Soil Organic Matter Across a Chronosequence of Cultivated Switchgrass (*Panicum virgatum*)

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Abstract

Switchgrass (*Panicum virgatum*) is an indigenous North American warm season grass developed as a perennial biofuel crop. Switchgrass cultivation has the potential to improve or protect certain soil properties, but there is mixed evidence on the effect of continuous switchgrass cultivation on soil organic matter (SOM). In this study, I collected soil and biomass samples from switchgrass stands of different ages (1-17 years) to investigate the effect of age, aboveground biomass (AGB), and belowground biomass (BGB) on SOM concentration and mass. SOM concentration had no correlation with stand age, and SOM mass was negatively correlated (R^2=0.51) to stand age. BGB and total biomass displayed no correlation to stand age, though BGB and total biomass were lowest for the youngest stand. AGB was negatively correlated (R^2=0.35) with stand age. AGB was positively correlated weakly with SOM concentration (R^2=0.12) and more strongly with SOM mass (R^2=0.88), despite annual AGB harvest. BGB was positively correlated with SOM concentration (R^2=0.67; p=0.046) but not correlated with SOM mass. These results suggest that SOM and biomass respond to variation within sites and, although SOM was not shown to accumulate in older sites, the concentration of SOM was not found to be depleted over years of continuous switchgrass cropping. This work contributes to the evolving understanding of SOM dynamics under switchgrass and perennial cropping systems which will inform biogeochemistry modeling and agro-ecosystem management.

Introduction

Organic matter is a critically important component of soil due to its ecological and agricultural functions and its role in carbon cycle dynamics. Some define soil organic matter (SOM) as all living organisms, detritus, and organically-derived molecules present in soil (Magdoff & Van Es, 2021) yet other definitions restrict discussion of SOM to the "chemically distinct non-living 'product' generated by biochemical processes" (Manlay et al, 2007). For the purposes of this paper, SOM is understood as detritus and organic products incorporated into the soil matrix. SOM serves a range of important biological, physical and chemical roles by acting as an energy and nutrient source for soil heterotrophs and a nutrient source for plants (Agostini et al., 2015; Gunina & Kuzyakov, 2022; Magdoff & Van Es, 2021), promoting soil aggregate stability (Fenton et al., 2008; Magdoff & Van Es, 2021), reducing bulk density (Blanco-Canqui et al., 2017), increasing soil cation exchange capacity and improving retention of bioavailable soil nutrients, as well as acting as a buffer for pH change and some soil contaminants such as heavy metals and pesticides (Fenton et al., 2008; Magdoff & Van Es, 2021). Depending on the situation, SOM pools can act as either net sinks (more SOM formation) or net sources (more SOM mineralization) for atmospheric carbon (C).

External factors of physical disturbance (i.e. tillage or mining; Anderson-Teixeira et al., 2009; Banning et al., 2008; Grover et al., 2024; Kantola et al., 2017), local topography (Banning et al., 2008; Juyal et al., 2021; Lai et al., 2018), and climate (Anderson-Teixeira et al., 2009; Haddix et al., 2020, Martinez-Feria & Basso, 2020) influence the accumulation and persistence of SOM. Though tillage can be useful for incorporating aboveground biomass (AGB) litter into the soil (Kantola et al., 2017), SOM tends to mineralize at a faster rate under intensive tillage practices (Martín-Lammerding et al., 2021). Major devegetation, for agricultural, industrial, or other purposes, also results in significant disruption of soil systems and reduction of SOM (Banning et al., 2008; Grover et al., 2024). Landscape topography results in higher concentrations of SOM at lower relative elevations (Banning et al., 2008; Juyal et al., 2021; Lai et al., 2018). Climate impacts the formation and persistence of SOM, with warmer temperatures increasing decomposition and greater precipitation simultaneously increasing biomass production (increased organic matter inputs) and decomposition rates (Anderson-Teixeira et al., 2009; Haddix et al., 2020).

Not all plants are equally effective for C sequestration. The longevity and mean residence time for belowground biomass, which is variable depending on root or rhizome size and seasonal changes, influences contribution to soil organic carbon (SOC; Agostini et al., 2015). The biochemical quality of plant litter or residues directly influence the potential for C sequestration while characteristics of canopy cover and plant growth indirectly affect SOC through their impact on the soil environment (Agostini et al., 2015; Anderson-Teixeira et al., 2009). Plants with greater productivity and greater root:shoot ratios are generally better at sequestering C (Anderson-Teixeira et al., 2009; Jackson et al., 2017). In summary, perennial cropping systems, such as switchgrass, have potential for increasing SOM, which could be applicable to remediation of SOM-depleted soils.

Switchgrass (*Panicum virgatum* L.) is a warm-season perennial bunchgrass indigenous to the continental United States east of the Rocky Mountains (Lovell et al., 2021; Natural Resources Conservation Service (NRCS), 2006). Once established, switchgrass can be harvested as an annual crop for up to 20 years (Jacobson, 2024). Across the North American Great Plains, switchgrass was a dominant species in tallgrass prairies which once covered extensive areas of the region before urbanization, mismanagement, and invasion by non indigenous species fragmented tallgrass prairies and reducing them to ‘relic’ sites (Bock & Bock, 1998; Lovell et al., 2021). There is debate and mixed evidence on the invasive potential of switchgrass (Ahrens et al., 2014; Flint et al., 2018) with some research suggesting gene flow and seed dispersal of non-locally derived cultivars (Ecker et al., 2015). In switchgrass, allocation of 65.86% of C to belowground biomass has been reported (Bazrgar et al., 2020) with more C allocated to roots than to rhizomes (Agostini et al., 2015), suggesting strong potential for C sequestration.

Switchgrass is a lignocellulosic biofuel feedstock named by the U.S. Department of Energy as a “model” perennial bioenergy crop in 1991 (Wright, 2007). Alternative markets outside of biofuel production exist, including animal and livestock bedding (Jacobson, 2024), forage and/or roughage (Renz et al., 2009), and liquid waste absorbance and disposal (Dykstra et al., 2019). Switchgrass has also been cultivated for ornamental landscaping, wildlife habitat and restoration, roadside planting and erosion control (Ecker et al., 2015; Parrish & Fike, 2005; Renz et al., 2009). Furthermore, switchgrass has demonstrated potential for cultivation on marginal land or disturbed soils not suitable for annual row crop agriculture (Blanco-Canqui, 2016; Grover et al., 2024). Switchgrass has potential for a range of phytoremediation applications, such as the

extraction of some metals (Bai et al., 2022) and NaCl (Kim et al., 2016), which makes it a potential crop for contaminated and/or saline soils (Blanco-Canqui, 2016). Impacts of switchgrass cultivation on soil characteristics include reduced runoff, improved aggregate stability (Blanco-Canqui et al., 2017; Evers et al., 2013; Wang et al., 2020), lower soil conductivity, lower soil salt concentrations, higher soil cation exchange capacity (CEC), more neutral soil pH (Brasher et al., 2021), and improvement or maintenance of soil nitrogen (N; Lai et al., 2018). An important effect of switchgrass cultivation can be increases in soil organic matter (Agostini et al., 2015; Anderson-Teixeira et al., 2009; Kantola et al., 2017; Evers et al., 2013).

Previous studies have found varying results regarding the influence of perennial switchgrass cultivation on SOM. Variation in the effect of switchgrass on SOM potentially relates to the age of the stand (Agostini et al., 2015; Lai et al., 2018), previous land use (Anderson-Teixeira et al., 2009; Grover et al., 2024), initial soil conditions (Evers et al., 2013), climate (Agostini et al., 2015; Anderson-Teixeira et al., 2009; Haddix et al., 2020; Martinez-Feria & Basso, 2020), seasonal variability (Grover et al., 2024), landscape topography (Juyal et al., 2021; Lai et al., 2018), soil texture and heterogeneity (Martinez-Feria & Basso, 2020; Anderson-Teixeira et al., 2009), fertilization (Agostini et al., 2015), harvest frequency (Anderson-Teixeira et al., 2009) and/or switchgrass ecotype and cultivar (Martinez-Feria & Basso, 2020). Under climate change projections of high or moderate emissions, the simulated rate of SOC gain under switchgrass production decreased due to reduced C inputs and increased soil respiration rates (Martinez-Feria & Basso, 2020).

