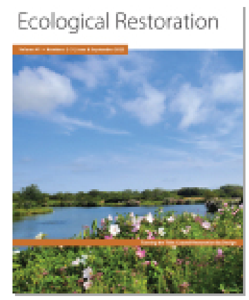
The Use of Dredged Sediments as a Soil Amendment for Improving Plant Responses in Prairie Restorations



Maureen E. Roddy, William E. Viney, Corry T. Platt, Megan A. Rúa

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(Timpane-Padgham et al. 2017). Future disturbances such as climate change and loss of *Fraxinus* spp. due to *Agrilus planipennis* (emerald ash borer) are likely to shift forest composition (Hufnagel and Garamvolgyi 2014, Herms et al. 2007) and create gaps where species with appropriate plant functional traits can establish alternative stable states (Fukami 2015, Perez-Hernandez and Gavilan 2021). The continued tree growth, low annual mortality and increase in diversity metrics suggest this restoration is on a trajectory to meet the goal of becoming a mature maple-basswood forest, able to adapt to environmental changes.

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The Use of Dredged Sediments as a Soil Amendment for Improving Plant Responses in Prairie Restorations

Maureen E. Roddy (Wright State University, Department of Biological Sciences, Dayton, OH, USA), William E. Viney (Wright State University, Department of Biological Sciences, Dayton, OH, USA), Corry T. Platt (Geosyntec Consultants, Raleigh, NC, USA) and Megan A. Rúa (corresponding author: Department of Biological Sciences, Wright State University, 3640 Colonel Glenn Hwy, Dayton, OH, 45435, USA, ORCID: 0000-0002-2883-2795, megan.rua@wright.edu)

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Grasslands are said to support 70% of the world's agricultural lands (Török et al. 2021). Only 4% of the original 66 million hectares of tall grass prairies in North America are still present (DeLuca and Zabinski 2011). The conversion from grassland to cropland has disrupted ecosystem functions leading to reduced soil organic matter, accelerated nutrient cycling, and compacted soils (Rosenzweig et al. 2016). Currently, former croplands are being converted back to grasslands and prairies to improve soil properties and re-establish the ecosystem services provided by soils including biodiversity, erosion control, and greenhouse gas mitigation (Rosenzweig et al. 2016, Farrell et al. 2020, Török et al. 2021).

One of the complications for restoring previously farmed lands to grasslands is the negative effect traditional agriculture has on soils including accelerated soil erosion, environmental pollution, and loss of organic matter (Lal 2015). To combat degradation, soil amendments can be added to improve restoration success (Farrell et al. 2020). Previous research suggests that successful restorations ultimately rely on soil manipulations that increase microbial activity, leading to increases in soil nutrient availability and ultimately successful plant performance (Ohsowski et al. 2012). Dredged sediments, or sediments removed (dredged) from waterways, represent a potential soil amendment because they are often rich in the nutrients and minerals that plants need (Darmody and Marlin 2002, Vermeulen et al. 2003) and contain microbes that stimulate nutrient cycling (Rúa et al. 2023). These sediments have been applied successfully in several agricultural systems (Canet et al. 2003, Daniels et al. 2007, Darmody and Diaz 2017), but their effectiveness for improving restoration success for prairie ecosystems is largely unknown (but see Suedel et al. 2022).

Typical restoration goals include restoring ecosystem processes (i.e., nutrient cycling and soil stabilization), creating vegetative structure (i.e., percent cover, biomass, vegetative profiles) and/or achieving diversity indices (i.e., organism richness, abundance; Ruiz-Jaen and Mitchell Aide 2005). To understand the value of dredged sediments for achieving these goals when used for prairie restorations, we grew a mixture of prairie grass seeds used in restorations in the Midwest. We used five ratios of agricultural soil to dredged sediments to determine if prairie grasses would grow on agricultural soil amended with dredged sediments and what application rates would maximize the number of species that germinate and their biomass. We predicted the use of dredged sediments would increase the diversity of plants grown from a restoration mix when applied to agricultural soils and those plants would have larger biomass than those grown on pure agricultural soil due to the high organic matter and water holding capacity of dredged sediments.

