WHAT DO WE KNOW ABOUT THE IMPACTS OF ENERGY CROPS ON SOIL PROCESSES?

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I WILL DISCUSS:

Impacts of crop residue removal and dedicated energy crops on:

- Soil physical processes and properties.

- Water erosion.

- Wind erosion.

- Soil carbon sequestration.

WHY NOT USE CROP RESIDUES AS BIOFUEL?

http://europeanclimate.org/wp-content/uploads/2014/02/WASTED-final.pdf

Excessive crop residue removal may:

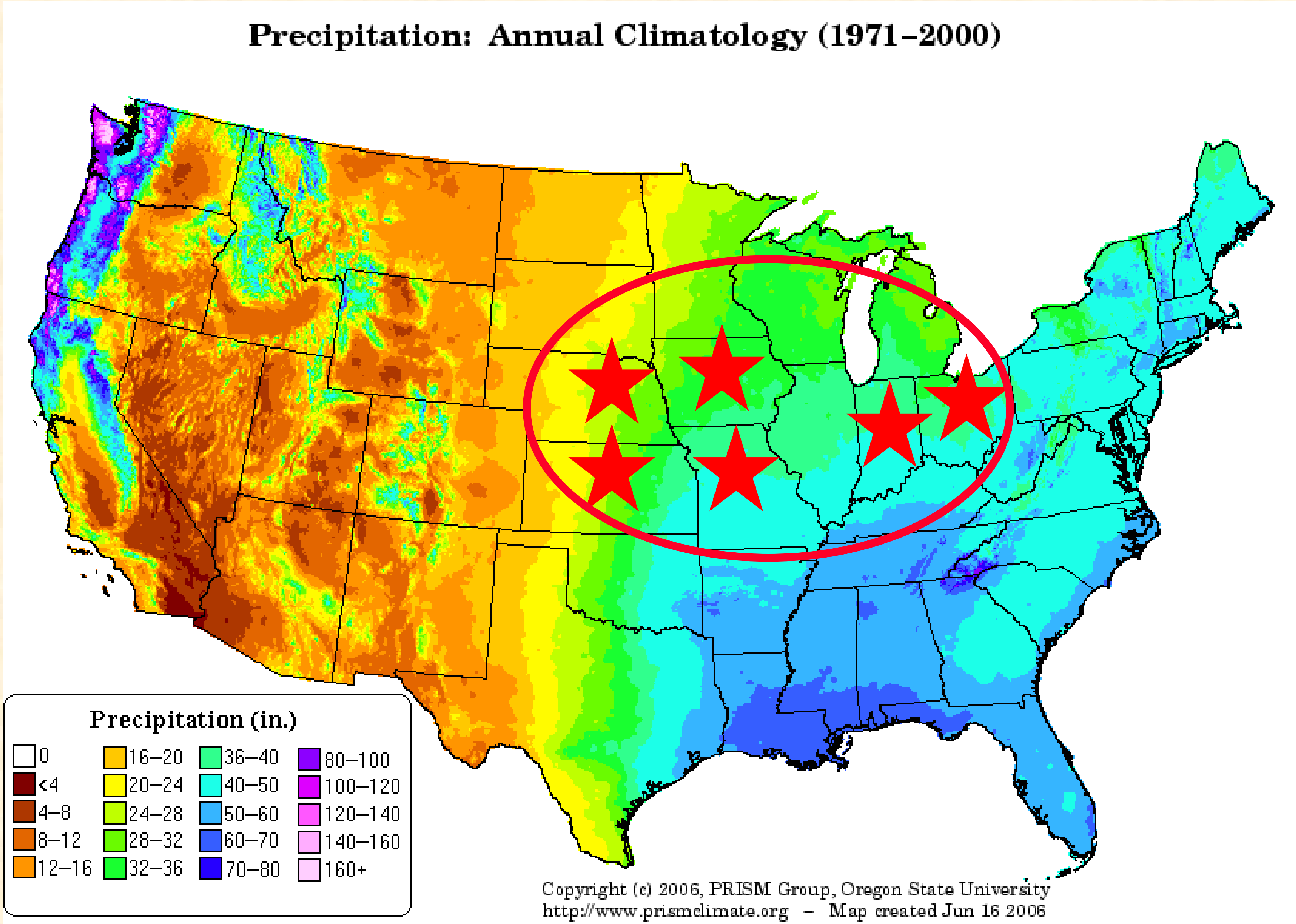
1. Increase water erosion and water pollution
2. Increase wind erosion and air pollution
3. Remove nutrients, increase fertilizer use and increase N_2O emissions
4. Reduce microbial biomass and activity
5. Remove C and reduce soil C storage
6. Reduce water storage

Positive impacts of crop residue removal

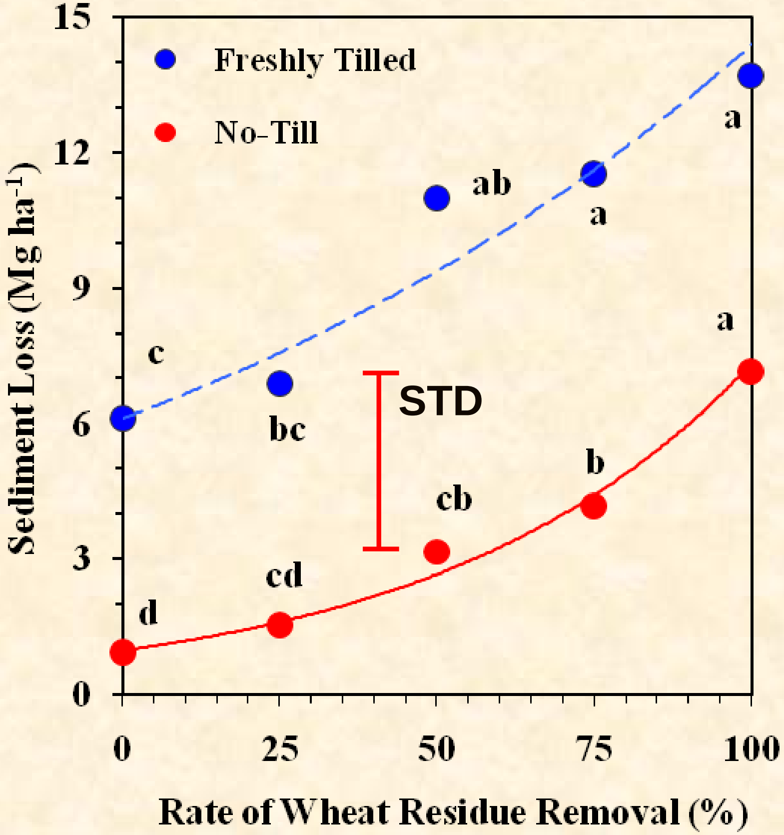
In some soils, crop residue removal may promote soil warming, increase seed germination, and reduce pest infestations.

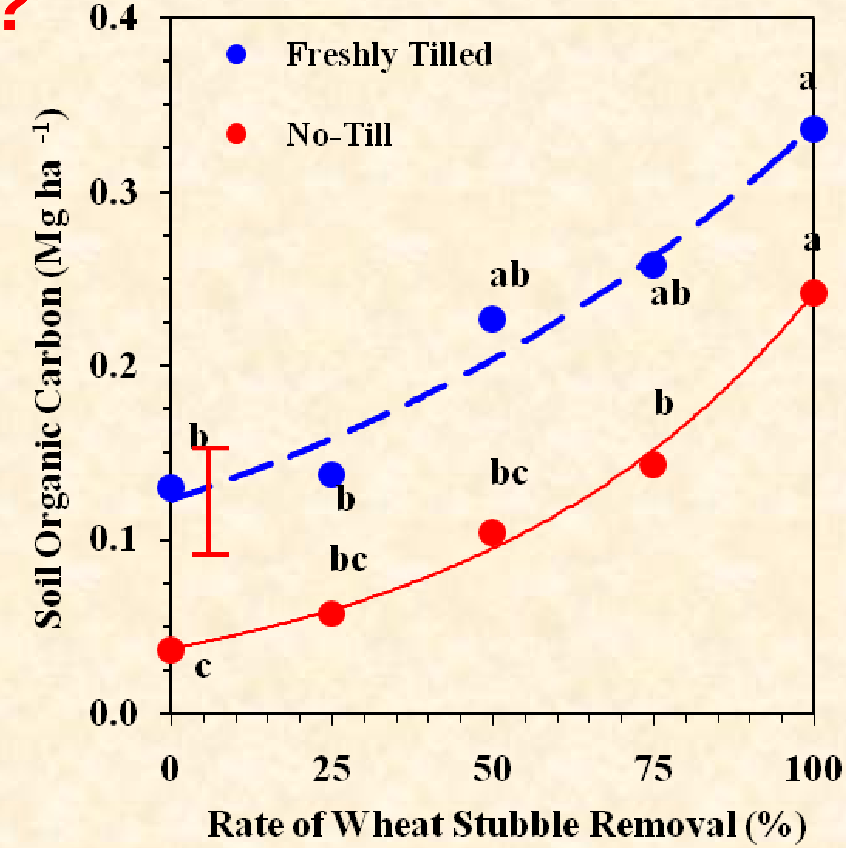
1. Blanco-Canqui, H. and R. Lal. 2009. Crop residue removal effects on soil, productivity and environmental quality. Crit. Rev. Plant Sci. 28:139-163.
2. Blanco-Canqui, H. and R. Lal. 2009. Corn stover removal for expanded uses reduces soil fertility and structural stability. Soil Sci. Soc. Am. J. 73:418-426.

