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Soil Respiration Across Arkansas Ecosystems and Cropping Systems

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Introduction

The principles of soil health (Fryer et al., 2022) guide best management practices towards sustainable agricultural production. Scientific reports have shown that key aspects of soil health are highly correlated to soil respiration, which is the release of carbon dioxide (CO_2) gas from oxygen-consuming soil microorganisms and plant roots.

Soil health refers to the soil's ability to maintain productivity through a well-balanced ecosystem above and below the soil surface (Cardoso et al., 2013). While soil health indicators range from physical (i.e., soil texture, aggregation, moisture, etc.), chemical (i.e., pH, mineral nutrients, soil organic matter (SOM), etc.) and biological (i.e., microbial biomass, soil enzymes and soil respiration, etc.), many of the factors are described as slow-response factors. This suggests that the effects of management practices on soil health indicators will be limited for the first few years after implementing new or altered practices, but effects are instead expected to manifest more thereafter until reaching a new equilibrium (Brye et al., 2004).

Developing recommendations and guidelines for management practices in various ecosystems, especially in agricultural settings, requires soil health indicators that operate on a short-time scale. Long-term factors can be used to validate the process. Soil respiration possesses the necessary characteristics to accomplish such a task.

Physical indicators of soil health can affect gas diffusion into and out of the soil, both directly and indirectly. This reinforces the correlation between soil respiration, soil surface CO_2 flux and physical parameters used to determine soil health (Cardoso et al., 2013). Among chemical soil health indicators, potentially plant-available nutrients have been highly correlated to resulting crop yields. Nutrient availability, in turn, is affected by soil pH, SOM and management practices such as irrigation, tillage and fertilization (Brye et al., 2016). When crops are supplied with sufficient nutrients at the appropriate time, soil respiration tends to increase during vegetative stages and tends to become more constant during reproductive stages (Cardoso et al., 2013; Della Lunga et al., 2024).

In agroecosystems, the relationships between soil health indicators and soil respiration, however, are generally non-linear and depend on many factors. These include what management practices are applied and for how long.

Management practices that reduce soil disturbance (i.e., reduced tillage) can often result in greater soil respiration during the first few growing seasons after the altered management. This is due to the generally greater nutrient cycling under conservation practices than under conventional practices (Tully and Ryals, 2017).

With time, soil respiration from conservation practices often reaches an equilibrium characterized by soil respiration rates that are generally lower than respiration rates in continuously disturbed soils (Iqbal et al., 2010; Paustian et al., 2000). Agricultural soils considered to have good soil health, however, commonly have soil respiration rates characterized by regular trends, while soils with poor soil health often have more variable soil respiration rates within a year and between years (USDA-NRCS, 2014; Hendrix et al., 1998). Therefore, an analysis of soil respiration rates in relation to soil health must consider the specific field and management conditions. Both directly and indirectly, soil respiration is an indicator of the soil health status of various ecosystems. Understanding temporal trends and magnitudes in soil respiration across various natural and managed ecosystems will assist producers in maintaining or improving soil health in those varied ecosystems, particularly in agroecosystems.

Purpose

The purpose of this factsheet is to summarize soil respiration magnitudes and temporal trends across various Arkansas ecosystems, as affected by numerous management practices, to provide measured ranges of soil surface CO_2 fluxes associated with several common Arkansas ecosystems. The ecosystems considered include flood- and furrow-irrigated rice (*Oryza sativa*), furrow-irrigated soybeans (*Glycine max*), furrow-irrigated corn (*Zea mays*), furrow-irrigated cotton (*Gossypium hirsutum*), grazed pasture and native tallgrass prairie. Each ecosystem included paired treatments or management practices associated with conservation and/or climate-smart practices and traditional or non-conservation practices. Studies were conducted under field conditions and in the greenhouse and soil respiration trends were evaluated over time from planting/early growing season to harvest/end of the growing season.

Measurements of Soil Respiration

Different analytical methods and approaches have been used to measure soil surface CO_2 fluxes across various ecosystems. Methodologies included syringe samples collected from vented, non-flow-through, closed chambers (hereafter referred to as the closed-chamber method) over a time period of generally one hour (Figure 1A); in-situ measurements using field-portable analyzers with a smart chamber for a period of five minutes (Figure 1B); and a solar-powered, automated, semi-permanent system (hereafter referred to as the automated system) that can be programmed to automatically close a field-deployed, long-term smart chamber and measure soil surface CO_2 fluxes at various pre-determined times (Figure 1C). Gas samples collected with the closed-chamber method are analyzed using gas chromatography in the laboratory, while field-portable instruments provide immediate, direct measurements in the field.

