Inspired

Science for the Public Good

Spring 2026

University of New Hampshire
NH Agricultural Experiment Station

Soils Research Report

A New Hampshire Agricultural Experiment Station Publication

Message from the Director

Dear members of New Hampshire's agricultural, forestry, and natural resources conservation communities and beyond:

The food we grow, the forests that define our surroundings, and the plant and animal ecosystems that support our environments, our economics, and our lives are all inextricably tied to our soils. They often go unnoticed, but as scientific methods and tools improve, we are increasingly recognizing the impacts that our soils have on so much of our everyday lives, livelihoods, and landscapes, and the impacts that our actions can have on those soils.

For over a century, the New Hampshire Agricultural Experiment Station has recognized the importance of understanding how the Granite State's soils are unique and uniquely contribute to the state's food production, forest management, and natural resources. While New Hampshire's soils are historical artifacts of global events many millennia ago, they are also teeming with ever-changing life that Station researchers are helping discover, understand, and provide insights into how humans can best coexist and support these ecosystems in ways that are mutually beneficial.

The locally inspired research that you'll find in this issue provides findings and perspectives about how science is helping us better understand the roles of soils in our state and region, and how that understanding helps improve the management and improvement of our lands. The briefs focus on two themes: How can decisions about food production management help better support soil health and, in turn, improve agricultural productivity? And, what new discoveries and innovations are available to practitioners to better understand soil properties and characteristics? Each research brief offers a perspective about the rigorous science and impactful takeaways that advance New Hampshire's agriculture, forestry, and natural resources.

Thank you for supporting our efforts to improve the lives of every Granite Stater through locally inspired, impactful scientific discoveries.

Anton Bekkerman

Director, NH Agricultural
Experiment Station




Contents

Science for the public good

Locally inspired. Globally important.

The mission of the New Hampshire Agricultural Experiment Station (NHAES) is to ensure the resilience of the Granite State's diverse communities and local economies through high-stakes research, world-class science, and sustainable advancement. For over 130 years, we've served as the agricultural, food, natural resource, and environmental research arm of the UNH land-grant mission. From the lab to the field, forest, and sea, our researchers push scientific frontiers in pursuit of sustainable food production and natural resource management across New Hampshire and beyond.

Soil is fundamental to agricultural production and sustainable land management, and as the Dust Bowl of the 1930s showed, supporting the growing U.S. population would require thoughtful, forward-looking, and science based approaches to successfully steward the country's food system and natural resources. The creation of the USDA Soil Conservation Service (now the Natural Resources Conservation Service) in 1935 signaled the country's commitment to public research and implementation of this approach. Today, food producers and land managers know that maintaining healthy soils enables resiliency for both short-term and long-term benefits from the land. Yet, the more that soils are studied, the more researchers understand that there are many more lessons that can be learned about ways that healthy, well-managed soils help reduce crop losses, protect food systems from unexpected weather events, and create conditions that help manage long-term production uncertainties.

Scientific discovery based in modern methods, highly integrated with input and contributions from producers and surrounding communities, will be key to continuing to build strong, data-informed capacity for a resilient agricultural sector and thoughtful land management in the Granite State. Station researchers are helping move forward these discoveries, which are, in turn, increasing the tools and strategies for practitioners and setting industry standards and policies that ensure that New Hampshire's land owners and agricultural producers are able to sustain the state's food- and eco-sytems far into the future.

Bottom left, a researcher collects samples for the Frey lab's research into how microbial communities react to stressors in warming soils. Right, soil samples collected by the Ernakovich lab provide insights into the roles of soil microbes in carbon cycling and nutrient turnover. Bottom right, soil research in the Grandy lab.

Soil impacts of cover crops: mixtures versus single species

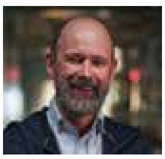
I. A. de Souza, A. B. Daly, J. Schnecker, N. D. Warren, A. R. Lobo Jr, R. G. Smith, A. F. Brito, and A. S. Grandy

Key takeaways

Seasonal cover crops showed limited short-term effects on soil carbon and nitrogen dynamics.

No significant differences were observed between cover crop mixtures and monocultures during the growth period.

Temporal variation in microbial biomass carbon and nitrogen was more pronounced than treatment effects.



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Cover crops are increasingly valued for improving soil health, and farmers are also looking to a mixture of cover crops because of the perceived advantages. However, there is continued uncertainty about the short-term benefits of using a single crop species or mixtures, and whether the potential increased costs and management needs of using a mixture are justified. Providing evidence of significant impacts or lack thereof could aid agricultural producers in making informed, optimal decisions in their sustainable production systems.

Cover crop options

The use of cover crops in agricultural systems has been shown to help prevent soil erosion, enhance soil organic matter, increase soil carbon sequestration, and increase nutrient availability. Mixtures of species are often thought to provide greater benefits by increasing plant diversity, improving resource capture, and supporting soil microbial communities. While this is often the case over a longer time period in perennial crop systems, the short growth periods of annual cover crops may lead to a limited set of these benefits.

The uncertainty in short-period cover crop mixture benefits could be because cover crops are grown for a substantially shorter amount of time, precluding the cover mixtures from fully activating microbial communities responsible for nutrient cycling. Additionally, seasonal variability in temperature, precipitation, and plant growth can further drive fluctuations in cover crop mixture impacts on soil health.

Testing cover crop types

Field experiments were conducted at the UNH's Kingman Research Farm, comparing monoculture cover crops, five- or six-species mixtures, and a 14-species mixture in each cover crop growing season niche (winter/spring, summer, and fall). Treatments included either individually planted species or a mixture of combinations of eight species of annual cool-season and warm-season grasses, three legumes, and three nonlegume forbs.

The study design was a randomized complete block with treatment levels (cover crop monocultures or mixes) replicated across four blocks. Soils were sampled at various stages of cover crop growth, and soil microbial biomass carbon (MBC) and nitrogen (MBN), and total soil carbon (C) and nitrogen (N) were measured.

The results found no significant differences in soil C, N, MBC, or MBN between cover crop mixtures and monocultures (**Table 1**). Temporal changes, rather than differences in mixtures, dominated the results. For example, in the summer group, MBC peaked mid-season before declining sharply, while MBN showed a similar trend. These fluctuations were likely driven by environmental factors and plant growth stages rather than cover crop composition.

Mixtures did not consistently outperform monocultures in improving soil properties, aligning with previous research suggesting limited short-term benefits of species diversity in annual systems. The lack of differences between cover crop treatments and the weedy fallow control further highlights the challenges of achieving rapid soil improvements through short-duration cover cropping.

Strategic recommendations and conclusion

While this study suggests limited short-term benefits of cover crop mixtures over monocultures, the results underscore the importance of long-term experiments to fully understand their impacts. This study differed from many previous ones because its measurements were taken during active cover crop growth, prior to when cover crop residues began decomposing. As such, it could be that the only cover-crop derived inputs to the soil during the study period were in the form of fine root turnover and root exudates, which may indicate that these two factors may not be strong drivers of C and N in the soil, or microbial communities, while cover crops are alive and actively growing.

Future research will be needed to better understand interactions between cover crop species, soil microbial dynamics, and environmental variables across diverse cropping systems and time periods.

Table 1. Average of nitrogen (N), carbon (C), carbon/nitrogen ration (C:N), microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) of soil samples collected in the fall group of cover crop treatments.

Variable	Forage Radish	Oats	Canola	Wheat	Triticale	Crotalaria	Six-species mixture	14-species Mixture	Fallow	SEM	*p* value
N (mg g^{-1} dry soil)	0.139	0.142	0.151	0.137	0.137	0.143	0.146	0.151	0.147	0.004	0.088
C (mg g^{-1} dry soil)	1.6	1.56	1.67	1.48	1.55	1.60	1.64	1.71	1.61	0.044	0.058
C:N	11.6	11.2	11.3	11.0	11.4	11.2	11.4	11.5	11.2	0.160	0.324
MBC (pg g^{-1} soil)	554.9	559.9	595.5	540.2	482.5	563.7	533.0	550.9	553.4	36.450	0.700
MBN (pg g^{-1} soil)	25.5	25.2	25.6	25.2	19.2	19.7	24.7	25.1	23.4	2.456	0.436

Notes: Means followed by different letters in the same row differ at 5% significance by Tukey's HSD test. SEM refers to the standard error of the mean.

