Quantifying Total and Sustainable Agricultural Biomass Resources in South Dakota – A Preliminary Assessment

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ABSTRACT

Conversion of biomass is considered the next major advance in biorenewable fuels, energy, and products. Wholesale conversion to biomass utilization could result in removal of current crop residues from agricultural fields (on prime agricultural lands) or even implementation of different crops and cropping strategies (i.e., switchgrass on marginal lands). To date, the driver for biomass processing has been economics and limitations on the conversion of the lignocellulose. Over the last forty years significant investments and resultant changes in management practices in the agricultural sector have focused on soil and water conservation. One of the major efforts has focused on conservation-till or no-till, with the goal of retaining biomass residues in the field on the surface to prevent erosion, improve soil structure, and increase biological diversity. Environmental implications of significant changes to current cropping systems have not been thoroughly addressed, however. This paper will focus on using South Dakota as a case study to determine the potential for biomass production and will discuss the implications thereof for the utilization of these materials. Optimizing the amount of biomass that can be harvested, both with and without a minimum level of crop residue left in the field, will be considered and discussed. Removal of all crop residues for biofuels and bio-based products is not a sustainable option. Instead, some level of residues must remain in each field, in order to reduce wind and water erosion, as well as maintain soil nutrients and carbon levels. Meeting the nation's transportation fuel needs can be accomplished sustainably, but these issues need to be discussed now, at the outset of this revolution.

Keywords: Bioenergy, Biomass, Ethanol, Environment, Resources, Sustainability, USA.

1. INTRODUCTION

The amount of oil imported into the U.S. has been steadily increasing during the last 20 years; the nation is now dependent on imported oil for approximately 65% of its needs, especially for transportation fuels (EIA AEO, 2006). The increasing cost and potential scarcity of fossil resources are contributing to a growing interest in the production of bio-based products and

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fuels, which will be manufactured at biorefining facilities. Biomass feedstocks can potentially be used to diversify our current fossil-based systems for fuels, power and products. Diversification can reduce our vulnerability to disruptions in energy supplies, as well as our dependence on imported energy sources for both fuels and consumer products. Biomass is carbon-fixing, and represents a way to meet needs with a 'net-zero' contribution to global warming. Thus, biorefineries represent a very viable part of the solution to the imported oil issue.

Biomass can be processed into liquid fuels that are then used to power transportation vehicles – currently the most prevalent of which is ethanol. Biofuels, which are renewable sources of energy, can help meet our increasing energy needs, and can be produced from various biomass sources including residue straw, corn stover, perennial grasses and legumes, and other agricultural and biological materials. At the moment, the most heavily utilized is corn grain, because corn starch can be readily fermented into ethanol on an industrial scale. Although directly tied to the market value of the grain itself, industrial ethanol production from corn is readily accomplished at a relatively low cost vis-à-vis other biomass sources. More information regarding the production of fuel ethanol can be found in (Dien et al., 2003; Jaques et al., 2003; Tibelius, 1996). In coming years, due to rapid technological advances, the hydrolysis and conversion of other lignocellulosic materials into ethanol is expected to become cost-competitive as this industry matures (DiPardo, 2000).

Toward this end, it is essential to understand the potential for supplying biomass for biorefineries. This endeavor will be geographically-dependent, as vegetation is not distributed equitably throughout the country. It is anticipated that South Dakota may be one of the leading production states when biorefineries that can utilize lignocellulosic feedstocks are eventually constructed and are operational. Thus, the objective of this paper is to examine South Dakota as a case study in biomass potential. Several key topics will be discussed, including general features of the state, agricultural production, potential biomass supplies, and implications for sustainable biomass harvesting.

2. GENERAL FEATURES OF SOUTH DAKOTA

South Dakota is a state in the north central region of the U.S. that encompasses 19.7 million ha (48.6 million acres). In 2002, it had approximately 17.7 million ha (43.8 million acres) of farmland (comprising 90.2% of the total land area). Of this farmland, approximately 50.3% (8.9 million ha; 22.0 million acres) was used as pastureland, while nearly 46.4% (8.2 million ha; 20.3 million acres) was cropland. The balance included timber, residential dwellings, roads, etc. The average farm consisted of 558 ha (1380 acres) (USDA-ERS, 2007).

Not all of this cropland is evenly distributed throughout the state, however. A large proportion of cropland is concentrated in the eastern half of the state where average annual rainfall is much greater. South Dakota has a very diverse landscape. The state has a range of elevations. Vegetation is spread throughout the state, and there are many waterways, the primary of which is the Missouri River.

3. AGRICULTURAL PRODUCTION IN SOUTH DAKOTA

Currently, the three row crops grown to the greatest extent are corn, soybeans, and wheat. In 2005, the value of each of these commodities were approximately $757,000,000, $736,000,000, and $446,000,000, respectively (USDA-ERS, 2007). To a lesser degree, several other row crops are also grown in South Dakota, including rye, oats, barley, sorghum, flax, sunflower, and hay. To estimate potential biomass resources for South Dakota, it is important to examine historic trends in crop production. To accomplish this, data from 1950 through 2005, for all of the main crops produced were downloaded from the National Agricultural Statistics Service (USDA-NASS, 2007) and analyzed using Microsoft Excel v. 2003 (Microsoft Corporation, Redmond, WA).