Data from Crop Residue Removal Experiments in the Midwestern States

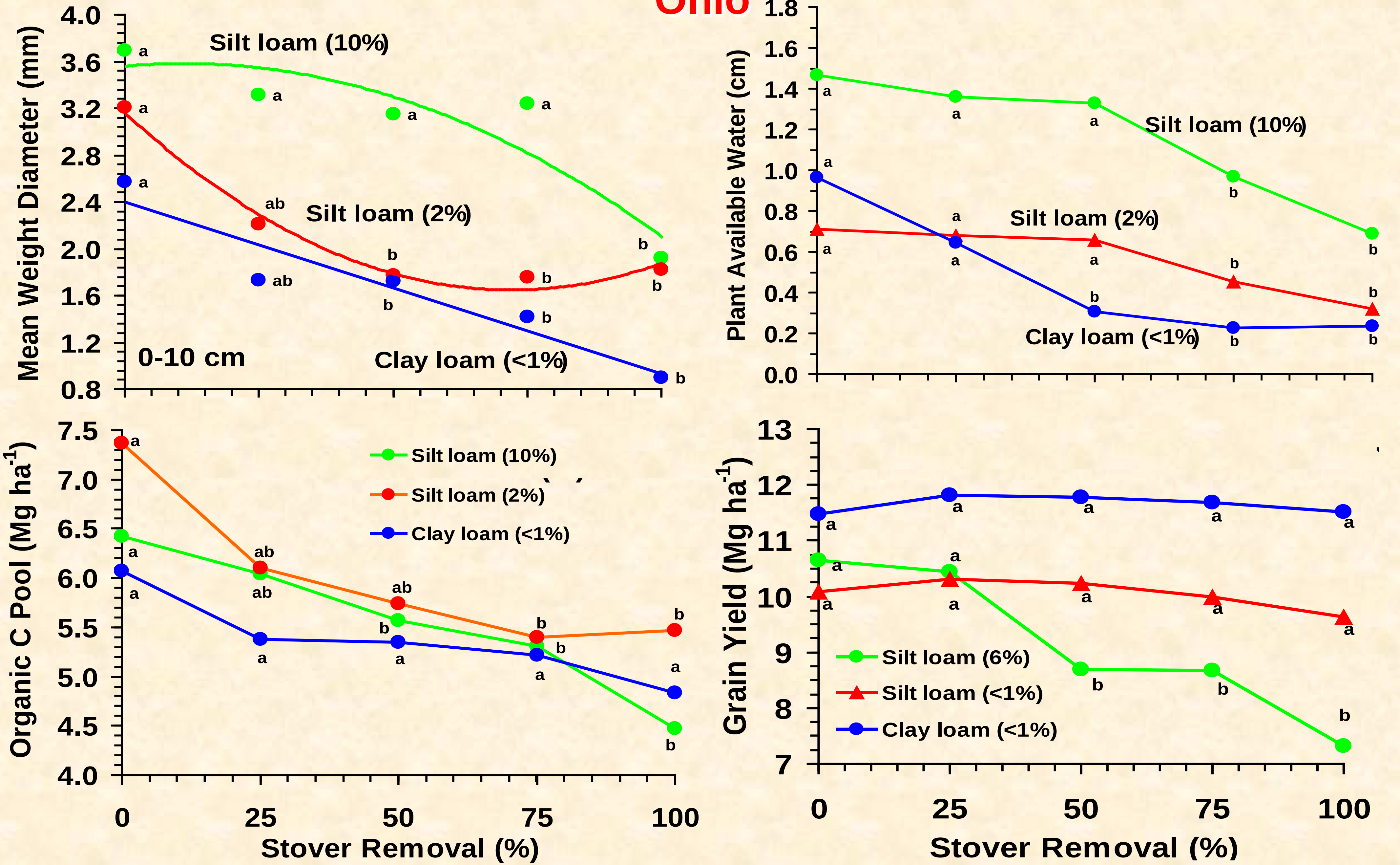


Sediment and Nutrient Loss in Runoff: Risks of Water Pollution?

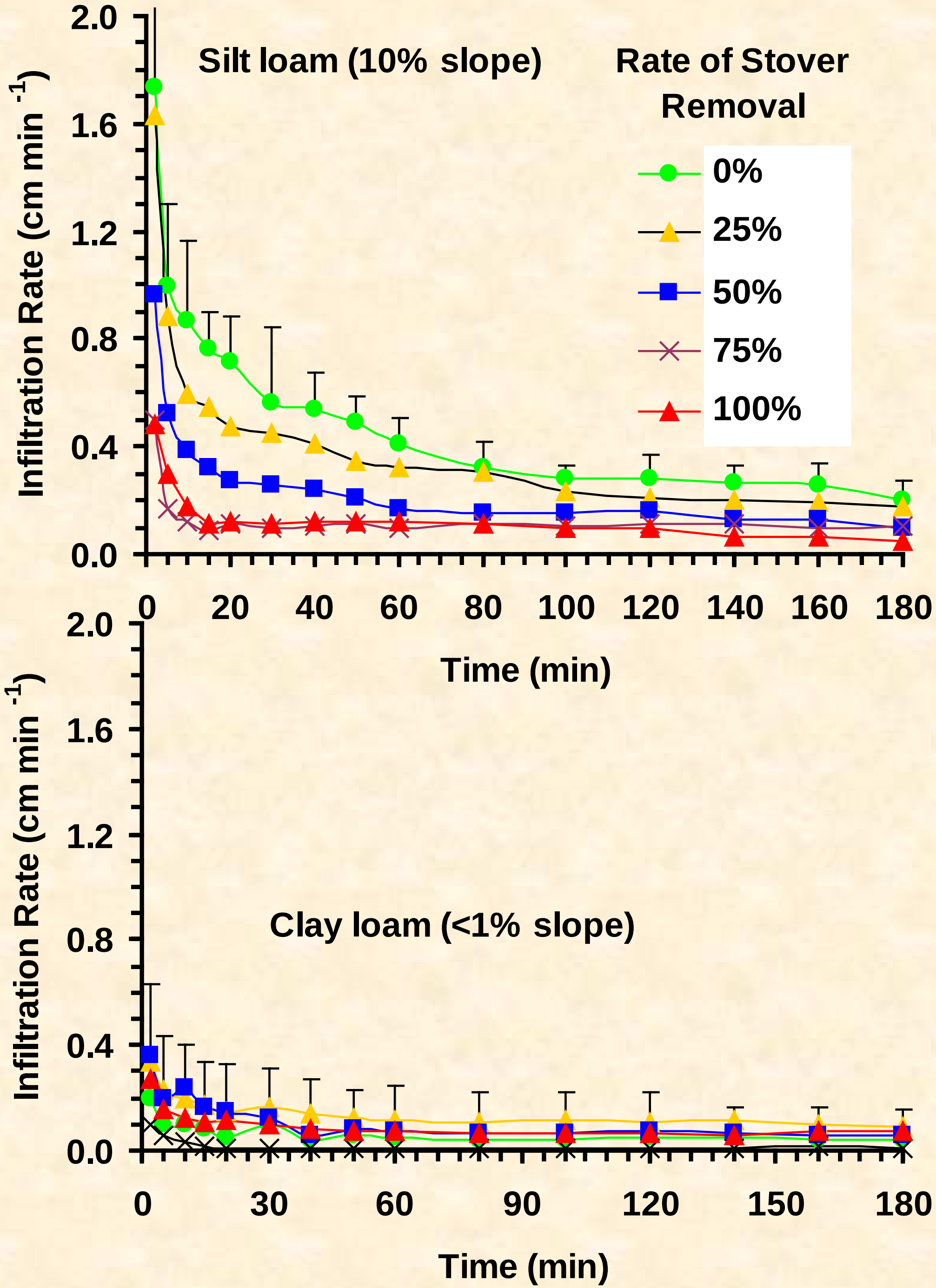




Crop residue removal and soil properties: Data from three soils in Ohio



Water Infiltration and Earthworm Counts



Soil	% Stover removal	Earthworm counts (Soil Volume= 0.027 m³)
Silt loam (10%)	0	160±51
	100	47±36
Clay loam (<1%)	0	40±22
	100	0

LETTERS
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nature climate change

Biofuels from crop residue can reduce soil carbon and increase CO_2 emissions

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Removal of corn residue for biofuels can decrease soil organic carbon (SOC; refs 1,2) and increase CO_2 emissions[3] because residue C in biofuels is oxidized to CO_2 at a faster rate than when added to soil[4,5]. Net CO_2 emissions from residue removal are not adequately characterized in biofuel life cycle assessment (LCA; refs 6–8). Here we used a model to estimate CO_2 emissions from corn residue removal across the US Corn Belt at 580 million geospatial cells. To test the SOC model[9–11], we compared estimated daily CO_2 emissions from corn residue and soil with CO_2 emissions measured using eddy covariance[12–14], with 12% average error over nine years. The model estimated residue removal of 6 Mg per ha^{-1} yr^{-1} over five to ten years could decrease regional net SOC by an average of 0.47–0.66 Mg C ha^{-1} yr^{-1}. These emissions add an average of 50–70 g CO_2 per megajoule of biofuel (range 30–90) and are insensitive to the fraction of residue removed. Unless lost C is replaced[15,16], life cycle emissions will probably exceed the US legislative mandate of 60% reduction in greenhouse gas (GHG) emissions compared with gasoline.