The influence of tillage and pesticide-treated crop seeds on beneficial arthropods

I. N. Ativor, N. D. Warren, and R. G. Smith

Key takeaways

No-till and strip-till systems promote more abundant beneficial arthropod communities than full-tillage systems.

Weed seed predation by arthropods was three-times higher in reduced-tillage systems compared to the full-tillage system.

Effects of pesticide-treated seeds on arthropod communities were inconsistent, yet detectable, even late in the cropping season.

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There's growing evidence from across the world that farming practices can play a critical role in maintaining soil health and the resilience of agricultural ecosystems. Tillage and pesticide-treated seeds are common management practices in many agricultural systems, but they may impact the beneficial organisms that contribute to soil health and agroecosystem resilience. Testing and understanding these impacts can provide important information for developing more sustainable agricultural practices.

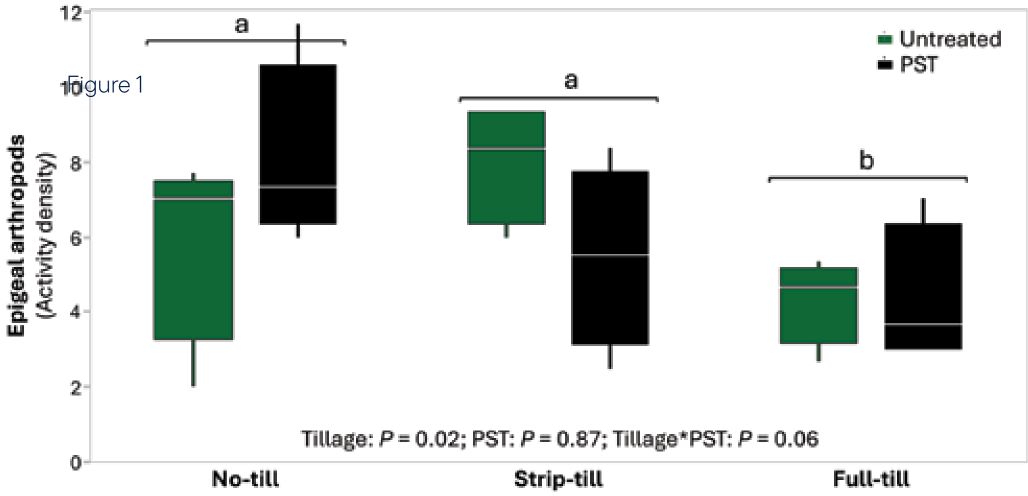

Figure 1. Boxplots showing activity densities of the total epigeal arthropod community sampled in 2018. Data are displayed for both the tillage and pesticide treatments due to the relatively low p-value for the tillage*PST interaction ($p = 0.06$). Tillage treatments sharing the same letter are not different at $p < 0.05$ (Tukey's HSD test).

Background and key concepts

Epigeal arthropods such as ground beetles, ants, and spiders contribute valuable ecosystem services, including pest control and weed seed predation. Weed seed predation reduces weed populations and could reduce the need for herbicides. Tillage intensity and pesticide seed treatments (PSTs), while effective for crop protection, can disrupt soil food webs. Reduced-tillage practices like strip-till and no-till are often promoted to conserve soil health and biodiversity, while maintaining the production benefits of soil disturbance. However, little is known about how tillage and PSTs interact to affect arthropod populations and weed seed predation.

Measuring management impacts

To evaluate how farming practices influenced arthropod populations, the researchers examined three tillage systems at the UNH Kingman Research Farm: strip tillage; full tillage, where soil is completely turned over to prepare for planting; and no tillage, which minimizes soil disturbance by planting seeds directly into undisturbed soil.

The study also compared the effects of using PSTs or untreated seeds to produce corn and soybeans. Arthropod abundance and diversity, as well as predation of weed seeds, were monitored over three growing seasons.

Arthropods were sampled using pitfall traps and weed seed predation was assessed by placing weed seeds on pads protected by exclusion cages. Data collection spanned late-season periods in 2017–2019.

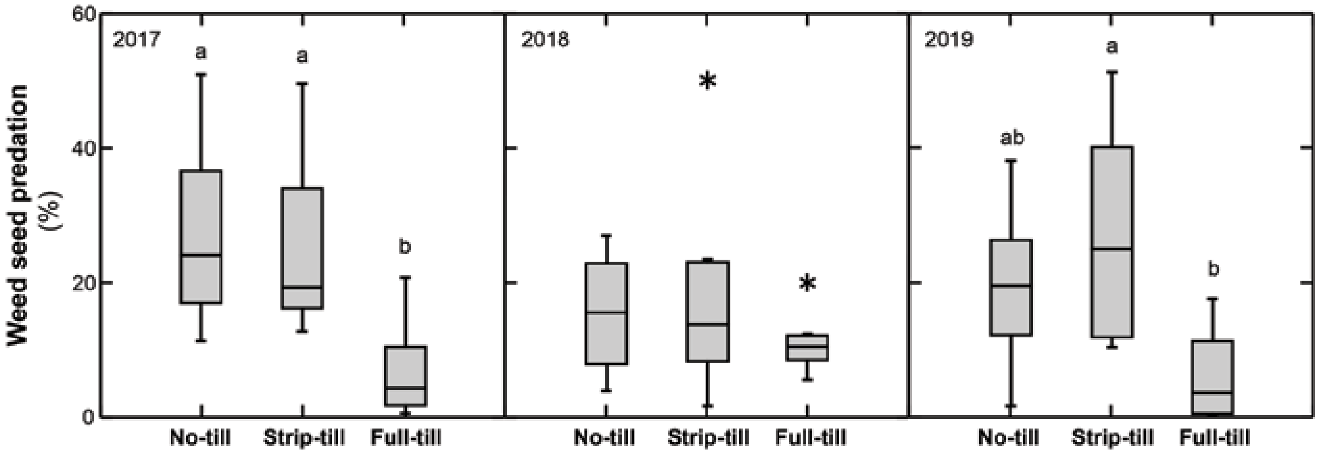

Figure 2. Boxplots showing effects of tillage treatment on the percentage of total weed seeds that were lost to post-dispersal weed seed predation by invertebrates over the growing season, n=8. Asterisks indicate outliers. Tillage treatments sharing the same letter are not different at $p < 0.05$ (Tukey's HSD test).

Discussion of findings

Over two years, 1,669 arthropods from 47 species were sampled. Epigeal arthropod abundance was higher in strip-till and no-till systems than in full-till, but this trend varied annually (**Fig. 1**). For example, in 2018, PSTs influenced arthropod communities more than tillage, while tillage effects dominated in 2019.

Weed seed predation was highest in no-till and strip-till systems, reaching 27.2% seed removal in some years compared to just 6.1% in full-tillage. PSTs did not significantly affect weed seed predation, nor was there significant interaction between tillage and PST practices (**Fig. 2**).

The data indicated year-to-year variability, likely driven by crop rotation and environmental factors.

Strategic recommendations and conclusion

The results indicated mixed evidence of tillage and PST impacts, with most of the impacts due to reduced tillage practices rather than seed treatments. Those effects may also be significantly affected by year-to-year weather and other environmental conditions. However, farmers who reduce tillage may see an increase in overall arthropod abundance, and possibly enhancement of beneficial ecosystem services such as biological control of weed seeds.

The minimal impact of PSTs on arthropod communities and weed seed predation may have been due to the timing of measurements, which happened later into the growing season when many of the pesticide residues would have dissipated into the environment.

Impacts of tillage and pesticides on soil microbial health

J. E. Mackay, L. T. Bernhardt, R. G. Smith, and J. G. Ernakovich

Key takeaways

Conservation tillage practices, such as no-till and strip-till, support healthier soil microbial communities than conventional tillage.

Pesticide seed treatments affect microbial substrate preferences and reduce the abundance of some soil fungi regardless of the type of tillage practice.

Strip tillage could be a viable compromise for maintaining microbial activity while allowing some tillage.

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Healthy soils are a key component of sustainable agriculture, and there is increasing evidence that soil health depends on diverse and active microbial communities. These microbes drive essential processes such as nutrient cycling and the maintenance of soil structure. However, agricultural practices such as tillage and pesticide applications can influence soil microbial health. Conservation tillage practices, such as no-till and strip-till, might ameliorate the effects of tillage but often require management tradeoffs like the use of pesticide seed treatments. Understanding how different tillage methods and pesticide seed treatments affect soil microbial communities is important to improving sustainable farming practices.

