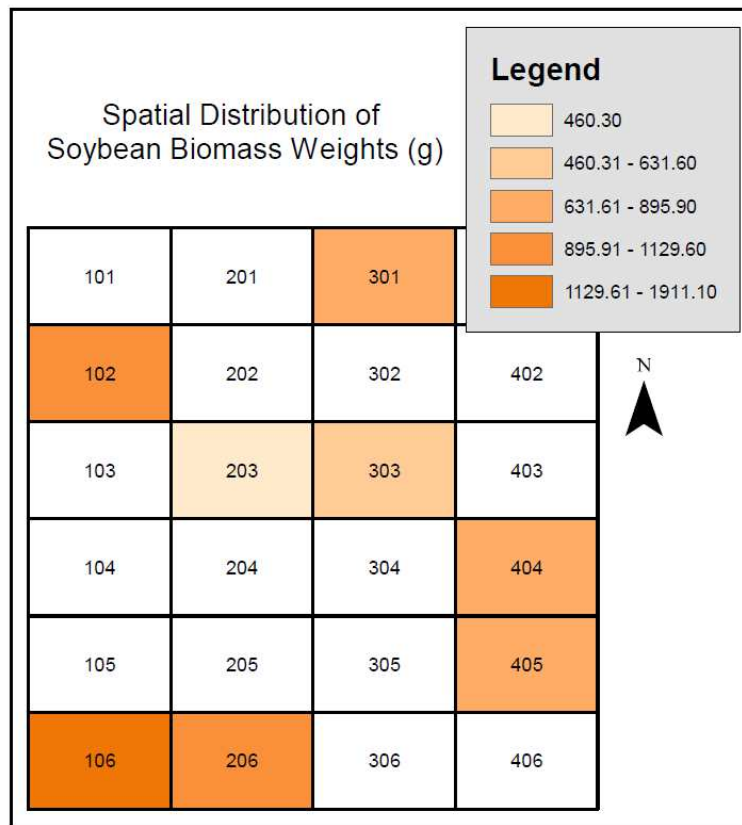
Figure 69: Spatial distribution of soybean biomass weight within the plot field.

CHAPTER FIVE: DISCUSSION

5. Major Findings

Overall, the findings of this research do not support the use of biochar as a soil amendment in Brookings County, South Dakota. However, this may not mean that biochar is a poor choice of amendment for the entire ecoregion of the Northern Glaciated Plains. The goal of the study was to gauge the productivity of biochar in a very small area of the Northern Glaciated Plains ecoregion to assess its ability to affect soil quality and soybean production. The addition of biochar to the soil in Brookings County did not significantly improve the soil or crop productivity during this study using soil pH and electrical conductivity (EC) testing, the use of normalized difference vegetation index (NDVI) on soybeans, or the accumulation of soybean biomass. Crop productivity nor soil quality was affected significantly enough within the parameters of the tested objectives to improve soybean production and advise the use of biochar as a biological precision technology for this study region.

5.1. Soil Property Change through Biochar

Soil properties such as pH and electrical conductivity are commonly tested because they assess the general health and productivity of a soil. Many studies in which biochar was used as a soil amendment show changes in soil pH and EC when compared to the natural soil. Many researchers have shown that biochar can increase pH in acidic soils, raise EC throughout the soil surface layer, improve nitrogen capture and slow its release, and store carbon. Much research in biochar occurs on nutrient poor soils, showing drastic changes in soil properties. However, soils in a highly agriculturally productive regions, such as areas within the United States, did not yield similar results. The few studies of biochar application in agriculturally productive regions show

that biochar has a much more moderate impact on soil productivity than in areas of lower natural soil fertility (Laird et al. 2017, 52);(Kimetu et al. 2008, 737);(Barrow 2012, 26);(Filiberto and Gaunt 2013, 720).

This research shows that the application of corn stover biochar did not have a significant effect on these basic soil properties, revealing neither positive nor negative results. Each soil test revealed only small variations in results between plot sections, and the spatial distribution of those results varied by soil test. Within plot sections, results were often very similar; however, some tests revealed differences within each plot section. Findings such as these were expected because the soil used for the study site is so productive to begin with. Corn stover biochar was not a highly effective soil amendment in this study because soil pH and EC did not show significant benefits from the biochar over the control plot sections. However, corn stover biochar could still potentially benefit other parameters of soil health that were not tested in this study such as water holding capacity, cation exchange capacity, bulk density, acidity, and soil microbial activity (Ding et al. 2016, 14);(Laird et al. 2017, 52);(Rawat et al. 2019, 9).

