COMMENTARY

Appropriate “marginal” farmlands for second-generation biofuel crops in North Carolina

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Abstract
Current research on bioenergy crops shows that perennial grasses can yield substantial amounts of dry biomass with relatively low inputs of water and fertilizer. In order to minimize competition with food production, it has been suggested that bioenergy crops could be directed to land areas less suitable for commodity crops, commonly referred to as “marginal” lands. These are land units with inherent limitations to vegetative growth and production, which may be due to several factors (soil physical and chemical properties, climatic conditions, etc.). However the term “marginal” is an adjective with imprecise meaning, and objective criteria for determining “marginal” lands for siting bioenergy crops are necessary. Here we propose that such criteria may be based on soil survey classifications and realistic yield estimates, and we show an example of its use to justify site selection for bioenergy crops in different regions of North Carolina.

1 INTRODUCTION

Doubling the productivity of existing agricultural farmlands for food, feed, fiber, and energy while maintaining earth’s natural resources was defined as the “grand challenge” of the 21st century by the American Society of Agronomy (ASA, 2010). Renewable energy sources represent a partial solution to this problem as they reduce dependence on finite fossil fuel reserves and have the potential to reduce carbon emissions. Globally, bioenergy crops include timber and oilseed trees, perennial grasses, sugar crops, root and tuber crops, and annual grains and oilseeds. These can be further classified as first- or second-generation bioenergy crops. First-generation bioenergy crops are converted into ethanol by fermentation of sugars and starches, which are typically derived from crops such as corn (Zea mays L.), sugarcane (Saccharum spp.), and wheat (Triticum aestivum L.), whereas second-generation bioenergy crops include those that consist primarily of cellulosic biomass from herbaceous grasses as well as woody perennials such as poplar (Populus spp.) and willow (Salix spp.) (Solomon et al., 2007; Ho et al., 2014).

In the United States, established commodity crops such as corn and soybean [Glycine max (L.) Merr.] are being converted to biofuel sources, but at present there are concerns about the environmental and socioeconomic consequences of such conversions. One of the key environmental issues related to the expansion of bioenergy crops is the possibility of displacing existing agricultural fields to areas that historically have not been used for food production, including forests, grasslands, wetlands, and peatlands (Ale et al., 2019). This process, known as indirect land-use change (Scarlat & Dallemand, 2019), could undermine the potential carbon sequestration benefits of bioenergy crops (Fritsche et al., 2010). Therefore, initiatives promoting bioenergy crops should strongly consider land availability and capability for cultivation and potential disruptions to food and feed production.
In North Carolina, a state in the mid-Atlantic, southeastern United States, research and development of second-generation bioenergy crops have focused on the use of perennial grasses that could be produced as a source of fermentable sugars for ethanol or other biobased chemicals. Perennial grasses such as giant miscanthus (Miscanthus x giganteus) and switchgrass (Panicum virgatum L.) have been studied in the North Carolina mountains (Palmer et al., 2014), Piedmont (Wang et al., 2017a), and Coastal Plain (Wang et al., 2017b). Results from these studies show that perennial grasses can reach high dry matter yields in these environments. We initiated new studies to evaluate the potential of miscanthus on “marginal” farmlands in different regions in North Carolina. We targeted areas with characteristics that are less suitable for commodity crop production where competition with food crops can be minimized. Because the term “marginal” is an adjective with imprecise meaning, objective criteria for determining “marginal” lands for siting bioenergy crop are needed. Here we outline the rationale we used for selecting sites less suitable for food and feed commodity crops that can be used for the production of bioenergy crops.

2 SITE SELECTION APPROACH FOR BIOENERGY CROPS IN NORTH CAROLINA

Site selection targeted locations representative of the three major physiographic regions of North Carolina—Coastal Plain, Piedmont, and Mountain regions—which encompass different cropping environments and collectively represent common agricultural production areas in the mid-Atlantic and southeastern United States (Figure 1). The criteria used for site selection were based on soil characteristics and realistic yield expectations for commodity crops such as corn and soybean. Soil factors included characteristics such as slope, susceptibility to erosion, nutrient leaching, flooding, or drought. Information about soils was obtained from USDA-NRCS soil survey classifications (https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm). Soil survey classifications also provided information on farmland designation (i.e., prime or statewide importance) and land capability class. Realistic yield estimates were obtained from the North Carolina Nutrient Management database, which is maintained by the North Carolina Interagency Nutrient Management Committee (NCINMC, 2014). For each physiographical region, we analyzed three soil map units on collaborating field sites (North Carolina Agricultural Research Service and North Carolina Department of Agriculture research stations) with contrasting potential for commodity crop production (Table 1). The land units we selected for our analysis are located in close proximity of each other such that drastically different meteorological conditions are not expected to be found between them.