From the early 1960s, wheat production in South Dakota increased until the early 1980s, at which time it has generally fluctuated between 2.45 and 3.27 million t/y (90 and 120 million bu/y) (Figure 1a). In 2005, South Dakota produced 3.63 million t (133.4 million bu) of wheat on nearly 1.3 million ha (3.2 million acres). Soybean production, on the other hand, has steadily increased since the mid 1970s. In 2005, South Dakota produced 3.77 million t (138.6 million bu) on approximately 1.6 million ha (3.9 million acres) (Figure 1b).

Corn production has also been increasing for the last two decades. In 2005, South Dakota produced 11.94 million t (470 million bu) of corn for grain on nearly 1.6 million ha (4 million acres) (Figure 1c). Corn silage, on the other hand, encompassed 4.17 million t (4.6 million tons) from 170,000 ha (420,000 acres) (Figure 1d). This number is often variable due to drought condition. More silage is typically produced in drought-affected years, as drought-damaged corn is harvested for silage use.

The smaller volume grains have shown a fairly substantial decline over the last few decades as more corn and soybean have replaced typical small grain areas. In 2005, South Dakota produced 16,500 t (649,000 bu) of rye on nearly 4450 ha (11,000 acres) (Figure 2a), 190,000 t (13 million bu) of oats on approximately 73,000 ha (180,000 acres) (Figure 2b), 50,000 t (2.3 million bu) of barley on nearly 19,000 ha (47,000 acres) (Figure 2c), 111,000 t (4.4 million bu) of sorghum on 34,400 ha (85,000 acres) (Figure 2d), 12,000 t (480,000 bu of flax) on 9700 ha (24,000 acres) (Figure 2e), and 398,000 t (877 million lb) of sunflowers on 214,500 ha (530,000 acres) (Figure 2f). Hay production, on the other hand, has not had either a steep decline or a drastic increase. In 2005, 6.89 million t (7.6 million tons) of hay was produced on 1.6 million ha (4 million acres) (Figure 2g – note there was a large gap in the available data set from 1976 through 1995).

4. POTENTIAL BIOMASS IN SOUTH DAKOTA

So, how much biomass can be harvested in South Dakota? By using the NASS crop production data from 1950 through 2005, and utilizing appropriate conversion factors, which are listed in Table 1 (based on Milbrant, 2005), estimates of the total dry biomass for these specific crops

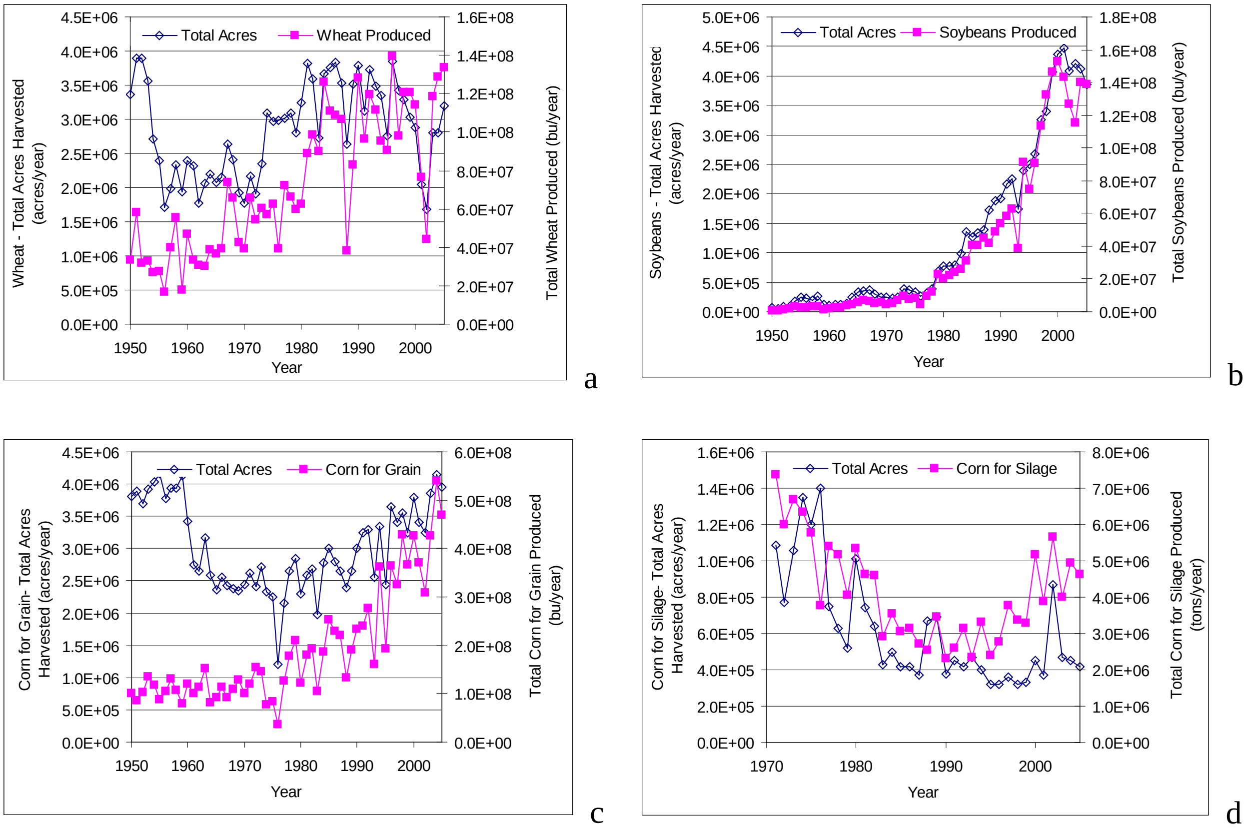
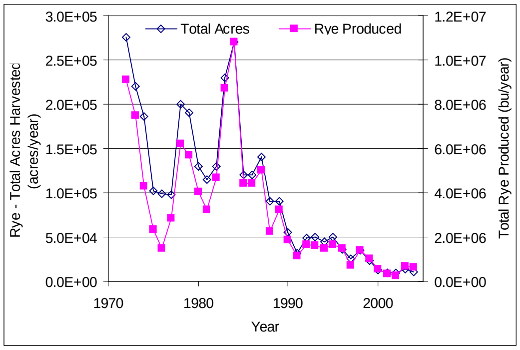


