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Conversion of Non-tilled Lands for Biofuel Production: Determination of Grasses and Estimation of Biomass Using Geo and Chemical Techniques

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Abstract

Biomass to fuel is quickly gaining popularity due to its carbon neutral status and the cost volatility of the traditional fossil fuel resources. Sulfur and nitrogen emissions from biomass fuels are greatly reduced compared to fossil fuels. Biomass feedstock's, such as switch grasses, require minimal fertilizers, labor, and land management. Typically, switch grasses may be harvested twice a year and need to be re-planted every ten years. Five areas of the University of Central Missouri (UCM) campus were investigated for potential biomass production. The acreages were found using geographic information system (GIS) analysis and the "improved" areas were eliminated from the total available acreage. The potential energy that UCM could produce and the cost savings realized from farm gate prices were estimated. From the calculations, UCM could potentially produce ~35 million total kWh per year from the combined biomass produced at UCM which more than enough to power UCM while sequestering more than 1,000 tons of carbon per year. The actual energy balance may be significantly lower and depends on local circumstances including transportation, land management, and energy plant efficiency. The initial study showed that soil for switch grass planting was rich in macronutrients and micronutrients.

Keywords: alternative fuel, biomass, land, nutrients, switch grass

1. Background

Biofuels are becoming one of the most important areas of research globally (Bhattarai et al., 2011). As an alternative to fossils fuels, biofuels are more environmentally friendly and are made using biomass. Biofuels are renewable energy source, unlike today's fossil fuels. The use of biofuels has several environmentally friendly advantages that include very low sulfur content, carbon neutrality of biomass production (Antal, 1978) and low aromatic and polyaromatic hydrocarbon emissions. Biomass can be used as fuel directly or it can be converted to biodiesel or gas.

Amongst transportation biofuels, bioethanol and biodiesel are the most feasible at the present time. The advantage of bioethanol and biodiesel is that they can be mixed with conventional petrol and diesel respectively (Enguidanos et al., 2002). The strong point in both bioethanol and biodiesel is that at low concentrations no engine modifications are necessary at this time. Bioethanol is obtained by fermentation of sugar-bearing and starch crops such as sugar beet, wheat, maize, potato, and etc (Enguidanos et al., 2002).

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Biodiesel is produced from vegetable oil, obtained by oil extractions from oilseed crops, such as sunflower and rapeseed, mixed with a small amount of methanol (Enguidanos et al., 2002; Bondioli, Ravasio, Zaccheria, 2006; Spirkin, Lykov, Bel'dii, 2001). The major problem with the production of bioethanol and biodiesel is the strong competition with other prime applications of agricultural land. Right now, these lands are being used for food and feed, which would be given up. Also the lands would battle cultivation specifics of biofuel crops including long crop rotation periods (Kavalov, 2004). Reallocating fertile crop lands from food production to energy production is highly controversial and not sustainable. Switch grass (Panicum virgatum), an endogenous prairie grass in eastern North America, is a promising herbaceous lignocellulosic energy crop. Therefore, switch grass has been the subject of increasing research to increase biomass and decrease recalcitrance of biomass to sugar conversion (Shen et al, 2012; Xie et al., 2014). There are millions of acres of semi managed lands available that would not affect food production in any way. This nearly untapped resource of untilled lands typically lie along roadsides, airports, state parks, railways and other set aside (unused or non producing) areas. The main purpose of this study is to map all the non-tilled lands available on the University of Central Missouri (UCM) campus and to predict the total potential biomass production of these areas. These lands could be utilized to produce biomass that can be converted into useable energy forms such as biodiesel, biomass pellets, and syngas. The other goal of this study was to analyze soil on the Mitchell farm for macronutrients and micronutrients, such as potassium, nitrogen, phosphorus, calcium, and zinc. This farm is being used to establish initial switch grass plots and use them for chemical and calorimetrical analysis.