5.1.1 pH Level Between Treatments

Soil pH in this plot field varied from acidic to neutral but differed between plot sections and the treatments those plot section received. The lowest acidic value was 4.94, while the highest neutral pH value was 7.13. Although one of the potential benefits of biochar application is increased pH value in acidic soils, the results of the pH tests did not show a statistically significant difference between the pH values in the biochar plot sections when compared to the control plot sections. Both treatments of biochar and control plot sections showed varying pH values from acidic to neutral with some plot sections having noticeably higher or lower pH values. The distribution of pH values had no particular pattern across the plot field.

Soils that are highly acidic often are not as agriculturally productive as soils with neutral or slightly acidic pH values depending on the type of crop produced. Some of the reasons behind loss of crop productivity through acidic soils are the higher levels of heavy metals, over solubility of minerals, and reduction in organic matter decomposition. The results of this study show that biochar affected soil pH slightly, but not significantly enough to alter crop productivity through pH increase. Most of the biochar plot sections had healthy ranges of pH values, except for plot section 106 that had very low pH values in comparison with the rest of the biochar plot section. PH values within the control plot sections followed a similar pattern as the biochar plot sections in that only one plot section had low pH values in comparison with the other control plot sections. The control plot section that had low pH values was control plot section 206. The acidic pH values in this plot section did not negatively affect soybean productivity significantly.

5.1.2 EC Level Between Treatments

Soil EC in the plot field was similar to pH findings, in that the values varied across the plot, but EC tests also revealed that EC values were more valued within each plot section. The lowest EC value recorded was 161.5, while the maximum was 300.2. The largest range in EC values were in the control plot sections. One of the potential benefits researched in biochar application was the increase in EC after the addition of biochar; however, the results of the EC tests did not show a statistically significant difference between the different control and biochar treatments. Given that EC values varied within plot sections, no significant spatial pattern of distribution was assessed across the plot field.

Electrical conductivity is the measure of dissolved salts in a soil solution, and it is often a parameter of how the soil absorbs and retains moisture. A soil with a low EC results in fewer usable minerals for crops, while high EC levels can be toxic and kill the crop. The addition of

biochar is researched to increase EC levels without raising salt levels too high for successful crop production, especially biochar produced with high temperature pyrolysis. The results of this study show that EC levels varied within each biochar plot section, while ranging very little between plot sections. This indicated that biochar stabilized EC results, while keeping EC at an appropriate level for crops to absorb water and nutrients. EC values had a much wider range in control plot sections. Though there were no significant differences between biochar and control plot section EC test results, control plot sections showed many much lower soil EC values than in biochar plot sections. This result shows that there were less soluble minerals in control plot sections than in biochar plot sections, but not enough to make a significant difference in soybean productivity.

5.2. NDVI Between Treatments

Crop productivity is increasingly being measured using NDVI because it assesses crop health without destroying the vegetation. NDVI is a useful tool that uses near infrared and red light to detect crop stress and predict crop productivity. This study used NDVI to assess soybean health over eight reproductive growth stages in a small plot in Brookings County, South Dakota, as the soybean matures from first bloom to full maturity. There are many studies within and outside of the study region that use NDVI to measure soybean health over the growing season (Ma et al. 2001, 1233);(Zhitao et al. 2014, 66);(Esquerdo et al. 2011, 3718); however, there are very few that use NDVI to assess plant growth in biochar-amended soils. This project is the first of its kind to use NDVI to measure soybean health in the Northern Glaciated Plains ecoregion.

Soybean NDVI over the course of the growing season remained similar in each reproductive growth stage throughout the plot field. Growth stages one and two, seven and eight mostly had minimum NDVI values at 0, while most of the minimums for the other stages, stages

three through six, had higher minimums because of enlarged biomass. Most all the plot sections

had NDVI maximums at 1 or slightly lower than 1. Mean NDVI values were the lowest at

reproductive growth stage one and two, but drastically increased in stage three and four. After

stage three, mean NDVI gradually decreased until the soybean crop was fully matured at stage

eight. Biochar plot sections had a higher mean NDVI value than control plot sections, but it was

not statistically significantly different in any of the growth stages. Spatially, only a few patterns

were visible. Control plot sections 206 and 405 in the southern part of the plot field had lower

mean NDVI values than adjacent biochar plot sections 106 and 404. Biochar plot section 301

and control plot section 102, located on the northern side of the plot field, had higher NDVI

values.