Crop residues are abundant feedstocks that are used for biofuel production globally[17,18]. By 2022, the US Energy Independence and Security Act (EISA) mandates production capacity for cellulosic ethanol and advanced biofuels to be 61 billion litres per year (bly) and 19 bly, respectively[17]. Corn residue is predominantly used in US cellulosic ethanol biorefineries, with a combined capacity of 0.38 bly in 2014 (ref. 19). An additional 0.42 bly of US hydrocarbon biofuels mostly uses wood[19], but could also be derived from crop residue[20]. Absolute changes in soil organic carbon (SOC) from corn residue removal have been estimated in LCA (ref. 6), but few have estimated net changes in SOC and CO_2 emissions compared with no residue removal[20,21,22], as required by consequential LCA (ref. 23).

Recent research suggests soil CO_2 emissions from residue removal could produce life cycle GHG emissions for cellulosic ethanol that exceed the mandated emissions reduction[3]. Incubation experiments with soil and corn residue showed that SOC is oxidized to CO_2 at 0.54–0.80 Mg C ha^{-1} per season when residues are completely removed[4]. Modelled removal of all corn residue in Austria projected an SOC loss of 0.35 Mg C ha^{-1} yr^{-1}, which represents nearly 50% of life cycle GHG emissions from a biorefinery system[24]. Modelled SOC oxidation to CO_2 from removal of sweet sorghum residue showed these emissions could eliminate all GHG emissions benefits of the resulting biofuel compared with gasoline[25]. Similar net losses of C stocks have also been projected for biofuels from forestry in some cases[26].

Changes in SOC occur by two dominant processes: soil erosion by water and wind, and soil respiration where SOC is oxidized to CO_2 (refs 4,5). Soil erosion has significantly depleted SOC across the US Corn Belt, with a recent loss of 1.7 billion tons of soil in the US in 2007 (ref. 27). Crop residue has conventionally been left on the field after harvest to reduce soil erosion and maintain the SOC stocks and soil fertility of the Corn Belt[1]. Although some soil measurements in the Corn Belt have shown that complete residue removal reduces SOC compared with no removal[28,29], other studies found no significant differences[16]. Measuring SOC change accurately is limited owing to the high spatial variability in SOC stocks, the inability to detect a small annual percentage change, short-term studies, and failure to express SOC results in an equivalent mass basis to account for changes in soil bulk density[30,31]. Furthermore, when crop residue is removed, it is essential to determine whether SOC loss is due to erosion or respiration, to accurately estimate the resulting net CO_2 emissions.

Models are necessary to confidently estimate small percentage annual changes in regional SOC stocks due to respiration[10,11], as extensive gas exchange measurements are too costly. Although soil moisture and texture are often used in SOC models[4], a robust model can estimate daily changes in SOC due to oxidation to CO_2 based on initial SOC (C_0), C inputs from agricultural crops (C_i), and average daily temperature (T_a), as shown below[9–11]. The SOC model used here is based on exponential oxidation coefficients for SOC (k_s, S_s) and cereal crop residues (k_r, S_r) from 36 field studies across North America, Europe, Africa and Asia[10] (see Supplementary Table 1 and Methods). An additional term in the equation is added for each year of new C inputs to the soil from residue and roots.

$$C_t = C_0 \cdot e^{-k_s\left(t Q_{10}^{\frac{T_a - T_r}{10}} \cdot t\right)^{1-S_s}} + C_i \cdot e^{-k_r\left(t Q_{10}^{\frac{T_a - T_r}{10}} \cdot t\right)^{1-S_r}}$$

To test the model in the central US, we compared model results with measured CO_2 emissions, residue biomass, and SOC from an irrigated no-till continuous corn field experiment in eastern Nebraska (Mead) from 2001 to 2010 (refs 12–14). The model estimated that 83% of initial residue C input was oxidized during the first three years, which closely agreed with field measurements that found an average of 20% remained[14] (Supplementary Fig. 1) Cellulose, hemicellulose and protein in residue rapidly oxidize, whereas the more recalcitrant lignin fraction (~18% dry matter[4]) undergoes a slower oxidation process and contributes to SOC (ref. 4). The model estimated 80.9% of initial SOC remained after nine years (56.1 of 69.4 Mg C ha^{-1}) in the 0–30 cm depth, and net C from residue (8.53 Mg C ha^{-1}) contributed to the maintenance of a total of 93.2% of the initial SOC stock (Fig. 1). When compared with soil measurements, the model predicted net SOC loss within

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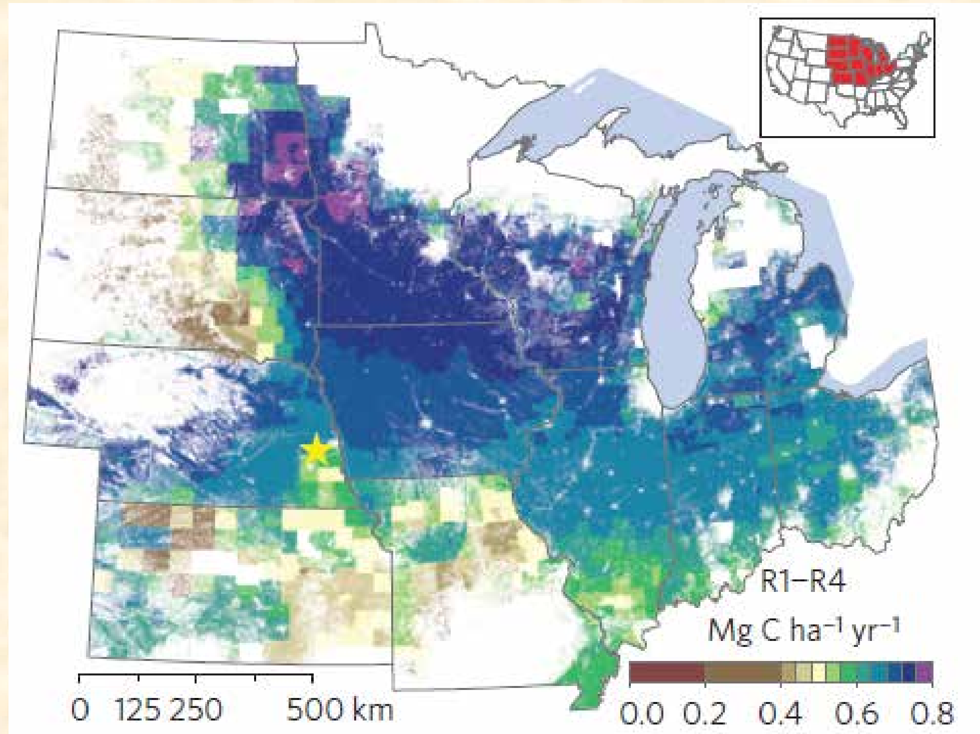

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Crop Residue Removal for Bioenergy Reduces Soil Carbon Pools: How Can We Offset Carbon Losses?

Humberto Blanco-Canqui

Abstract Crop residue removal for bioenergy can deplete soil organic carbon (SOC) pools. Management strategies to counteract the adverse effects of residue removal on SOC pools have not been, however, widely discussed. This paper reviews potential practices that can be used to offset the SOC lost with residue removal. Literature indicates that practices including no-till cover crops, manure and compost application, and return of biofuel co-products increase SOC pools and may thus be used to offset some SOC loss. No-till rotations that include semi-perennial grasses or legumes also offer a promise to promote soil-profile C sequestration and improve soil resilience after residue removal. No-till cover crops can sequester between 0.10 and 1 Mg ha^{-1} per year of SOC relative to no-till without cover crops, depending on cover crop species, soil type, and precipitation input. Animal manure and compost contain about 15 % of C and thus their addition to soil can enhance SOC pools and boost soil biological activity. Similarly, application of biofuel co-products such as biochar, which contain between 45 % and 85 % of C depending on the feedstock source and processing method, can enhance long-term C sequestration. These mitigation strategies may maintain SOC pools under partial residue removal in no-till soils but are unlikely to replace all the SOC lost if residue is removed at excessive rates. More field research and modeling efforts are needed to assess the magnitude at which the different mitigation strategies can overcome SOC loss with crop residue removal.