1. Methods

1.1. Estimation of non-tilled land

This research was carried out on the University of Central Missouri campus located in Warrensburg, Missouri, west central Missouri. UCM has a great deal of land that is currently being cut and other acreage that could be converted to higher yielding crops such as switch grasses. Five areas of the UCM campus were studied: UCM proper (58 acres plus 35.7 acres for the south athletic fields), Pertle Springs (489.7 acres), Sky Haven Airport (748.4 acres), Mitchell Farm (122.7 acres), and Prussing Farm (90.5 acres). The acreages used in this initial study were found using a GIS analysis and areas that were not useable were eliminated (Figure 1). The total area of grass on UCM's campus was calculated using the programs software ESRI® ArcMap™ 9.2.

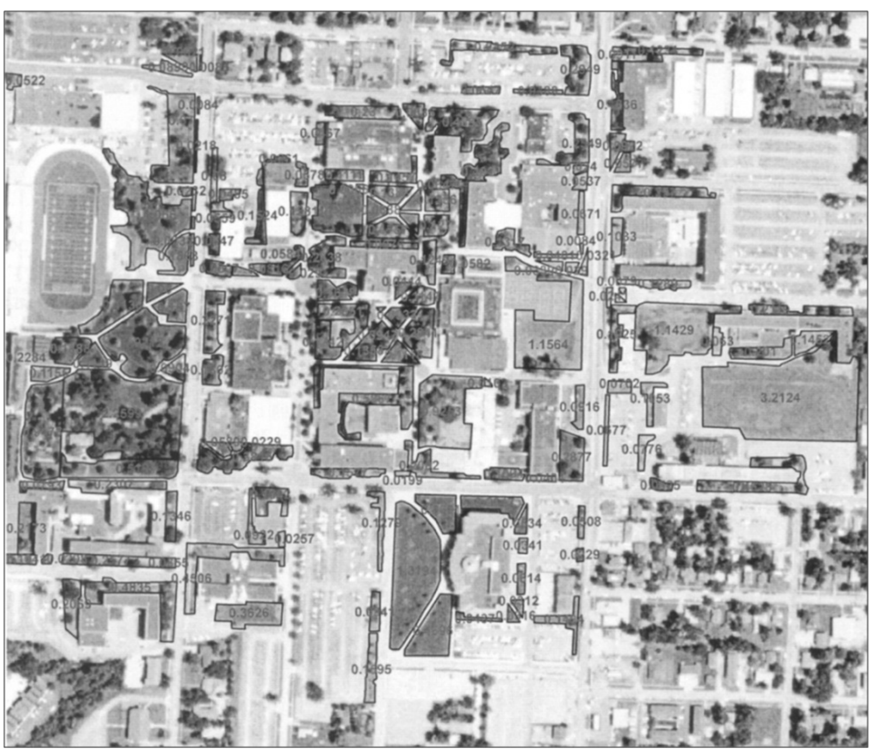

Figure 1: GIS analysis of UCM campus.

1.2. Chemical Analysis of Soil

1.2.1. Digestion

Mehlich 3 extract ant stock solution was prepared by dissolving ammonium fluoride in reagent water and adding EDTA to this mixture. Mehlich 3 extract ant was prepared by dissolving ammonium nitrate in reagent water and adding Mehlich 3 extract ant stock solution, concentrated acetic acid, 10% v/v nitric acid to this mixture. This extract ant was prepared biweekly.

Soil nutrients were extracted using 30 mL of Mehlich 3 extracting agent and then was shaken for five minutes and filtered (Sparks, 1996). To analyze for nitrogen content, the soil was first digested in the Kjeldahl flask where nitrogen was decomposed utilizing sulfuric acid resulting in ammonium sulfate solution using a 6030000 Labconco Micro Digestor.

1.2.2. Instrumentation

To analyze for phosphorus, the samples were analyzed using a manual colorimetric method. Solution B was mixed with sample and let stand for 10 minutes for color development and then measured at an absorbance of 845 nm on a Varian Cary 300 Bio UV-visible spectrophotometer (Mills, Jones, 1996).

To analyze for nitrogen, the digested samples were distilled at a rate of 5 mL/minute. The sample and two rinses of the Kjeldahl flask were loaded into the reaction chamber. A 20 mL of a boric acid receiving solution was placed on the receiving shelf of the Labconco 6500000 RapidStill I distillation unit. Then 20 mL of a 10M sodium hydroxide solution was added to the reaction chamber and the sample was distilled for three minutes and the distillate was captured in the receiving solution. The receiving solution was then titrated with a 0.005M sulfuric acid for quantitation (Benton, 1991).