Key concepts

Conservation tillage methods, such as strip-tillage and no-tillage, aim to reduce soil disturbance, retain crop residues and improve soil health compared to conventional tillage such as moldboard plowing. In part, these methods are intended to better preserve microbial diversity and function, which have been shown to be important indicators of soil health—the ability of the soil to support crops, store carbon, and resist disturbances.

While no-tillage has been repeatedly shown to enhance microbial diversity and activity, the effects of strip-tillage remain less studied. Additionally, the potential benefits of conservation tillage may be affected by using crop seeds that are coated with fungicides and insecticides, intended to protect crops from diseases and pests but which may be harmful to soil microbes.

The study hypothesized that strip-till would maintain microbial diversity and function better than conventional tillage but not as well as no-till, and that pesticide seed treatments (PSTs) would exacerbate these impacts, particularly in undisturbed, no-till soils.

Methods and findings

The field experiment employed a fully factorial design, testing three tillage regimes—no-till, strip-till and conventional tillage—with and without PSTs. Soil samples were collected after 5 years of tillage treatments and 3 years of PSTs and analyzed for physicochemical properties, microbial enzyme activity, community composition, and soil substrate preferences. DNA sequencing assessed bacterial and fungal diversity, and respiration assays measured microbial activity.

Strip-tillage showed intermediate effects on soil properties and microbial health, performing better than conventional tillage but not as well as no-till (**Fig. 1**). For example, the activity of microbial enzymes essential to nutrient cycling were highest in no-till soils, intermediate in strip-till, and lowest in conventional tillage. Similarly, microbial functional capacity, measured by the ability to degrade various substrates, followed the same trend.

PSTs altered microbial community composition, particularly among fungi, and shifted microbial substrate preferences to the higher use of nitrogen-containing compounds. The relative abundance of certain fungal taxa increased or decreased depending on pesticide exposure, suggesting that PSTs can disrupt fungal communities outside the pathogens the treatments are intended to suppress. PSTs did not affect microbial enzyme activity or diversity.

Despite the hypothesized interaction between tillage practices and PSTs, the results indicated that the effect of PSTs was universal, regardless of tillage practices.

Strategic recommendations and conclusion

This study highlights the potential advantages of strip-tillage as a conservation strategy that balances reduced soil disturbance with crop management needs. Farmers and policymakers should consider limiting PST use or seeking alternative pest control methods, especially when adopting conservation tillage practices to maintain soil health. Further research is needed to explore long-term effects of PSTs and to identify strategies that minimize their impact on beneficial soil microbes.

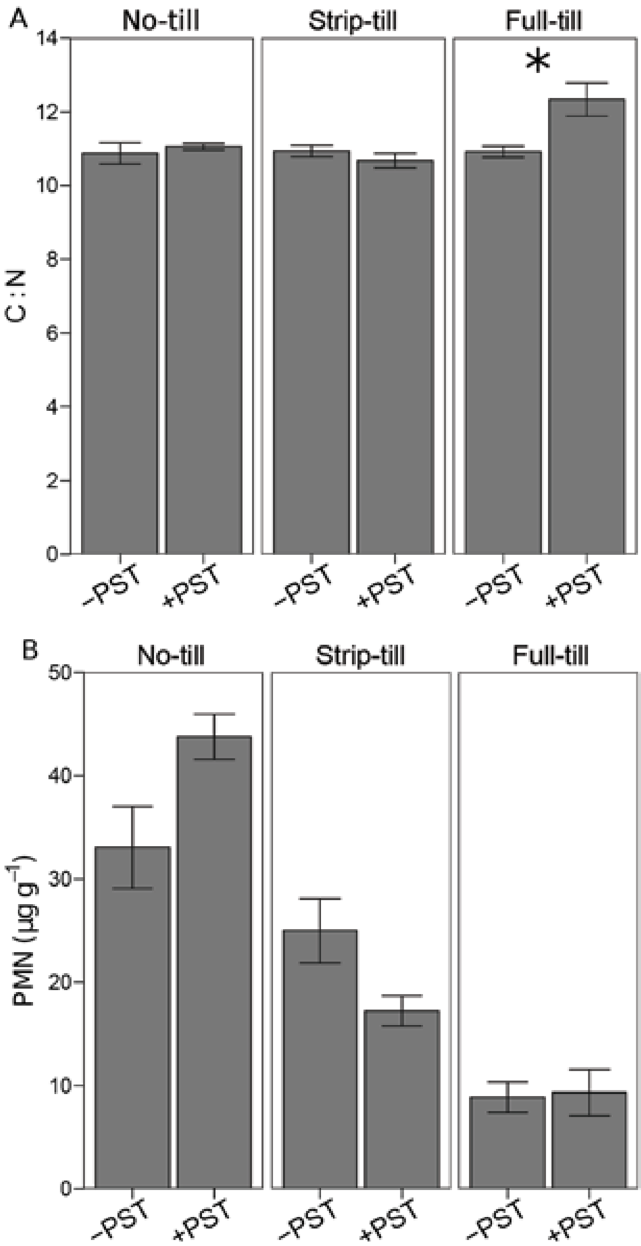
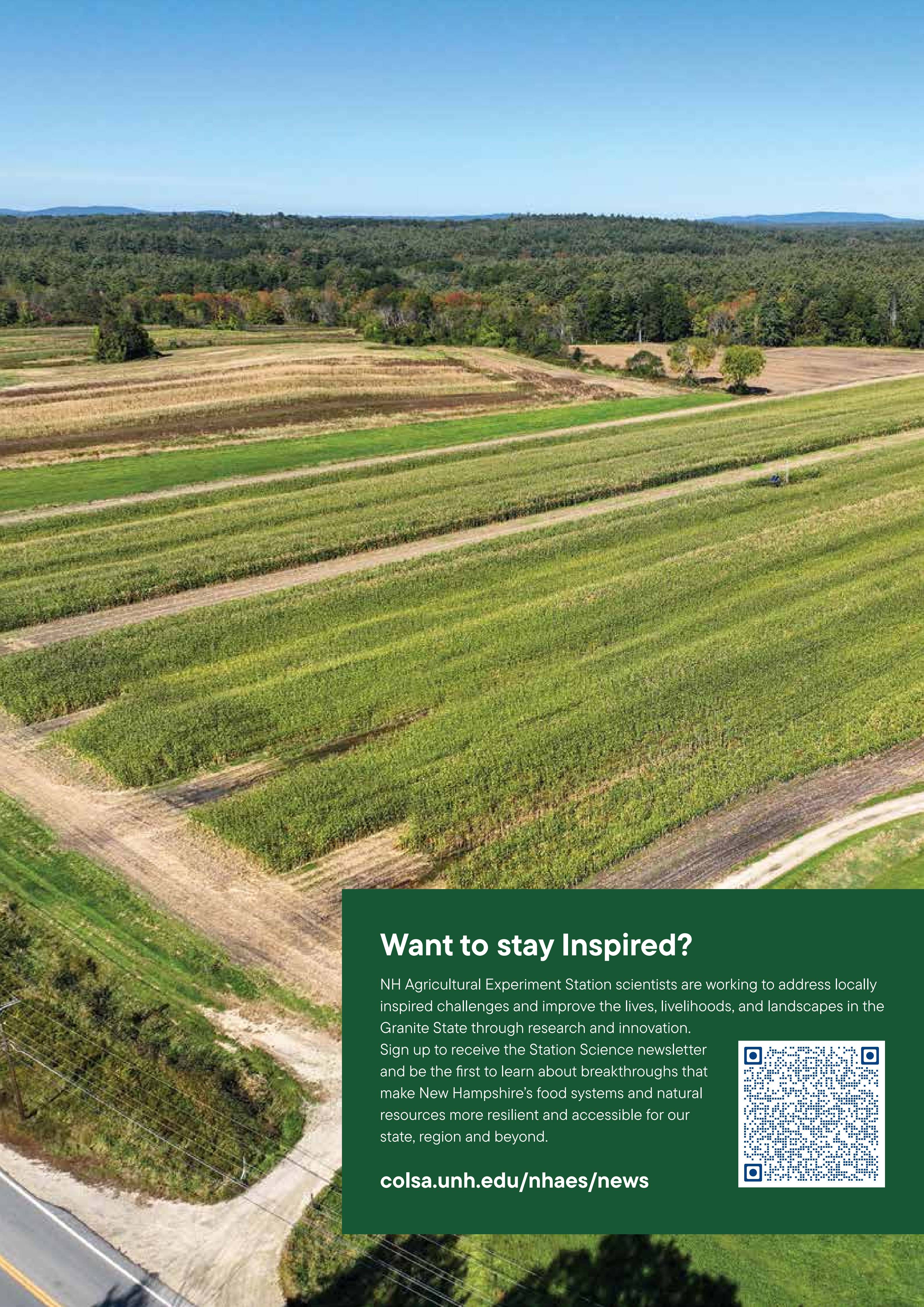


Figure 1. Effects of pesticide seed treatment (–PST, seeds without pesticide treatment; +PST, seeds with pesticide treatment) and tillage on (A) soil C:N ratio and (B) potentially mineralizable nitrogen (PMN). There was a significant interaction between tillage and PST on both C:N and PMN ($p < 0.10$). Asterisks indicate significant differences within each tillage treatment ($p < 0.05$).