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Keywords Crop residue removal · Bioenergy · Soil carbon · Cover crops · Biochar · Manure · Compost · No-till rotations · Dedicated energy crops · Switchgrass · Perennial grasses

Introduction

Bioenergy production is expected to increase exponentially in the near future [72]. Potential feedstock sources for bioenergy production include corn (*Zea mays* L.) stover and wheat (*Triticum aestivum* L.) straw [72, 74, 84]. Corn stover is considered the main feedstock for cellulosic ethanol production, but crop residues from small grains can also be used as bioenergy feedstock [84]. In Europe, generation of electricity from wheat straw is expected to rapidly increase [74]. Crop residues will probably be harvested at large scales in the near future as bioenergy industry develops [72].

While production of energy from renewable resources is a plausible initiative, the potential implications of crop residue removal on soil organic carbon (SOC) pools and dynamics deserve attention. Crop residues remaining on agricultural fields are not a waste but provide numerous ecosystem services including SOC sequestration, nutrient cycling, control of water and wind erosion, and crop production. Particularly, crop residues are a direct source of SOC pool. Large-scale removal of crop residues at high rates can deplete SOC pools [9]. The SOC is needed for maintaining or improving soil physical, chemical, and biological properties, reducing soil's susceptibility to erosion, filtering non-point source pollutants in runoff, and sustaining crop production [4].

The impacts of crop residue removal on SOC pools have been reviewed [1, 9, 74, 93], but management strategies that can be used to counteract the SOC lost with residue removal

Strategies to ameliorate possible negative effects of residue removal effects on soil and environment

Figure 1. Cover crop experiment at the former Harvey County Experiment Field in Hesston (*Photo by Dr Mark M. Claassen, K-State Research and Extension*)

Animal manure?

TAKE HOME MESSAGE

- **Studies indicate that residue removal (≥50%) may adversely affect soil properties, particularly in the long-term.**
- **The magnitude of effects are site-specific.**
- **Crop residue removal may not be the best option in the long term.**
- **The threshold levels of removal have to be established before residue removal.**
- **How about alternative cellulosic feedstocks?**

Energy Crops and Their Implications on Soil and Environment

Humberto Blanco-Canqui*

Review & Interpretation

ABSTRACT

Interest in producing cellulosic ethanol from renewable energy sources is growing. Potential energy crops include row crops such as corn (*Zea mays* L.), perennial warm-season grasses (WSGs), and short-rotation woody crops (SRWCs). However, impacts of growing dedicated energy crops as biofuel on soil and environment have not been well documented. This article reviews the (i) impacts of growing WSGs and SRWCs on soil properties, soil organic carbon (SOC) sequestration, and water quality, and (ii) performance of energy crops in marginal lands. Literature shows that excessive (≥50%) crop residue removal adversely impacts soil and environmental quality as well as crop yields. Growing WSGs and SRWCs can be potential alternatives to crop residue removal as biofuel. Warm-season grasses and SRWCs can improve soil properties, reduce soil erosion, and sequester SOC. Crop residue removal reduces SOC concentration by 1 to 3 Mg ha^{-1} yr^{-1} in the top 10 cm, whereas growing WSGs and SRWCs increase SOC concentration while providing biofuel feedstocks. The WSGs can store SOC between 0 and 3 Mg C ha^{-1} yr^{-1} in the top 5 cm of soil, while the SRWCs can store between 0 and 1.6 Mg ha^{-1} yr^{-1} of SOC in the top 100 cm. The WSGs and SRWCs have more beneficial effects on soil and environment when grown in marginal lands than when grown in croplands or natural forests. Indeed, they can grow in nutrient-depleted, compacted, poorly drained, acid, and eroded soils. Development of sustainable systems of WSGs and SRWCs in marginal lands is a high priority.

PRODUCING ETHANOL from lignocellulosic feedstocks is gaining an unprecedented interest to meet the 30 × 30 goal (30% replacement of fossil fuels by biofuel by the year 2030; USDOE, 2007a). Potential lignocellulosic energy crops include row crops such as corn, WSGs such as switchgrass (*Panicum virgatum* L.), and SRWCs such as poplar (*Populus* spp.) and willow (*Salix* spp.). Mixed native prairie grasses (Jefferson et al., 2004; Tilman et al., 2006) and cool-season grasses such as reed canarygrass (*Phalaris arundinacea* L.; Wrobel et al., 2009) are also being considered as potential energy crops. At present, crop residues, mainly corn stover, are considered as the prime lignocellulosic feedstock for producing ethanol. The goal of energy industries is to use crop residues as cellulosic ethanol feedstocks in the short term while other biomass sources from dedicated energy crops are being developed in the long term (Pacala and Socolow, 2004; Ragauskas et al., 2006; USDOE, 2007b; Abengoa Bioenergy, 2007).

Crop residues will soon be harvested as lignocellulosic feedstocks for the production of ethanol because technologies for the conversion of cellulose into liquid fuels are well advanced and cellulosic ethanol plants are being constructed. Indeed, production of ethanol from lignocellulosic feedstock materials, known as second generation of biofuels, is expected to grow rapidly as the production of ethanol from grain may raise food prices. A number of ethanol plants are being constructed across the United States (USDOE, 2007b). One of the first cellulosic ethanol plants in the United States will be sited in southwestern Kansas and launch its operations in 2011. This plant will process large quantities of biomass, mainly corn stover, into ethanol (Abengoa Bioenergy, 2007).

While production of biofuel from renewable energy sources is a valuable inititiative, the potential negative and positive impacts of removing crop residues and growing dedicated energy crops on soil and environmental quality must be, however, comprehensively assessed. Most of the current research on energy crops is focused on (i) developing technologies for conversion of cellulosic feedstocks into ethanol, and (ii) increasing production of biomass. As a result, impacts of energy crops such as growing herbaceous and woody plants on soil and environmental quality have not been widely documented. Little comparative analysis exists between crop residue removal and growing energy crops in regards to their differential effects on soil and water conservation, SOC dynamics, soil erosion, and other soil and environmental factors.

Therefore, the specific objectives of this article are to review the (i) potential impacts of growing WSGs and SRWCs on soil properties, SOC sequestration, sediment and nutrient loss in runoff, and wind erosion, and (ii) performance of growing energy crops in marginal lands. This paper presents a state-of-the-knowledge compendium of the available published information on the implications of growing energy crops on soil and

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Abbreviations: ψ, water potential; CRP, Conservation Reserve Program; EPIC, Erosion-Productivity Impact Calculator; GHG, greenhouse gas; NPS, nonpoint source; NT, no-till; RUSLE, Revised Universal Soil Loss Equation; SRWCs, short-rotation woody crops; SOC, soil organic carbon; SWAT, Soil and Water Assessment Tool; WSGs, perennial warm-season grasses.

BIOFUELS NEED TO BE DONE RIGHT

Need to develop biofuels from systems that:

- **Reduce net emissions of GHG.**
- **Maintain or increase soil C pools.**
- **Reduce soil erosion**
- **Do not compete with food crops**
- **Improve wildlife habitat and diversity.**

Potential Alternatives

1. Growing energy crops (i.e., perennial grasses) in marginal lands?.
2. Warm season grasses and short-rotation woody crops may have beneficial effects on soil and environment.
3. Some perennial grasses can grow in nutrient-depleted, compacted, poorly drained, and acid, soils.

Blanco-Canqui. H. 2010. Energy crops and their implications on soil and environment. Agronomy Journal. 102:403-419.

Soil Carbon Accumulation under Switchgrass Barriers

Humberto Blanco-Canqui,* John E. Gilley, Dean E. Eisenhauer, Paul J. Jasa, and Alan Boldt

ABSTRACT

The benefits of grass barriers or hedges for reducing offsite transport of non-point-source water pollutants from croplands are well recognized, but their ancillary benefits on soil properties have received less attention. We studied the 15-yr cumulative effects of narrow and perennial switchgrass (*Panicum virgatum* L.) barriers on soil organic C (SOC), total N, particulate organic matter (POM), and associated soil structural properties as compared with the cropped area on an Aksarben silty clay loam (fine, smectitic, mesic Typic Argiudoll) with 5.4% slope in eastern Nebraska. Five switchgrass barriers were established in 1998 at ~38-m intervals parallel to the crop rows in a field under a conventional tillage and no-till grain sorghum [*Sorghum bicolor* (L.) Moench]–soybean [*Glycine max* (L.) Merr.]–corn (*Zea mays* L.) rotation. Compared with the cropped area, switchgrass barriers accumulated about 0.85 Mg ha^{-1} yr^{-1} of SOC and 80 kg ha^{-1} yr^{-1} of total soil N at the 0 to 15 cm soil depth. Switchgrass barriers also increased coarse POM by 60%. Mean weight diameter of water-stable aggregates increased by 70% at 0 to 15 cm and by 40% at 15 to 60 cm, indicating that switchgrass barriers improved soil aggregation at deeper depths. Large (4.75–8 mm) macroaggregates under switchgrass barriers contained 30% more SOC than those under the cropped area. Switchgrass-induced changes in SOC concentration were positively associated with aggregate stability ($r = 0.89^{***}$) and porosity ($r = 0.47^{*}$). Overall, switchgrass barriers integrated with intensively managed agroecosystems can increase the SOC pool and improve soil structural properties.