NDVI measures greenness, but it is often associated with plant health. Plants with higher

NDVI values are healthier, more productive, and they generally produce better yields. Soybeans

with higher NDVI values yield increased bushels of beans. The relationship between biochar as

a soil amendment and crop NDVI is not well documented, but the few studies completed on this

topic report that the addition of biochar could prevent crop stress leading to crop failure or

decreased crop productivity. The NDVI results in this study conclude that the addition of

biochar did not have a significant impact on soybean NDVI over the eight stages of reproductive

growth. Soybean productivity remained similar throughout the entirety of the plot field.

5.3. Biomass Findings

Biomass accumulation assessment can be used as a measurement of plant health and

overall productivity. However, even if biomass increases, it does not mean that the biomass is

evenly distributed on the plant. Agricultural productivity does not necessarily increase with crop

biomass increase. Some plants, such as many legumes, support their crop output in their

biomass, therefore increasing biomass as yield. Soybeans are legumes; however, they are not legumes that rely on biomass for their crop output. Although soybeans do not derive their crop output through accumulation of biomass, increase in biomass may also provide an increase in soybean yield. Soybean yield, however important was not a part of this study.

Biochar-amended soils have been shown to increase biomass accumulation in plants, especially legumes. Not only does biochar increase above-ground biomass, but it also extends root lengths. Biochar supports the establishment of nutrients important to healthy plant development in the soil; therefore, allowing the plants to take in more nutrients that influence growth. In some cases, biochar can increase biomass through increased water storage instead of through increased percentages in nutrient availability. Studies show that soybeans have increased biomass growth when paired with biochar distributed in both plant size and crop yield (Wang et al. 2016, 1501);(Sanvong and Nathewet 2014, 98).

Although biochar has been shown to increase biomass in legumes in other studies, it did not significantly increase soybean biomass in any of the biochar plot sections compared to the control plot sections in this study. Plot pairs had only slight differences in biomass. Overall, the biochar plot sections had a higher mean biomass weight by about 100 grams. Some plot sections had a higher rate of soybean germination, which lead to some plot section pairs having higher biomass weights than others. Spatially, biomass weights did not have any specific distribution pattern. Biomass weights were influenced by the amount of weed pressure in the plot field, but it did not affect results of biomass between plot section pairs.

5.4.3 Importance of this Study

Most biochar research projects focus in tropical regions of the world, often in nutrient-poor soils, and with cash crops (Lehmann and Rondon 2006, 517). Few studies focus on biochar application in combination with soybeans in the Northern Glaciated Plains ecoregion of the United States because this region is highly agriculturally productive and very agriculturally intensive. Of those studies, very few studies record NDVI and soybean phenology in accordance with biomass measurements and biochar's effect on soil fertility. Since soybeans are such an important rotational crop for many U.S. farmers in the Northern Glaciated Plains ecoregion, it is essential to test what opportunities biochar may provide this region. Although the results of this study conclude that biochar did not have a significant effect on soil pH, soil EC, soybean NDVI, or soybean biomass accumulation, different results may be achieved in a longer-term study. The long-term effects of biochar on soybeans are under-researched and could produce positive or negative results based on location and soil fertility (Sorensen and Lamb 2016, 710). Nonetheless, it is crucial to understand the role biochar could play in the production of the Northern Glaciated Plains ecoregion.

Agriculturalists in the United States need broader knowledge in sustainable biotechnologies to prevent a distrust in research, while providing appropriate options that "sustain food production and do this while coping with environmental change in ways that avoid further land degradation (a doubly green revolution)" (Barrow 2012, 26). Zhang et al. acknowledged that feeding the world's growing population will require a more comprehensive knowledge of the effects of biochar on agriculturally productive areas of the world (2016, 28). After completing this study in a region that is highly agricultural, it increases our knowledge of the extent of chemical and physical soil and soybean change biochar is capable of.

Since very few studies involving biochar application have been completed in the Northern Glaciated Plains ecoregion, it was challenging to estimate the effect biochar would have on this ecoregion's soils and crops. However, the results of this study could be used as a guide for other researchers as to which assessments they choose to pursue not only in this ecoregion, but also in others. Biochar may not increase soil pH or EC effectively in soils like soil series within the Northern Glaciated Plains ecoregion, but it may affect water holding capacity or nutrient capture, which were not tested. Likewise, biochar may not increase soybean health or biomass accumulation in this ecoregion, but it may affect other crops such as corn or alfalfa, another legume. Researching the results of biochar on soybean growth was very beneficial for environmental sustainability because it revealed the accessibility of biochar benefits for this ecoregion and answered the question of whether biochar was an appropriate soil amendment for this ecoregion in terms of soil pH, soil EC, soybean NDVI, and soybean biomass.