Want to stay Inspired?

NH Agricultural Experiment Station scientists are working to address locally inspired challenges and improve the lives, livelihoods, and landscapes in the Granite State through research and innovation.

Sign up to receive the Station Science newsletter and be the first to learn about breakthroughs that make New Hampshire's food systems and natural resources more resilient and accessible for our state, region and beyond.

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Diversifying crop rotations enhances nitrogen cycling efficiency

L. C. Breza, M. Mooshammer, T. M. Bowles, V. L. Jin, M. R. Schmer, B. Thompson, and A. S. Grandy

Key takeaways

Complex crop rotations accelerate soil nitrogen cycling, improving organic nitrogen availability.

High fertilizer rates suppress the benefits of diverse cropping systems, reducing organic nitrogen cycling potential.

Combining optimal fertilizer use with diverse crop rotations can optimize nitrogen use efficiency and reduce environmental losses.

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Agricultural systems rely on fertilizers to maintain nitrogen availability for crops, but their suboptimal application—often too much—can lead to inefficient nutrient use and significant environmental impacts. Management practices that enhance soil organic nitrogen cycling offer an approach that could reduce reliance on fertilizers while improving ecosystem health. However, how crop rotation complexity and nitrogen fertilization interact to influence soil nitrogen cycling processes and the resulting transformation of organic nitrogen into bioavailable forms remains unknown.

Soil organic nitrogen cycling

Soil organic nitrogen cycling involves the breakdown of complex organic compounds into forms readily usable by plants and microbes. This process, known as protein depolymerization, is critical for maintaining soil fertility. High fertilizer application rates can undermine these benefits by reducing microbial activity and suppressing organic nitrogen processing, deepening the dependence on external nitrogen sources.

Complex crop rotations—such as those that include cover crops, legumes, and diverse cereals—can enhance nitrogen cycling by increasing the quality and diversity of organic inputs. Existing research has also shown that more complex rotations increase soil organic matter that can act as a reservoir pool of nutrients that plants can access. However, processes that regulate bioavailability of nitrogen are not well understood, constraining practical recommendations that can be made to inform sustainable agricultural production.

Methodology

This study's goal was to understand how complex crop rotations change soil microbial activity, soil organic matter dynamics, and organic nitrogen cycling, as well as the moderating impacts of external nitrogen fertilizer application. The data were collected from a long-term cropping system experiment in Nebraska, comparing three levels of rotational complexity: continuous corn (low complexity), corn-soybean (medium complexity), and a four-crop rotation (high complexity).

The study compared soil samples that received zero (0 kg N per hectare) and high (180 kg N per hectare) levels of added fertility in each cropping system's complexity, with the high treatment being above the recommended rate for the region. The zero and high fertilizer treatments allowed measurement of N flux responses on either end of the fertilizer application spectrum. Rates of protein depolymerization, amino acid consumption, ammonium mineralization, and extracellular enzyme activities were measured using isotope-based methods and fluori- and photo-metrically to quantify nitrogen cycling processes.

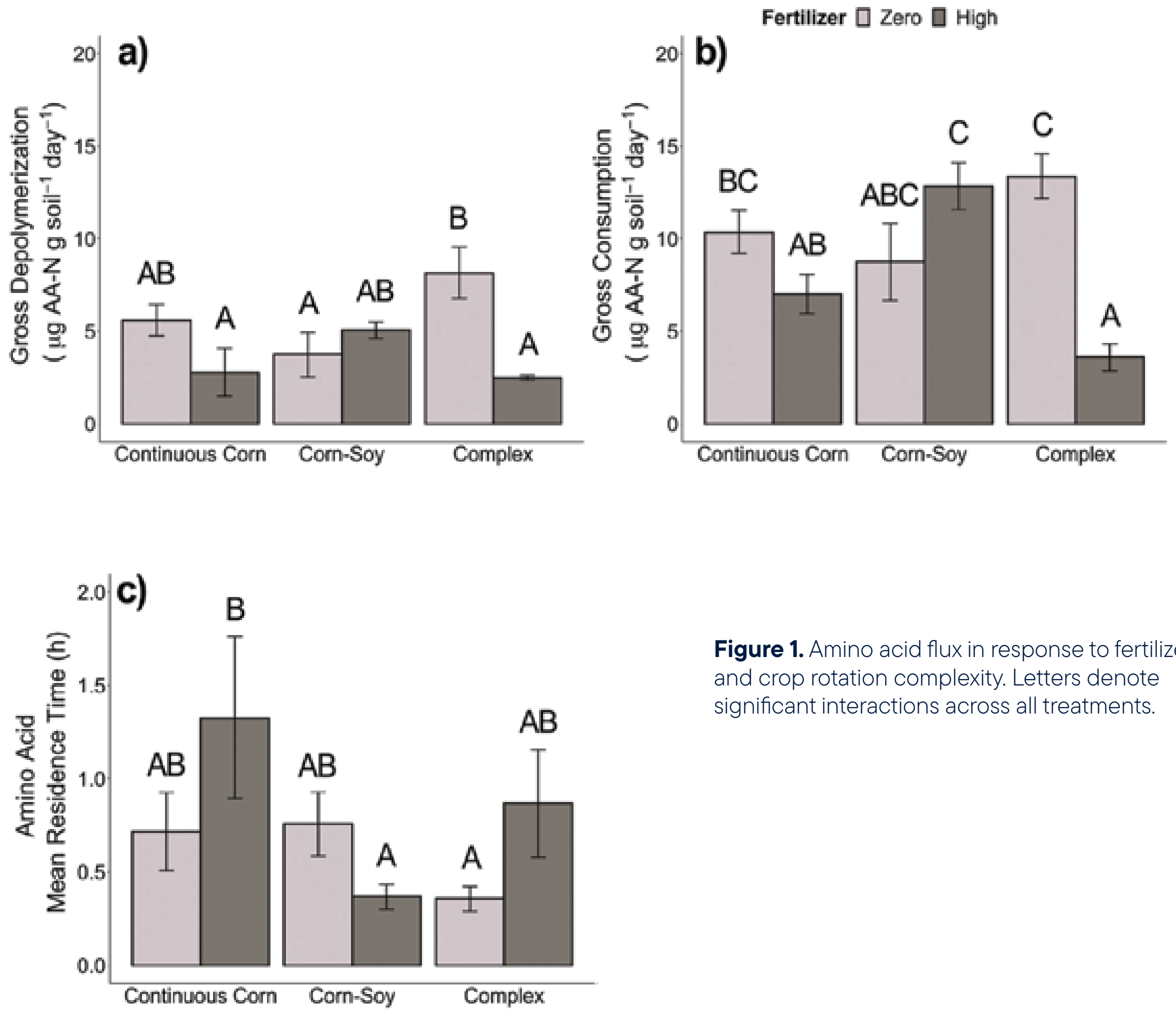

Figure 1. Amino acid flux in response to fertilizer and crop rotation complexity. Letters denote significant interactions across all treatments.

Discussion of findings

Complex crop rotations stimulated nitrogen cycling processes, with unfertilized systems showing the highest rates of protein depolymerization and amino acid consumption. For example, depolymerization rates—the breaking down of proteins into amino acids that become available for soil microbes—were up to 3.3-times higher in systems where no fertilizer was applied compared to those that received high rates of fertilization (**Fig. 1a**). High fertilizer rates suppressed organic nitrogen cycling the most in low- and high-complexity systems (continuous corn and complex), compared to the medium-complexity system (corn-soy), reducing microbial processing of nitrogen-rich compounds and increasing reliance on synthetic inputs.