At the Coastal Plain location, the Noboco loamy fine sand (fine-loamy, siliceous, subactive, thermic Oxyaquic Paleudults) with 2–6% slopes is less suitable to commodity crop production than the Goldsboro loamy sand
TABLE 1 Characterization of contrasting potential sites for bioenergy crops in three different physiographic regions in North Carolina. Data obtained from USDA-NRCS Web Soil Survey and realistic yield expectations for North Carolina soils.

| Soil map unit (slope) | Farmland designation | Land capability class | Limitation | Drainage class | Available water in profile cm | Bermudagrass ton ha⁻¹ | Corn | Soybean | Tobacco |
|-----------------------|----------------------|-----------------------|------------|---------------|-----------------------------|------------------------|------|---------|---------|
| **Coastal Plain (Duplin County)** | | | | | | | |
| Noboco loamy fine sand† (2–6%) | Prime | 2e | Erosion | Well | 18 | 15.8 | 8.5 | 2.9 | 3.6 |
| Goldsboro loamy sand‡ (0–2%) | Prime | 2w | Wetness | Moderately well | 19.8 | 16.1 | 9.8 | 3.0 | 3.8 |
| Lumbee sandy loam§ (0–1%) | Prime if drained | 6w | Wetness, riparian buffer | Poorly | 11.2 | 11.1 | 10.5 | 3.0 | 2.7 |
| **Piedmont (Granville County)** | | | | | | | |
| Helena loamy sand†† (2–6%) | Prime | 2e | Erosion | Moderately well | 19.3 | 8.4 | 7.0 | 2.6 | 2.6 |
| Appling sandy loam‡‡ (2–6%) | Prime | 2e | Erosion | Well | 20.1 | 13.3 | 10.0 | 3.6 | 3.6 |
| Wehadkee§ (0–2%) | Prime if not frequently flooded | 6w | Wetness, riparian buffer | Poorly | 25.1 | na | | |
| **Mountain§ (Henderson County)** | | | | | | | |
| Hayesville loam† (7–15%) | Statewide importance | 3e | Erosion | Well | 25.1 | 11.9 | 6.9 | 2.4 | 2.5 |
| Codorus loam‡ (0–2%) | Prime if drained & flood protected | 4w | Drainage | Somewhat poorly | 18.8 | 9.9 | 11.3 | 4.0 | 2.4 |
| Evard§ (25–45%) | Not prime | 6e | Erosion | Well | 20.8 | 7.9 | 7.1 | 1.8 | 2.0 |

**Note.** Symbols indicate (†) less suitable for commodity crop production, (‡) more suitable for commodity crop production, and (§) undesirable due to severe restrictions and/or riparian buffer habitat.

*Helena sandy loam site in the USDA-NRCS survey and Helena loamy sand in a more detailed soil survey at the location.

*bNo crop yield estimates available due to severe site restrictions.

*Hay and tobacco production systems differ in the mountain region.

(fine-loamy, siliceous, subactive, thermic Aquic Paleudults) with 0–2% slopes due to its greater erosion susceptibility and lower realistic yield estimates for Bermudagrass [**Cynodon dactylon** (L.) Pers.], corn, soybean, and tobacco (**Nicotiana tabacum** L.). The Lumbee sandy loam (fine-loamy over sandy or sandy-skeletal, siliceous, subactive, thermic Typic Endoaquults) with 0–1% slope is an example of a soil with severe limitations for agricultural use because of poor drainage and also because it provides ecosystem service benefits as a riparian buffer. For the Piedmont region, the Helena loamy sand (fine, mixed, semiactive, thermic Aquic Hapludults) is less suitable for commodity crop production than the Appling sandy loam (fine, kaolinitic, mesic Typic Kanhapludults) with 7–15% slopes is less suitable to commodity crop production than the Codorus loam (fine-loamy, mixed, active, mesic Fluvaquentic Dysdrupts) with 0–2% slopes because of its slope, greater susceptibility to erosion, and lower realistic yield estimates for corn and soybean. The Evard soil (fine-loamy, parasquie, mesic Typic Hapludults) with 25–45% slope has severe limitations since it is extremely steep for agricultural activities and susceptible to erosion. Considering that erosion is a limitation common to all sites, it is expected that the introduction of a perennial grass such as miscanthus to the locations that are...
less suitable for commodity crops, but not severely limited, should have a positive impact since, once established, miscanthus provides ground cover during a large fraction of the year and a layer of residue covering the soil is built up from previous harvest operations. Reports in the literature indicate that perennial bioenergy crops were found to improve soil structure (e.g., aggregate stability, bulk density, macroporosity) through carbon sequestration and soil stabilization (Rachman et al., 2004; Blanco-Canqui, 2010; Ho et al., 2014; Tiemann and Grandy, 2015; Das et al., 2016; Lai et al., 2018). These studies suggest that bioenergy crops may help reduce soil erosion as well as improve water infiltration. In the North Carolina Piedmont, Wang et al. (2017a) showed that perennial bioenergy crops had no detrimental effects on soil physical properties after 3 yr of establishment.