5.5. Relevance to Other Studies

This study was completed in the hope that the results would provide similar beneficial results as it provided in other studies. The work of others was crucial to the design of this project and influenced the expected results, although many expected results did not occur in this study. Much of the previous research on this topic focused on the benefits of biochar in agricultural settings in nutrient poor soils. However, some studies focused on nutrient rich soils, closer to the study location in this research, that also benefitted from the use of biochar in at least one way. In almost all cases, biochar influenced soil or plant productivity in a positive way. Some of the methods within those studies were implemented in this research in the hope that it could be recreated. Some methods in this research went beyond the scope of most research in biochar, pioneering new possibilities in this field of research. Although many of the results from this

study did not mimic results of the others, they are still valuable to the collective knowledge of biochar research.

5.5.1. Comparison to Other Soil Studies

Biochar did not significantly increase soil pH in this study, even if the pH mean in the biochar plot sections was higher than the control plot sections. Other studies show that pH rose when biochar was applied (Obia et al. 2015, 6);(Masud et al. 2014, 794);(Jien and Wang 2013, 230), dependent on the pyrolysis temperature and feedstock of the biochar Ahmad et al. (2012);(Randolph et al. 2017, 276). For example, Rogovska et al. (2016, 104) found that soil pH increased after application of a hardwood biochar in the topsoil of a similar soil series in the state of Iowa. This study occurred over five years and showed a significant increase in soil pH in biochar amended soils in comparison to control soils. The research done previously in this field did not see an increase in pH in the study location, but did see a significant increase in soil pH in a more eroded soil very similar to the study location (Sandhu 2016, 25). Very few studies had results in which soil pH decreased (Kishimoto and Sugiura 1985).

Biochar application did not significantly change soil EC, although soil EC was slightly higher in control plot sections than in biochar plot sections. Soil EC, in some other studies, increased in biochar amended soils (Randolph et al. 2017, 279);(Khan et al. 2017, 1151);(Mohamed et al. 2015, 69). The increase in EC was often dependent upon the climate of the area or the amount of time biochar was incorporated with the soil, and the rise in EC resulted from an increase in soil water holding capacity. In many cases, such as in this study, soil EC is not affected by biochar. An example of stagnant EC levels is a study by Drake et al. (2015, 365) in sandy loam Australian soils in which soil EC did not change significantly in biochar amended

soils. Sandhu (2016, 26-27) reported a significant decrease in soil EC in this plot field in 2013 after crop planting, and no change in EC after crop harvest.

5.5.2. Comparison to Other Soybean Studies

NDVI measurement was the most important component to this study because it is very under researched in biochar application studies. Soybean NDVI was not significantly affected by biochar use in this study, even if mean NDVI was higher in biochar plot sections than in control plot sections. Although other biochar studies do not use NDVI as a measurement tool, it is clear that biochar affects crop productivity. Periodical NDVI assessments are used to be able to interpret and improve systems of production and land cover on the surface of the earth for mapping growth, photosynthetic activity, and the duration of growth (Van Leeuwen et al. 2006, 68). Some studies showed strong linear relationships between NDVI and biomass accumulation (Goswami et al. 2015, 8), while other studies show that biochar application improves crop productivity either through biomass growth or increased yield output (Jeffery et al. 2011, 185);(Liu et al. 2013, 589);(Sohi et al. 2010, 68). Since NDVI has not been used as a measurement technique for biochar studies before, it is appropriate to assume that NDVI was a measurement for plant health in this study.

The soybeans in this study did not respond to the addition of biochar by means of biomass growth, even though mean biomass was slightly higher in biochar plot sections. Many researchers have found that biochar-amended soils increase crop biomass (Rogovska et al. 2014, 7);(Parmar et al. 2014, 1677);(Houben et al. 2013, 200);(Sigua et al. 2015, 747). Moreover, much of the research has shown that this increase in biomass is especially true with legumes (Schulz et al. 2013, 820);(Rondon et al. 2007, 702);(Oram et al. 2014, 96). Soybeans in particular also benefit from biochar application in most cases. Both Reyes-Cabrera et al. (2017,

458) and Tawadchai (2012, 247) found that biochar application led to increased soybean biomass production in both leaves, pods, stems, and roots of the plants; however, these studies both occurred in greenhouses with biochar of differing feedstocks. Wang et al. (2016, 1501) found that corn stover biochar increased soybean biomass in a loam soil in China. Overall, the reason for increased vegetative biomass growth was because of increases in soil pH, water holding capacity, or nutrients such as potassium or nitrogen.

