Spatial Analysis of Biomass Supply: Economic and Environmental Impacts

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Introduction

Cellulosic bioenergy feedstock production analyses often include simple breakeven comparisons of production alternatives versus current cropping practices, ignoring effects of spatial and temporal production variability and transportation costs. While this approach provides a rough estimate of potential biomass feedstock costs, it can lead to erroneous conclusions about the production practices that are likely to occur. This is particularly important when evaluating potential environmental impacts of bioenergy feedstock production, since these impacts are closely tied to production practices. As biomass price increases, producers will have a profit incentive to increase biomass harvest. For crop residues this may mean harvesting residues more frequently within a crop rotation, or, if prices become high enough, lead to shifts in rotation to increase biomass production. Inclusion of transportation costs can mean that fields with identical productivity may result in different profit maximizing practices given the same plant-gate biomass price due to differences in transportation costs. Differences in productivity can also lead to differences in profit maximizing practices for a given biomass price. As a result, there could be substantial spatial variability in biomass production practices among producers within a region. The objective of this analysis was to evaluate potential biofeedstock supply, production practices, and environmental impacts for a bioenergy plant in West Central Minnesota.

Methods

Bioenergy feedstock supply was estimated for a bioenergy plant located at the University of Minnesota, Morris (UMM). For this analysis, potential biomass supplies from crop residues only were evaluated. Three crop rotation were included: continuous corn (CC), corn-soybean (C-SB), corn-spring wheat-soybean (C-SW-SB). Four residue harvest scenarios were evaluated: no residue harvest (none), corn stover harvest (stover), wheat straw harvest (straw), and both corn stover and wheat straw harvest (stover and staw). Enterprise budgets were constructed, using 2009 prices, based on field research conducted at the Swan Lake Research Farm near Morris, MN. The EPIC model was used to simulate crop yields and environmental impacts for each of 186 SSURGO soil map units within Stevens and Pope Counties. EPIC was calibrated using field research yields. Crop fields were delineated using the 2007 cropland data layer (NASS). Road network base maps were obtained from MN Department of Transportation. Transportation costs were calculated using in-field and on-road unit cost estimates with ArcGIS Cost Path Analysis on a 56 meter grid. Net returns were calculated for each field using 20-year average EPIC simulation results and transportation costs aggregated to the field level for $1 Mg^{-1} plant-gate biomass price increments ranging from $45-$70 Mg^{-1}.

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Biomass Price $54 Mg^{-1}

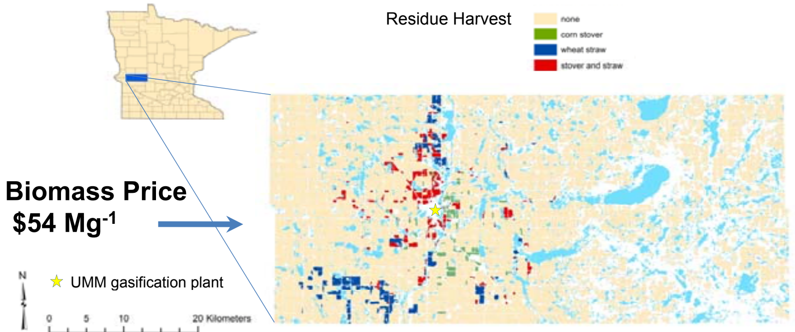

Figure 1a. Location of profit maximizing residue harvest practices for a plant-gate biomass price of $54 Mg^{-1}.

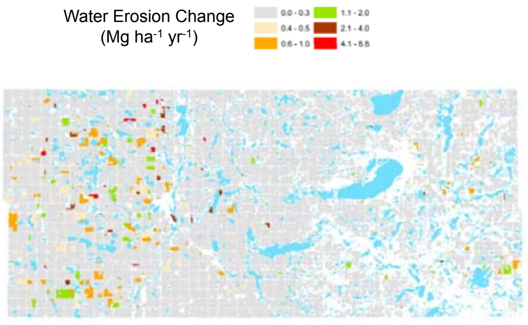

Figure 2a. Water erosion impacts of profit maximizing residue harvest practices for a plant-gate biomass price of $54 Mg^{-1}.