3 | DISCUSSION

According to the data in Table 1, apart from the Evard soil at the Mountain region, all sites were classified as either prime farmland, prime if drained and flood protected, or farmland of statewide importance. Although these classifications may rank these sites as valuable farmland, there are clearly recognizable differences in the inherent limitations among them. Therefore, farmland sites for bioenergy crops require specification of objective criteria to justify utilization of a subset of the arable lands that have some, but not severe productivity limitations, in order to minimize the negative impacts of indirect land-use changes.

Our site selection approach suggests that rational and defensible criteria can be obtained from independently developed and published sources such as soil surveys and crop productivity ratings. The land capability classes described in soil surveys provide objective indicators of the type and relative degree of limitations for productive agricultural land management. The crop productivity ratings given in state nutrient management planning guidelines provide relative indicators of crop productivity associated with different soil map units. Both of these information sources should reflect local expertise in assessing site suitability and potential.

It is important to recognize that land with severe limitations for conversion to productive agricultural lands might also be described as marginal lands. Nevertheless, these would be most appropriately left undisturbed for wildlife habitat, to prevent erosion or flood damage, or to serve other valuable ecosystem functions such as riparian buffers. Even though perennial bioenergy grasses will result in complete ground cover, there is still a need for mechanized operations such as vegetation clearing before planting, management practices during crop establishment, and annual harvesting. According to Fargione et al. (2008), biofuel-induced vegetation clearing can cause a “biofuel carbon debt,” where the CO₂ emissions from the converted land can exceed the CO₂ sequestration potential of the bioenergy crops by a factor of 17 to 420. If not performed properly, mechanized field operations can cause soil compaction, which negatively affects soil properties (e.g., increased soil bulk density and decreased macroporosity) as well as other physical, chemical, and biological processes in the soil (Batey, 2009). Soil compaction is associated with reduced permeability to water and air, which in turn may result in increased surface runoff, erosion, flooding, and reduced groundwater recharge (Douglas et al., 1998; Mooney and Nipattasuk, 2003; Hamza and Anderson, 2005; Schack-Kirchner et al., 2007). Such activities may result in greater degradation of these land units with more severe management limitations associated with poor drainage and riparian buffers, which should also be considered when selecting sites for second-generation bioenergy crops.

4 | CONCLUSION

Objective and defensible criteria will be needed to justify site selection for second-generation bioenergy crops that satisfy the likely sustainability assumptions inherit in carbon credit marketing decisions. Our study presents use of specific guidelines likely to be available for many agricultural regions that can distinguish between the most productive agricultural lands that should be dedicated to commodity crops, appropriate marginal lands to support bioenergy crops, and sites with severe management limitations that should be preserved for long-term environmental benefit. This approach should be useful to farmers and land managers in making decisions regarding land-use planning and management.

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CONFLICT OF INTEREST
The authors declare no conflict of interest.

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REFERENCES

Ale, S., Femeena, P. V., Mehan, S., & Cibin, R. (2019). Environmental impacts of bioenergy crop production and benefits of multifunctional bioenergy systems. In J. C. M. Pires & A. L. D. C. Gonçalves (Eds.), Bioenergy with carbon capture and storage (pp. 195–217). Academic Press. https://doi.org/10.1016/B978-0-12-816229-3.00010-7

ASA. (2010). Grand challenge. https://www.agronomy.org/files/science-policy/asa-grand-challenge-2010.pdf

Batey, T. (2009). Soil compaction and soil management: A review. Soil Use and Management, 25, 335–345. https://doi.org/10.1111/j.1475-2743.2009.00236.x

Blanco-Canqui, H. (2010). Energy crops and their implications on soil and environment. Agronomy Journal, 102(2), 403–419. https://doi.org/10.2134/agronj2009.0333