Results of the following rice studies were obtained using the closed-chamber method (Figure 1A), while the following soybean, native prairie and grazed pasture data were obtained using field-portable analyzers paired with a

Figure 1. Analytical methods for greenhouse gas measurement. Vented, non-flow-through, closed-chamber method (A); portable, in-field LI-COR carbon dioxide/methane analyzer paired with a LI-COR smart chamber (B); and an automated, semi-permanent LI-COR system paired with LI-COR long-term chambers powered by solar panels (C).

smart chamber (Figure 1B). Results for the following corn study were obtained using an automated system (Figure 1C).

Although different methods of data collection and analysis were used in the following studies, results for soil surface CO_2 fluxes are reported in the same format to allow visual comparison. The visually greater proximity of the data points to the smoothed trend line in each treatment or ecosystem indicates a low degree of variability, a low standard error and, generally, a uniform and stable overall trend. Data points that visually appear more scattered and further from the smoothed trend line indicate wider data fluctuations, a large degree of variability and, generally, a non-uniform or unstable trend (Figures 2, 3, 4, 5, 6, 7).

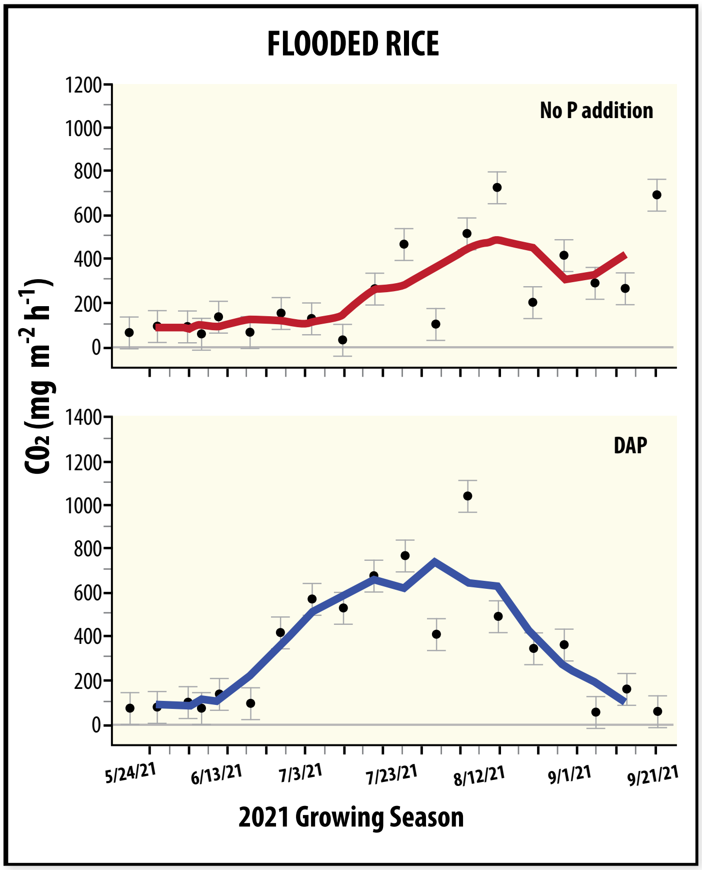
Greater variability and CO_2 flux magnitudes are often associated with disturbed soils, where soil health indicators commonly show a decreasing trend of soil health. Larger CO_2 flux magnitudes with narrower fluctuations can be indicative of a more stable environment with less disturbance and/or an environment that has achieved a greater degree of equilibrium. Furthermore, lower soil respiration variability over time is often indicative of an environment with a stable microbial community that has reached a beneficial equilibrium and likely has greater resilience to climate change (Tiwari et al., 2021).

Rice Production

Soil respiration was measured in the greenhouse from a phosphorus (P)-deficient Calhoun silt-loam soil (*Typic Glossaqualfs*) under flood-irrigation (Arel, 2024) and in the field in a study conducted at the Rice Research Extension Center near Stuttgart, Arkansas on a Dewitt silt-loam soil (*Typic Albaqualfs*) under furrow irrigation (Della Lunga et al., 2023).