Grass barriers, also called grass hedges, are narrow (<1.5 m) and permanent strips of dense, tall, and stiff-stemmed perennial grasses established on the contour within croplands to control soil erosion (Kemper et al., 1992; NRCS, 2003). Grass barriers differ from other grass strips (e.g., vegetative filter strips, riparian buffers) because they are established within croplands at short intervals (<20 m) in parallel rows and are commonly planted to native perennial warm grass species such as switchgrass. Unlike vegetative filter strips, which are relatively wide strips (5–15 m) normally planted to short-growing and cool-season grasses at the bottom perimeter of croplands, switchgrass barriers are integrated along the slope profile with crops in parallel rows.

The benefits of switchgrass barriers for reducing water erosion are well documented (Kemper et al., 1992; Gilley et al., 2000, 2011; Blanco-Canqui et al., 2004; Rachman et al., 2004; Dabney et al., 2012). Switchgrass barriers intercept, retard, and pond runoff (Dabney et al., 1999); increase runoff water infiltration opportunity time (Rachman et al., 2004); promote sediment deposition; filter sediment and nutrients; and reduce losses of pesticides and other pollutants in surface runoff (Gilley et al. 2000, 2011). Switchgrass barriers may also decrease the field slope length by forming mini-terraces upslope of the barriers with time as result of sediment deposition (Dabney et al., 1999). Grass barriers can therefore serve as an important ecological and biological practice for managing agricultural soils.

Switchgrass barriers are multifunctional systems and can provide numerous ancillary benefits, including improvements in wildlife habitat, as well as providing forage for livestock. An additional ancillary benefit associated with switchgrass barriers could be the accumulation of SOC with time and an improvement in associated soil structural properties within the barriers. Such improvements in soil properties could explain the mechanisms by which switchgrass barriers increase water infiltration within barriers and reduce runoff from croplands. However, switchgrass barrier-induced changes in SOC concentration and soil structural properties have not been widely documented. Previous research on grass barriers has often focused on assessing their effectiveness in reducing water erosion and improving associated water quality parameters (Dabney et al., 1999; Gilley et al., 2000; Blanco-Canqui et al., 2004; Gilley et al., 2011; Dabney et al., 2012). Because switchgrass barriers are under perennial vegetation and are not subject to cultivation or tillage operations relative to the cropped area, they may significantly favor accumulation of SOC and improve soil structural processes compared with row crops.

Switchgrass barriers could increase SOC concentration in sloping lands by trapping sediment-associated C and by

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Abbreviation: POM; particulate organic matter; SOC, soil organic carbon.

SOIL ORGANIC C

- Crop residue removal may **REDUCE** soil organic C concentration by 1 to 3 Mg ha^{-1} yr^{-1} in the top 10 cm in the long term.
- Warm season grasses can **INCREASE** soil organic C concentration between 0 and 3 Mg C ha^{-1} yr^{-1} for similar depth **while providing biofuel feedstocks**
- Woody rotations can **INCREASE** soil organic C concentration between 0 and 1.6 Mg ha^{-1}yr^{-1} in the top 100 cm.


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Agronomy, Soils & Environmental Quality

Dedicated Bioenergy Crop Impacts on Soil Wind Erodibility and Organic Carbon in Kansas

Byron J. Evers, Humberto Blanco-Canqui,* Scott A. Staggenborg, and John Tatarko

ABSTRACT

Dedicated bioenergy crops such as perennial warm-season grasses (WSGs) may reduce soil erosion and improve soil properties while providing biomass feedstock for biofuel. We quantified impacts of perennial WSGs and row crops on soil wind erodibility parameters (erodible fraction, geometric mean diameter of dry aggregates, and aggregate stability) and soil organic carbon (SOC) concentration under a dedicated bioenergy crop experiment in eastern Kansas after 4 and 5 yr of management. Soil properties were measured under switchgrass (*Panicum virgatum* L.), big bluestem (*Andropogon gerardii* L.), miscanthus (*Miscanthus* × *giganteus*), and annual row crops including continuous corn (*Zea mays* L.), photoperiod sorghum [*Sorghum bicolor* (L.) Moench.], sweet sorghum, and grain sorghum. Perennial WSGs reduced wind erodible fraction by 1.08 to 1.16 times compared with row crops. The geometric mean diameter of dry aggregates under switchgrass and miscanthus was 2.8 to 4.5 times greater than under row crops. Dry soil aggregate stability under miscanthus and big bluestem was greater than under row crops. After 5 yr, differences in SOC concentration between WSGs and row crops were not statistically significant for the 0- to 15-cm depth. Photoperiod sensitive and sweet sorghum had greater biomass yield than WSGs. In 2011, miscanthus yielded more biomass than corn by 5.3 Mg ha^{-1}. Overall, growing dedicated bioenergy crops can reduce the soil's susceptibility to wind erosion but may not significantly increase SOC concentration in this region in the short term.

Development of environmentally sustainable dedicated energy crops may address concerns about soil and environmental degradation. Dedicated energy crops such as perennial WSGs can be a potential alternative to crop residue removal to provide cellulosic biomass for renewable energy production while improving soil and environmental quality (Blanco-Canqui, 2010). Excessive crop residue removal can adversely affect soil structural stability, SOC pools, water transmission characteristics, soil microbial activity, and other soil properties (Wilhelm et al., 2004; Blanco-Canqui and Lal, 2009). In contrast, perennial WSGs due to their year-round surface cover may protect soil from erosion, improve soil properties, soil productivity, and wildlife habitat and diversity. In addition to their potential as biofuel, perennial WSGs may also serve as a valuable animal feedstock, which is particularly important in years of drought (Craine et al., 2010).

In the Great Plains, wind erosion is a major environmental concern. This region witnessed the worst dust storms in United States history during the 1930s (Colacicco et al., 1989). It is well recognized that herbaceous wind barriers can reduce wind erosion, improve crop yield, prevent sandblast damage to crops and trap snow to improve soil moisture (Bilbro and Fryrear, 1988). Similar to wind barriers, plantations of WSGs when grown for forage and biofuel may be an effective management practice to reduce wind erosion. Perennial WSGs provide permanent vegetative cover which can adsorb wind energy, reducing wind velocity (Bilbro and Fryrear, 1997). Extensive and deep root systems under perennial WSGs may also stabilize and anchor soil, increasing soil aggregate size and stability. In the Great Plains, wind erosion is usually the greatest between February and May when winds are strong and crops are sparse or not present to protect the soil surface. Presence of dormant WSGs in early spring may reduce wind erosion compared with row crops with limited surface residue cover. Bilbro and Fryrear (1997) concluded that tall and lodge-resistant plants, such as switchgrass, increased the effective distance of wind barriers. Grasses are able to absorb blowing soil particles and reduce the loss of windblown materials (Bilbro and Fryrear, 1997).

Current research on dedicated bioenergy crops mostly focuses on increasing production of biomass (Propheter et al., 2010). As a result, data on dedicated bioenergy crop impacts on soil and water conservation, soil physical properties, SOC dynamics, and other soil and environmental factors are limited, particularly in Kansas. This information is, however, needed to assess the potential benefits of growing dedicated energy crops under different regions. Benefits for WSGs for improving soil properties may be inconsistent, depending on the length of management, grass species, soil type, and climate (Schwartz et al., 2003).