5.6. Alternative Explanations

Despite the research behind biochar as a soil amendment, this study did not yield the results found in other studies of similar methodology. When designing the methodology for this study, many of the anticipated results were significantly positive. Biochar did not end up being an amendment that could significantly impact the face of agriculture in this county, and perhaps even the entire Northern Glaciated Plains ecoregion. Although results of the study were underwhelming, they still pointed toward the possibility of biochar being a healthy additive to the soil in this region. The soil pH and EC, along with the soybean health and biomass accumulation, did not significantly differ between treatments, but many of the mean results show that the biochar treatment improved farming conditions slightly. Many alternative explanations can be found for the results of this project, even if biochar was not proven to significantly improve agriculture in this region.

One reason for the slight positive change in soil health conditions after biochar addition could be the increase in water holding capacity. Biochar adds density to the soil that is very porous, allowing the soil to retain more water for longer periods (Rogovska et al. 2016, 102, 104). This quality often occurs when the soil conditions are dry and there is a lack of water that prevents crops from growing to capacity. Drier regions with a soil moisture regime that does not

provide adequate moisture for crops throughout the summer have reacted well to biochar, since crops in these regions often need a additional moisture throughout the growing season. Biochar is an excellent additive in cases in which moisture retention is crucial.

In more fertile regions, biochar may be added to the soil to prevent the use of irrigation and retain moisture in periods of drought. The study area, being within the Northern Glaciated Plains ecoregion, has a moisture regime that allows many moisture dependent crops to grow. Although this area does not necessarily require biochar to retain moisture, it retains enough moisture to prevent stress on the crop during the dry season and during any droughts that may occur during the growing season. The climate during the growing season of the study period was very average in amount of rainfall and temperature. The spring came with high moisture levels from snowmelt and rainfall, followed by a summer that resulted in drier periods. The higher levels of soil pH, EC, and soybean NDVI may have been attributed to the available biochar retaining an increased amount of water in the soil in July and August when the available water in the soil is at its lowest.

Another reason for the increase in soil and crop productivity in biochar amended plot sections could be a decrease in soil bulk density. Biochar, being porous and filled with many air pockets, decreases the compaction in the soil and allows the roots of the crops to grow more efficiently (Rogovska et al. 2016, 102, 104). This process often increases the rate of crop biomass growth and could have been the reason soybeans in the biochar amended plot sections had higher biomass growth rates than in control plot sections. The reduction of bulk density is helpful in any ecoregion, especially in regions with a precipitation-rich moisture regime, such as the Northern Glaciated Plains ecoregion. In this study, the reduction of bulk density could have contributed to the slight increase in biomass because of more efficient root growing.

An increase in carbon and the retention of carbon and other minerals could be another explanation for the results of the study. Biochar both supplies carbon directly available to the soil and retains it for longer periods than man-made carbon inputs. Biochar retains this carbon and other elements and minerals, making it available for crops to flourish throughout the growing season. This process is crucial in soils with low native fertility, and very effective in fertile soils that have been over-cultivated. Some researchers report increased concentrations of nutrients such as phosphorous, calcium, manganese, and potassium in soils with biochar (Laird et al. 2010a). The Northern Glaciated Plains ecoregion, being heavily agriculturally intensified in the last century, is subject to nutrient leaching and loss of key soil elements necessary for mass crop production. The soil in this study may have benefitted from the extra nutrient retention within the biochar amended plot sections.

One last possible explanation for slightly increased results in biochar amended plot sections could be increased microbiological activity in the soil. Biochar increases porosity in soils that foster the growth of diverse microbiological activity. The microbes found in soils amended with biochar have been found to increase electron transfers in soil, increase soil organic matter content, and reduce soil toxicity from heavy metals. All these benefits provide crops a healthy environment to flourish and could have influenced the soybeans in this study.

5.7 Limitations and Assumptions of the Study

This project had its share of limitations and assumptions that may have hindered the results of the study. The study aimed to test biochar as a soil amendment in Brookings county to identify whether it is an appropriate amendment for the Northern Glaciated Plains ecoregion. The study sufficiently tested the soil for changes in pH and EC and the soybeans for NDVI and

biomass accumulation. However, some alterations to the study could have been made to make the study more accurate, useful, and impactful.

Soil health can be measured using a multitude of tests, while this study only utilized two soil tests. The two tests, soil pH and EC, mainly tested soil acidity and salt levels. These two tests are important in understanding a soil's nutrient availability, fertility, salinity, and crop growing potential. Although these tests offer a glimpse into general properties of soil health, it does not necessarily give a complete picture of how each individual soil series will behave. Other tests include total carbon, nitrogen, phosphorous and other major and minor soil nutrients such as potassium, sulfur, calcium, magnesium, and other metals. This study could have benefitted from testing additional nutrient resources in the study soil. Soil test results may have shown a change in a soil nutrient rather than a change in just pH or EC. Further study on biochar supplement in this ecoregion may focus on carbon sequestration through total carbon testing.