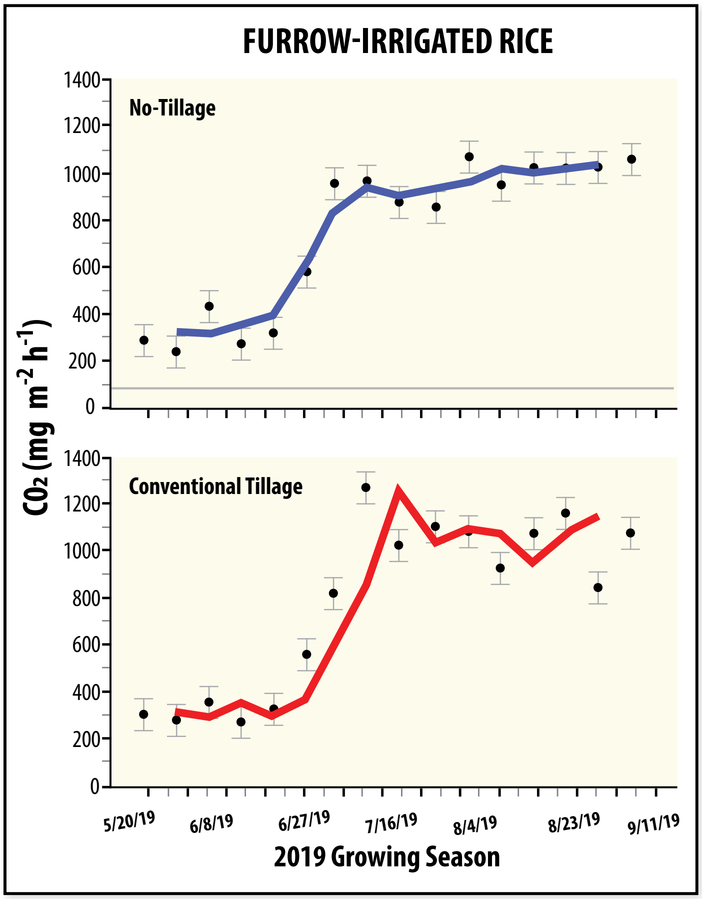
Soil respiration from flood-irrigated rice production showed a slow increasing trend during vegetative stages, followed by a slight decline during late reproductive stages (Figure 2). Appropriate P fertilization in rice systems represents an essential management practice to optimize yields. Soil respiration from diammonium phosphate (DAP)-treated rice showed a steeper increase in soil surface CO_2 flux compared to rice that received no fertilizer-P addition (Figure 2). Soil respiration from rice that did not receive any P addition showed greater variability than the DAP-treated rice in the second half of the growing season, when P deficiencies likely started to drastically affect plant growth, creating unstable conditions. Soil respiration from rice that received no fertilizer-P addition ranged from 33 to 727 mg CO_2 m^{-2} h^{-1}, while DAP-fertilized rice had soil respiration ranging from 57 to 1041 mg CO_2 m-2 h^{-1}, reinforcing the concept that deficient nutrient conditions can limit biogeochemical cycles and negatively affect soil health.

Figure 2. Soil respiration over the 2021 growing season from rice grown under flooded-soil conditions in a Calhoun silt loam (Typic Glossaqualfs) in the greenhouse in Fayetteville, Arkansas. Top panel shows soil respiration means (n = 5 on any one date) and weighted-average temporal trend (for visualization only) from rice that received no phosphorus (P) addition. Bottom panel shows soil respiration means (n = 5 on any one date) and weighted-average temporal trend (for visualization only) from rice fertilized with diammonium phosphate (DAP). Bars on data points represent the standard error for the whole data set, thus all data points within a panel have the same error bar.



Compared to flood-irrigation, furrow-irrigated conditions allow for more aerobic conditions, under which soil respiration is often substantially enhanced (Figure 3). Soil respiration from rice under furrow-irrigated conditions rapidly increased in the early vegetative stages and leveled off around maturity (Figure 3). Soil

Figure 3. Soil respiration over the 2019 growing season from rice under furrow-irrigated conditions in a DeWitt silt loam (Typic Albaqualfs) at the Rice Research and Extension Center near Stuttgart, Arkansas. Top panel shows soil respiration means (n = 9 on any one date) and weighted-average temporal trend (for visualization only) from rice grown under no-tillage. Bottom panel shows soil respiration means (n = 9 on any one date) and weighted-average temporal trend (for visualization only) from rice grown under conventional tillage. Bars on data points represent the standard error for the whole data set, thus all data points within a panel have the same error bar.