High-complexity systems with zero fertilizer application demonstrated highest microbial biomass, relative to other systems. Additionally, high-complexity rotations maintained the highest inorganic N (ammonium) flux even under high fertilization conditions.

Strategic recommendations and conclusion

Results of this study provided evidence that fertilizer inputs reduced soil organic nitrogen cycling, which reduces the potential benefits that complex cropping systems can provide to the soil. However, the results also suggest that organic nitrogen cycling in more complex systems is more sensitive to nitrogen fertilizer inputs, reducing the nitrogen cycling rates in these systems to the point where complex systems are similar to less complex ones (**Fig. 2**).

The findings indicate that agricultural systems that prioritize diverse crop rotations, including cover crops and legumes, can enhance soil nitrogen cycling and reduce fertilizer dependency. Reducing nitrogen application rates in these systems can further optimize nutrient use efficiency, decreasing environmental impacts while maintaining crop productivity.

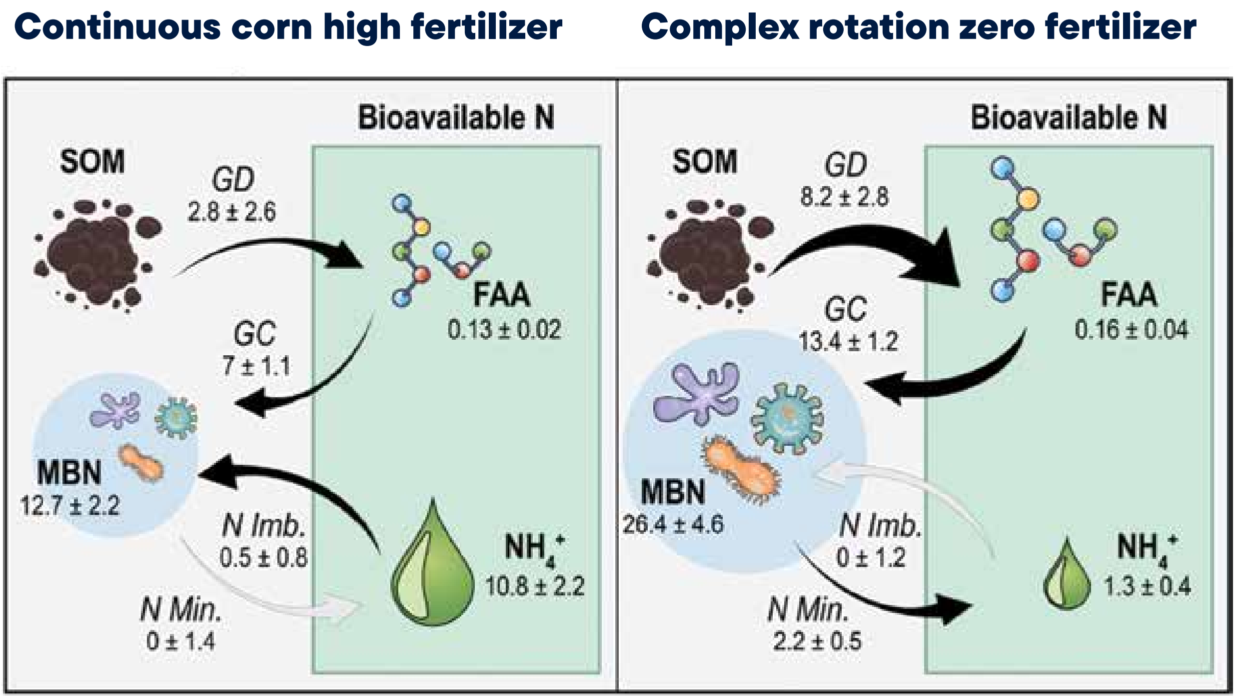

Figure 2. Conceptual model depicting the changes in N pools and fluxes in the two most distinct treatments. The left panel shows pools and fluxes for the high fertilizer, continues corn (HFCC) treatment and the right panel shows the zero fertilizer, complex rotation (ZFCR) treatment. N pools are shown in bold and expressed in units of μg N g−1 dw soil. N fluxes are italicized and expressed in units of μg N g−1 dw soil d−1. Pools and arrows are scaled by the comparison between treatments. Abbreviations: soil organic matter (SOM); free amino acids (FAA); microbial biomass N (MBN); ammonium (NH4+); gross depolymerization (GD); gross amino acid consumption (GC); N mineralization (N min.); N immobilization (Imb.). Light gray arrows indicate zero flux.

Root respiration responses to warming and nitrogen addition

T. J. Muratore, M. A. Knorr, M. J. Simpson, R. B. Stephens, R. P. Phillips, and S. D. Frey

Key takeaways

Soil warming and nitrogen (N) addition independently reduce root respiration but show neutral effects when combined.

Maple and oak roots differ in their responses, with maple roots contributing more CO_2 under combined warming and N treatments.

Tree species-specific interactions highlight the importance of studying root dynamics to predict soil carbon fluxes in a warming climate.

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Soil respiration, which includes significant contributions from roots, plays a critical role in the global carbon cycle, releasing carbon dioxide (CO_2) to the atmosphere at rates exceeding those from fossil fuel combustion. Understanding how roots respond to environmental changes like warming and nitrogen enrichment is essential for predicting soil carbon fluxes. In New England, the root respiration of two common tree species—maple and oak—are of particular interest under conditions of long-term soil warming and nitrogen addition.

Overview of root respiration

Root respiration is driven largely by fine roots—roots less than 2 mm in diameter—and represents 40–60% of total soil respiration. Fine roots include absorptive roots, which actively acquire nutrients, and transport roots, which store and move resources. Root respiration rates vary by species and depend on factors such as biomass and environmental conditions. Maple and oak roots represent contrasting nutrient acquisition strategies: maples rely on arbuscular mycorrhizal fungi and oaks depend on ectomycorrhizal fungi.

As separate factors, soil warming often reduces fine root biomass and limits respiration, while nitrogen addition decreases root biomass by reducing plant nutrient demand, also constraining respiration. When these factors are combined, their interactive effects may lead to unpredictable soil respiration, influencing the balance between soil carbon storage and release. For maples and oaks, the difference in nutrient acquisition could further increase the unpredictability of soil warming and nitrogen addition interactions.

Testing effects of soil warming and nitrogen addition

The study was conducted at the Harvard Forest Long-Term Ecological Research site (Petersham, MA) using a factorial design with warming (soil heated by 5°C), nitrogen addition, or a combination of both treatments. Fine roots were sorted into absorptive and transport roots by tree species, and mass-specific respiration rates were measured monthly during the growing season. Root biomass and fungal colonization were also assessed to understand the contributions of different tree species and fungal partners to soil carbon fluxes.

Soil warming and nitrogen addition reduced root respiration rates by 40% when applied individually, primarily through decreased biomass of transport roots (**Fig. 1**). However, when combined, the treatments had neutral effects, returning root respiration to levels observed in control plots. This response was attributed to a shift in the balance between maple and oak absorptive roots.

Maple roots showed higher respiration rates than oak roots, particularly under combined warming and