Most dedicated bioenergy crops are expected to be grown in marginal lands to reduce concerns over competition for land with prime agricultural production (Kort et al., 1998; Cai et al., 2011). Throughout the central Great Plains in general and

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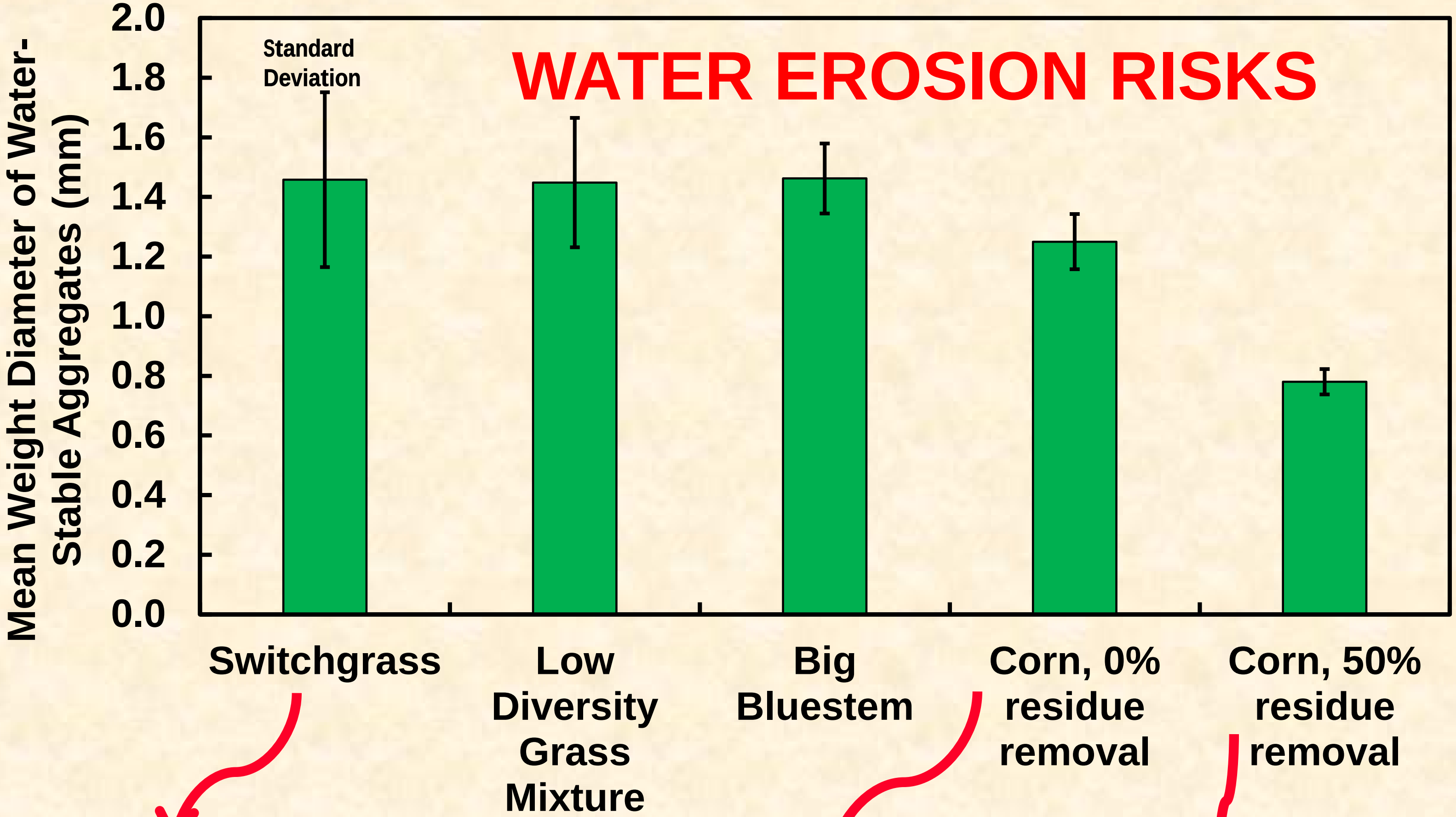
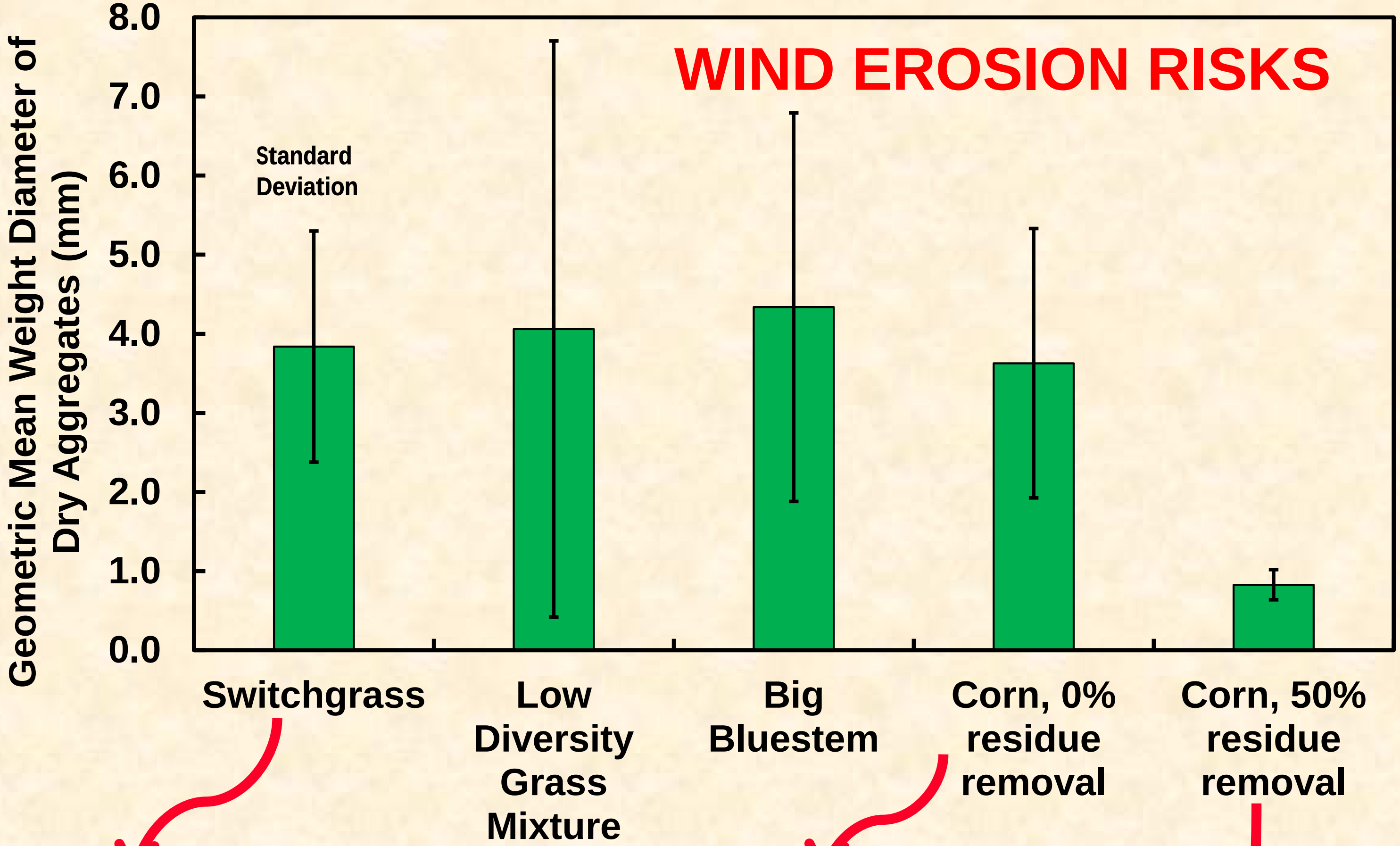
Abbreviations: SOC, soil organic carbon; WSGs, warm-season grasses.

- In eastern Nebraska, switchgrass **sequestered about 2 Mg/ha/yr of C at the 0- to 150-cm soil depth and ~50% of the increase in C was below 30 cm** (Follett et al., 2012).
- Across 10 on-farm fields in North Dakota, South Dakota, and Nebraska, **increases in soil organic C after switchgrass establishment varied among locations** (Schmer et al., 2011).
- In Indiana, warm-season grasses **increased soil C in 4 out of 10 soils** compared with croplands (Omonode and Vyn, 2006).