Methods

To investigate the use of dredged sediments as a soil amendment in restorations, a prairie grass seed mix was grown across five ratios (100:0, 30:70, 50:50, 70:30, 0:100) of conventionally farmed agricultural soils to dredged sediments in a greenhouse experiment located at Wright State University (WSU) in Dayton, Ohio. Each treatment combination was replicated five times, totaling 25 pots (5 soil mixes × 5 replicates). Dredged sediments were obtained from the Black River, Lorain, Ohio. Sediments were hydraulically dredged from the federal navigation channel, rapidly dewatered using the GeoPool technology (Ellicott Dredge Technologies, LLC, New Richmond, WI, USA), and exposed to one seasonal (natural) freeze-thaw cycle. The sediments were largely silts (20% fine sands, 52% silt, 29% clay) with an organic matter content at 750°C of 7.4%. Agricultural farm soil was sourced from a conventionally farmed field in Lorain County, Ohio that is still actively farmed; the soil was largely silts (17% sand, 44% silt, 38% clay) with an organic matter content at 750°C of 5.8%. All materials were collected during the last week of March 2021 before being transported to WSU on 5 April 2021.

The sediments and soils were transported to Dayton and stored in the greenhouse for immediate use. Each ratio blend was made in a large batch and homogenized by hand. The ratios were then potted in 3.8 L pots (1-gallon) which weighed approximately 2.5 kg each. Each pot was planted on 26 April 2021 with 100 mL of prairie grass restoration seed mix (Type B Seed Mix, Ernst Conservation Seeds Inc., Meadville, PA). Mixes were allowed to grow in the WSU greenhouse (average 26.2°C with humidity at 41.03%) for an entire growing season (April–November 2021) before being placed outside to overwinter.

The number of species that germinated in each mix was assessed three times during the experiment: halfway through the growing season (July 2021, Survey Time 1), following the growing season (November 2021, Survey Time 2) and following overwintering (May 2022, Survey Time 3). At harvest, plants were sorted by species, dried at 60°C for 72 hours and weighed (g).

All analyses were conducted in R version 4.2.0 (R Core Team 2022). A generalized linear model with the Poisson distribution was used to determine if the number of species present in each pot differed by agricultural soil:dredged sediment ratio and time of assessment using the glm function from the stats package (R Core Team 2022). One-way ANOVA was used to determine if the Shannon Diversity Index, aboveground biomass, belowground biomass, total biomass and total biomass per species differed by soil:sediment ratio using the lm and anova functions from the stats package (R Core Team 2022). The Shannon Diversity Index was calculated using the diversity function from the vegan package (Oksanen et al. 2022).