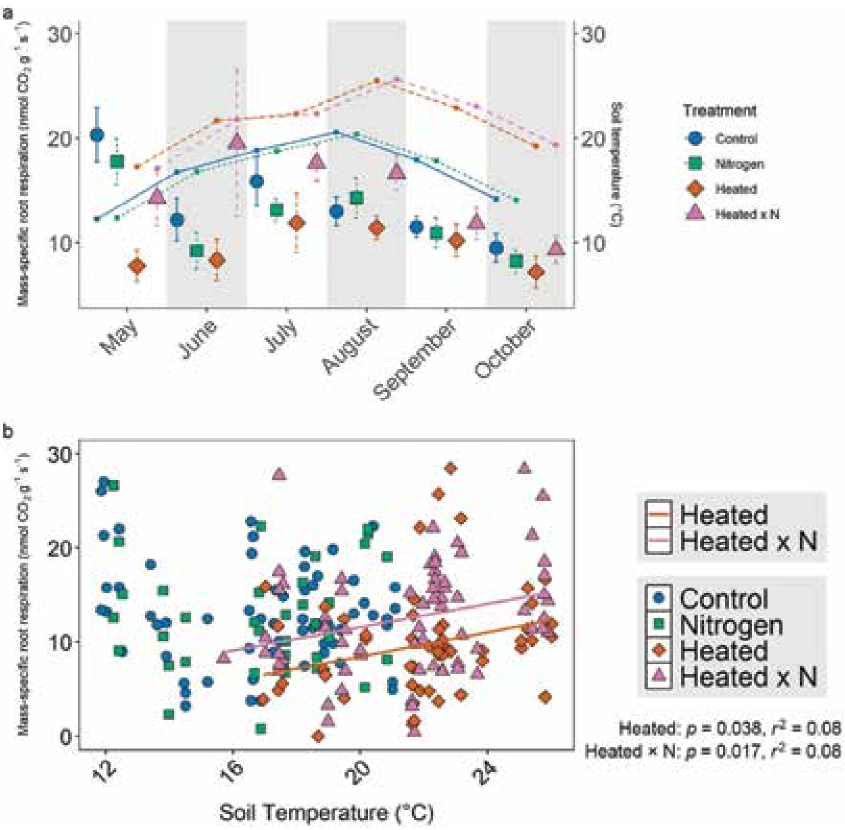


Figure 1. Mass-specific root respiration over the growing season and its relationship with soil temperature. (a) Temporal dynamics of mass-specific root respiration between May and October (points) and average soil temperature in unwarmed and warmed plots (line). p-values indicate the effects of sample date, treatment, and their interaction on mass-specific root respiration rates. Reported values represent the mean ± one standard error. (b) Relationships between soil temperature and mass-specific root respiration rates over the duration of the growing season by treatment. p-values indicate the significance of the relationship between soil temperature and root respiration.

nitrogen addition, where maple absorptive root biomass increased (**Table 1**). This shift resulted in a proportional increase in maple contributions to ecosystem root respiration. Oak roots, in contrast, maintained or reduced their biomass and respiration rates, highlighting species-specific responses.

Ectomycorrhizal fungal colonization declined under warming and nitrogen treatments alone but returned to control levels when combined, suggesting complex interactions between roots and their fungal partners.

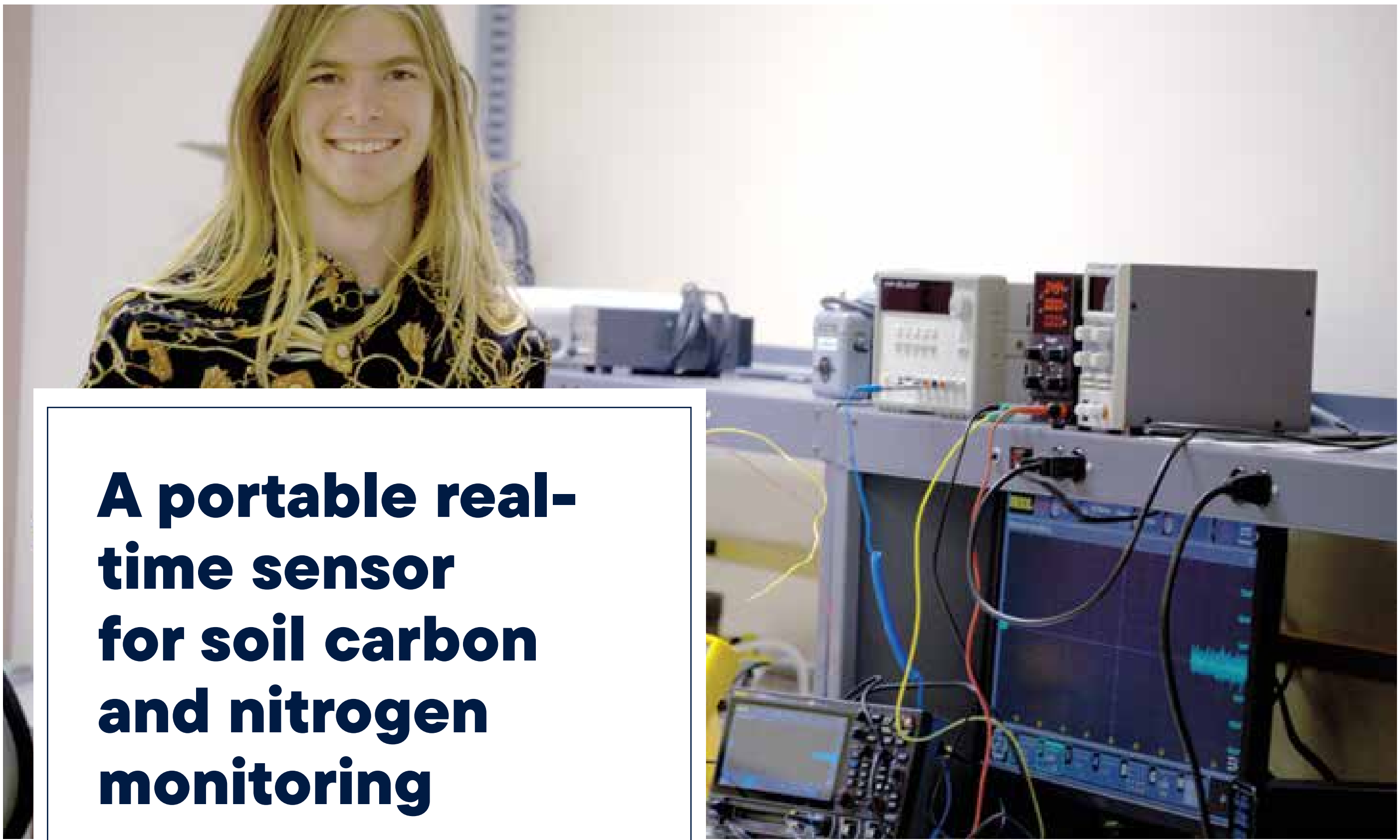
Strategic recommendations and conclusion

The results indicate the need to incorporate species-specific root dynamics into models of soil carbon flux. Maple roots' increased contribution to root respiration under combined warming and nitrogen addition may offset reductions in other components of soil respiration, but this effect is less evident in oak trees. More broadly, however, the research demonstrates that when assessment of factors that influence soil respiration are studied independently, the impacts of those factors may be over- or underestimated relative to when those factors are measured in combination.

A key takeaway from the research is that understanding how the roots of specific tree species mediate soil respiration is critical for land managers to develop strategies to enhance soil carbon retention in forests facing global change pressures. In New England, the differences observed in the impacts of warming and N additions on maples and oaks are important to account for when building forest management plans. The findings suggest that maple and oak roots respond differently to changes in soil fertility and temperature, which in turn affects carbon retention. To make informed land management decisions, it is essential to consider not just soil fertility and future climate changes, but also how different tree species influence belowground carbon dynamics at a given site.

Table 1. Mass-specific and ecosystem root respiration rates for maple and oak trees. Total ecosystem root respiration rates represent the sum of maple and oak ecosystem root repiration. Significant differences ($p<0.05$) between treatments are indicated by different letters. Reported values represent the mean ± one standard deviation.

	Mass-specific root respiration		Ecosystem root respiration		
Treatment	(nmol$CO_2 g^{-1} s^{-1}$)		(mgCO_2-C$m^{-2}h^{-1}$)		
	Maple	**Oak**	**Maple**	**Oak**	**Total**
Control	15.9 ± 7.2 a	12.1 ± 6.7 a	15.8 ± 15.1 a	34.6 ± 24.7 a	50.4 ± 39.8 a
Nitrogen	14.0 ± 6.6 ab	10.5 ± 5.7 ab	5.6 ± 3.8 b	24.7 ± 14.4 a	30.3 ± 18.2 b
Heated	11.2 ± 7.0 b	8.3 ± 4.4 b	5.4 ± 7.4 b	24.6 ± 15.1 a	30.0 ± 22.7 b
Heated x N	16.0 ± 14.6 a	13.7 ± 7.5 a	16.3 ± 16.8 a	28.9 ± 22.7 a	45.2 ± 39.4 ab



A portable real-time sensor for soil carbon and nitrogen monitoring

M. S. Mahmud, W. M. Wollheim,
M. F. Yousuf, J. Lariviere, and Z. Holt

Key takeaways

A handheld in situ sensor enables real-time, field-based analysis of soil organic carbon and nitrogen.

The system uses photoacoustic sensing and machine learning for carbon and nitrogen measurement precision comparable to lab-based methods.