An assumption of the study was that the biochar used, that was applied in 2013, was both potent enough to provide significant results years after initial application. Some biochar studies show that the effects of biochar are compounded years after application, yet this was not a testable parameter in this study. The results of this study may have been altered because the biochar has changed chemically and physically over time. This study could benefit from further years of the same testing to determine if time in the soil influences biochar effectiveness.

Some limitations of the soybeans included weed density and camera placement and angle for crop NDVI. Weeds were problematic throughout the entire field due to the nature of the no-till field. The study was designed to deter the influence of weeds by pairing plot sections by location. Paired plot sections had similar weed pressure, but some plot sections experienced more than others, affecting the soybean NDVI results.

NDVI was likely influenced by the angle of the spectral camera and the position relative to the plot sections. This study assumed that NDVI would not change significantly by changing the angle or position of the spectral camera. The camera was positioned on the east side of each plot section and only included soybeans from that position within the same plot section throughout the growing season. The main limitation from this assumption was talking photos from multiple positions would have given the opportunity to normalize results by comparing the two positions. NDVI results be have been altered slightly from comparative data.

5.8 Biochar Use in Brookings County, and the Greater Ecoregion

This study did not find significant evidence that biochar aided soil fertility in Brookings County. The soil in the study did not show any significant change in pH or EC, nor did the soybeans reveal significant benefits from biochar addition. The native fertility of the study area and the greater Northern Glaciated Plains ecoregion make it difficult to see beneficial results. It is difficult to predict whether biochar would significantly alter soil chemistry or crop productivity throughout the ecoregion simply using the tests that this study employed. However, this study area, and likely a large portion of the ecoregion, is unlikely to experience significant soil and crop results from an addition of biochar. Following the study, biochar is not a recommended soil amendment for soil pH and EC increase, nor is it recommended for soybean NDVI or biomass increase.

The results of this study do not conclude that biochar is a poor soil amendment in this ecoregion. Contrarily, this study shows that the tests used did not result in a significant enough change to recommend biochar to agriculturists in the ecoregion. Many studies conducted in or near this ecoregion show significantly positive results in other soil and crop tests. Although the

tests chosen for this study were not significant, biochar does increase crop fertility in other ways throughout the ecoregion.

5.9 Impacts of Biochar on the Region and Greater Land Management

This study has an impact on how we approach crop production in this ecoregion and asks questions about how agriculture will operate in the future. The agricultural practices of today may not be applicable in the future due to decreased arable land, increased soil toxins, decreased crop productivity, and other woes. Biochar may not be the amendment of the future, but it may open a door to future possibilities of organic, biocentric agricultural solutions. As global population continues to rise and demand more, biochar may meet the demand with a heavy supply of more nutritious crops, healthy soils, and biological ingenuity.

CHAPTER SIX: CONCLUSION

Heavily intensive, after previously extensive, crop production has increased to the point in which it is impacting soil health negatively through fertility loss. The practice of intensifying and extensifying agricultural land dates to the end of human nomadic travel and the start of food production. Small at first, global agricultural production became widespread and, in many cases, detrimental. Humans used both agriculturally suitable and marginal lands for agriculture, even if the land was suited for production or lacked the qualities to sustain agriculture completely. Soils suffered fertility and productivity losses because of the production intensity humans required to fit their needs.

Today, agriculture faces the same problems, but on a greater scale. This study's purpose was to understand the relationship between the soils of the Northern Glaciated Plains ecoregion and biochar, a soil amendment aiming to prevent crop yields decreasing over time in soils because of over-intensification. Biochar had the potential to hold and prevent the escape of the large amounts of nutrients agricultural crops demand from soils. Sustainable or biotechnological farming practices that also benefit crop yield are not common among commercial farming in the United States because of a lack in supported research and perception of immediate necessity, yet are essential to creating a more sustainable future for agriculture in the United States. This study set out to explore the potential biochar had on soil pH, soil EC, crop health, and crop biomass weight and sought to apply that knowledge to broader agricultural systems with the goal of creating more sustainable faming across the Northern Glaciated Plains ecoregion and the greater United States.

6.1 Method Development and Results

The methodology in this study aimed to assess soil and soybean health in biochar-amended soil over a summer of growth in a region composed of rich soils under constant agricultural production. Since biochar first affects the soil it is applied to, it was crucial to test the soil for variation between the control and the biochar-amended plot sections. Soil pH and electrical conductivity were an important parameter to test because it showed how the soil in the plot reacted to the biochar over time. While the soil benefitted from the effect of the biochar, it did not affect it enough to significantly alter the soil chemistry.