Duration of switchgrass management likely influences the magnitude of switchgrass effects on soil properties, particularly SOM concentrations. Initial soil conditions may influence the rate of SOM change under switchgrass and SOM concentrations may increase to significantly greater levels than row crops if managed for longer than five years (Evers et al., 2013). Land conversion to switchgrass production can be associated with an initial loss of SOC, but SOM may accumulate in subsequent years (Anderson-Teixeira et al., 2009). SOM accumulation results have varied across geographic locations and of the 3,926 acres of switchgrass harvested commercially in the US in 2022, over 65% were in Pennsylvania (National Agricultural Statistics Services, 2025), so research specific to this region is pertinent. In light of the variation in reported SOM change under switchgrass cultivation and in response to indication that the age of

switchgrass stands may influence levels of SOM, the objective of this research was to determine (a) does SOM accumulate over time under continuously cultivated switchgrass and (b) which biomass component, above- or belowground, correspond most to the accumulation of SOM.

Methods

Site Description

Sampling locations were chosen from Ernst Conservation Seeds fields planted in the Cave-In-Rock cultivar of switchgrass. All fields were within Crawford County in northwestern Pennsylvania, USA. The predominant soils at all sites were silt loams with 8.5-20% clay content (NRCS Soil Survey Staff, 2024). The fields were selected to represent a range of ages (**Table 1**).

Table 1. Field sampling site history of SOM sites.

Field ID	**Age (years)**	**Field description**
KOZ 1	17	Venango silt loam and Frenchtown silt loam, 17-20% clay, previously fallow (former pasture reverting back to wild)
Dahl 5	15	Cambridge silt loam, 12% clay, previously crop field (corn and/or soybeans)
Dahl 1	13	Cambridge silt loam, 12% clay, previously crop field (corn and/or soybeans)
KOZ 4	13	Venango silt loam, 17% clay, previously fallow (former pasture reverting back to wild)
KOZ 2	8	Venango silt loam and Frenchtown silt loam, 17-20% clay, previously fallow (former pasture reverting back to wild)
KOZ 3	3	Cambridge silt loam, 12% clay, previously fallow (former pasture reverting back to wild)

Tau 3	3	Cambridge silt loam and Chenango gravelly silt loam, 12% clay, previously cow pasture
Tau 2	1	Scio silt loam, 8.5% clay, previously cow pasture

Note. Predominant soil series and clay content derived from USDA Web Soil Survey data (NRCS Soil Survey Staff, 2024). Field history from G. Kedzierski, personal communication, 2024.

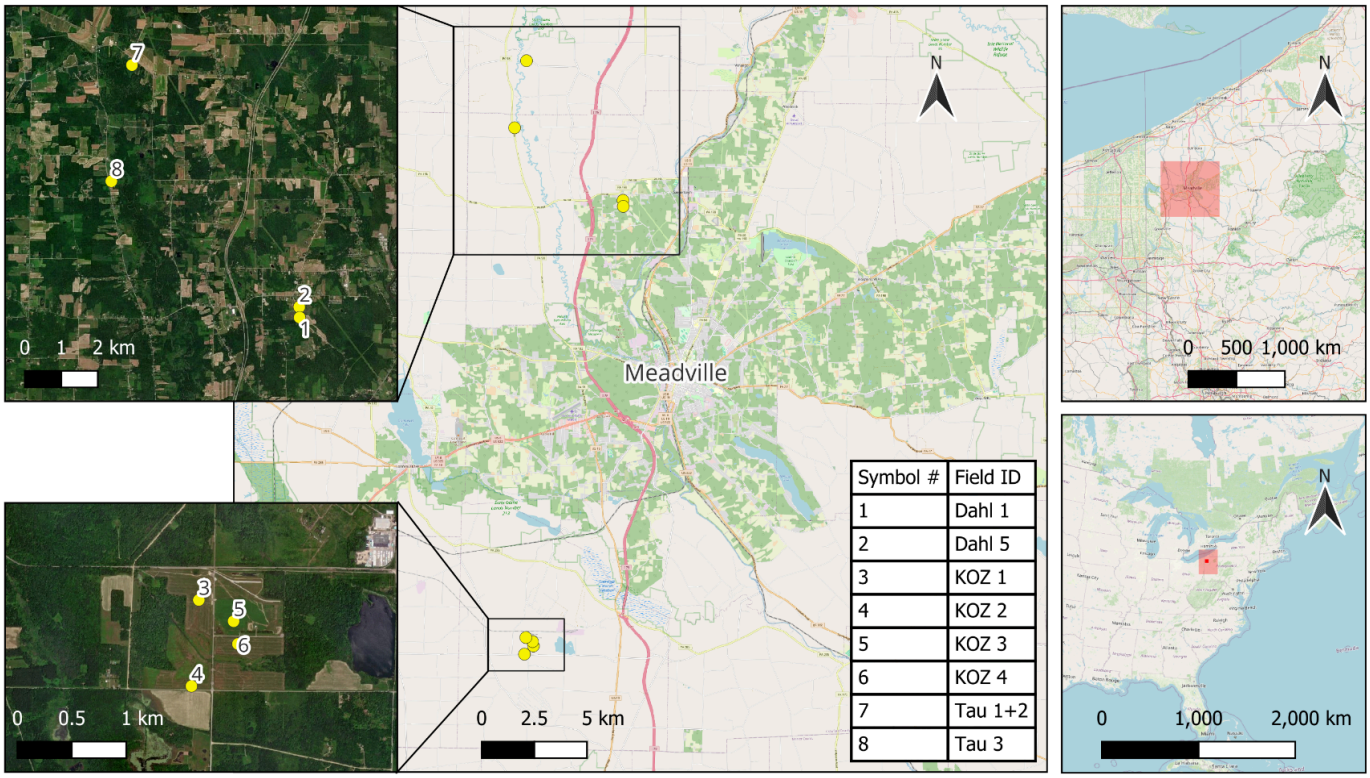


Fig. 1: Map of site locations. Base maps from Google Satellite and Open Street Maps.

Sample Collection

All soil and biomass samples were collected in November, 2024. Three soil, root, and above ground biomass samples were collected at each field site with the exception of aboveground biomass samples at the 17 and 8 year old fields, which had been mowed prior to sampling. Each sample was taken at approximately 35 meters into the field when the size of the field allowed (maintaining 35 m distance from the edge of the 15 year old field was not possible due to the small size of the field). At each randomly selected site, all standing plant material in a 1 m^2 area was cut by hand to 2 cm above ground level. This material and any fallen plant

material within the quadrat were collected. In the approximate center of this cleared area, a 20 by 20 cm hole was dug to a depth of 15 cm. All soil from this excavation was collected, including all the roots within the volume. Each of the three sampling locations per field site were 30 to 40 m apart and GPS coordinates for each were recorded (+/- 20 m) using Google Maps.

Sample Processing

All samples were stored in woven plastic bags (not airtight) until processing. After about a week of initial storage at room temperature, soil samples were refrigerated while awaiting sample processing. The aboveground biomass was dried at 105 degrees C for a minimum of 48 hours and then the dry mass was recorded. Soil samples were sieved to 5.6 mm. All roots and all rocks that were removed via sieve were collected and the mass recorded for each category. Non-root plant materials and anthropogenic debris removed via sieve were discarded. A subsample of the initial soil sample was then sieved to 2 mm. The difference in mass before and after sieving and the mass of roots and rocks removed by this step were used as proportions to estimate the total mass for soil, roots, and rocks for the whole sample. A subsample of the 2 mm sieved soil was used to determine soil moisture for the sample, and subsequently this ratio of fresh to dry mass was used to calculate total dry mass for the total sample. Loss-on-ignition of 10 g samples sieved to 2 mm was used to determine the percent organic matter. The roots removed from each soil sample were washed with water, dried at 105 degrees C for 48 hours, and then weighed. Bulk density was calculated by subtracting the total volume of rocks per sample (based on measured rock mass and reported density (R. Bowden, personal communication, 2025)) from the sampling volume then dividing soil dry mass by this corrected sample volume.