Das, A., Lal, R., Somireddy, U., Bonin, C., Verma, S., & Rimal, B. K. (2016). Changes in soil quality and carbon storage under biofuel crops in central Ohio. Soil Research, 54(4), 371–382. https://doi.org/10.1111/srj.12155

Douglas, J. T., Koppi, A. J., & Crawford, C. E. (1998). Structural improvement in a grassland soil after changes to wheel-traffic systems to avoid soil compaction. Soil Use and Management, 14, 14–18. https://doi.org/10.1111/j.1475-2743.1998.tb00604.x

Fargione, J., Hill, J., Tilman, D., Polasky, S., & Hawthorne, P. (2008). Land clearing and the biofuel carbon debt. Science, 319(5867), 1235–1238. https://doi.org/10.1126/science.1152747

Fritsche, U. R., Sims, R. E. H., & Monti, A. (2010). Direct and indirect land-use competition issues for energy crops and their sustainable production: An overview. Biofuels, Bioproducts, & Biorefining, 4, 692–704. https://doi.org/10.1002/bbb.258

Hamza, M. A. & Anderson, W. K. (2005). Soil compaction in cropping systems: A review of the nature, causes, and possible solutions. Soil and Tillage Research, 82, 121–145. https://doi.org/10.1016/j.still.2004.08.009

Ho, D. P., Ngo, H. H., & Guo, W. (2014). A mini review on renewable sources for biofuel. Bioresource Technology, 169, 742–749. https://doi.org/10.1016/j.biortech.2014.07.022

Lai, L., Kumar, S., Osborne, S., & Owens, V. N. (2018). Switchgrass impact on selected soil parameters, including soil organic carbon, within six years of establishment. CATENA, 163, 288–296. https://doi.org/10.1016/j.catena.2017.12.030

Mooney, S. J. & Nippatausk, W. (2003). Quantification of the effects of soil compaction on water flow using dye tracers and image analysis. Soil Use and Management, 19, 356–363. https://doi.org/10.1111/j.1475-2743.2003.tb00326.x

NCINMC. (2014). Realistic yields and nitrogen application factors for North Carolina crops. North Carolina Interagency Nutrient Management Committee. https://realisticyields.ces.ncsu.edu

Palmer, I. E., Gehl, R. J., Ranney, T. G., Touchell, D., & George, N. (2014). Biomass yield, nitrogen response, and nutrient uptake of perennial bioenergy grasses in North Carolina. Biomass Bioenergy, 63, 218–228. https://doi.org/10.1016/j.biombioe.2014.02.016

Rachman, A., Anderson, S. H., Gantzer, C. J., & Alberts, E. E. (2004). Soil hydraulic properties influenced by stiff-stemmed grass hedge systems. Soil Science Society of America Journal, 68(4), 1386–1393. https://doi.org/10.2136/sssaj2004.1386

Scarlat, N. & Dallemand, J. F. (2019). Future role of bioenergy. In C. Lago, N. Caldes, & Y. Lechon (Eds.), The role of bioenergy in the bioeconomy: Resources, technologies, sustainability and policy (pp. 435–547). Academic Press. https://doi.org/10.1016/B978-0-12-813056-8.00010-8

Schack-Kirchner, H., Fenner, P. T., & Hildebrand, E. E. (2007). Different responses in bulk density and saturated conductivity to soil deformation by logging machinery on a Ferralsol under native forest. Soil Use and Management, 23, 286–293. https://doi.org/10.1111/j.1475-2743.2007.00096.x

Solomon, B. D., Barnes, J. R., & Halvorsen, K. E. (2007). Grain and cellulosic ethanol: History, economics, and energy policy. Biomass Bioenergy, 31(6), 416–425. https://doi.org/10.1016/j.biombioe.2007.01.023

Tiemann, L. K., & Grandy, A. S. (2015). Mechanisms of soil carbon accrual and storage in bioenergy cropping systems. GCB Bioenergy, 7(2), 161–174. https://doi.org/10.1111/gcbb.12126

Wang, Z., Heitman, J. L., Smyth, T. J., Crozier, C. R., Franzluebbers, A., Lee, S., & Gehl, R. (2017a). Soil responses to bioenergy crop production in the North Carolina Piedmont. Agronomy Journal, 109(4), 1368–1378. https://doi.org/10.2134/ajr2017.02.0068

Wang, Z., Smyth, T. J., Crozier, C. R., Gehl, R. J., & Heitman, A. J. (2017b). Yield and nutrient removal by bioenergy grasses on swine effluent spray fields in the Coastal Plain Region of North Carolina. BioEnergy Research, 10(4), 979–991. https://doi.org/10.1007/s12155-017-9856-1

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