This kind of reaction to the biochar became a pattern throughout the study and continued through the soybean normalized difference vegetation index. The NDVI was an important tool to understand how the soybean plants were reacting to biochar-amended soil. NDVI changed between the control and biochar-amended plots insignificantly, showing no visible change in soybean vitality over the growing season. Soybean biomass weights had a similar trend. Biomass weights at the end of the eighth reproductive stage showed no significant difference between the biochar and control plot sections. This parameter of the study was important because it offered a concrete measurement of difference between the two plot treatments.

6.2 Conclusion

This study aimed to show the relationship biochar has to the soils and crops grown in Brookings County, South Dakota. Biochar is an understudied soil amendment in areas with high native soil fertility, even if some of the highest levels of soil degradation occur in these areas. Soil pH and EC in this study increased slightly from the application of biochar and soybean plants grew marginally healthier with more biomass. However, none of this study's increases in

soil pH, EC, soybean NDVI, or biomass were significant enough to recommend farmers use biochar to alter soil health to increase soybean yields. Further, this study did not measure other soil health parameters to determine whether biochar can be helpful in enhancing soybean yield. This research was meant to determine the effect of biochar on select soil properties and crops in this county and the greater ecoregion, and this data suggest that biochar is not an effective amendment to increase soil pH and EC, and soybean health and biomass. Future studies for longer durations that can assess biochar impacts on soils and crop production under different locations and soil types are important to confirm biochar's effect in soils in the Northern Glaciated Plains ecoregion.

The results of this study could have been strengthened by performing and comparing the study in various locations within the ecoregion or with an ecoregion that was not as naturally fertile as the Northern Glaciated Plains ecoregion. This would have given a better understanding to the actual benefits of biochar on the soybeans without relying on the fertility of the soil being a major contributor to soybean health. Another way to improve the study was to watch growing conditions in the study plot over a longer period to see if long-term action is needed to see the desired results of the study.

The results of this study do not determine how the United States agricultural system will function in the future, nor does lessen the rate of soil degradation. Yet, this study shows the potential for biochar research in this region and others and begins to test the benefits of this soil amendment. Although this study did not provide significant results, it carves a path for similar questions to be answered. Agriculturalists and policy makers in this ecoregion may use this knowledge to begin a dialogue about more sustainable farming options to reduce soil

degradation. Biochar may not have been an overwhelmingly positive soil amendment for this region, but it may be part of a solution in the future of agriculture in the United States.

APPENDICES

Appendix A. Statistical Analysis on Soil pH and Soil EC

Biochar Samples	pH	EC
106-A	5.19	237.5
106-B	5.14	251.4
106-C	5.17	198.1
106-D	5.2	209.9
106-E	4.96	215.4
203-A	6.16	172.3
203-B	6.31	232.4
203-C	6.44	199.1
203-D	6.63	186.1
203-E	6.33	183
301-A	6.94	194.5
301-B	6.81	196.7
301-C	6.83	197.4
301-D	6.93	205.2
301-E	7.13	199.6
404-A	6.65	165.4
404-B	6.51	214
404-C	6.52	210.2
404-D	6.42	177.4
404-E	6.17	195.7
Mean	6.222	202.065

Control Samples	pH	EC
102-A	6.44	181.4
102-B	6.61	200.3
102-C	6.19	189.5
102-D	6.65	221.3
102-E	6.32	285
206-A	4.94	300.2
206-B	5.2	190.4
206-C	5.32	179.8
206-D	5.5	216.5
206-E	5.42	226.5
303-A	6.41	225
303-B	6.64	167.5
303-C	6.38	171.1
303-D	6.36	161.5
303-E	6.39	166.8
405-A	5.73	189.4
405-B	6.98	264.2
405-C	6.04	174.9
405-D	5.98	189.5
405-E	5.68	241.3
Mean	6.059	207.105

Biochar Plot Section T-Test Value: 0.210

Control Plot Section T-Test Value: 0.312

Appendix B. Statistical Analysis on Soybean NDVI

Biochar Plot Section 106

Growth Stage	Min	Max	Mean	StandDev	One-Tailed T-Tests	
106-R1	0.000	1.000	0.607	0.147		0.832
106-R2	0.000	1.000	0.670	0.135		
106-R3	0.285	1.000	0.853	0.040	**Mean**	
106-R4	0.285	1.000	0.853	0.040		0.688
106-R5	0.000	1.000	0.773	0.148		
106-R6	0.151	1.000	0.757	0.070		
106-R7	0.000	0.999	0.524	0.153		
106-R8	0.000	0.999	0.468	0.158		
	0.090	1.000	0.688			