Data Analysis

Data were analysed using correlation tests between age, SOM, and biomass variables to determine the strength of the relationship between each. Mean and standard error was calculated by grouping all samples of a given age. Data from Dahl 1 and KOZ 4 were combined for age 13 and data from KOZ 3 and Tau 3 were combined for age three, otherwise each age was represented by samples from one field site. For correlations with more than four data points (i.e. excluding aboveground and total biomass), p-values were calculated using an online calculator from Social Science Statistics.

Results

Soil Characteristics

The mean soil dry mass tended to increase as switchgrass stand age increased (p=0.13). Across all samples, soil mass ranged from 114 to 185 kg m^{-2}. Bulk density also displayed a moderate positive correlation with stand age (p=0.22). Bulk density at all sites was within 0.6 g cm^{-3}, ranging from 0.76 to 1.3 g cm^{-3}.

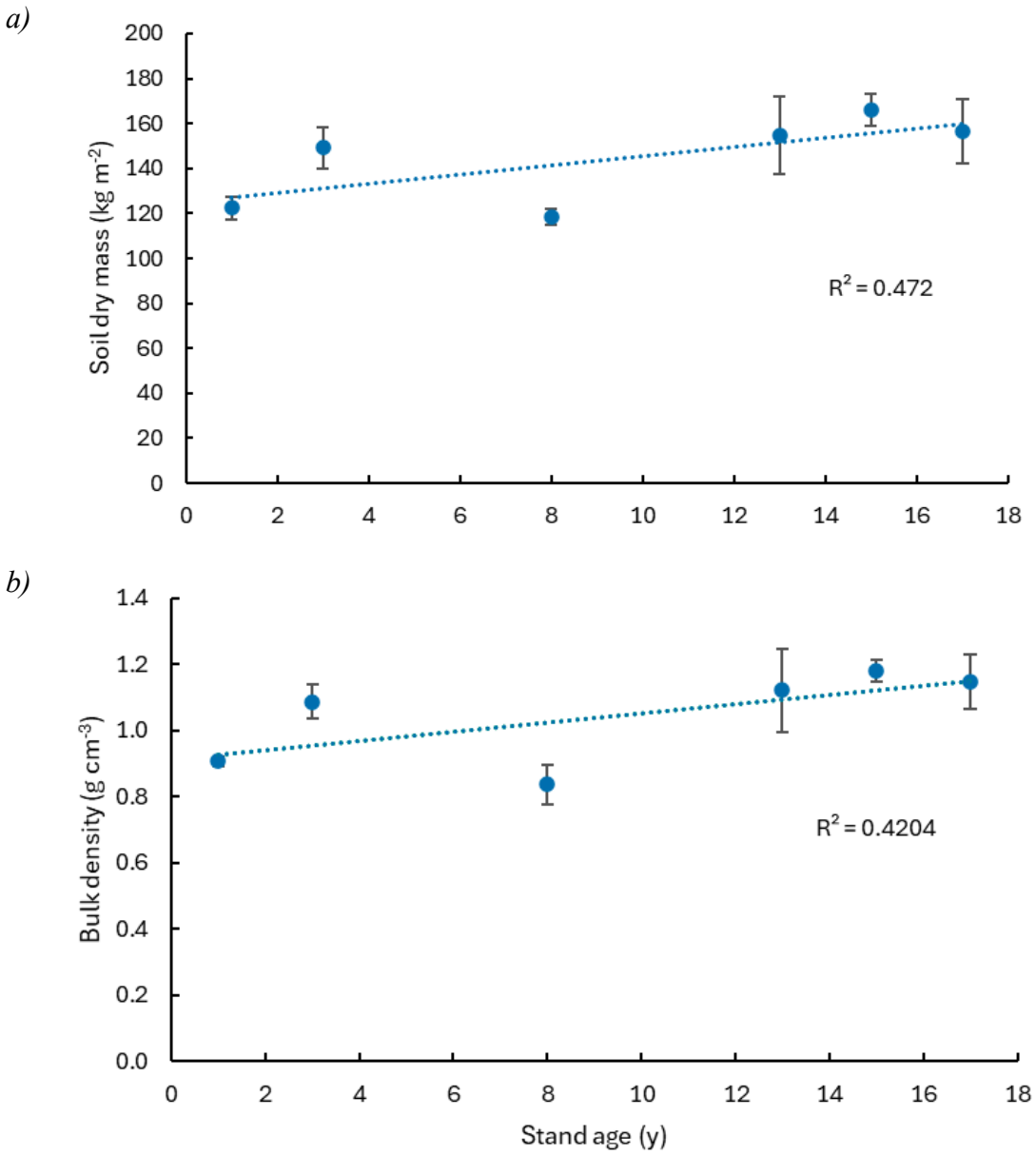


Fig. 2: Relationship between soil mass (a) or bulk density (b) in upper 15 cm of soil and switchgrass stand age in northwestern PA.

Mean SOM mass per surface area to a depth of 15 cm displayed a moderate negative trend as stand age increased (p=0.11). SOM mass ranged from 6.00 to 11.7 kg m^{-2} across all samples. Mean SOM concentration had no trend as stand age increased (p=0.96) and ranged from 5.14 to 9.31 %.