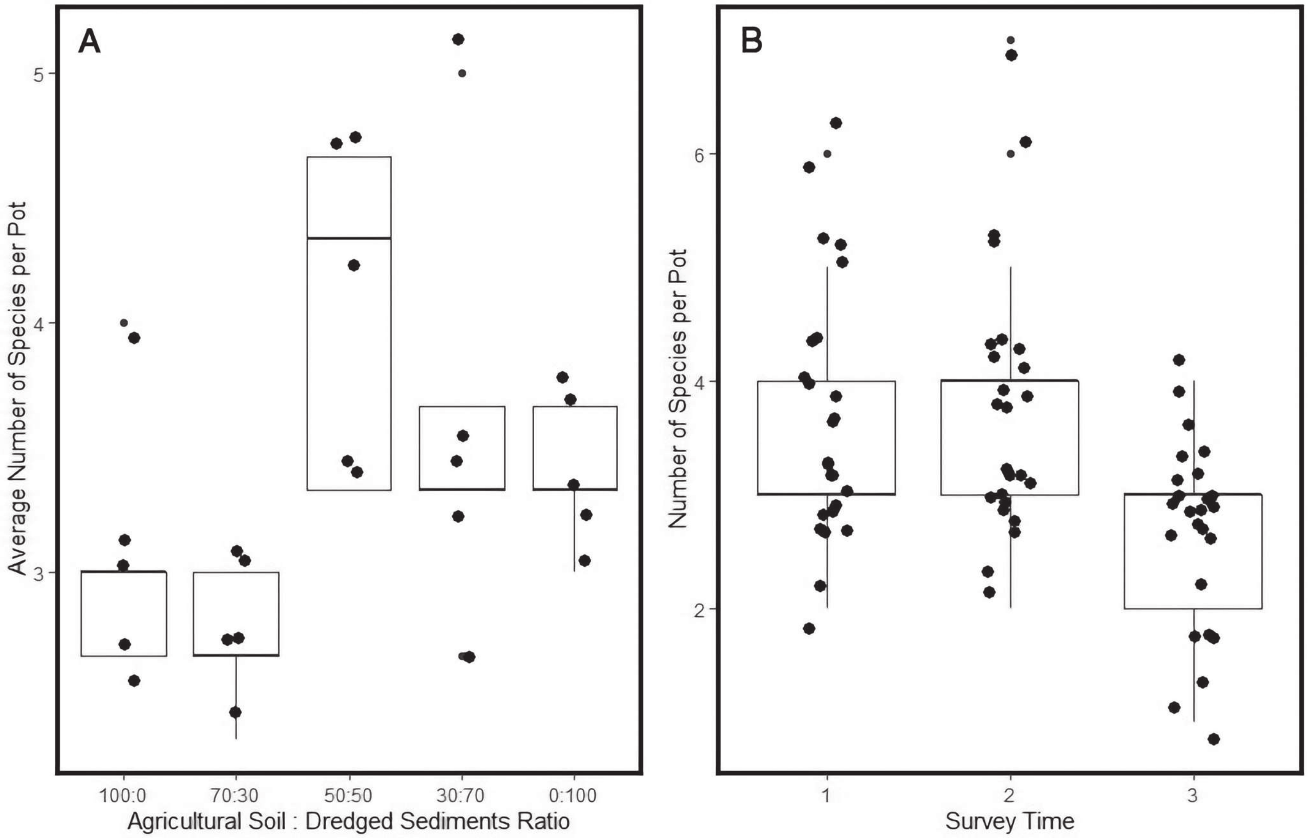

Figure 1. Box and whisker plots for A) average number of species present in pots planted with a prairie restoration mix when grown on varying ratios of agricultural soil to dredged sediments across time and B) number of species per pot by sampling time. Individual points represent raw data for individual pots with bars representing 95% confidence intervals and smaller points outliers. Points are jittered to avoid overlap.

Results

The number of species significantly differed by soil:sediment ratio (Figure 1A, p = 0.0009) and time (Figure 1B, $p <$ 0.0001), but not their interaction (p = 0.3779). Across collection time, the 50:50 ratio had the greatest number of species followed by the 30:70 and the 0:100 treatments (Figure 1A).

There were no statistically significant differences in the species composition present in one ratio compared to another, suggesting that each species had equal likelihood of being found in any of the treatments (p = 0.398). However, the overall Shannon diversity index, which considers not just the number of species present but also the distribution of those species, increased with increasing amounts of dredged sediments ($F_{4,20} = 3.436$, $p = 0.0271$). We had one plant germinate that was unidentifiable in the 70:30 soil:sediment treatment (Table 1). Of the 23 species present in the seed mix, 11 species did not germinate in any treatment: *Bouteloua curtipendula* (sideoats grama), *Festuca arundinacea* (tall fescue), *Elymus canadensis* (Canada wildrye), *Panicum virgatum* (switchgrass), *Sorghastrum nutans* (Indiangrass), *Andropogon geradii* (big bluestem), *Panicum clandestinum* (deertongue), *Agrostis perennans* (autumn bentgrass), *Melilolus officinalis* (yellow sweetclover), *Monarda fistulosa* (wild bergamont), *Agrimonia parviflora* (small-flowered agrimony), and *Geum canadense* (white avens). There was no germination from species absent from the seed mix, suggesting no external input from the seedbank in either the agricultural soil or the dredged sediments. A full species list of what germinated from the prairie mix can be found in Table 1, along with the percentage of pots for which those species germinated by agricultural soil:sediment ratio.