Control Plot Section 206

Growth Stage	Min	Max	Mean	StandDev	
206-R1	0.000	0.000	20374.964		
206-R2	0.001	1.000	0.672	0.141	
206-R3	0.418	1.000	0.910	0.029	**Mean**
206-R4	0.015	1.000	0.854	0.038	0.707
206-R5	0.000	1.000	0.781	0.139	
206-R6	0.358	1.000	0.777	0.057	
206-R7	0.000	1.000	0.499	0.148	
206-R8	0.000	0.999	0.453	0.152	
	0.099	1.000	0.618		

Biochar Plot Section 404

Growth Stage	Min	Max	Mean	StandDev	One-Tailed T-Tests	
404-R1	0.000		0.000	20225.881		0.351
404-R2	0.004	1.000	0.676	0.113		
404-R3	0.245	1.000	0.887	0.041	**Mean**	
404-R4	0.133	1.000	0.826	0.057		0.715
404-R5	0.000	1.000	0.735	0.180		
404-R6	0.285	1.000	0.767	0.060		
404-R7	0.000	1.000	0.570	0.139		
404-R8	0.000	1.000	0.546	0.143		
	0.083	1.000	0.626	2528.327		

Control Plot Section 405

Growth Stage	Min	Max	Mean	StandDev	
405-R1	0.000	1.000	0.627	0.135	
405-R2	0.000	0.123	0.014	0.013	
405-R3	0.318	1.000	0.868	0.062	**Mean**
405-R4	0.159	1.000	0.809	0.077	0.611
405-R5	0.000	1.000	0.717	0.181	
405-R6	0.230	1.000	0.770	0.060	
405-R7	0.000	1.000	0.593	0.132	
405-R8	0.000	0.998	0.487	0.147	
	0.088	0.890	0.611		

Biochar Plot Section 203

203-R1	0.000	1.000	0.600	0.135		0.919
203-R2	0.007	1.000	0.640	0.118		
203-R3	0.207	1.000	0.865	0.060	**Mean**	
203-R4	0.221	1.000	0.805	0.074		0.689
203-R5	0.000	1.000	0.735	0.178		
203-R6	0.307	1.000	0.775	0.057		
203-R7	0.000	1.000	0.572	0.139		
203-R8	0.000	1.000	0.517	0.145		
	0.093	1.000	0.689			

Control Plot Section 303

303-R1	0.000	1.000	0.564	0.141	
303-R2	0.000	1.000	0.642	0.120	
303-R3	0.174	1.000	0.868	0.058	**Mean**
303-R4	0.161	1.000	0.807	0.073	0.682
303-R5	0.000	1.000	0.740	0.176	
303-R6	0.280	1.000	0.776	0.057	
303-R7	0.000	1.000	0.569	0.141	
303-R8	0.000	1.000	0.490	0.167	
	0.077	1.000	0.682		

Biochar Plot Section 301

301-R1	0.000	1.000	0.600	0.134		0.939
301-R2	0.000	0.996	0.636	0.123		
301-R3	0.221	1.000	0.867	0.056	**Mean**	
301-R4	0.088	1.000	0.806	0.071		0.684
301-R5	0.000	1.000	0.711	0.188		
301-R6	0.304	1.000	0.773	0.057		
301-R7	0.000	1.000	0.572	0.133		
301-R8	0.000	1.000	0.506	0.144		
	0.077	1.000	0.684			

Control Plot Section 102

102-R1	0.000	1.000	0.600	0.135	
102-R2	0.000	0.997	0.611	0.140	
102-R3	0.345	1.000	0.881	0.058	**Mean**
102-R4	0.213	1.000	0.835	0.060	0.689
102-R5	0.000	1.000	0.790	0.145	
102-R6	0.360	1.000	0.784	0.056	
102-R7	0.000	0.999	0.547	0.143	
102-R8	0.000	0.998	0.465	0.148	
	0.115	0.999	0.689		

Mean of all biochar plot section means: 0.535

Mean of all control plot section means: 0.526

Appendix C. Statistical Analysis on Soybean Biomass

Biochar Sample #	Weight (g)		Control Sample #	Range of Weight
106	1911.1	1129.6	206	781.5
404	895.9	817.5	405	78.4
203	460.3	631.6	303	171.3
301	813.9	1058.6	102	244.7

Biochar Plot Section Biomass Mean: 1020.30   **Control Plot Section Biomass Mean: 909.33**

Soybean Biomass T-Test Value: 0.756

Appendix D. Supplemental Project Photos

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