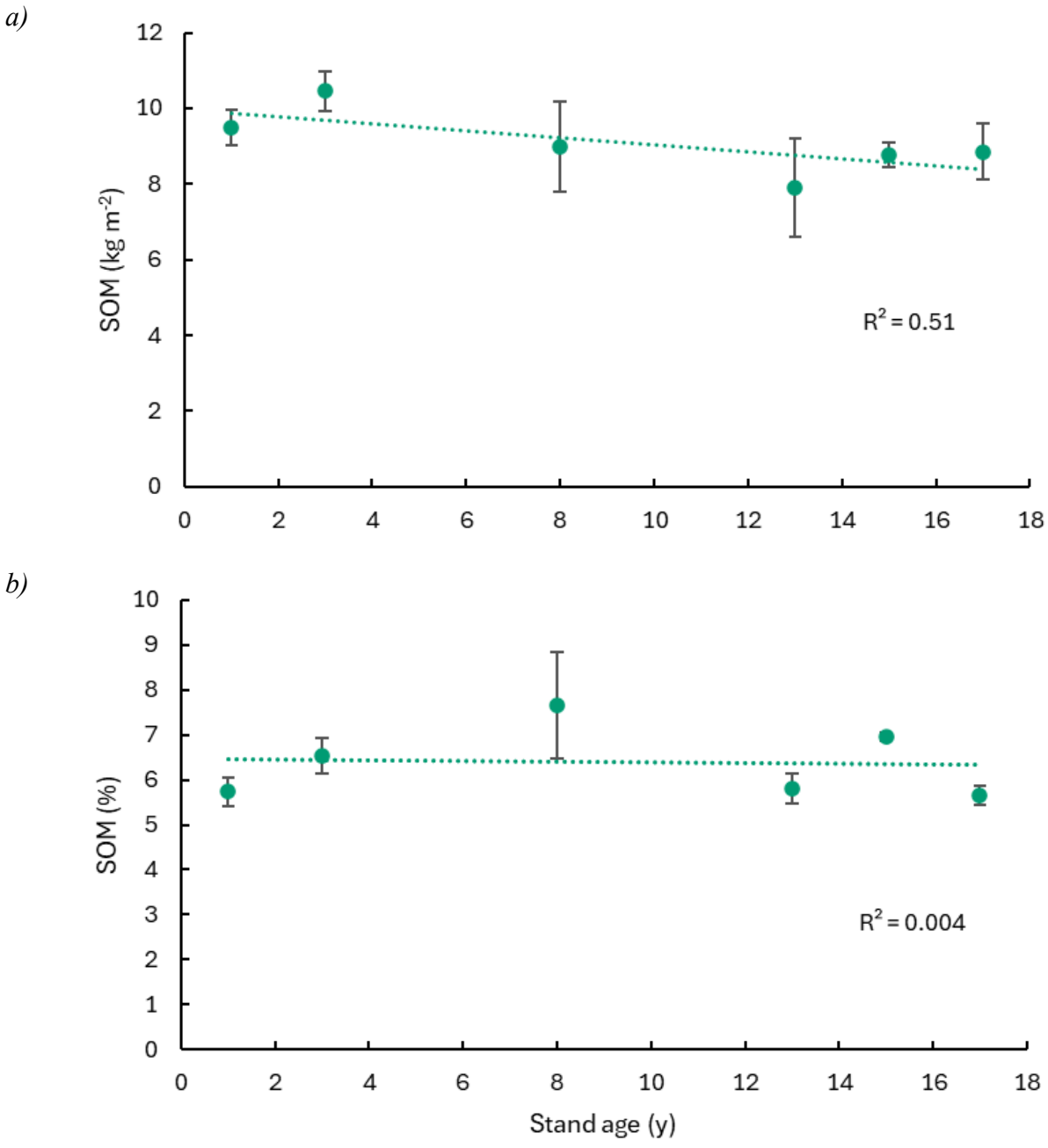


Fig. 3: Correlation of SOM mass (a) and SOM concentration (b) in the upper 15 cm of soil with switchgrass stand age in northwestern PA.

Neither SOM concentration nor SOM mass correlated strongly with bulk density; SOM concentration demonstrated a weak negative trend (p=0.47) and SOM mass had no notable correlation (p=0.67).

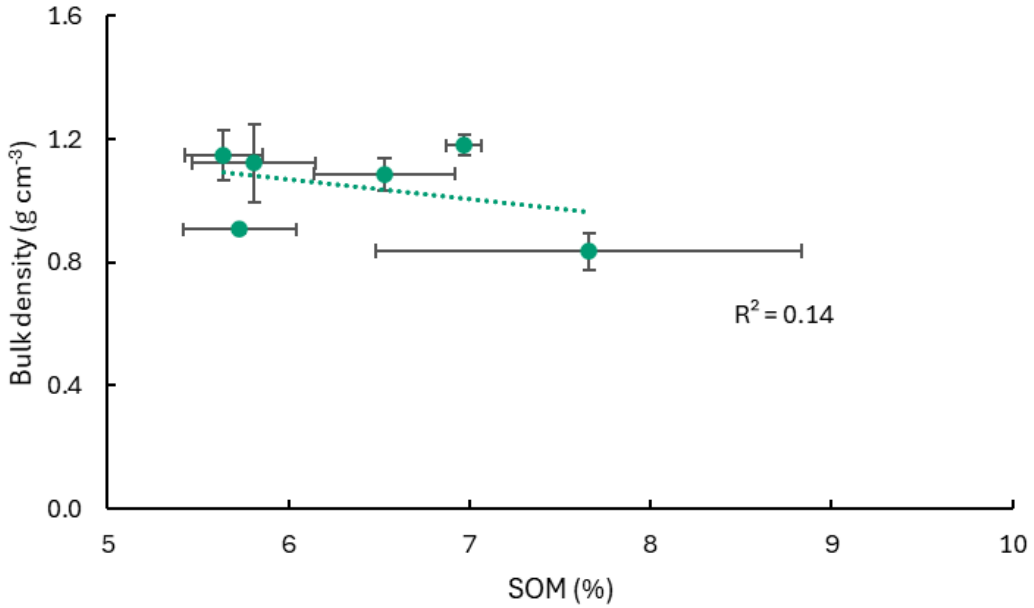


Fig. 4: Correlation between SOM concentration and soil bulk density in the upper 15 cm of soil under switchgrass stands in northwestern PA.

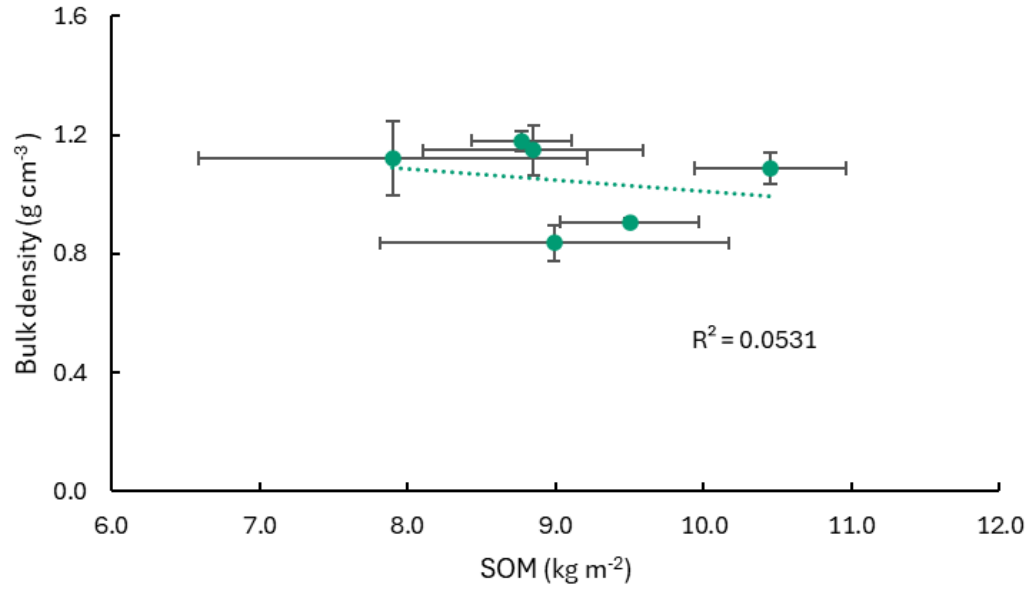


Fig. 5: Correlation between soil bulk density and SOM mass in the upper 15 cm of soil under switchgrass stands in northwestern PA.

Biomass

No significant correlation was observed between biomass (aboveground, belowground (p=0.97) or total) and stand age. Aboveground biomass (AGB) tended to decrease over time, especially for age three and older. ABG ranged from 0.532 to 1.41 kg m^{-2} with the highest AGB occurring in three year old fields. Belowground biomass (BGB) ranged from 0.2260 to 3.541 kg m^{-2}, with the highest biomass occurring in the eight year old field, which was nearly three times the average BGB (1.33 kg m^{-2}). The lowest BGB also occurred at a three year old site, however, the average lowest BGB occurred in the youngest switchgrass stand (one year). BGB displayed greater variability than AGB across all sites (coefficient of variance (CV) = 0.80; 0.27 respectively) and within each year (mean % difference between samples by year = 131%; 35% respectively). Total biomass, as the sum of AGB and BGB when both metrics were available, ranged from 1.17 to 4.30 kg m^{-2}. AGB and BGB were not correlated to each other (R^2= 0.04).