The biomass of plant material found in the pots was also responsive to the soil:sediment ratio (Figure 2). Total biomass of plant material was significantly greater in the 70:30 ratio compared to any other treatment ($F_{4,20} = 3.766$, p = 0.0193, Figure 2A). This was driven by changes in belowground biomass, which showed a similar pattern ($F_{4,20}$ = 9.645, p = 0.0002, Figure 2B), but not in aboveground biomass, which did not significantly differ by treatment ($F_{4,20} = 1.003$, $p = 0.4292$, Figure 2C).

When the weight of the plant material in each pot was adjusted for the number of species in each pot, there was still a significant effect of soil: sediment ratio ($F_{4,20} = 4.921$, $p = 0.0063$) such that biomass in the 70:30 ratio was significantly greater than plant material in the other treatments.

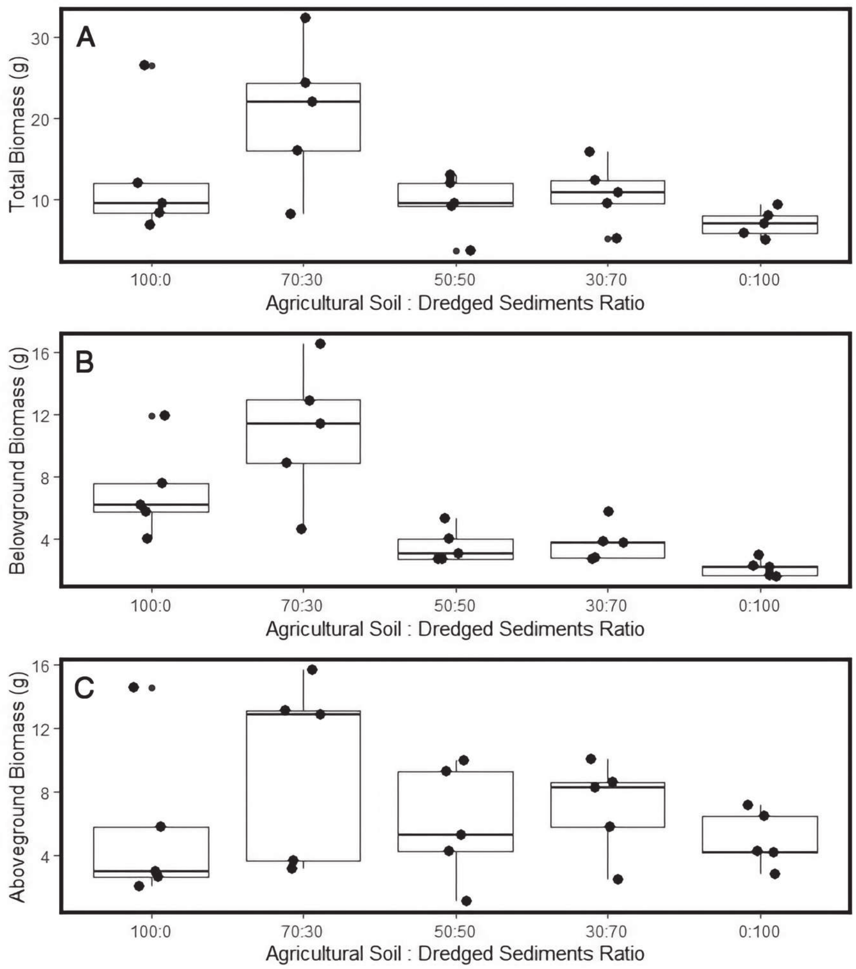

Figure 2. Box and whisker plots for A) total biomass, B) belowground biomass and C) aboveground biomass of plant material in pots planted with a prairie restoration mix over time when grown on varying agricultural soil:dredged sediment ratios. Points represent raw data for individual pots and are jittered to avoid overlapping. Bars represent 95% confidence intervals and smaller points reflect outliers.

Table 1. Percent of pots with each species from the prairie mix. Pots had varying agricultural soil:dredged sediment ratios. Values shown are percentages (%).

Plant Species	100:0	70:30	50:50	30:70	0:100
Ambrosia spp. (ragweed)	0	0	20	0	0
Asclepias syriaca (common milkweed)	0	20	20	0	20
Brassica spp. (mustard)	20	0	0	20	0
Chamaecrista fasciculata (partridge pea)	60	60	80	100	60
Coreopsis tinctoria (plains coreopsis)	0	0	40	20	40
*Helianthus maximiliani (*Maximillian's sunflower)	0	0	40	20	0
Trifolim repens (clover)	100	100	100	100	100
Secale cereale (rye)	0	0	0	0	40
Schizachyrium scoparium (little bluestem)	100	100	100	100	100
Solidago rugosa (wrinkleleaf goldenrod)	0	0	20	0	0
*Symphyotrichum leave (*smooth blue aster)	20	0	60	20	20
Unknown spp.	0	20	0	0	0