The samples for potassium analysis were analyzed using Varian 240 atomic emission spectrometer.

The samples for calcium and zinc analysis were analyzed by using Varian 240 atomic absorption spectrometer.

2. Results and Discussion

2.1. Fescue

UCM proper, south athletic fields and Pertle Springs (583.4 acres) are predominantly fescues, although there may be some small patches of Bluegrass or Zoysia. The different grass types would not affect the calculation significantly. The fescue collected from the grounds at UCM produces 16.3 Btu/g or 1.6×10^7 Btu/ton (Beach, 2008). Approximately 2.5 tons/acre of fescue grass may be collected annually in the Midwest region. According to Perrin et al. (2008) production of fescue grass to biomass would cost approximately \$70/ton, however, there would be a large reduction of these costs because the fescue grasses on the UCM campus and Pertle Springs are already managed for aesthetic purposes. The cost per ton is expected to be lower for a warmer climate such Missouri than in Perrin's study (2008) of the northern plains marginal areas. This would result in an estimated total 2.4×10^{10} Btu or 6.9×10^6 kWh from the Fescue grass currently grown at UCM.

2.2. Switch grass

The airport and farms could potentially provide 962 acres of switch grass. On a local switch grass test-plant (Mitchell farm), it was determined that the biomass yielded 16.5 Btu/g or 1.7×10^7 Btu/ton (Beach, 2008). Previous research has shown that the biomass would yield 6-10 ton/acre (Schmer et al., 2008). Although, this is a fairly high yielding switch grass, it is reasonable for the favorable Missouri growing conditions. Based on a rather conservative 6 tons/acre biomass yield, 9.5×10^{10} Btu or 2.8×10^7 kWh from the switch grass feed stocks is expected (8)

Because there is no free energy, the production costs, which include management, harvesting, feedstock storage and preparation, and transportation to the processing plant if applicable, must be fully accounted for within any biomass study. Production of the biomass varies greatly from \$30-\$70 per ton (e.g. \$70/ton in Nebraska and the Dakotas (Perrin et al., 2008), \$30/ton in the corn-belt region (Morrow, Griffin, and Scott, 2007), \$55/ton in southern Iowa (Duffy and Virginia, 2002)).

Since UCM is in the corn-belt region, the $30/ton cost of production should apply. Taking into account the production costs, the cost for producing energy from switch grass is estimated to be $0.0062/kWh, while the cost for producing energy from Fescue grass is estimated to be $0.015/kWh. There is an additional cost for efficiency of the burner, the plant, and the labor required to generate and transmit the electricity (Curtis, 2004). UCM currently receives energy from Kansas City Power and Light (KCP&L) at a rate of $0.0828/kWh in winter and $0.0994/kWh in summer at a total cost of $1,446,796 annually. Using an average cost of $0.090/kWh, UCM receives approximately 16 million kWh annually from KCP&L.

The calculations show that UCM could potentially produce ~35 million total kWh per year from the combined biomass produced at UCM, which is more than enough to power UCM. This is more than twice the estimated energy used by UCM annually at a cost of less than 20% of what UCM currently pays for energy. The typical household in the U.S. uses about 900 kWh per month (U.S. EIA, 2015). Therefore the excess 19 million kWh produced could power more than 1,750 US households annually.

It is a long term goal to provide a plan to transform UCM to an energy independent and carbon neutral university. This may include technical assistance in land management, energy plant design or consulting on sustainable initiatives.

Table 1: Calculated Energy Potential of UCM Campus.

	Fescue	Switchgrass
Approximate Production Costs	$70/ton	$30/ton
Annual Harvest Per Acre	2.5 tons/acre	6 tons/acre
Energy Potential	1.6×10^7 Btu/ton	1.7×10^7 Btu/ton
Current Acreage Available	583 acres	962 acres
Projected Energy Production of UCM Campus	6.9×10^6 kWh	2.8×10^7 kWh

2.3. Carbon Sequestration

Based on different literature sources, soil carbon may be sequestrated at a rate of 1.0 to 1.7 tons of carbon per acre per year for switch grass (Owens and Doolittle, 2007; Ney and Schnoor, 2002) Therefore, UCM should expect 961.6 to 1634.7 tons of carbon to be sequestered per year for the 961.6 acres of switch grass. This is sequestered through root and debris matting and eventually leached, oxidized and incorporated into compounds such as calcium carbonate, $CaCO_3$. Due to the low land management energy expenditures, the carbon in the switch grass itself will be ostensibly carbon neutral.