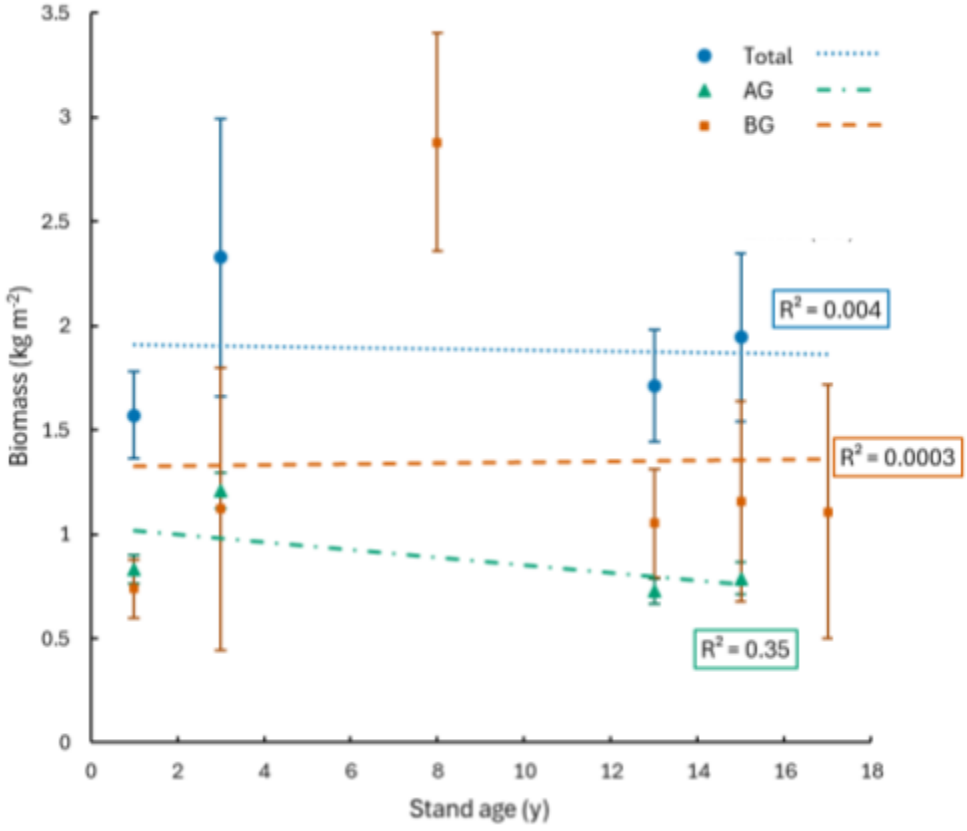


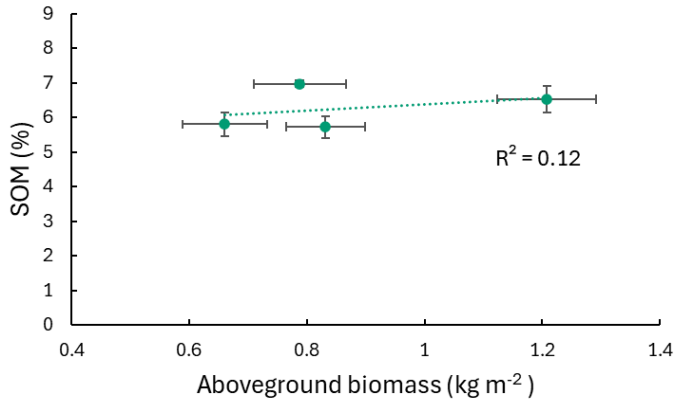
Fig. 6: Correlation of aboveground (AG), belowground (BG) and total switchgrass biomass with switchgrass stand age in northwestern PA. Less data are available for AG and total because two sites were mowed by the land managers prior to sampling.

SOM and Biomass

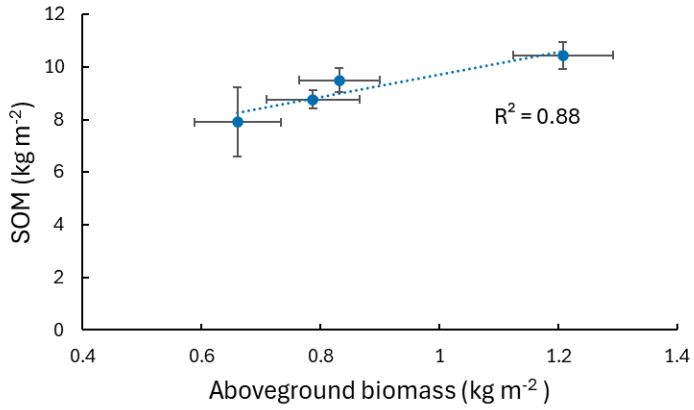
AGB exhibited a weak positive correlation with SOM concentration, and a stronger positive correlation with SOM mass. BGB had a significant positive correlation with SOM concentration (p=0.046), but no correlation with SOM mass (p=0.891). Total biomass exhibits a weak positive correlation with both SOM concentration and mass.

Aboveground biomass

(a)

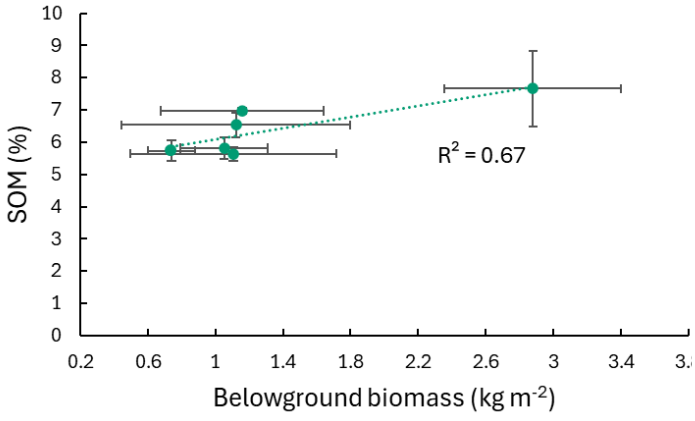


(b)

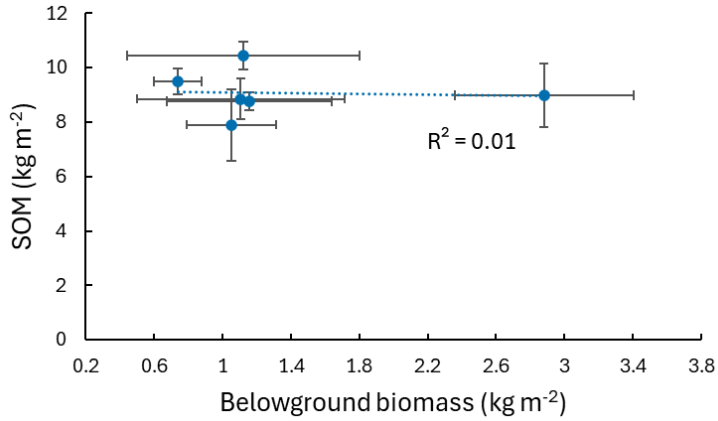


Belowground biomass

(c)



(d)



Total biomass

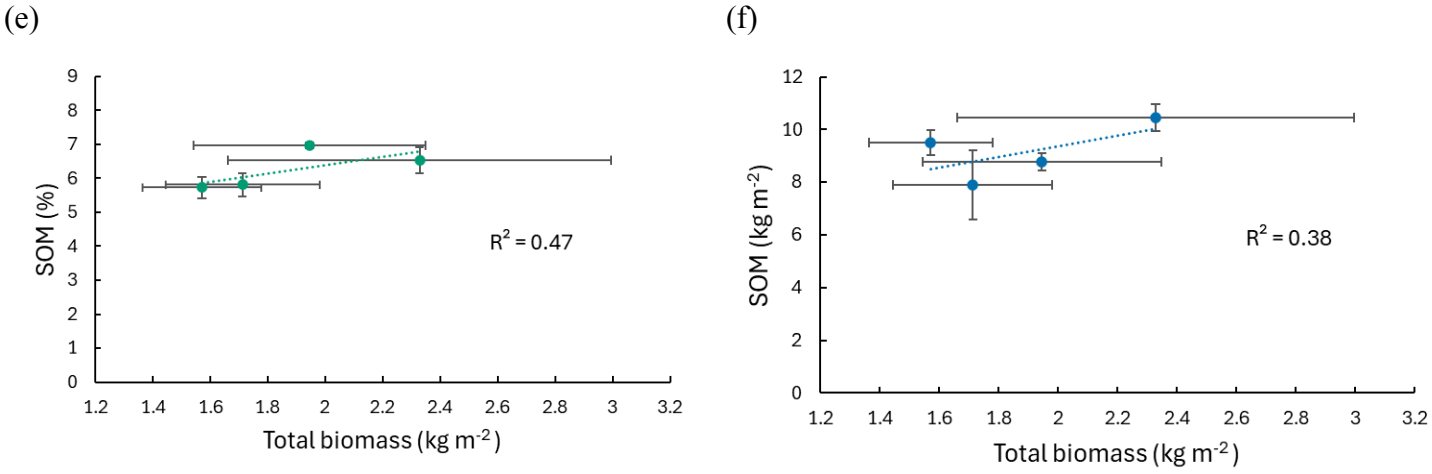


Fig. 7: Relationships between components of switchgrass biomass (aboveground (a-b), belowground (c-d), and total (e-f)) and SOM (concentration and mass). Less data are available for aboveground and total because two sites were mowed by the land managers prior to sampling.