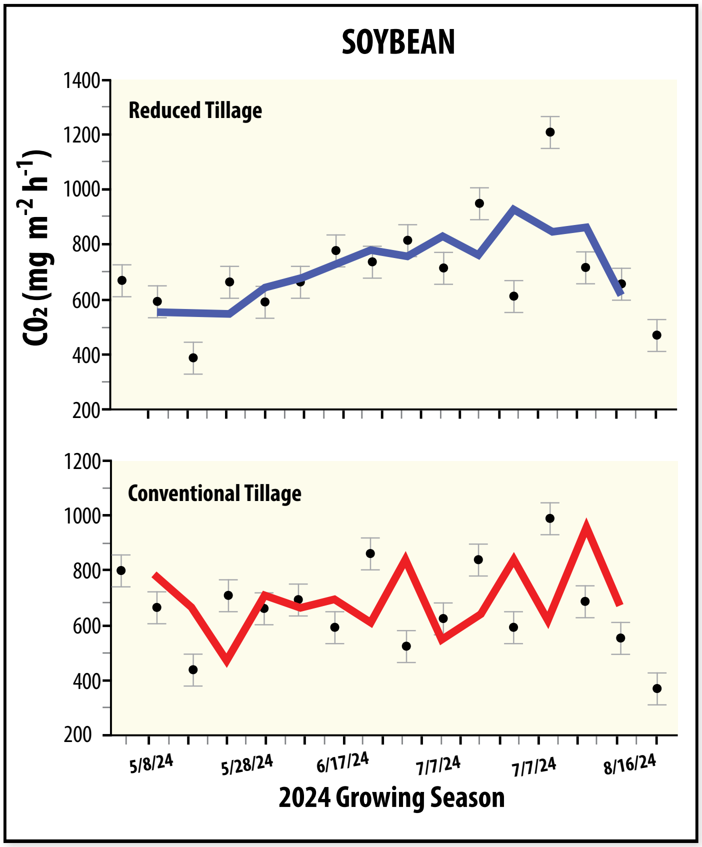


respiration from furrow-irrigated rice under conventional tillage (CT) ranged from 272 to 1269 mg CO_2 m^{-2} h^{-1}, while soil respiration from no-tillage (NT) ranged from 235 to 1072 mg CO_2 m^{-2} h^{-1} (Figure 3). Soil respiration from furrow-irrigated rice under NT had lower variability and more consistent soil surface CO_2 fluxes compared to CT, reinforcing the concept that conservation practices can help maintain an equilibrium, where soil health can be better achieved, potentially reducing soil-C loss through soil respiration from disturbed conditions (Figure 3).

Soybean Production

Soil respiration was measured from an ongoing field study near Dumas, Arkansas on a McGehee silt loam (*Aeric Epiaqualfs*). In soybean production, plant biomass tends to gradually increase up to flowering. Soil respiration trends closely match soybean growth stages, with a gradual increase up to maturity, followed by a decline thereafter related to plants reaching full maturity and leaf senescence. Soil respiration from soybeans under CT ranged from 369 to 989 mg CO_2 m^{-2} h^{-1}, while soil respiration under reduced tillage ranged from 387 to 1209 mg CO_2 m^{-2} h^{-1} (Figure 4). The numerically greater CO_2 fluxes from NT were likely related to the short-term NT had been implemented in the specific field (i.e., < 1 year). Despite the numerically greater CO_2 flux from NT, as in rice production, reduced-tillage practices produced a more uniform soil respiration trend compared to CT, suggesting that the disturbance caused by CT can create more variability in soil surface CO_2 flux and potential soil-C losses.