In order to help pay the costs of the energy infrastructure to actually supply the energy to the campus, the UCM could begin growing and harvesting the switch grass and fescue feedstock. Initially this feedstock could be sold via farm gate prices to companies that produce pellets. According to the literature (Marrow, Griffin, Scott, 2007), it would be possible to sell the feedstock for ~$40/dry in the corn-belt region and therefore make a profit of approximately $58,000 or $72,000 for both switch grass and fescue. Implementing the plan by steps would allow for little start up costs and time to collect data on actual harvest yields for the university so that infrastructure can be better planned. Although, the profits will be modest from the selling of the feedstock by the university, it will significantly move the university forward in becoming a completely carbon neutral campus from the carbon sequestration gains by harvesting the biomass.

2.4. Nutrient Analysis

The initial study of soil has shown that it is rich in macronutrients – potassium, phosphorus and nitrogen and calcium. The results showed that nitrogen concentrations ranged from 980-2500 mg/kg of soil, potassium concentrations ranged from 100-235 mg/kg of soil, phosphorus concentrations ranged from 80-180 mg/kg of soil, calcium concentrations ranged from 2000-3400 mg/kg of soil. The optimum concentrations for nitrogen in soil are 30+ mg/kg, for phosphorus, it is 50+ mg/kg, and for potassium, it is 100+ mg/kg (Espinoza, Slaton, and Mozzafari, 2015). However, soil was lower on zinc, zinc concentrations ranged from 0.5-3.1 mg/kg of soil, optimum concentrations of zinc are above 8.0 mg/kg. However, switch grass does not require additional zinc for optimal growth. Since switch grass requires minimal fertilizers, the results show that no additional fertilizers are needed to grow switch grass on Mitchell farm as long medium-low soil test P and K values are sustained (Tables 2 & 3).

It is also important to note that if the biomass is not harvested until the plant has gone completely dormant (late November or later in the fall or winter), many of the nutrients within the plant will have been remobilized and transported to the roots for overwintering. It is recommended that stands of switch grass grown as a biomass/bioenergy crop should receive 50 - 75 lbs of nitrogen (N) per acre each year, applied within two weeks of spring green-up (The University of Georgia College of Agricultural and Environmental Sciences, 2011)).

Table 2: Experimental and Literature Values for Macronutrients - Potassium, Phosphorus and Nitrogen Content in Soil.

Soil Test Level	Mehlich - 3 Nutrient Concentrations					
	K (lit)	K (exp)	P (lit)	P (exp)	N (lit)	N(exp)
---------------------------------mg/kg---------------------------------------						
Low	0-60		0-25		0-15	
Medium	60-100		25-50		15-30	
High	100+	100-325	50+	80-180	30+	980-2500

Table 3: Experimental and Literature Values for Micronutrients – Calcium and Zinc Content in Soil.

Soil Test Level	Mehlich - 3 Nutrient Concentrations			
	Ca (lit)	Ca (exp)	Zn (lit)	Zn (exp)
---------------------------------mg/kg---------------------------------------				
Low	≤ 400		1.6-3.0	0.5-3.1
Medium			3.1-8.0	
High		2000-3400	8.0+	

3. Conclusion

Our results have determined potential biomass (switch grass) production from non-tilled lands such as athletic fields, airports and two farms at University of Central Missouri. In addition, chemical analysis was performed on the surrounding soil (Mitchell farm – test plots of switch grass) to determine overall quality of the soil. The results showed that soil was rich in macronutrients and micronutrients, which are so significant for the growth of the plants. We believe that in the future the production of significant amounts of alternative fuel will replace the need for fossil fuels and mark a significant reduction in green house gas emissions. Our long term plan is to produce mixed alternative fuels such as biodiesel, biomass pellets, and syn gas from the pellets.

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