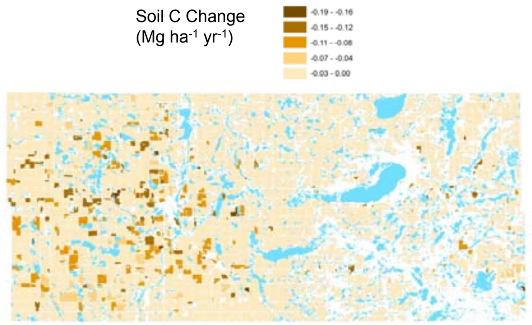

Figure 3a. Soil organic carbon impacts of profit maximizing residue harvest practices for a plant-gate biomass price of $54 Mg^{-1}.

Biomass Price $56 Mg^{-1}

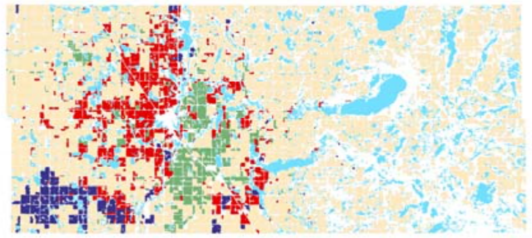

Figure 1b. Location of profit maximizing residue harvest practices for a plant-gate biomass price of $56 Mg^{-1}.

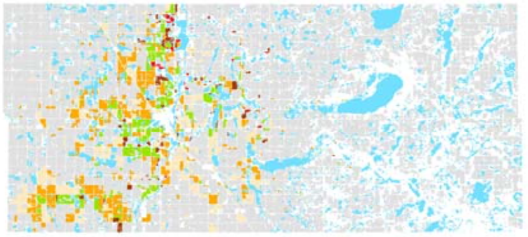

Figure 2b. Water erosion impacts of profit maximizing residue harvest practices for a plant-gate biomass price of $56 Mg^{-1}.

Figure 3b. Soil organic carbon impacts of profit maximizing residue harvest practices for a plant-gate biomass price of $56 Mg^{-1}.

Biomass Price $58 Mg^{-1}

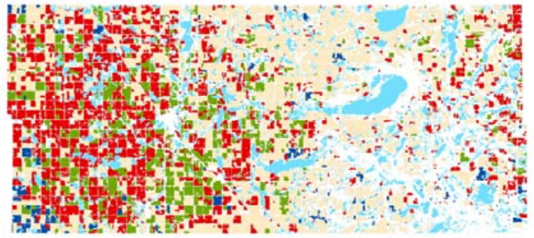

Figure 1c. Location of profit maximizing residue harvest practices for a plant-gate biomass price of $58 Mg^{-1}.

Figure 2c. Water erosion impacts of profit maximizing residue harvest practices for a plant-gate biomass price of $58 Mg^{-1}.

Figure 3c. Soil organic carbon impacts of profit maximizing residue harvest practices for a plant-gate biomass price of $58 Mg^{-1}.

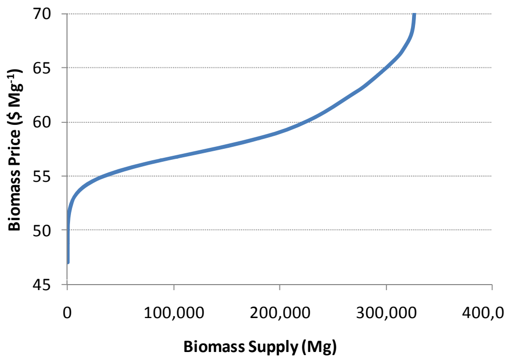

Figure 4. Estimated biomass supply for Pope and Stevens county delivered to the UMM gasification plant.

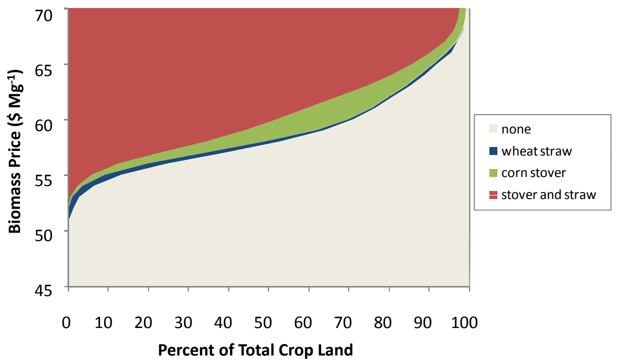

Figure 5. Profit maximizing biomass harvest practices as related to plant-gate biomass price.