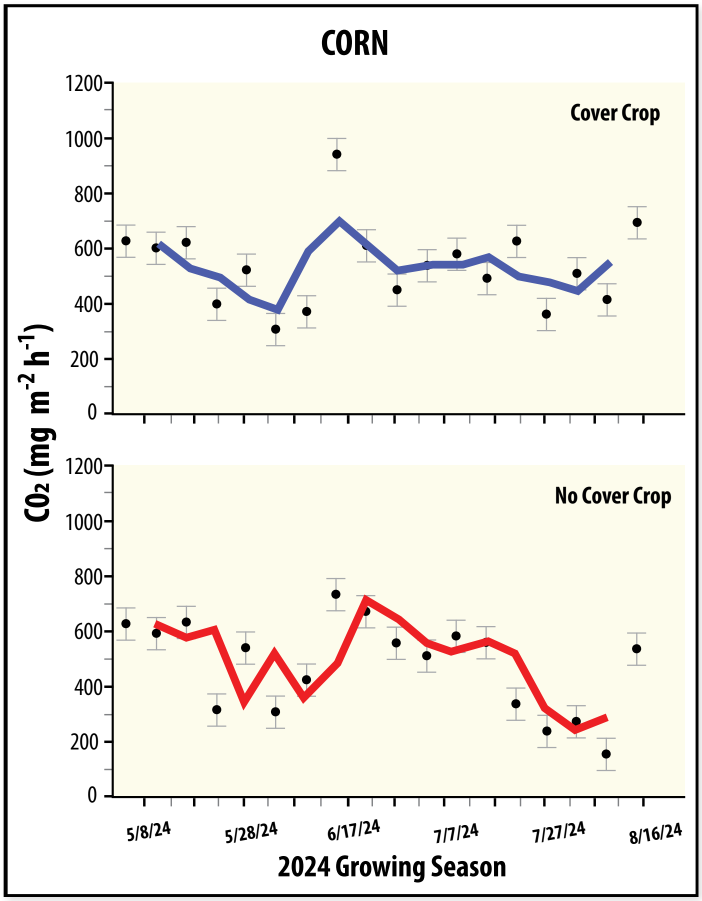
Figure 4. Soil respiration over the 2024 growing season from soybean under furrow-irrigated conditions in a McGehee silt loam (Aeric Epiaqualfs) near Dumas, Arkansas. Top panel shows soil respiration means (n = 5 on any one date) and weighted-average trend (for visualization only) from soybean grown under no-tillage. Bottom panel shows soil respiration means (n = 5 on any one date) and weighted-average temporal trend (for visualization only) from soybean grown under conventional tillage. Bars on data points represent the standard error for the whole data set, thus all data points within a panel have the same error bar.



Corn Production

Soil respiration was measured from a field study conducted in Clarksdale, Mississippi on a Dubbs silt loam (*Typic Hapludalfs*). Soil respiration from corn, with and without a cover crop, appears to follow similar trends, although more stable soil surface CO_2 flux occurred in the middle of the growing season from the cover-crop treatment compared to the trend observed in the treatment without cover crops (Figure 5). The fluctuation of soil respiration under both treatments was directly correlated to the irrigation frequency, highlighting the known influence soil moisture has on soil respiration. Soil respiration under both treatments showed a slightly increasing trend in the first half of the growing season, followed by narrower fluctuations that stabilized to an almost constant trend in the second half of the growing season (Figure 5). Soil respiration with cover crops ranged from 230 to 940 mg CO_2 m^{-2} h^{-1}, while soil respiration without cover crops ranged from 150 to 970 mg CO_2 m^{-2} h^{-1} (Figure 5). Cover crops can help maintain more uniform and stable environmental conditions, such as soil temperature and moisture content, limiting wide fluctuations of respiration and reducing potential soil-C losses (Figure 5).

Figure 5. Soil respiration over the 2024 growing season from corn under furrow-irrigated conditions in a Dubbs silt loam (Typic Hapludalfs) near Clarksdale, Mississippi. Top panel shows soil respiration means (n = 8 on any one date) and weighted-average temporal trend (for visualization only) from corn grown with a cover crop. Bottom panel shows soil respiration means (n = 8 on any one date) and weighted-average temporal trend (for visualization only) from corn grown without a cover crop. Bars on data points represent the standard error for the whole data set, thus all data points within a panel have the same error bar.



Cotton Production

Soil respiration was measured in an on-going field study conducted near Dumas, Arkansas on a Hebert silt loam (*Aeric Epiaqualfs*). Similar to rice and soybeans, soil respiration from cotton under reduced tillage, without cover crops, showed a rapidly increasing trend in the first half of the growing season, likely related to progressing plant growth, followed by a rapidly decreasing trend after maturity. Soil respiration from cotton ranged from 228 to 1246 mg CO_2 m^{-2} h^{-1} (Figure 6). Treatment comparisons in cotton

Figure 6. Soil respiration over the 2024 growing season from cotton under furrow-irrigated conditions in a Hebert silt loam (Aeric Epiaqualfs) near Dumas, Arkansas. Panel shows soil respiration means (n = 4 on any one date) and weighted-average temporal trend (for visualization only) from cotton grown under reduced tillage. Bars on data points represent the standard error for the whole data set, thus all data points within a panel have the same error bar.