Figure 1. South Dakota crop acreage and production data from 1950 to 2005. a) wheat; b) soybean; c) corn for grain; d) corn for silage.

were calculated (Figure 3a). Additionally, nonlinear regression was used to summarize this data. The best-fit regression line was determined to be ($R^2 = 0.8716$; $F = 179.94$):

$$TBA = 8.850x10^9 - 6.932x10^3 \text{ x } Y^2 + 2.363 \text{ x } Y^3 \qquad (1)$$

where TBA is the estimated total biomass available (t/y, db – dry basis), and Y is year. Using this prediction equation, projections of future growth in biomass were then estimated through 2025 (Figure 3a). During this time frame, the crop residue biomass available in South Dakota should increase from approximately 22 million t (db) in 2005 to nearly 38.9 million t (db) by 2025 – assuming, of course, that yield trends continue to increase at the same rate. As depicted, these estimates quantify the total amount of biomass which could be available if 100% of the biomass is harvested and removed. Of course, however, this does not mean that all of the available biomass can or even should be removed and utilized as feedstocks for the emerging biobased industries. Many questions abound regarding how much can be sustainably taken. Thus, to provide wide latitude in addressing this dilemma, Figure 3b also provides estimates of the total biomass available for removal rates of 75%, 50%, and 25%.



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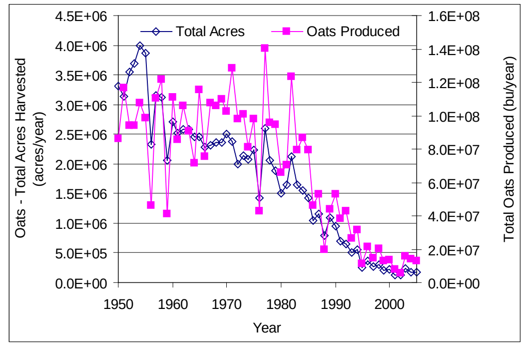

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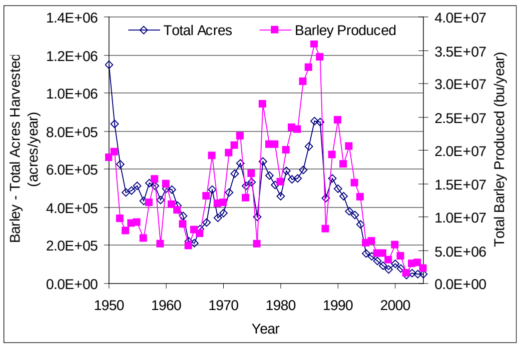

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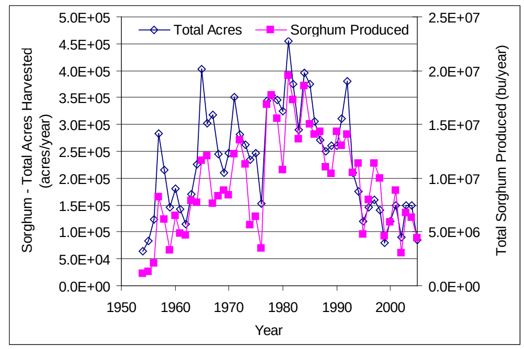

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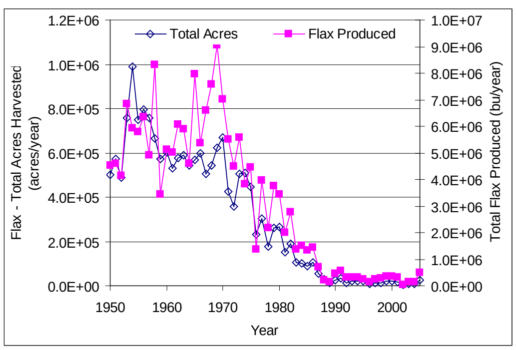

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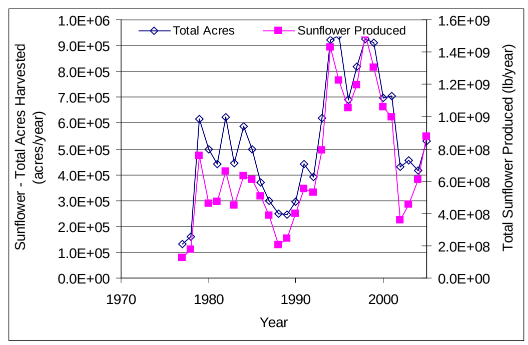

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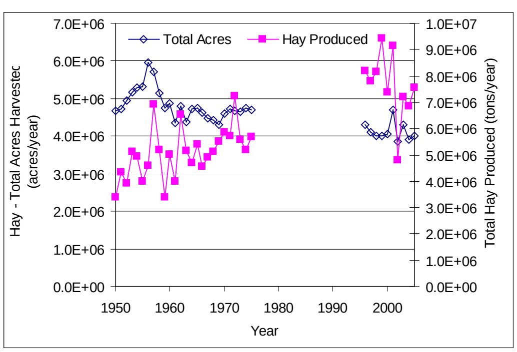

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Figure 2. South Dakota crop acreage and production data from 1950 to 2005. a) rye (only 1972 to 2004 data were available); b) oat; c) barley; d) sorghum; e) flax; f) sunflower (only 1977 to 2005 data were available); g) hay.