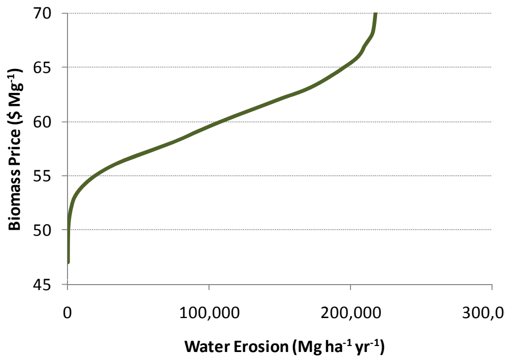

Figure 6. Cumulative water erosion impacts (change from baseline) for profit maximizing biomass harvest as a function of plant-gate biomass price.

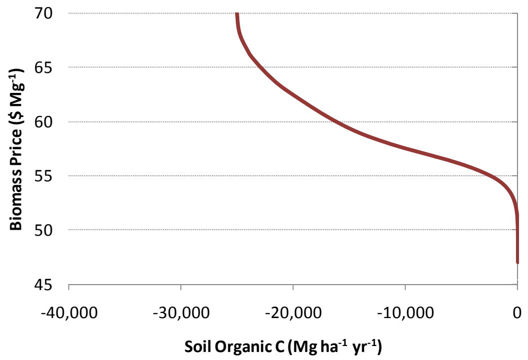

Figure 7. Cumulative soil organic C impacts (change from baseline) for profit maximizing biomass harvest as a function of plant-gate biomass price.

Results

- Profit maximizing residue harvest practices varied spatially as influenced by both soil productivity and transportation costs (Figures 1a,1b, 1c).
  - Fields where wheat straw harvest, or both corn stover and wheat straw harvest was optimal were generally in a C-SW-SB rotation in the baseline, while fields where corn stover harvest was optimal were generally in a C-SB rotation. Some rotation shifts occured at higher biomass prices.
  - Baseline rotation differences reflected differences in soil productivity.
  - Increasing biomass price increased both harvested area and harvest intensity.
- Differences in optimum harvest practices and soil erodibility resulted in differing impacts on soil erosion levels (Figures 2a, 2b, 2c).
  - Higher soil erosion levels occurred on fields where both stover and straw harvest were optimal.
  - Greater incentives for higher harvest rates occurred where transportation costs were low. Since a local highway parallels the river that flows near Morris this could lead to higher erosion rates near the river (Figure 2b).
  - Increasing biomass price increased both area eroding, and erosion intensity.
- Differences in optimum harvest practices and initial soil organic C content resulted in differing impacts on soil organic C (Figures 3a, 3b, 3c).
  - Higher soil organic C losses occurred on fields where both stover and straw harvest were optimal.
- Estimated biomass supply for UMM plant-gate prices ranging from $45-70 Mg^{-1} are shown in Figure 4. At a price of $56 Mg^{-1}, an annual average of 69,000 Mg of biomass could be profitably produced. However, this would result in an additional 33,000 Mg of soil erosion and a loss of 4,900 Mg of soil organic C if offsetting conservation practices were not implemented.

Conclusion

In evaluating biofeedstock supplies it is important to include spatial characteristics, transportation costs and variations in soil productivity, to understand potential effects of bioenergy production on management practices and the environment. Inclusion of spatial information allows for the identification of a range of practices likely to be adopted, and, important for determining environmental impacts, the locations of these practices. Although this analysis only evaluated use of annual crop residues, this effect could be particularly important in evaluating perennial biofuel crops such as switchgrass. Just as spatial variation in productivity can lead to variation in optimum production practices, it is anticipated that temporal variablity could have similar impacts. This is a planned area for future analysis. The analytical approach used in this example can be used to evaluate potential biomass supplies and environmental impacts for other cellulosic bioenergy facilities.