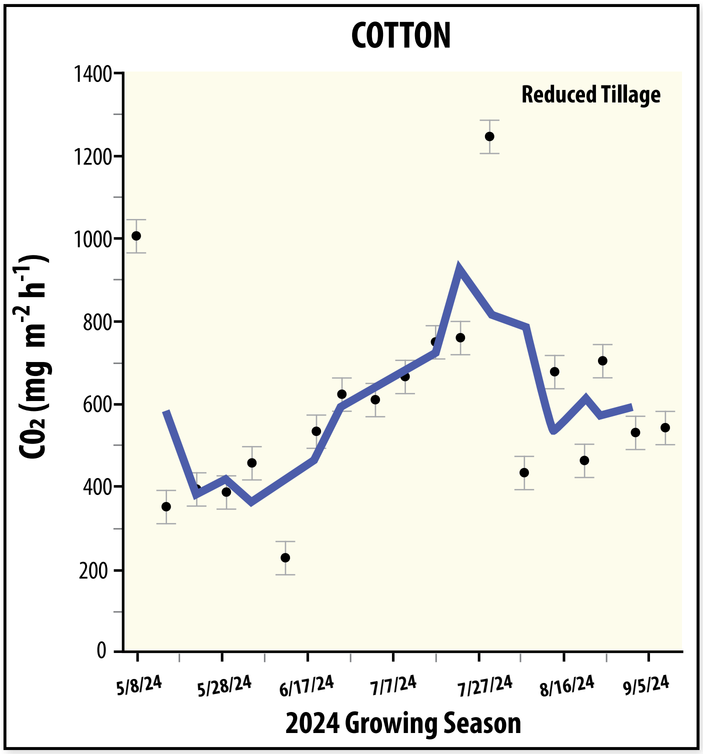
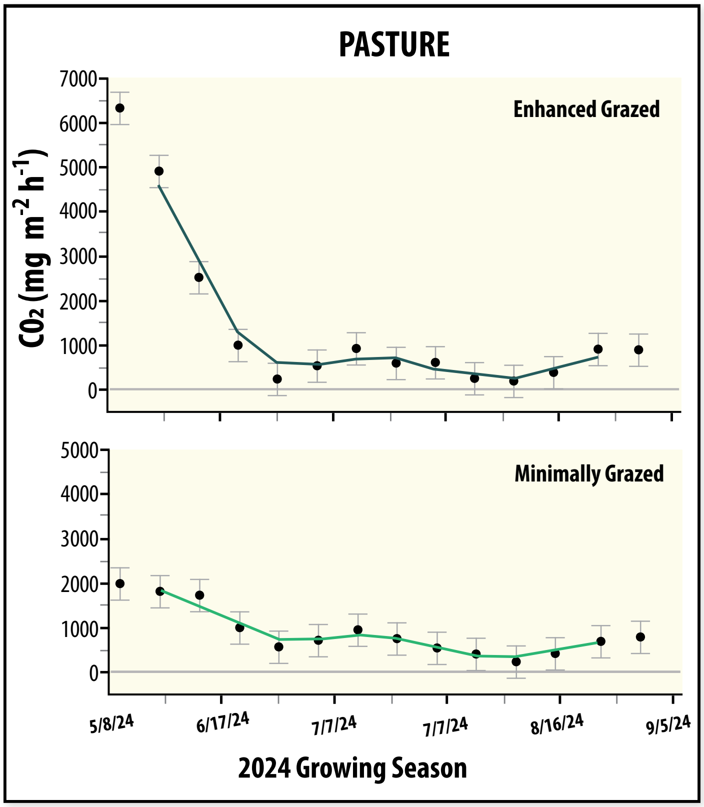


Figure 7. Soil respiration over the 2024 growing season from a non-irrigated pasture system near Decatur, Arkansas. Top panel shows soil respiration means (n = 5 on any one date) and weighted-average temporal trend (for visualization only) from an enhanced-grazed pasture in a Newtonia silt loam (Typic Paleudolls). Bottom panel shows soil respiration means (n = 5 on any one date) and weighted-average temporal trend (for visualization only) from minimally grazed pasture in a Peridge silt loam (Typic Paleudalfs). Bars on data points represent the standard error for the whole data set, thus all data points within a panel have the same error bar.



fields are currently ongoing in Arkansas, and no conclusive statement on climate-smart practices can be made yet. However, reduced tillage, widely considered a climate-smart practice, can help reduce large soil respiration rates and the potential for soil-C losses in any agroecosystem.