Table 1. Factors used to convert various crops produced in SD to available biomass (based on assumptions used by Milbrant, 2005)

Crop	Approximate Harvest Moisture Content	Approximate Test Weight		Approximate Ratio of Biomass to Crop Grain
	(%)	(lb/bu)	(kg/m^3)	(-)
Barley	14.5	48.0	619.15	1.2
Corn	15.5	56.0	722.34	1.0
Flax	8.0	56.0	722.34	1.2
Oats	14.0	32.0	412.76	1.3
Rye	10.0	56.0	722.34	1.6
Sorghum	12.0	56.0	722.34	1.4
Soybean	13.0	60.0	772.31	2.1
Sunflower	10.0	30.0	386.16	2.1
Wheat	13.5	60.0	772.31	1.3

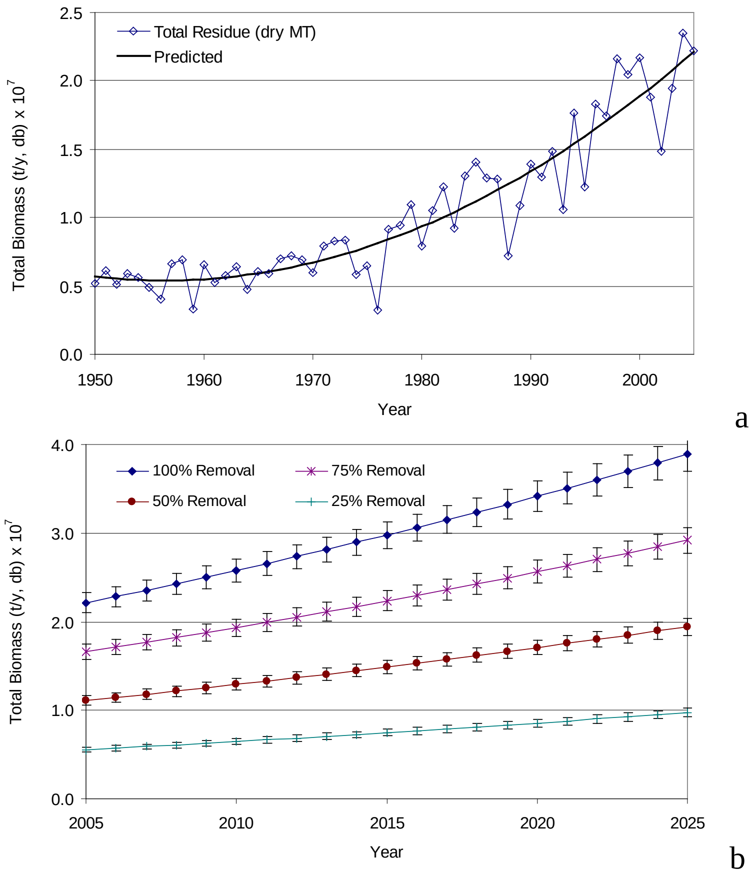

Figure 3. a) Historic estimates of total South Dakota biomass from 1950 to 2005 (db - dry basis); b) predictions of total South Dakota biomass that may be available from 2005 to 2025 (db - dry basis). Error bars represent ± 5% prediction error.

Another question prompted is what crops are grown and the amount of biomass associated with those crops. During the last 15 years South Dakota has seen conversion of much land from small grains to corn and soybeans. Corn and soybean yield trends are much higher because of more work on improving yields for these crops instead of small grains. Two climate changes (to be discussed subsequently) have allowed this to be possible in the state. Continued conversion of more land to different crops may add more potential biomass, if these weather patterns do not change drastically. Furthermore, cropping changes could be put in place depending on soil quality – good soils could be planted to row crops, while marginal soils could be planted to grasses. Or, perhaps cover crops could be used to maintain soil health (Wilhelm, 2008).

5. IMPLICATIONS FOR BIOMASS UTILIZATION

Agricultural producers and various agencies have invested significant resources in minimizing soil loss and improving soil tilth; therefore, biomass utilization needs to be developed with an understanding of the environmental management that may be necessary to create a truly sustainable and renewable energy supply. Wilhelm et al. (2004) described the current literature and understanding of crop and soil productivity from removal of corn residue. Excessive biomass removal of material such as corn stover, can lead to a reduction in soil organic matter and additional soil erosion losses from the excessive removal of crop residue. These two consequences not only have the potential to move excess sediment and nutrients off-site, but will decrease the overall productivity of the soil. Lastly, if additional unit operations that include harvest of biomass increase the number of trips across a field, soil compaction might become a consideration. Wilhelm et al. (2007) and Powlson (2006) have indicated that soil nutrients, quality, and carbon may be even greater concerns than either water or wind erosion. For example, a retention of up to 12.5 Mg/ha of corn stover may be necessary to maintain soil productivity in fields used for corn. Given this, perhaps no residue should be removed at all.