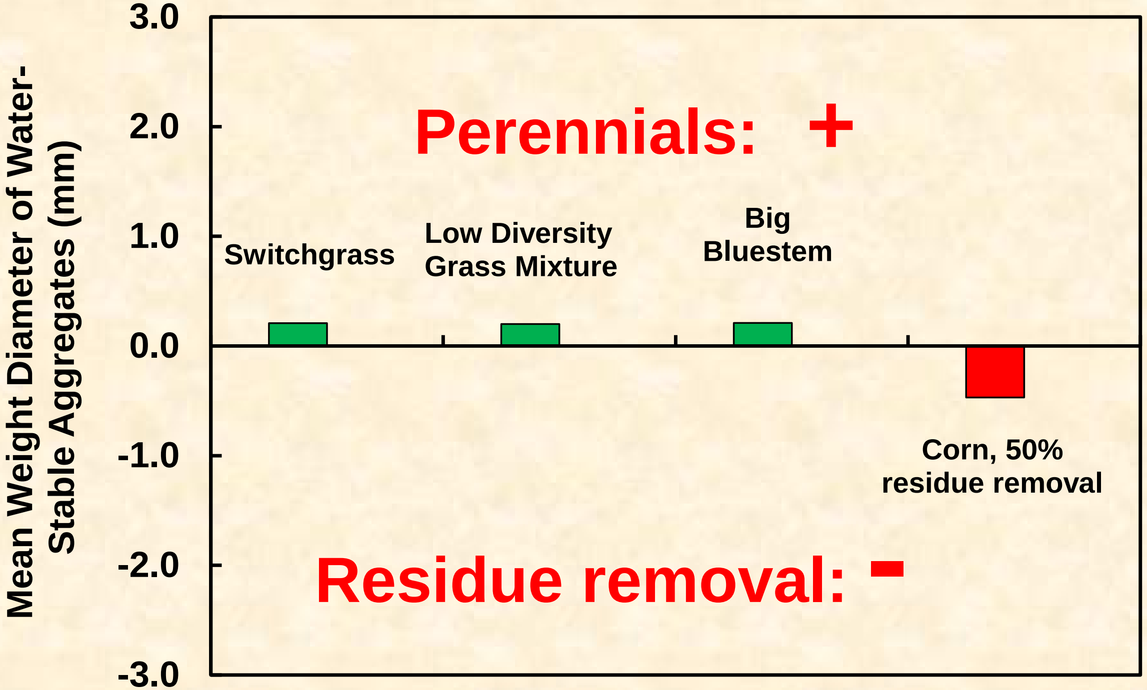
Data from Nebraska, spring 2014



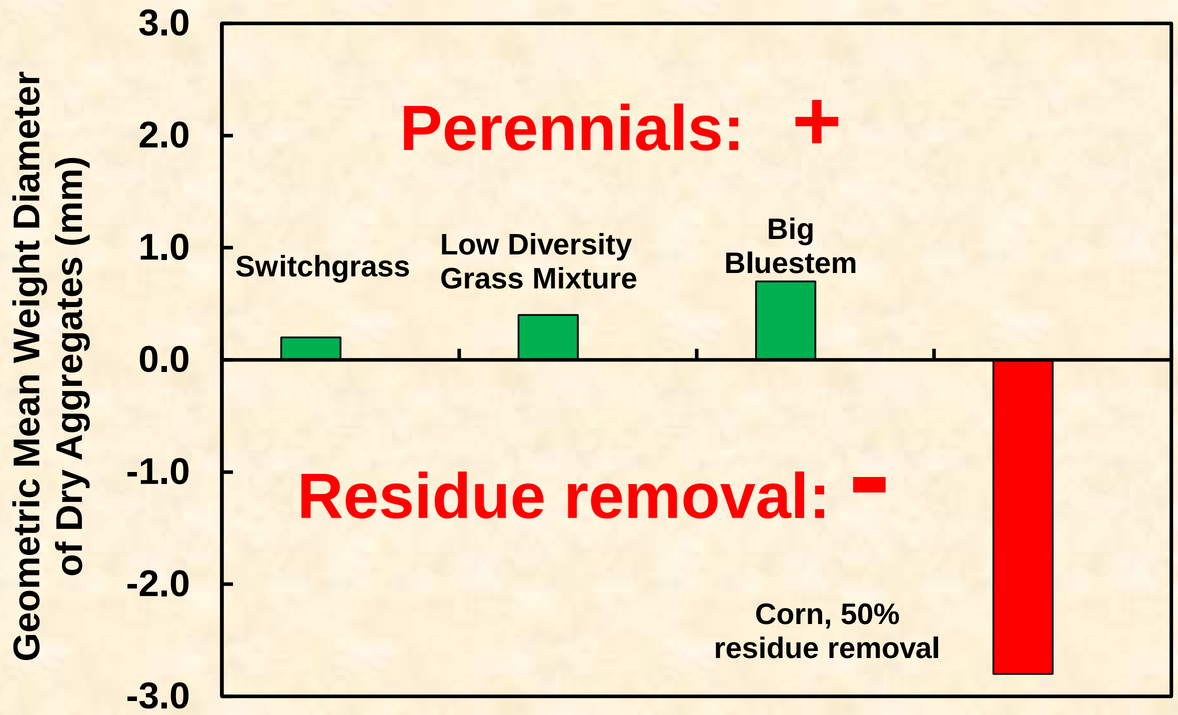
Data from Nebraska, spring 2014



WATER EROSION RISKS



WIND EROSION RISKS



BIOMASS YIELD: Eastern Kansas

Crop	Yield (Mg/ha)
Continuous Corn	12.16 bc
Photo Period Sorghum	34.61 a
Big Bluestem	3.79 d
Miscanthus	9.68 c
Switchgrass-Kanlow	7.90 cd

SOIL PROPERTIES

Perennial grasses reduced soil erosion risks but had no effects on C.

Studies done by others

Location	Duration (yr)	Soil Property	Cropland	Warm Season Grasses	Reference
Minnesota, North Dakota, and South Dakota	2-19	Bulk density (Mg m^{-3})	1.12a	1.07b	Liebig et al. (2005)
Iowa	10		1.28a	1.22b	Rachman et al. (2004a)
Iowa	5		1.34a	1.12b	Bharati et al. (2002)
Texas	10		1.18b	1.25a	Schwartz et al. (2003)
Missouri	12		1.41a	1.18b	Udawatta et al. (2008)
Iowa	5	Water-stable aggregates (%)	21b	39a	Acosta-Martínez et al. (2004)
Iowa	6		70.1a	73.6a	Anderson et al. (1997)
Missouri	12	Macroporosity (m^3 m^{-3}	0.005b	0.027a	Udawatta et al. (2008)
Iowa	10	Saturated hydraulic conductivity (mm h^{-1})	115b	668a	Rachman et al. (2004a)

High input system

Corn

Switchgrass or other perennial grass

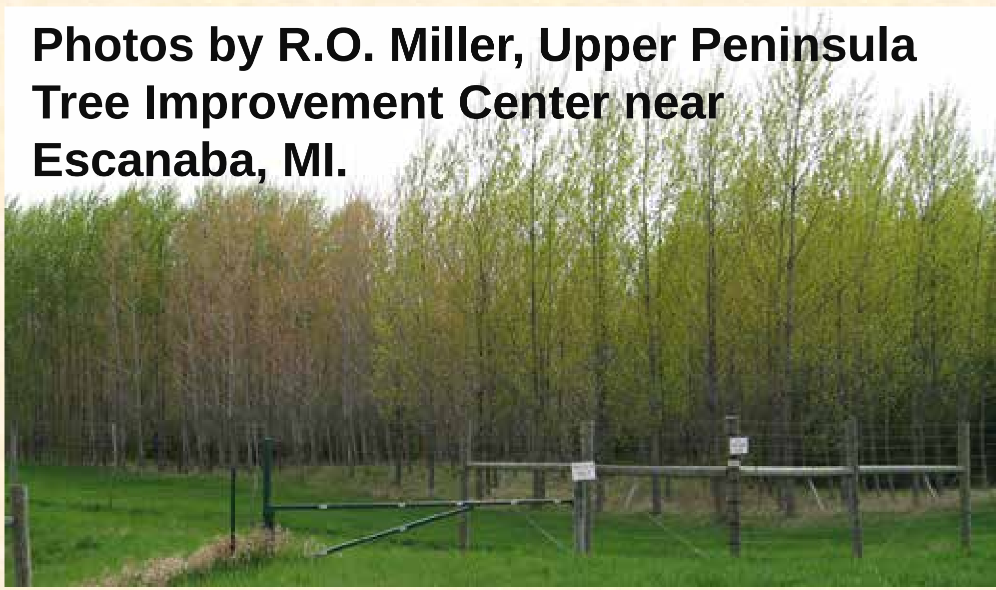
Low input system

Mixed prairie grass

Improvement in Soil Properties, wildlife habitat, reduced soil erosion, water quality

Reduced bulk density, increased Porosity, increased water retention, increased soil aggregate stability, and enhanced soil organic C aacumulation