In general, our results suggest that dredged sediments that are high in organic matter provide a valuable amendment to enhance plant growth. This was particularly true when used in combination with agricultural soil from a traditionally farmed environment; growth in the amended soils consistently exceeded growth in the 100% dredged sediments and 100% agricultural soil treatments (Figure 1). Specifically, a 50:50 mix of existing soil and dredged sediments had the greatest diversity, but the treatments with high levels of dredged sediments (both the 0:100 and the 30:70 soil:sediment) also had high diversity, suggesting these applications are also appropriate for initial prairie restoration projects. While such projects are not common, land managers of riverfronts that have been damaged by industry and agriculture are increasingly attempting to naturalize their shorelines and restore wetlands, forests and prairies by replacing existing soils (Stanturf et al. 2001, Suedel et al. 2022). Our work suggests that the application of dredged sediments to agricultural soils could be an option for enhancing restoration success under certain conditions.

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Effects of Ridges and Furrows on Passive Vegetation Recovery in Oldfields

Matimu Mabunda (Department of Environmental Science, Rhodes University, Makhanda 6140, South Africa) and Sheunesu Ruwanza (corresponding author: Department of Environmental Science and Centre for Invasion Biology, Rhodes University, Makhanda 6140, South Africa, ruwanza@yahoo.com or s.ruwanza@ru.ac.za)

Agricultural land abandonment is on the increase in South Africa because of several socio-political (urban migration), economic (markets), and environmental (soil fertility) factors (Blair et al. 2018). Although the impacts of agricultural land abandonment are often viewed negatively (e.g., soil erosion, loss of livelihoods, and reduced agricultural productivity), ceasing agricultural activities presents opportunities for ecological restoration (Haddaway et al. 2013). Ecological restoration of abandoned agricultural lands (hereafter oldfields) has been shown to increase biodiversity, which in turn improves livelihoods and human wellbeing (Blair et al. 2018). For example, Mills and Cowling (2006) reported that planting *Portulacaria afra* in degraded oldfields in South Africa's Eastern Cape province increases carbon sequestration, reduces soil erosion, and improves water infiltration and retention. There is no doubt that ecological restoration of oldfields is important, yet little is known regarding the vegetation recovery

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