Wilhelm et al. (2004) also suggests that biomass economics need to be derived from the ability or availability of between approximately 20% to 30%. Graham et al. (2007) reports that wholesale conversion to no-till practices would have a substantial impact on increasing the amount collectable stover, but that only 50% of the total would remain collectable. Conservation tillage has resulted in significant environmental gains by maintaining at least 30% of the crop residue on the field. Maintaining 30% residue cover has been expressed as the small grain equivalent of 1,120 kg/ha, and the values in Table 2 below can be used as a basis for estimating the sustainable amount of biomass available. The use of this estimate is for maintaining protection of the field from wind erosion (MWPS, 2000). Estimates show that management (especially tillage) and the ability to collect biomass vary between 20-50% of what is produced.

In addition to erosion losses from stover removal, biomass production has several unanswered environmental questions that will need to be addressed before full-scale implementation. Most important is how will biomass production be implemented and with what types of crops?

Table 2. Estimates for maintaining protection of fields from wind erosion (MWPS, 2000)

Vegetative Cover (1120 kg/ha)	Small Grain Equivalents (kg/ha)
Standing Winter Wheat Stubble (25.4 cm high, in 25.4 cm rows perpendicular to wind)	3920
Flat Winter Wheat Stubble (25.4 cm long, randomly distributed)	1792
Growing Winter Wheat (late fall), flat surface	2240
Flat Corn Stalks	224
Standing Millet Stubble	1904
Standing Grain Sorghum Residue	1456
Flat Sorghum Stalks	392
Standing Alfalfa Residue, stalks only	3248
Dry Bean and Soybean (random flat residue)	672
Standing Cotton Stubble (34.3 cm high, 76.2 cm rows perpendicular to wind)	588
Standing Sunflower Residue (43.2 cm high, 76.2 cm rows perpendicular to wind)	252
Properly Grazed Western Wheatgrass, 10.2 cm High	5376

How many nutrients are removed from the field? Are there ways to add back nutrients and organic matter through manure application? Answering these questions will further show the need for field scale modeling to assess conservation impacts coupled with watershed modeling to understand the larger implications to water quality. The success of these modeling efforts will also hinge on our ability to collect baseline data.

Another aspect of the increase in biomass production has been two current trends. Precipitation during this period has increased over the state, improving the potential yield. Temperatures during this time have not increased overall during the main part of the growing season (Lobell and Asner, 2003). This combination has provided improved growing season conditions throughout much of the period. Water is typically the limiting factor in crop production in South Dakota. Main dips in yields per acre in Figures (1-2) were due to drought years (2002, 1988, 1976, and others).

The next step to this type of analysis would be to examine not just the overall quantities of biomass that will be available over the next several years in the state, but also to refine the analysis to examine biomass availability on a county-by-county basis.

Biomass availability is a very geographic-dependent quantity, and will vary throughout the state. As a step toward that direction, we have examined, at the county level, the production of wheat, soybeans, corn, and sunflowers during both 1990 and 2005. Agricultural production in South Dakota has been very dynamic over the years, and definite changes are evident.

Wheat production in South Dakota has fluctuated greatly over the years, as has the yield produced (Figure 1a). On a regional level, the areas that were planted to wheat (Figures 4a-4b) have shifted over the years. Compared to 1990, the counties along the border regions of the state