Discussion

Soil Characteristics

SOM mass tended to decrease as switchgrass stand age increased; however, SOM concentration displayed no clear correlation with age. Theoretically, the difference in the trends of the two SOM metrics over time may stem from differences in bulk density. SOM is generally less dense than mineral soil and SOM improves aggregate stability (Magdoff & Van Es, 2021), so with increased SOM concentration, the bulk density of the soil is expected to decrease (Ruehlmann & Körschens, 2009). My collected data somewhat support this with a weak negative correlation between SOM concentration and bulk density. Comparatively, the correlation between SOM mass and bulk density was very weak. If increasing SOM concentration decreases bulk density, then although the portion of total soil mass that is SOM has increased, SOM mass will appear relatively lower because there is less total soil mass per volume.

Soil mass and bulk density had weak correlation with age, however the positive trends suggest an increase in density at greater age. Similarly, bulk density increased after five years of switchgrass cultivation in Nebraska (Schmer et al., 2011) and increased under some N

application rates after five years of cultivation in South Dakota (Lai et al., 2018). In contrast, bulk density decreased after five years of switchgrass cultivation in North and South Dakota (Schmer et al., 2011). Whereas the observed impact of switchgrass on soil bulk density seems variable, the observed increase in density in this study does not explain the negative correlation of SOM mass with age. Additionally, SOM concentration did not correlate with age, so SOM concentration may not be the primary factor influencing soil bulk density in this context. Another factor is the expected decrease of bulk density with the cessation of tillage following conversion from annual row crops to switchgrass, which applies to some field sites in this study.

Because the correlation between age and bulk density suggested a positive trend, bulk density is likely not a complete explanation for the decrease in SOM mass over time. Another potential explanation is priming, where adding organic material to the soil matrix changes the turnover rate of existing SOM pools (Kuzyakov et al., 2000). The result of priming can be a net decrease in SOM when the added SOM serves to stimulate microbial activity and increase SOM turnover rate (Kuzyakov et al., 2000). The establishment of switchgrass stands, especially in replacement of previously cropped fields, has the potential to increase C input through greater C allocation to roots and root exudates (Agostini et al., 2015; Jackson et al., 2017), which can in turn destabilize existing SOM through priming, thus decreasing SOM mass (Chari et al., 2024).

In contrast to the observed decrease in SOM mass over time in this research, other studies found SOM mass to increase over time (Anderson-Teixeira et al., 2009), the increased average dissolved organic carbon (DOC) mass in years two and three of switchgrass trials in Michigan and Wisconsin (Li et al., 2022), and a significant increase in SOC under switchgrass after nine years in Ontario (Barzgar et al., 2020). Despite these cases of SOM increase, other research is in agreement with my results and has found similar decreases in SOC stocks when agricultural sites were converted to switchgrass for one to four years in Virginia (Pryatel, 2015) and decreases in POM C after two years in West Virginia (Grover et al., 2024). It is possible that if given more time, switchgrass could accrue SOM to a level similar to that seen under grasslands because the chronosequence in this study, a range of 16 years, falls vastly short of the ~350 years estimated for total C steady state recovery under restored grassland conditions (Rosenweig et al., 2016).

The finding that SOM concentration was not correlated to age is in contrast to some previous studies, but is in agreement with others. A meta-analysis by Anderson-Teixeira, et al. (2009) found that SOC in the upper 30 cm of soil tended to increase with switchgrass age,

however they also note that SOC accumulation in previous cropland may be due to the cessation of tillage. Switchgrass had no significant effect on SOC concentration at 0-10 cm or 10-30 cm depths over six years in Illinois, though POM-C increased in the upper 10 cm of soil in the study (Kantola et al., 2017). SOC differences were not significant after five years of switchgrass cultivation in Kansas, though mean differences between switchgrass and row crops were more notable at 7.5-15 cm depth (Evers et al., 2013).

Soil depth has factored into SOM accumulation observed in other studies. SOC concentration and mass over time have increased over time, but only for medium to high N input treatments and only in the top 0-5 cm of soil (Lai et al., 2018). In contrast, Evers et al. (2013) suggest more notable accumulation at slightly deeper depths. My samples were 0-15 cm in depth, so if SOM increased as seen by Lai et al. in the upper 5 cm, the change could have easily been masked by SOM decrease or stability in the 5-15 cm depth portion of the sample. The same could be true if SOM increase was present in the 7.5-15 cm depth portion as per Evers et al. and not the shallower half. This variability could relate to climate and leaching of SOM as DOC (Agostini et al., 2015).

By nature of the coincidental time series provided by decades of expanding switchgrass cultivation, the equivalence of certain factors important to SOM could not be guaranteed across all sites. All sites were within Crawford County, PA, so although they have the same climate, underlying geology, and similar soils, there are local differences in topography, soil texture and composition, land management history, and soil microbial communities. Topographic position is a significant predictor of SOC concentration and mass (Lai et al., 2018). Soil heterogeneity can drive SOC variation (Martinez-Feria & Basso, 2020) and Anderson-Teixeira et al. (2009) highlight the pattern of clay content reducing net SOC change. The previous land use can influence the initial SOM levels as well as influence soil and microbial factors that control SOM stability (Anderson-Teixeira et al., 2009; Evers et al., 2013; Grover et al., 2024).

The SOM concentration found at sites in this study (5-9%) exceeds the typical concentration of SOM in agricultural topsoil ranges (1-6%; Magdoff & Van Es., 2021). SOM accumulation under switchgrass can be greater where SOM is initially low (Evers et al., 2013), so it is conceivable that somewhat elevated SOM concentrations of sites in this study reduced the potential for relative change. Alternatively, if SOM did accumulate under switchgrass fields, it may have reached a point of saturation instead of continued accumulation (Stewart et al., 2007).

Although there was no apparent positive association between SOM concentration and the age of switchgrass stands, it is worth noting that there was not a strong negative association as is found with repeated conventional annual cropping systems (Anderson-Teixeira et al., 2009).

Biomass

AGB tended to decrease as stand age increased, especially after the first year of establishment. This is in keeping with findings of Jager et al. (2010). As reviewed by Parrish and Fike (2005), switchgrass stands can take up to three years to reach full establishment. Indeed, the maximum average AGB was from the three year old stand in this study. The maximum AGB yield observed (14.1 Mg ha^{-1}) was half the general maximum yield (28 Mg ha^{-1}) reported in the literature (Jager et al., 2010).

BGB was not correlated with age. However, the lowest BGB occurred at the youngest site (age = 1 y), which meets expectations that lowest BGB will occur in the first year of stand establishment (Parrish & Fike, 2005). Though the majority of switchgrass roots were expected to be located in the upper 15 cm of soil, this sampling depth does not exhaustively capture all BGB (Waidelich personal observation; Parrish & Fike, 2005). Although these potential differences in root depth were not reflected in my collected data, the greatest root density did appear to be in the upper 15 cm of soil.

As with SOM, biomass was potentially influenced by variables outside the scope of this study. N availability is an important factor of aboveground growth (Agostini et al., 2015) and the rate and frequency of N application varied between sites (G. Kedzierski, personal communication, 2024). Other variable factors influencing switchgrass productivity may include weed competition (Parrish & Fike, 2005; Yatso, 2011), mycorrhizal symbiosis (Baysal & Walker, 2023; Parrish & Fike, 2005) and soil nutrients, texture and water-holding capacity (Parrish and Fike, 2005). While the predominant soils in the fields sampled for this study were all silt loams, they were not all the same soil series (NRCS Soil Survey Staff, 2024), thus adding variability to soil physical and chemical conditions between and within sites. Additionally, there are known and unknown differences between field history in terms of previous crops, management strategies, and other land uses.