Scalable designs, including drone-mounted systems, allow for localized and large-scale soil monitoring.

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Monitoring soil organic matter (SOM)—which includes carbon and nitrogen—is crucial for sustainable agriculture management, enabling farmers to optimize the timing and amount of nutrient applications. Traditional soil sample, lab-based methods for SOM analysis are costly, time-consuming, and fail to provide frequent, dynamic, spatially explicit data. By developing a real-time soil sensor, farmers may be able obtain high-frequency, cost-effective assessments of soil health directly in the field.

A new approach to soil testing

Soil organic carbon and soil organic nitrogen are vital indicators of soil health, influencing nutrient cycling, carbon sequestration and greenhouse gas emissions. Despite their importance, the analysis of these components often requires specialized facilities and expertise. Traditional methods, such as Loss-On-Ignition (LOI) and elemental analysis, are resource-intensive and slow, requiring hand-based soil samples that are then sent to lab facilities for analyses. For frequent or large-scale use, these traditional methods are impractical.

An in situ sensor—one that is inserted and remains in the soil—that can provide readings on demand can help overcome these challenges, as long as these readings are as precise as lab-based assessments. This study developed a pilot sensor that combined a heating probe and a photoacoustic gas detector to measure CO_2 (from carbon oxidation) and N_2O (from nitrogen decomposition). Integrated machine learning algorithms were developed to account for soil-specific variables, ensuring accuracy across diverse conditions. The result is a portable, scalable tool for rapid SOM analysis in various environments.

Sensor system overview

The system (**Fig. 1**) consists of:

(a) The sensor probe:

- A heating probe that thermally decomposes soil samples in a soil chamber, releasing CO_2 for carbon detection and N_2O for nitrogen detection.
- An AI-enabled sensing node that detects and quantifies the released gases in real time.
- A dual-layer structure, consisting of an inner rod and outer tube, to provide stability and precision in soil penetration.

(b) Data processing and model deployment:

- Sensor measurements are processed and calibrated using machine learning models trained on laboratory-validated datasets.

The system performs real-time predictions of soil carbon and nitrogen content, eliminating the need for traditional lab-based soil sampling.

To validate the sensor, it was tested at an active UNH agricultural field over the span of a production season. The sensor was inserted into the soil, analyzed produced gases, and processed the results via machine learning models. The assessments were then validated against LOI and elemental analysis from traditional soil sampling methods. Additionally, a controlled laboratory test was conducted to further validate the sensor's accuracy. The sensor's performance was assessed by detecting gas emissions released from the heated soil sample, with results being calibrated and validated using machine learning algorithms against known laboratory methods.

This controlled study provided critical insights into the sensor's accuracy, reliability, and responsiveness, demonstrating its ability to deliver precise, real-time soil health assessments without the need for traditional laboratory analysis.

Findings and strategic recommendations

The research demonstrated the sensor's reliability and efficiency, with SOC and SON measurements aligning closely with lab-based results. Its lightweight design supports in situ use, helping eliminate logistical challenges associated with traditional sampling.

This in situ sensor marks a significant advancement in soil organic matter analysis, bridging gaps between lab precision and field applicability. For farmers, it can provide actionable, frequent insights into soil nutrient dynamics, enabling them to more optimally apply fertilizers only when extra fertility is needed rather than over- or underestimating the timing or amount. This would reduce both economic and environmental costs.

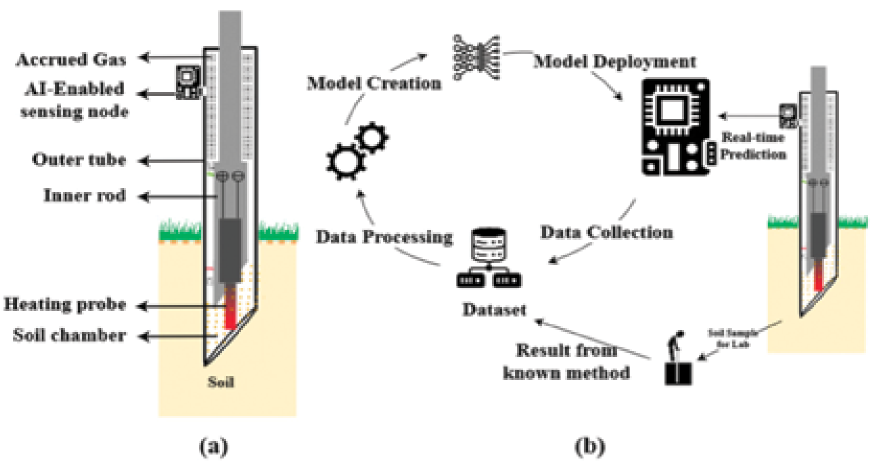

Figure 1. Schematic of the portable in situ soil sensor system for real-time carbon and nitrogen monitoring.

The role of microbial traits in soil carbon storage and stability

E. D. Whalen, A. S. Grandy, K. M. Geyer, E. W. Morrison, and S. D. Frey

Key takeaways

Soil organic matter (SOM) formation is closely linked to microbial traits, with fungi playing a pivotal role.

Fungal species exhibiting intermediate to high carbon use efficiency, growth and biomass turnover rates, and biomass protein and phenol contents contributed most effectively to SOM formation.

Incorporating multiple microbial traits into SOM models can enhance predictions for soil carbon stability and ecosystem functions.

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Soil microbes, particularly fungi, are critical to the formation and stabilization of soil organic matter (SOM), the largest terrestrial reservoir of carbon. While previous research often focused on single microbial traits, such as carbon use efficiency (CUE), understanding how links among multiple interacting traits could drive SOM dynamics could be critical to developing more effective soil management strategies and promoting soil carbon storage under climate change. Specifically, these more holistic frameworks can be more accurate in predicting which microbial characteristics contribute most to SOM stability.

Key concepts of soil organic matter

Microbial traits, including growth rates and growth efficiency, enzymatic activity, and biomass chemical composition, influence how effectively organic matter transitions into soil organic matter (SOM) pools. While high carbon use efficiency (CUE) has been traditionally associated with SOM formation, other traits such as biomass protein and phenol contents could play equally critical roles. This research asked which fungal traits were most important for promoting the formation of different SOM functional pools, for example particulate organic matter (POM) and mineral-associated organic matter (MAOM). The results demonstrated the importance of synergies among traits for the formation of multiple SOM pools and suggest that “multifunctional” microbes and microbial communities are essential for promoting SOM quantity, stability, and chemical complexity.

Methods for testing fungal species contributions

This study used a controlled laboratory setup with eight fungal species from three major phyla. Fungi were incubated in sterile, SOM-free model soils to isolate their effects on SOM formation. Researchers measured physiological traits (e.g., growth rate and CUE), biochemical traits (e.g., biomass protein and phenol contents), and morphological traits (e.g., hyphal lengths and surface areas).

Fungal contributions to SOM pools were quantified—including total SOM, POM, MAOM, and chemically and biologically stable fractions of the MAOM pool. Advanced techniques, such as pyrolysis-gas chromatography/mass spectrometry, were used to assess the chemical composition of fungal-derived SOM. Statistical analyses linked fungal traits to their SOM formation potential across these functional pools.

Discussion of findings

Fungal species differed in their ability to form SOM, with distinct traits emerging as key predictors of different SOM pools. Species with intermediate to high CUE growth rates and biomass protein and phenol contents contributed the most to SOM formation across functional pools, including both total SOM and stable SOM pools (**Fig. 1**). In contrast, fungi specializing in only one trait, such as high CUE, were less effective in forming SOM.

Importantly, the study demonstrated that the chemical diversity of SOM, including the abundance of proteins and phenols, is positively correlated with its stability. This finding suggests that multifunctional microbes contribute not only to SOM quantity but also to its structural and functional complexity, which are essential for long-term carbon storage and soil health.

Strategic recommendations and conclusion

To improve soil carbon models, researchers and land managers should account for multiple microbial traits rather than focusing solely on CUE or other single metrics. By embracing the complexity of microbial traits and their interactions, future studies can better predict the impacts of climate change and land use on soil carbon dynamics, improving more effective soil management strategies.