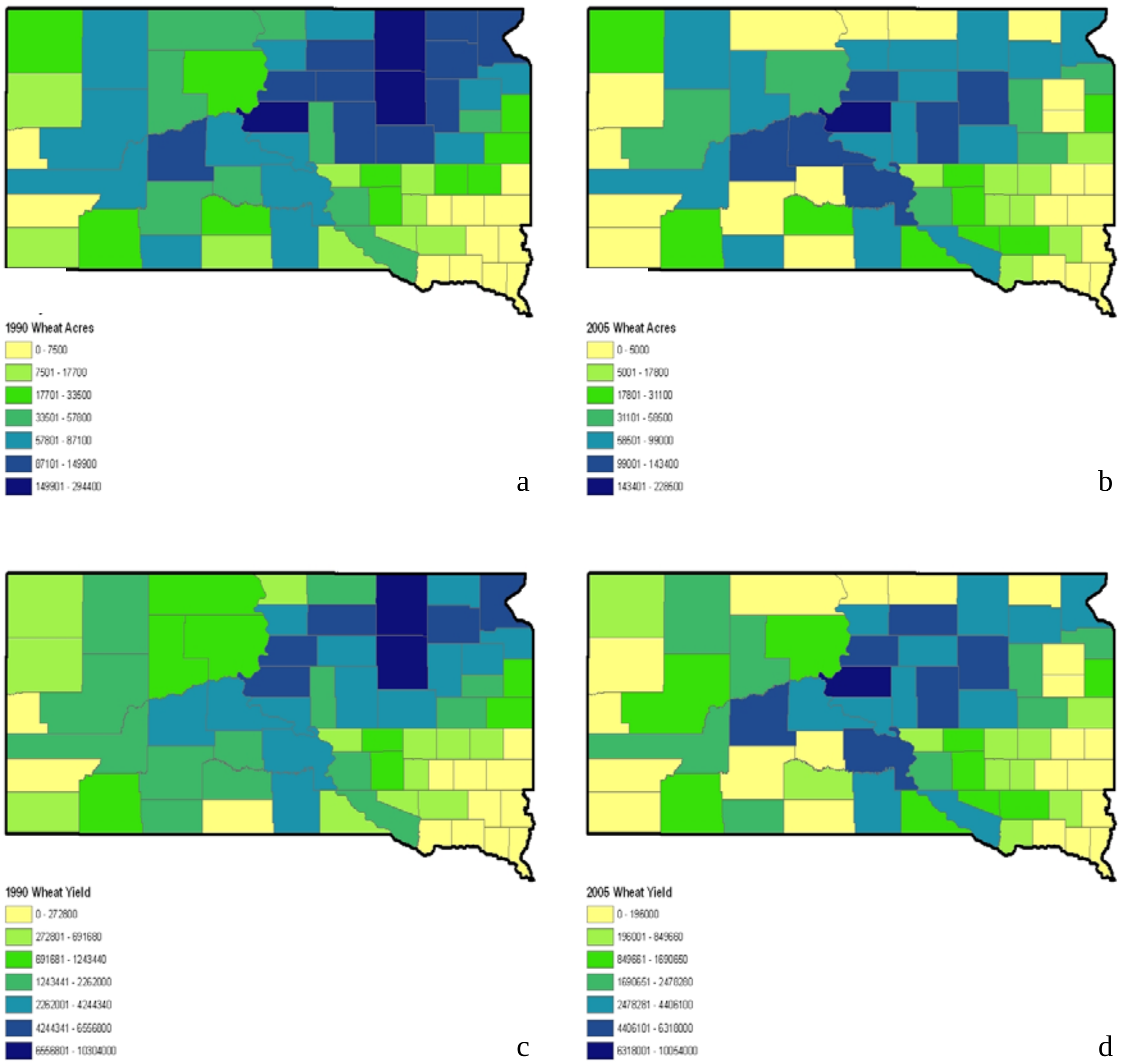

Figure 4. South Dakota wheat acreage a) in 1990 (acres) and b) in 2005 (acres); South Dakota wheat production c) in 1990 (bu) and d) in 2005 (bu).

have shifted away from wheat to other crops. Wheat yield for the counties where the wheat is grown have remained fairly stable (Figures 4c-4d). Soybeans, on the other hand, have shown a rapid growth over the years (Figure 1b). In 1990, most of the soybeans were grown in the eastern ¼ of the state (Figure 5a). In 2005, on the other hand, soybeans were grown on the eastern ½ of the state; in fact, soybean production has shifted all the way to the Missouri River (Figure 5b). Added to this, the yields have also increased in tandem (Figures 5c-5d).

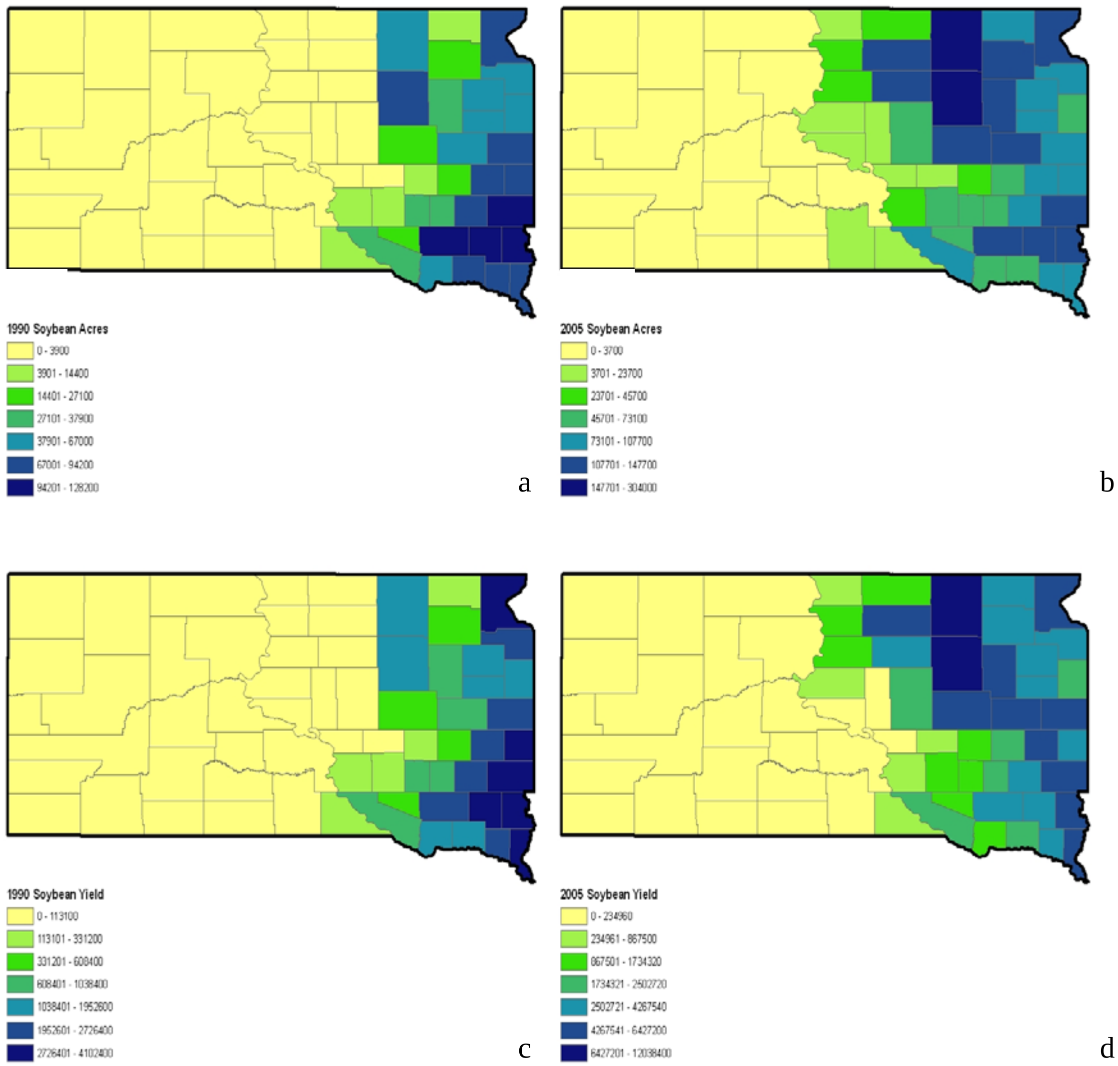

Figure 5. South Dakota soybean acreage a) in 1990 (acres) and b) in 2005 (acres); South Dakota soybean production c) in 1990 (bu) and d) in 2005 (bu).