Grazed Pasture

Soil respiration was measured in an on-going field study conducted near Decatur, AR on Newtonia silt loam (*Typic Paleudolls*) that was managed as enhanced grazed and on a Peridge silt-loam soil (*Typic Paleudalfs*) that was managed as minimally grazed. Soil respiration from a rotationally grazed pasture system showed a decreasing trend under enhanced grazing management at the beginning of the growing season followed by a stable, slightly increasing trend for the remaining part of the growing season (Figure 7). In contrast, minimally grazed management was characterized by a stable soil respiration trend for the entire growing season, suggesting that a biogeochemical equilibrium had been previously achieved with minimal animal disturbance and management (Figure 7). The presence of soil disturbance, such as from grazing practices, can alter the biogeochemical equilibrium which requires time to stabilize (Figure 7). Soil respiration in the enhanced-grazed pasture ranged from 286 to 6355 mg CO_2 m^{-2} h^{-1}, while soil respiration ranged from 179 to 1940 mg CO_2 m^{-2} h^{-1} in the minimally grazed pasture (Figure 7). Thus, even non-cultivated agroecosystems can play a key role in C cycling and storage.

Native Tallgrass Prairie

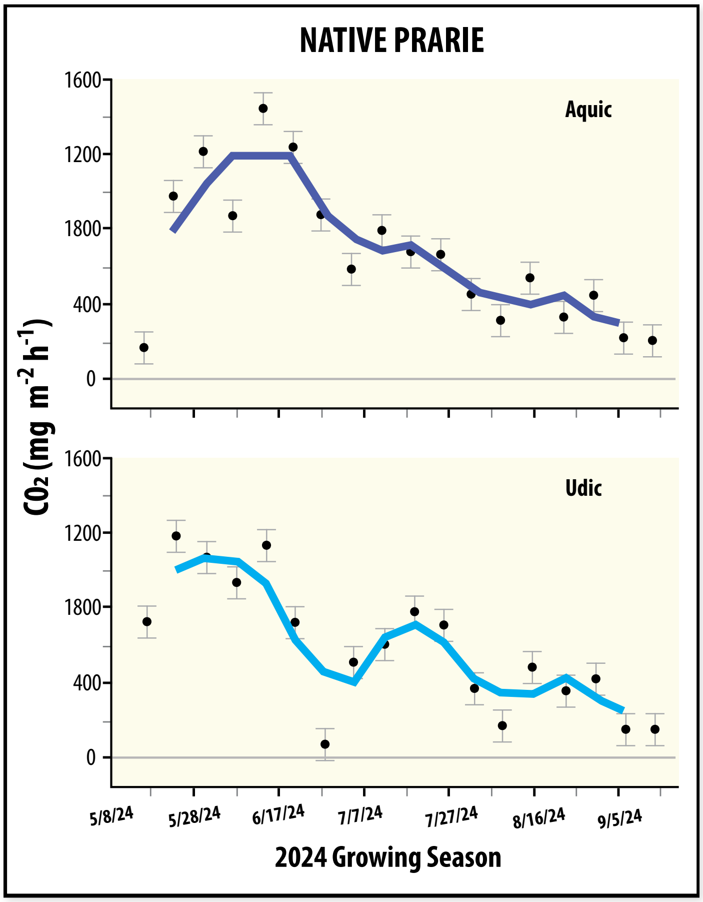
Soil respiration was measured in an ongoing study conducted near Siloam Springs, Arkansas on Taloka (*Mollic Albaqualfs*) and Jay silt-loam soils (O*xyaquic Fragiudalfs*). Soil respiration from the native tallgrass prairie, under both aquic and udic soil moisture regimes, showed a rapidly increasing trend at the beginning of the growing season followed by a constant, slightly decreasing trend for the remaining part of the growing season (Figure 8). The udic section of the prairie had wider soil respiration fluctuations, while the aquic portion was characterized by a narrower soil respiration range, again highlighting the fundamental role of soil water content in regulating soil respiration across ecosystems (Figure 8).