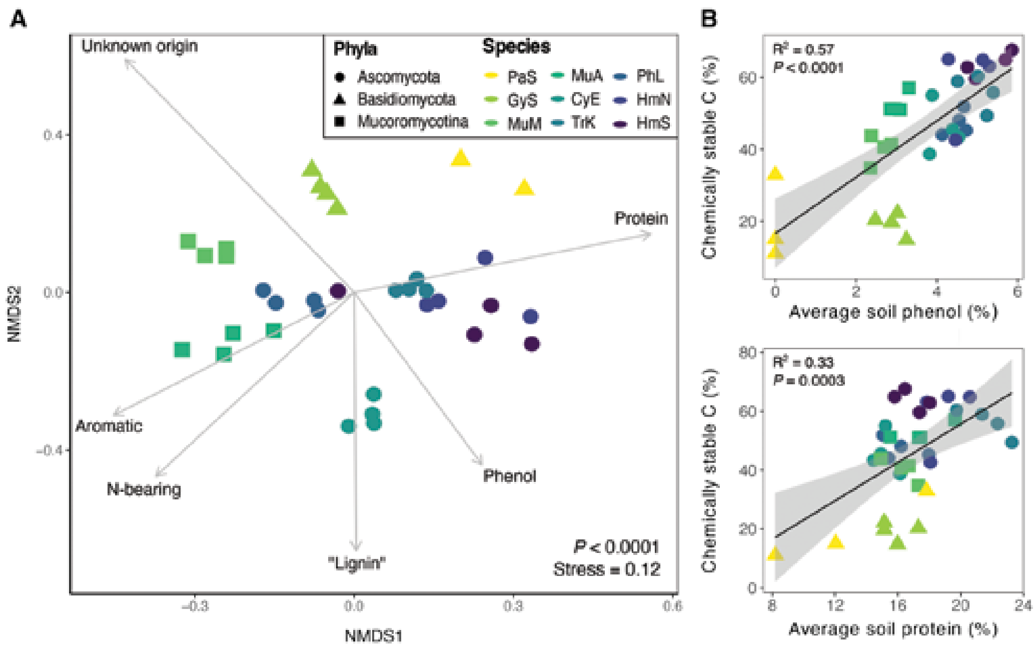

Figure 1. A NMDS ordination of SOM chemical composition after long-term incubation with fungal isolates (n = 4, except P. stipticus, n = 3). (A) Results for a single temperature fraction (503oC) from the ramped pyrolysis GC/MS analysis ($p < 0.0001$; PERMANOVA). Point color represents fungal species, while point shape represents fungal phyla. Environmental vectors representing broad chemical compound classes were included in the plot if significant ($p < 0.05$). (B) Correlations between the relative abundances of phenols (top) or proteins (bottom) in soils at the end of the long-term incubations and the proportion of chemically stable C produced by each fungal species (n = 27). One-way ANOVA results are presented (both $p < 0.001$). Error bands represent 95% confidence interval.

Nitrogen uptake strategies of common agricultural weeds

N. D. Warren, E. A. Hobbie, J. Chen, and R. G. Smith

Key takeaways

Agricultural weeds can take up both inorganic and organic nitrogen—including intact amino acids—highlighting diverse nutrient acquisition strategies.

Uptake of organic nitrogen across tested species ranged between 3% and 10%.

Differential nitrogen uptake patterns among weed species suggest the potential for resource partitioning, which may influence crop-weed competition, especially in systems with high levels of soil organic matter or organic soil amendments.

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Nitrogen is a limiting nutrient in many agricultural systems, and this drives competition between crops and weeds for this critical soil resource. Understanding how weeds vary in their uptake of organic and inorganic nitrogen could lead to new management strategies for reducing the impacts of weeds on crops. Collectively these strategies could reduce herbicide use, optimize fertility practices, and increase sustainable food production.

Organic and inorganic nitrogen

Weeds are often viewed as competitors for soil nutrients, reducing crop yields and efficiency. However, they also play roles in nutrient cycling by accessing nitrogen (N) pools that might otherwise be lost. Organic nitrogen, primarily in the form of amino acids, represents a significant yet underutilized soil N pool. Unlike inorganic N, such as synthetic nitrogen products and animal-based fertilizers, organic N uptake has been less studied in weed species.

Differential N uptake patterns among weeds may allow for resource partitioning, where species specialize in accessing specific N forms. This behavior can reduce direct competition between weeds and other plants, such as agricultural crops, and shape overall nutrient dynamics in cropping systems. As such, assessing organic and inorganic N uptake and partitioning behaviors across numerous species of crop and weed plants can provide insights about better fertility management strategies in agroecosystems.

Tracking N uptake

The study was conducted at the UNH Macfarlane Research Greenhouses and examined N uptake in seven weed species (common lambsquarters, redroot pigweed, wild mustard, barnyardgrass, giant foxtail, large crabgrass, wild oat) and one crop species, sorghum-sudangrass. Plants were grown for 24 days at an average temperature of 26.1 degrees Celsius in a semi-hydroponic system.

Different mixes of organic (algal-derived amino acids) and inorganic (ammonium and nitrate) N fertilizer were applied. Stable isotope-labeled ammonium, nitrate and amino acids were applied to track N acquisition and partitioning in root and shoot tissues. The experimental design controlled for environmental factors, focusing on intrinsic differences in species' nutrient strategies.

Discussion of findings

All species demonstrated the ability to take up organic and inorganic N, with notable differences in preferences (**Table 1**). Relative uptake of organic N uptake ranged from 3% to 10% of total N, indicating differences in preferences across species. Large crabgrass (Digitaria sanguinalis) and barnyardgrass (Echinochloa crus-galli) had higher uptake of amino acid-derived N compared to other species, while wild mustard (Sinapis arvensis) showed a preference for nitrate.

Intact amino acid uptake, though a minor fraction of total N acquisition, was observed in all species. This highlights a potential avenue for weeds to exploit organic N pools, particularly under low-fertility conditions where inorganic N is scarce.

Strategic recommendations and conclusion

The study indicates that weed management could begin to consider nutrient management strategies that account for differential N-form preferences by weeds. Practices that limit the availability of preferred N forms for dominant weed species, such as varying timing of fertilizer applications or enhancing soil organic matter, may reduce weed impacts on crop yields while minimizing the need for herbicides.

Future research will need to assess similar questions under field conditions, where factors such as microbial activity and plant-microbe interactions may alter N availability. Understanding the interplay between nutrient management and weed–crop dynamics is critical for developing sustainable agroecosystems.

Table 1. Relative recovery of each of the three nitrogen (N) forms calculated for each species using the amount of label measured in the whole plant (atom percent excess ^{15}N[^{15}N APE]).

		Relative ^{15}N Uptake		
Common name	Scientific name	Amino acid	Ammonium	Nitrate
Lambsquarters	*Chenopodium album*	8 ± 4	46 ± 3	46 ± 17
Redroot pigweed	*Amaranthus retroflexus*	5 ± 2	50 ± 16	44 ± 13
Wild mustard	*Sinapis arvensis*	3 ± 1	56 ± 14	41 ± 9
Barnyardgrass	*Echinochloa crus-galli*	4 ± 1	55 ± 15	42 ± 15
Giant foxtail	*Setaria faberi*	7 ± 2	50 ± 2	42 ± 9
Large crabgrass	*Digitaria sanguinalis*	9 ± 1	45 ± 8	46 ± 8
Wild oat	*Avena fatua*	9 ± 2	53 ± 5	38 ± 5
Sorghum-sudangrass	*Sorghum bicolor*	10 ± 1	45 ± 3	46 ± 4

Further reading and acknowledgements

Partial funding was provided by the New Hampshire Agricultural Experiment Station through the USDA National Institute of Food and Agriculture. Additional funding and acknowledgments are listed below.

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This work was supported by a University of New Hampshire Dissertation Year Fellowship, as well as a research grant from the U.S. Department of Agriculture National Institute of Food and Agriculture through the New Hampshire Agricultural Experiment Station (NHAES; Hatch NH-00701). This is NHAES Scientific Contribution Number 3001.

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Partial funding was provided by the New Hampshire Agricultural Experiment Station. This project was supported by USDA-NIFA Hatch Project 1006827 and USDA-NIFA AFRI grant no. 2013-67014-21318.

Inspired support

The research in this report could not have been accomplished without the support and contributions of New Hampshire Agricultural Experiment Station and University of New Hampshire staff, graduate and undergraduate student researchers, partners in UNH Cooperative Extension, and collaborating landowners and non-profit organizations across New Hampshire and the region. Their efforts have helped with collection of research data, analyses and assessments, responsible stewardship of public resources and communication of knowledge across many diverse communities in New Hampshire.

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