Corn production has been increasing over the last few decades as well, but more sporadically than soybean production (Figures 1c-1d). Most of the corn production in South Dakota has historically been east of the Missouri River (Figures 6a-6b). Although areas planted to corn have been steadily increasing, the yield produced has experienced a tremendous growth (Figures 6c-6d).

County-level trends across the state have varied among the three major crops over the period 1970-2005. Linear trends for each county have been determined for the last 35 years of crop data (Todey and Shukla, 2005). County level yield trend slopes for corn and soybean (Figures 7a-7b)

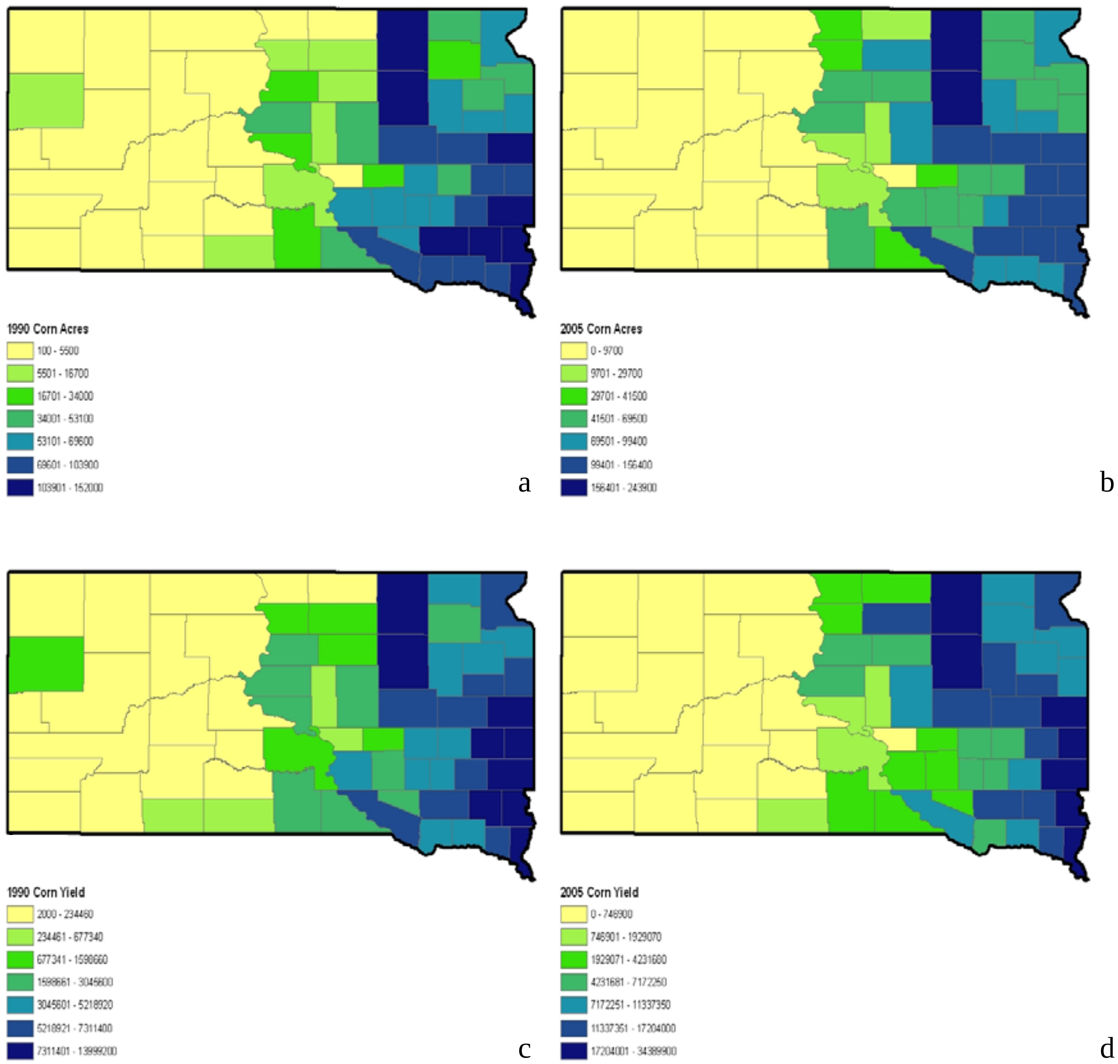

Figure 6. South Dakota corn acreage a) in 1990 (acres) and b) in 2005 (acres); South Dakota corn production c) in 1990 (bu) and d) in 2005 (bu).

have been among the largest in the country during this time. These trends seem related to the conversion from small grains to corn soybean as well as to improved climate conditions for such crops in South Dakota in the last 15 years. But these growth areas are still confined mainly to the eastern part of the state. Wheat trends are generally increasing, but at a rate between the two major crops at around a 0.07 t/ha/y (1 bu/acre/yr) (Figure 7c), whereas corn yield trends reach over 0.20 t/ha/y (3 bu/acre/yr) in some counties in the state. Wheat is spread across more areas of the state. It is this difference in yield trend that can also affect the biomass estimates in the future.

