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# Soil response to perennial herbaceous biofeedstocks under rainfed conditions in the northern Great Plains, USA

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ABSTRACT

Perennial herbaceous biofeedstocks (PHB) have been proposed to confer multiple ecosystem services to agricultural lands. However, the role of PHBs to affect change in soil condition is not well documented, particularly for treatments with multiple species. The objective of this study was to quantify potential changes to soil properties resulting from PHB treatments in central and western North Dakota over a 5-yr period. Treatments with multiple perennial plant species were hypothesized to induce greater improvements in soil condition compared to monocultures. Soil properties were evaluated in seven PHB treatments (four monocultures, three mixtures) at five sites with sampling occurring immediately prior to treatment establishment in 2006 and again in 2011 across a 0 to 1.2 m depth. Perennial herbaceous biofeedstocks had minor and inconsistent effects on soil bulk density, electrical conductivity, and soil pH, and no effect on available P and soil organic C (SOC) in 2011. Contrasts between monoculture and mixtures in 2011 yielded no significant differences for any soil property at any site. However, PHB treatments did induce significant changes in soil properties between 2006 and 2011, with substantial declines in available P (>10 kg P $ha^{-1}$ $yr^{-1}$) at sites with high initial P and modest increases in SOC (0.9–5.7 Mg C $ha^{-1}$ $yr^{-1}$) at sites with low initial SOC. Electrical conductivity decreased at two sites, though changes were minor (−0.08 to −0.18 dS $m^{-1}$). Soil pH did not change over the 5-yr study. Results from this study underscore the value of PHBs to remediate nutrient-laden and/or degraded soils, while concurrently resisting increased salinity and fertilizer-induced acidification.

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## 1. Introduction

As the portfolio of biofuel production options expand globally, it is essential to understand how different biofeedstocks affect soil ecosystem services across spatial and temporal scales. Currently, production of first-generation biofuel crops such as corn (*Zea mays* L.) have significant negative environmental consequences, including increased net greenhouse gas (GHG) emissions (Adler et al., 2007; Scharlemann and Laurance, 2008), compromised water quality (David et al., 2010), and decreased wildlife habitat (Wright and Wimberly, 2013). Utilization of second-generation perennial herbaceous crops as biofuel sources has been suggested to reduce these negative consequences (McLaughlin et al., 2002), due mainly to their lower requirements of agricultural inputs and their ability to be grown on marginal land (Hill et al., 2006). Many ecosystem service benefits associated with perennial herbaceous biofeedstocks (PHB) have been found to be derived from changes to soil properties (Blanco-Canqui, 2010). Limited soil disturbance, coupled with increased organic matter inputs and water uptake in comparison to annual crops, contribute to changes in soil properties that can affect climate and water regulation, nutrient cycling, and salinity mitigation (Franzluebbers, 2015; Stewart et al., 2015).

In the northern Great Plains of North America, most assessments of PHB have focused on switchgrass (*Panicum virgatum* L.), where previous modeling efforts have shown its production for bioenergy to be economically feasible (Walsh, 1998). Information associated with the production of other grasses and forbs in the region for potential use as biofeedstocks, such as tall and intermediate wheatgrass [*Thinopyrum ponticum* (Podp.) Z.-W. Liu and R.-C. Wang; *Thinopyrum intermedium*

*Abbreviations:* CRP, Conservation Reserve Program; ESM, equivalent soil mass; GHG, greenhouse gas; P, phosphorus; PHB, perennial herbaceous biofeedstock; SOC, soil organic carbon.

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(Host) Barkworth and D.R. Dewey], alfalfa (*Medicago* spp.), sweetclover [*Melilotus officinalis* (L.) Lam.], big bluestem (*Andropogon gerardii* Vitman), and species mixtures, is limited (Lee et al., 2009). Moreover, previous multisite perennial biofeedstock trials in the northern Great Plains have focused on on-farm environments (Schmer et al., 2008), where management options and experimental controls can be limited and inconsistent across sites.

Species mixtures are purported to induce greater improvements in soil condition relative to monocultures given more abundant and deeper distribution of root biomass in the former (Blanco-Canqui, 2010). Though positive associations between species richness and soil organic C (SOC) have been observed (Skinner and Dell, 2016; Cong et al., 2014; Fornara and Tilman, 2008), outcomes are far from consistent as some studies have observed decreased SOC with increased species richness (Skinner et al., 2006) or an absence of an association altogether (Bonin et al., 2014). Moreover, studies evaluating species mixture effects on soil properties often focus on SOC, with limited information on other properties known to affect soil function.

In this study, we sought to quantify potential changes to soil properties resulting from different PHB at five sites in central and western North Dakota over a 5-yr period. Soil properties investigated in the study were selected for their association with water regulation (soil bulk density), salinity mitigation (electrical conductivity), buffering capacity (soil pH), nutrient cycling (available P), and climate regulation (SOC). This investigation was done in conjunction with a broader study objective that sought to determine appropriate grass and legume species, harvest methods, and management practices to maintain productive perennial biomass stands throughout North Dakota (Wang et al., 2013, 2014). We hypothesized PHB treatments with multiple plant species would induce greater improvements in soil condition compared to monoculture PHB treatments.