SOM and biomass

AGB was harvested from the fields each year, so it contributes minimally to SOM through litter input. Despite this constraint, AGB displayed a positive correlation with SOM mass and a weak positive correlation with SOM concentration. Aboveground productivity could indirectly support C input through increased photosynthetic activity and root exudates (Chari et al., 2024). It is also possible that instead of increased AGB contributing to SOM, higher SOM may have supported greater AGB through improvement of soil aggregates, nutrients, or water-capacity (Magdoff & Van Es., 2021; Parrish & Fike, 2005).

Belowground biomass is expected to contribute to SOM through root turnover and exudates (Agostini et al., 2015; Jackson et al., 2017; Martinez-Feria & Basso, 2020). Despite a significant positive correlation observed between BGB and SOM concentration, no correlation was observed between BGB and SOM mass. BGB did have a weak negative correlation with bulk density ($R^2 = 0.35$) that was stronger than the correlation between stand age and bulk density. A potential explanation of the observed results could therefore be that increased BGB increased SOM additions through higher levels of root turnover and exudates such that the resulting increase in SOM concentration, or the greater BGB in and of itself, caused bulk density to decrease. This suggests that the argument for decreasing bulk density creating an apparent decrease in SOM mass may be fitting to explain the lack of correlation between BGB and SOM mass in contrast to the positive correlation between BGB to SOM concentration. Additionally, BGB composition, size, and shape influence decomposition and turnover, thus adding complexity to the relationship between BGB and C inputs (Agostini et al., 2015).

Total biomass displayed moderate positive correlations with both SOM concentration and mass, which is expected as the correlation to SOM concentration appears to be predominantly driven by BGB and the correlation to SOM mass by AGB. In light of the different relationships to SOM exhibited by the two biomass components, the strength of the relationship between total biomass and either SOM concentration or mass is limited by the lack of correlation between AGB and BGB.

Conclusion

SOM is a complex soil parameter that does not appear to be strongly predicted by switchgrass stand age in this study. Tracking SOM levels over longer periods of time may reduce the impact of site-specific history and conditions and may reveal eventual SOM increase. Above and belowground biomass tend to positively correlate with SOM with BGB more strongly connected to SOM concentration and AGB more associated with SOM mass. Importantly, maintenance of SOM under perennial switchgrass cultivation at greater concentrations than expected under conventional row crop agriculture was demonstrated in this study. The understanding of the dynamic ecosystem relationships controlling SOM continues to evolve, and this research provides an examination of part of the larger picture still being uncovered.

References

Agostini, F., Gregory, A. S., & Richter, G. M. (2015). Carbon sequestration by perennial energy crops: Is the jury still out? *BioEnergy Research*, *8*(3), 1057–1080. https://doi.org/10.1007/s12155-014-9571-0

Ahrens, C. W., Meyer, T. H., & Auer, C. A. (2014). Distribution models for Panicum virgatum< (Poaceae) reveal an expanded range in present and future climate regimes in the northeastern United States. *American Journal of Botany*, *101*(11), 1886–1894. https://doi.org/10.3732/ajb.1400047

Anderson-Teixeira, K. J., Davis, S. C., Masters, M. D., & Delucia, E. H. (2009). Changes in soil organic carbon under biofuel crops. *GCB Bioenergy*, *1*(1), 75–96. https://doi.org/10.1111/j.1757-1707.2008.01001.x

Banning, N. C., Grant, C. D., Jones, D. L., & Murphy, D. V. (2008). Recovery of soil organic matter, organic matter turnover and nitrogen cycling in a post-mining forest rehabilitation chronosequence. *Soil Biology and Biochemistry*, *40*(8), 2021–2031. https://doi.org/10.1016/j.soilbio.2008.04.010

Bazrgar, A. B., Ng, A., Coleman, B., Ashiq, M. W., Gordon, A., & Thevathasan, N. (2020). Long-Term monitoring of soil carbon sequestration in woody and herbaceous bioenergy crop production systems on marginal lands in southern Ontario, Canada. *Sustainability*, *12*(9), 3901. https://doi.org/10.3390/su12093901

Blanco-Canqui, H. (2016). Growing dedicated energy crops on marginal lands and ecosystem services. *Soil Science Society of America Journal*, *80*(4), 845–858. https://doi.org/10.2136/sssaj2016.03.0080

Blanco‐Canqui, H., Mitchell, R. B., Jin, V. L., Schmer, M. R., & Eskridge, K. M. (2017). Perennial warm‐season grasses for producing biofuel and enhancing soil properties: An alternative to corn residue removal. *GCB Bioenergy*, *9*(9), 1510–1521. https://doi.org/10.1111/gcbb.12436

Bock, J. H., & Bock, C. E. (1998). Tallgrass prairie: Remnants and relicts. *Great Plains Research*, *8*(2), 213–230. JSTOR. https://doi.org/10.2307/23778875

Bowden, R. (2025, February 18). *Rock density calculations* [Email to Elsa Waidelich].

Brasher, J. H., Boone, E., Delaney, D., Gamble, A., Monks, D., & Bruckner, S. (2021). Use of Halophytes to Manage Soil Characteristics in Joint Use Environments. *OnePetro*. https://onepetro.org/NACECORR/proceedings-abstract/CORR21/9-CORR21/463894

Chari, N. R., Tumber-Dávila, S. J., Phillips, R. P., Bauerle, T. L., Brunn, M., Hafner, B. D., Klein, T., Obersteiner, S., Reay, M. K., Ullah, S., & Taylor, B. N. (2024). Estimating the global root exudate carbon flux. *Biogeochemistry*, *167*(7), 895–908. https://doi.org/10.1007/s10533-024-01161-z

Dykstra, B., Iverson, A., Jacobs, K., Kinzel, A., Moore, K., & Raman, R. (2019). *Emerging markets for switchgrass in the US Midwest: Challenges and opportunities*. CenUSA Bioenergy.

Ecker, G., Zalapa, J., & Auer, C. (2015). Switchgrass (Panicum virgatum L.) genotypes differ between coastal sites and inland road corridors in the northeastern US. *PLOS ONE*, *10*(6), e0130414. https://doi.org/10.1371/journal.pone.0130414

Evers, B. J., Blanco‐Canqui, H., Staggenborg, S. A., & Tatarko, J. (2013). Dedicated Bioenergy Crop Impacts on Soil Wind Erodibility and Organic Carbon in Kansas. *Agronomy Journal*, *105*(5), 1271–1276. https://doi.org/10.2134/agronj2013.0072

Fenton, M., Albers, C., & Ketterings, Q. (2008). *Agronomy fact sheet series: Soil organic matter*. Cornell University Cooperative Extension. https://franklin.cce.cornell.edu/resources/soil-organic-matter-fact-sheet

Flint, S. A., Jordan, N. R., & Shaw, R. G. (2018). Plant community response to switchgrass (Panicum virgatum) population source in establishing prairies. *Ecological Applications*, *28*(7), 1818–1829. https://doi.org/10.1002/eap.1772

Grover, S., Anderson, H. M., Fleck, J., Kelly, C. N., Schuler, J., Ruark, M. D., & Freedman, Z. B. (2024). Early production of switchgrass (Panicum virgatum L.) and willow (Salix spp.) indicates carbon accumulation potential in Appalachian reclaimed mine and agriculture soil. *Soil Science Society of America Journal*, *88*(3), 602–619. https://doi.org/10.1002/saj2.20647

Gunina, A., & Kuzyakov, Y. (2022). From energy to (soil organic) matter. *Global Change Biology*, *28*(7). https://doi.org/10.1111/gcb.16071

Haddix, M. L., Gregorich, E. G., Helgason, B. L., Janzen, H., Ellert, B. H., & Francesca Cotrufo, M. (2020). Climate, carbon content, and soil texture control the independent formation

and persistence of particulate and mineral-associated organic matter in soil. *Geoderma*, *363*, 114160. https://doi.org/10.1016/j.geoderma.2019.114160