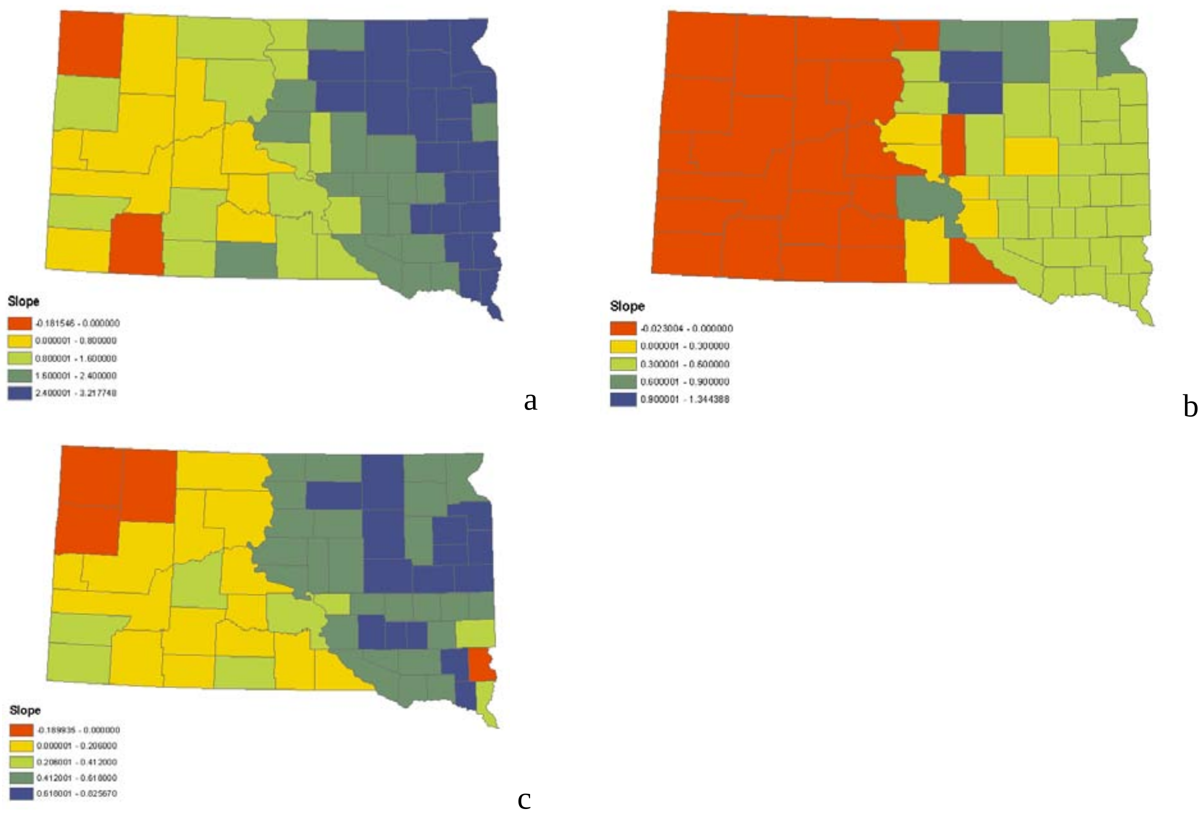

Figure 7. Slope of linear yield trend (on a per county basis) in South Dakota using 1970-2005 data for a) corn, b) soybean, and c) wheat.

Why have these changes occurred? Agricultural production in South Dakota has been evolving due to a number of reasons, including advances in technologies, production practices and cropping strategies, improved genetics and hybrids, climate changes, as well as emerging diseases and pests. Ultimately, the potential for returns on investment has driven many management decisions by agricultural producers. And, when the potential to utilize biomass becomes an industrial reality, then dramatic shifts to cropping patterns may rapidly occur. Hopefully they will be accomplished sustainable. This, however, raises the question: what is sustainable? Yield has increased, but so has the use of fertilizers and energy inputs. Can we sustain this indefinitely, especially if soil resources are degraded or the climate changes over time?

6. CONCLUSIONS

Wholesale conversion to biomass as a resource base for fuel ethanol and other biobased products has significant potential, but as this technology comes to fruition, it is vital to consider the long-term sustainability of the source of the biomass: our natural resources. Prior to this work, however, biomass estimates have been made at various scales, mostly on a national level. Coupled with the development of advancing technologies and increased efficiencies, various biomass crops have the potential to lead to future expansion in the ethanol industry and to the development of a complimentary biomass-based ethanol production industry. The objective of this paper was to examine the potential biomass production in South Dakota through 2025, as a case study, and to consider biomass removal to maximize crop production and minimize environmental implications. This research has provided a tailored state-wide analysis for South Dakota, and provides useful estimates and considerations for both grain producers and the ethanol industry. This information should be useful as the biomass conversion into ethanol becomes commercially viable and deployed. As the need for this information increases, it will be necessary to narrow the scale of this analysis to a county-by-county basis, or even at a finer scale, such as a soil type/soil productivity (i.e., field) scale. Of course, as biomass-based biofuels and biomaterials industries expand, this type of analysis will need to be conducted for each geographic area of interest (i.e., in vicinities near the processing plants). The biomass which is available will be largely dependent upon the geography and climate. But, if these types of industries responsibly examine biomass availability, then environmental and economic sustainability should be able to proceed cooperatively, not competitively.

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