## 2. Materials and methods

### 2.1. Site descriptions

Sites were located in central and western North Dakota USA at North Dakota State University (NDSU) Research Extension Centers near towns of Carrington, Hettinger, Minot, Streeter, and Williston (Fig. 1). Major land resource areas represented in the study included 53B (Central dark brown glaciated plains; Minot), 54 (Rolling soft shale plain; Hettinger and Williston), and 55B (Central black glaciated plains; Carrington and Streeter), which encompass approximately 17 Mha (USDA-NRCS, 2006). Climate within the study region is characterized as semiarid to sub-humid continental, with cold and dry winters, warm to hot summers, and erratic precipitation (Bailey, 1995). Mean annual temperature and precipitation at the sites ranged from 4.5 to 5.8 °C and 381 to 505 mm, respectively (Table 1). Soils at the sites were of moderate to high inherent fertility, characterized by Albolls, Ustolls, and Udolls as taxonomic suborders, and occupied a spatial extent of 45 Mha (USDA-NRCS, 1999).

Previous land management was typical for crop and hay production in central and western North Dakota. A two year crop rotation including small grains and pulse crops was used at Carrington and Minot. Continuous spring wheat (*Triticum aestivum* L.) using no-till practices was used at Hettinger. At Streeter, previously cropped land was fallowed for four years prior to establishment of the study. The site at Williston was used for hay production in grassland dominated by crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] (Wang et al., 2014). All sites reported in this study were rainfed and did not receive supplemental irrigation.

Ten perennial plant species and species combinations, each split by two harvest schedules (annual and biennial), were seeded at all sites the week of 15 May 2006 (Wang et al., 2014). Plots were seeded with a drill designed for small-seeded grasses and legumes with 0.15 m row centers. Plot dimensions were 4.6 × 9.2 m. The experimental design was a randomized complete block design with four replications. For purposes of this study, seven of ten perennial plant treatments harvested annually were evaluated for their effects on soil properties. Treatments included four monocultures and three mixtures (Table 2).

Following establishment, plots were sprayed and mowed at least once at all sites except Hettinger, where they received only chemical applications. Due to poor stands from exceptionally dry conditions, plots were reseeded at Hettinger in 2008. Treatments without leguminous species received fertilizer N annually at a rate of 56 kg N $ha^{-1}$ as $NH_4NO_3$ or urea from 2007 onward. Additional information on site history, plot establishment, management, and biomass harvest may be reviewed elsewhere (Wang et al., 2013, 2014).

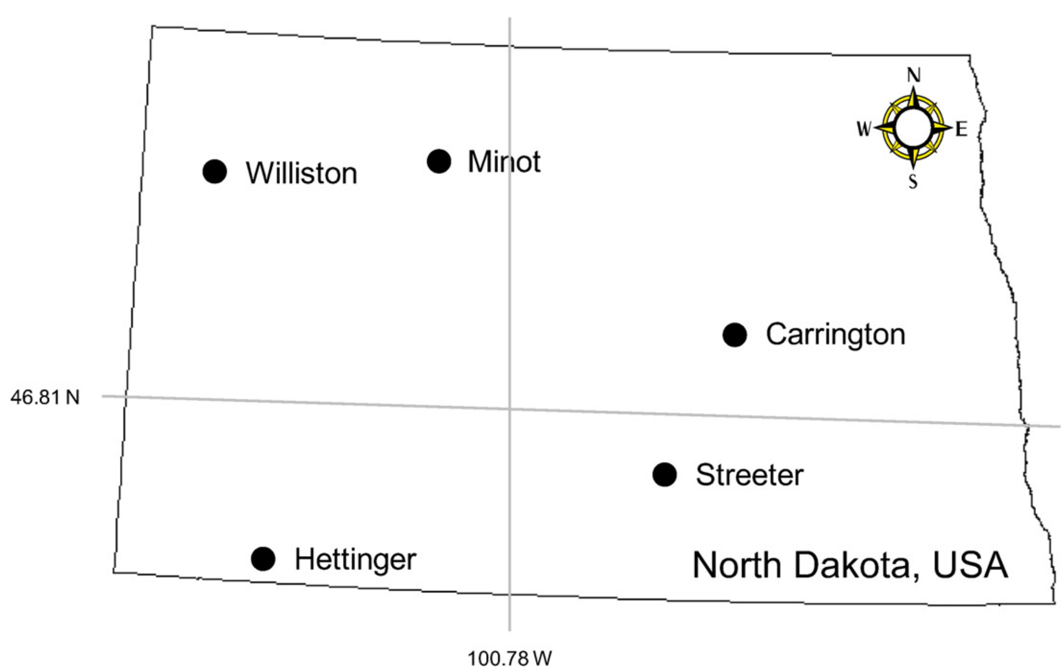


**Fig. 1.** Approximate location of sites included in study.