Jackson, R. B., Lajtha, K., Crow, S. E., Gustaf Hugelius, Kramer, M. G., & Gervasio Piñeiro. (2017). The Ecology of Soil Carbon: Pools, Vulnerabilities, and Biotic and Abiotic Controls. *Annual Review of Ecology Evolution and Systematics*, *48*(1), 419–445. https://doi.org/10.1146/annurev-ecolsys-112414-054234

Jacobson, M. (2024). *Energy crop profile: Switchgrass*. PennState Extension; College of Agricultural Sciences of the Pennsylvania State University. https://extension.psu.edu/energy-crop-profile-switchgrass

Jager, H. I., Baskaran, L. M., Brandt, C. C., Davis, E. B., Gunderson, C. A., & Wullschleger, S. D. (2010). Empirical geographic modeling of switchgrass yields in the United States. *GCB Bioenergy*, *2*(5), 248–257. https://doi.org/10.1111/j.1757-1707.2010.01059.x

Juyal, A., Guber, A., Oerther, M., Quigley, M., & Kravchenko, A. (2021). Pore architecture and particulate organic matter in soils under monoculture switchgrass and restored prairie in contrasting topography. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-021-01533-7

Kantola, I. B., Masters, M. D., & DeLucia, E. H. (2017). Soil particulate organic matter increases under perennial bioenergy crop agriculture. *Soil Biology and Biochemistry*, *113*, 184–191. https://doi.org/10.1016/j.soilbio.2017.05.023

Kedzierski, G. (2024, December 3). *Field inputs* [Email to Elsa Waidelich].

Kim, J., Liu, Y.-M., Zhang, X., Zhao, B., & Childs, K. L. (2016). Analysis of salt-induced physiological and proline changes in 46 switchgrass (Panicum virgatum) lines indicates multiple response modes. *Plant Physiology and Biochemistry*, *105*, 203–212. https://doi.org/10.1016/j.plaphy.2016.04.020

Kuzyakov, Y., Friedel, J. K., & Stahr, K. (2000). Review of mechanisms and quantification of priming effects. *Soil Biology and Biochemistry*, *32*(11-12), 1485–1498. https://doi.org/10.1016/s0038-0717(00)00084-5

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

Li, X., Petipas, R. H., Antoch, A. A., Liu, Y., Stel, H. V., Lukas Bell‐Dereske, Smercina, D. N., Bekkering, C. S., Evans, S. E., Tiemann, L. K., & Friesen, M. (2022). Switchgrass cropping systems affect soil carbon and nitrogen and microbial diversity and activity on marginal lands. *Gcb Bioenergy*, *14*(8), 918–940. https://doi.org/10.1111/gcbb.12949

Lovell, J. T., MacQueen, A. H., Mamidi, S., Bonnette, J., Jenkins, J., Napier, J. D., Sreedasyam, A., Healey, A., Session, A., Shu, S., Barry, K., Bonos, S., Boston, L., Daum, C., Deshpande, S., Ewing, A., Grabowski, P. P., Haque, T., Harrison, M., & Jiang, J. (2021). Genomic mechanisms of climate adaptation in polyploid bioenergy switchgrass. *Nature*, *590*(7846), 438–444. https://doi.org/10.1038/s41586-020-03127-1

Magdoff, F., & Van Es, H. (2021). Organic matter: What is it and why is it so important. In *Building Soils for Better Crops: Ecological Management for Healthy Soils* (pp. 13–30). Sustainable Agriculture Research and Education (SARE). https://www.sare.org/resources/building-soils-for-better-crops/

Manlay, R. J., Feller, C., & Swift, M. J. (2007). Historical evolution of soil organic matter concepts and their relationships with the fertility and sustainability of cropping systems. *Agriculture, Ecosystems & Environment*, *119*(3-4), 217–233. https://doi.org/10.1016/j.agee.2006.07.011

Martín-Lammerding, D., Gabriel, J. L., Zambrana, E., Santín-Montanyá, I., & Tenorio, J. L. (2021). Organic amendment vs. mineral fertilization under minimum tillage: Changes in soil nutrients, soil organic matter, biological properties and yield after 10 years. *Agriculture*, *11*(8), 700–700. https://doi.org/10.3390/agriculture11080700

Martinez‐Feria, R., & Basso, B. (2020). Predicting soil carbon changes in switchgrass grown on marginal lands under climate change and adaptation strategies. *GCB Bioenergy*, *12*(9), 742–755. https://doi.org/10.1111/gcbb.12726

National Agricultural Statistics Service (NASS). (2025). *Quick Stats: Census: Crops: Field crops: Switchgrass* (2022) [Data set]. United States Department of Agriculture (USDA).

Natural Resources Conservation Service (NRCS). (2006). *Plant fact sheet: Switchgrass Panicum virgatum L*. In https://plants.usda.gov/DocumentLibrary/factsheet/pdf/fs_pavi2.pdf. United States Department of Agriculture Natural Resources Conservation Service.

NRCS Soil Survey Staff. (2024). *Web Soil Survey*. Natural Resources Conservation Service, United States Department of Agriculture. http://websoilsurvey.sc.egov.usda.gov/

Parrish, D. J., & Fike, J. H. (2005). The biology and agronomy of switchgrass for biofuels. *Critical Reviews in Plant Sciences*, *24*(5-6), 423–459. https://doi.org/10.1080/07352680500316433

Pyratel, M. J. (2015). *The influence of switchgrass establishment on soil organic matter pools in an agricultural landscape* [MSc Thesis]. https://vtechworks.lib.vt.edu/server/api/core/bitstreams/b1aca70c-7e74-4a38-8a6c-32011f2391a2/content

Renz, M., Undersander, D., & Casler, M. (2009). *Establishing and managing switchgrass*. University of Wisconsin-Madison Extension; Team Forage Division of Extension. https://fyi.extension.wisc.edu/forage/establishing-and-managing-switchgrass/

Rosenzweig, S. T., Carson, M. A., Baer, S. G., & Blair, J. M. (2016). Changes in soil properties, microbial biomass, and fluxes of C and N in soil following post-agricultural grassland restoration. *Applied Soil Ecology*, *100*, 186–194. https://doi.org/10.1016/j.apsoil.2016.01.001

Ruehlmann, J., & Körschens, M. (2009). Calculating the effect of soil organic matter concentration on soil bulk density. *Soil Science Society of America Journal*, *73*(3), 876–885. https://doi.org/10.2136/sssaj2007.0149

Schmer, M. R., Liebig, M. A., Vogel, K. P., & Mitchell, R. B. (2011). Field-scale soil property changes under switchgrass managed for bioenergy. *GCB Bioenergy*, *3*(6), 439–448. https://doi.org/10.1111/j.1757-1707.2011.01099.x

Stewart, C. E., Paustian, K., Conant, R. T., Plante, A. F., & Six, J. (2007). Soil carbon saturation: concept, evidence and evaluation. *Biogeochemistry*, *86*(1), 19–31. https://doi.org/10.1007/s10533-007-9140-0

Wang, E., Cruse, R. M., Sharma‐Acharya, B., Herzmann, D. E., Gelder, B. K., James, D. E., Flanagan, D. C., Blanco‐Canqui, H., Mitchell, R. B., & Laird, D. A. (2020). Strategic switchgrass (Panicum virgatum) production within row cropping systems: Regional‐scale assessment of soil erosion loss and water runoff impacts. *GCB Bioenergy*, *12*(11), 955–967. https://doi.org/10.1111/gcbb.12749

Wright, L. (2007). *Historical perspective on how and why switchgrass was selected as a "model" high-potential energy crop.* Bioenergy Resources and Engineering Systems Environmental Sciences Division.

https://www.energy.gov/eere/bioenergy/articles/switchgrass-high-potential-energy-crop#:~:text=Economic%20and%20environmental%20assessments%20by,as%20a%20%E2%80%9Cmodel%E2%80%9D%20or%20%E2%80%9C