SHORT-ROTATION WOODY CROPS



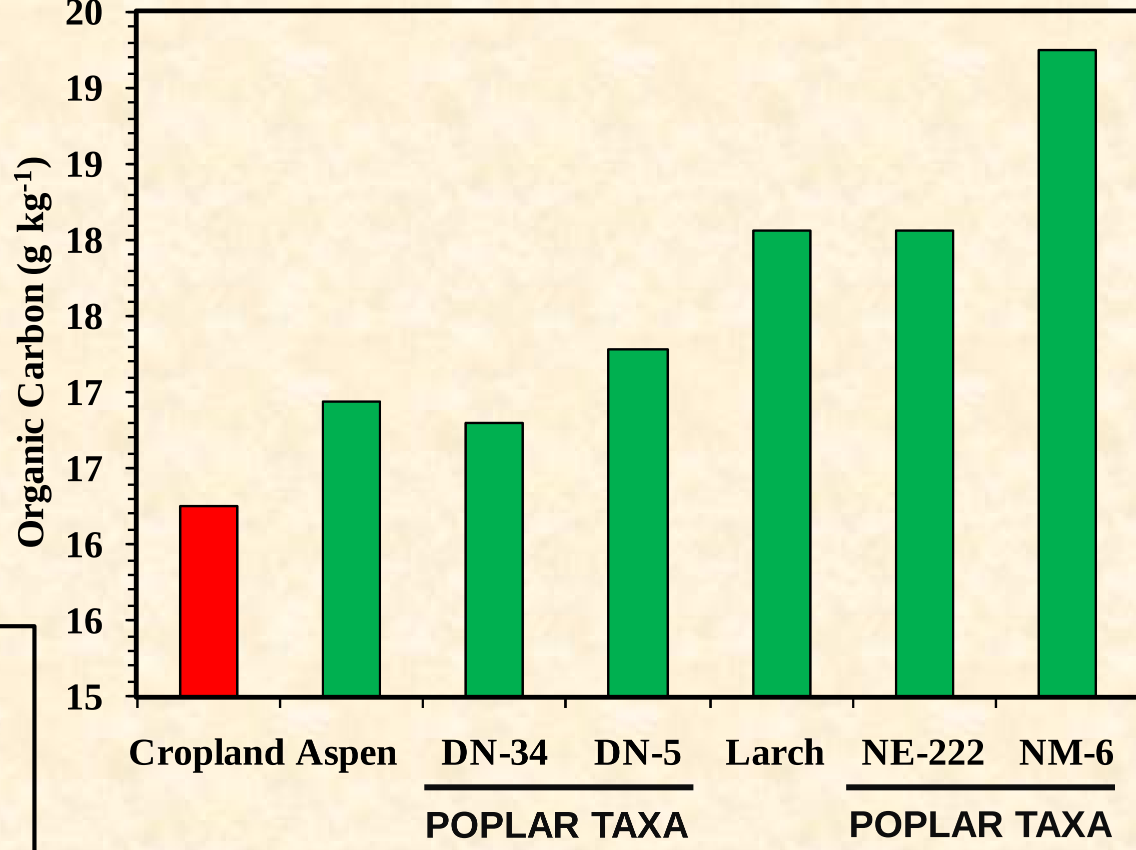
Photos by R.O. Miller, Upper Peninsula Tree Improvement Center near Escanaba, MI.

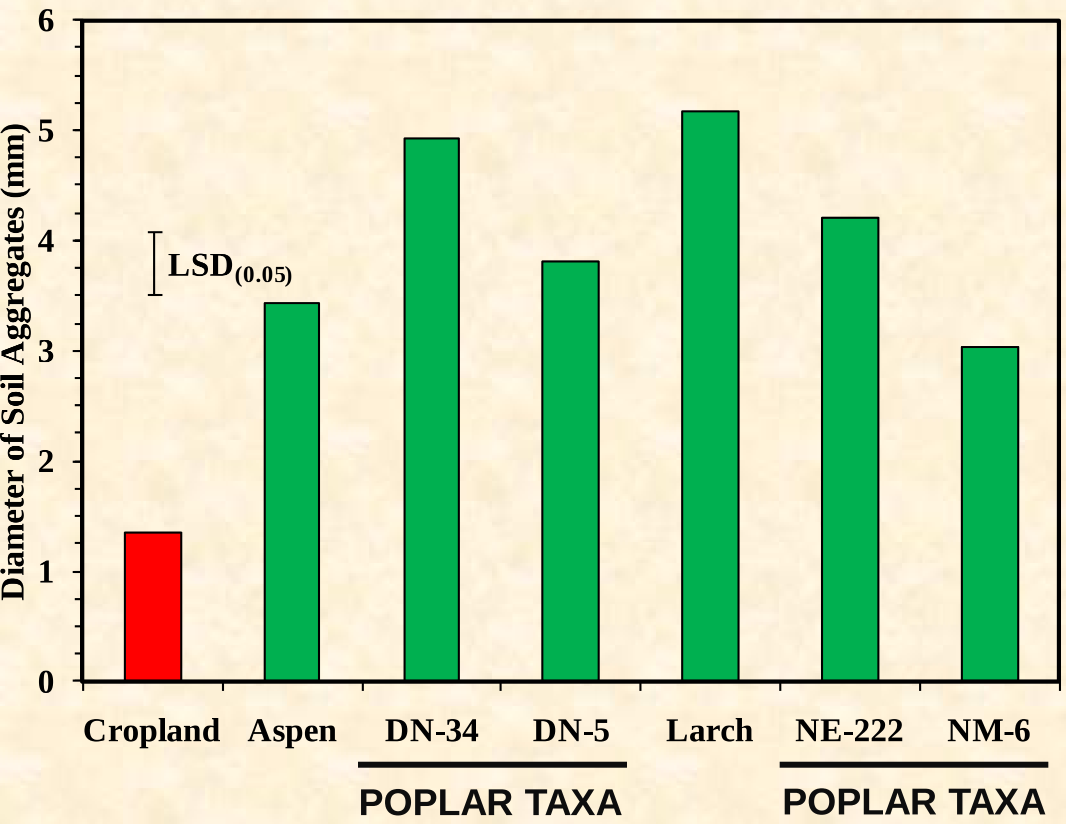
Six tree taxa:

1. **European larch (*Larix deciduas* Mill.),**
2. **Hybrid aspen (*P. tremula* x *P. tremuloides*)**
3. **Four poplar taxa: NE-222 (*P. deltoids* x *P. nigra* var. *caudina*), DN-5 (*P*. x *euramericana*, cv. “Gelrica”), DN-34 (*P*.x *euramericana,* cv. “Eugenei”), and NM-6 (*P. nigra* x *P. maximowiczii*).**

Soil Response to Short-Rotation Woody Crops

Upper Peninsula Tree Improvement Center, Michigan

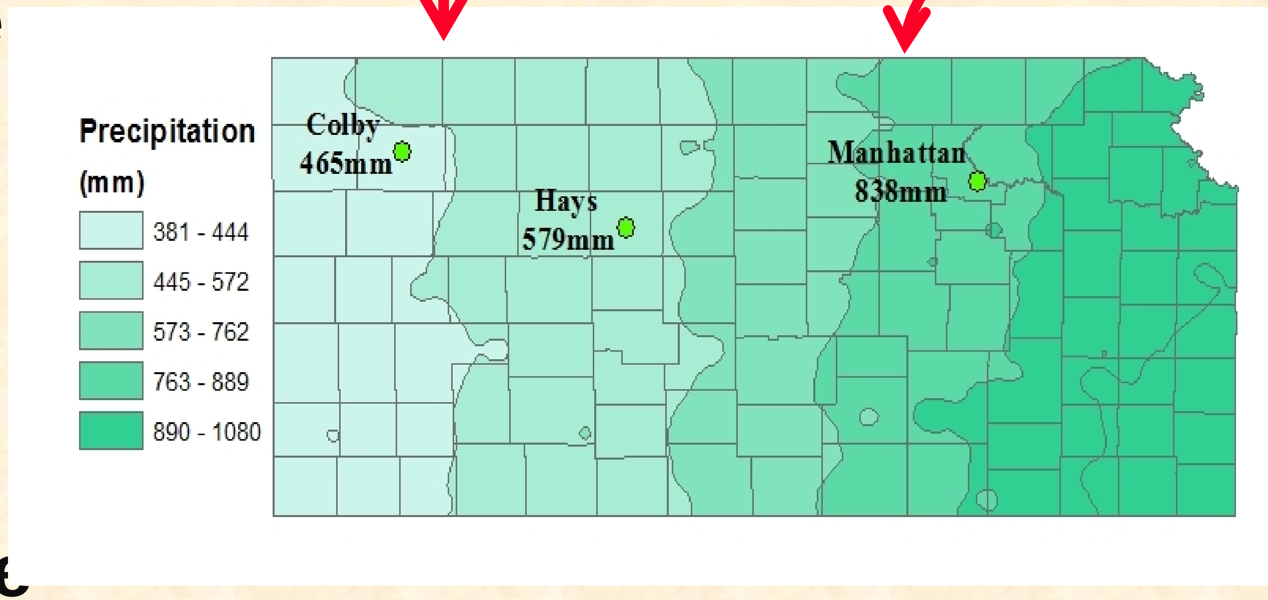




Blanco-Canqui, H., R. Lal, F. Sartori, and R.O. Miller. 2007. Changes in soil aggregate properties and organic carbon following conversion of agricultural lands to fiber farming. Soil Sci. 172:553-564.

CHALLENGES

- Can marginal lands meet biofuel demands?
- What is the definition of marginal lands?
- Large variability in biomass yield among soil types and climate zones.
- Establishment
- Fertilizer use
- Slow or small increase in soil C in some soils.



TAKE HOME MESSAGE

- Dedicated energy crops such as perennial grasses maintain or improve soil properties and environmental quality compared with crop residue removal.
- Growing warm season grasses and short rotation woody crops can be potential alternatives to crop residue removal.
- Regional-and site-specific management strategies are required to further develop sustainable biofuel production systems.
- The existing challenges must be addressed.

TIME FOR QUESTIONS