Soil water contents above field capacity but below saturation, as is commonly observed in aquic soil conditions, can act as a regulator of soil respiration. Soil respiration from the native prairie under an aquic moisture regime ranged from 215 to 1445 mg CO_2 m^{-2} h^{-1}, while soil respiration ranged from 79 to 1132 mg CO_2 m^{-2} h^{-1} in the udic portion (Figure 8). The magnitudes of soil respiration measured under native tallgrass prairie were similar to those measured in cultivated agroecosystems. In native prairie, the large aboveground biomass and dry matter present frequently and rapid nutrient cycling often results in large soil respiration rates.

Season-long CO_2 Emissions Across Ecosystems

Season-long emissions are obtained by interpolating between weekly measured fluxes and

Figure 8. Soil respiration over the 2024 growing season from two sections of Chesney Prairie Natural Area near Siloam Spring, Arkansas. Top panel shows soil respiration means (n = 5 on any one date) and weighted-average temporal trend (for visualization only) from a section of the native prairie under aquic soil moisture regime in a Taloka silt loam (Mollic Albaqualfs). Bottom panel shows soil respiration means (n = 5 on any one date) and weighted-average temporal trend (for visualization only) from a section of the native prairie under udic soil moisture regime in a Jay silt loam (Oxyaquic Fragiudalfs). Bars on data points represent the standard error for the whole data set, thus all data points within a panel have the same error bar.



summing for the whole growing season. Season-long emissions provide additional information on the impact of management practices on greenhouse gases generally and soil respiration specifically. Considering one of the main goals of conservation practices is to reduce C losses by soil respiration, large season-long CO_2 emissions under specific management can indicate the potential for substantial C losses that can impact the long-term sustainability of agricultural and farming activities (Table 1). In Arkansas, direct measurements of season-long CO_2 emissions were lowest from flood-irrigated rice production with no phosphorus fertilization and were largest from rotationally grazed pastureland with enhanced management (i.e., frequent rotational grazing and annual seeding of winter-hardy grasses) (Table 1).

If the difference in season-long CO_2 emissions between management practices in the same ecosystems is substantial, results need to be further evaluated to understand what mechanisms were involved in the production and release of CO_2. However, large season-long CO_2 emissions do not necessarily indicate the presence of an unhealthy or mismanaged production system or ecosystem. Relatively low variability associated with CO_2 emissions, such as low standard errors (Table 1), can represent a more appropriate parameter to evaluate the stability and health of an ecosystem. Low standard errors often indicate low levels of disturbance and therefore represent a relatively stable ecosystem. Season-long CO_2 emissions that vary by 10 percent or less between management practices are commonly considered similar, as the variability is likely related to the measurement technique rather than inherent differences between ecosystems or treatments within an ecosystem.

Summary

Analyzing soil respiration across ecosystems and under various management practices provides essential information to characterize scenarios where soil-C losses can be reduced while biogeochemical cycles are kept active. Soil respiration studies can help identify ecosystem traits and management practices that can enhance productivity while maintaining or improving soil health by reducing soil-C losses. Understanding expected ranges in soil respiration among various

Ecosystem	Sub-treatment	CO_2 (± SE) (kg ha^{-1} $season^{-1}$)
Rice	Flooded, no phosphorus addition Flooded, fertilized with DAP†	7,381 (978) 10,533 (1,626)
	Furrow-irrigated, no tillage Furrow-irrigated, conventional tillage	19,049 (838) 20,008 (1,394)
Soybean	Reduced tillage Conventional tillage	17,971 (1,166) 16,950 (1,139)
Corn	Cover crop No cover crop	13,117 (2,436) 11,428 (704)
Cotton	Reduced tillage	17,702 (358)
Pasture	Enhanced grazed management Minimally grazed	30,140 (4,229) 15,051 (1,102)
Native prairie	Aquic soil moisture regime Udic soil moisture regime	20,090 (3,123) 17,346 (811)

†DAP, diammonium phosphate

Table 1. Summary of mean [± standard error (SE)] carbon dioxide (CO2) emissions measured during the typical growing season (i.e., April to September) in various ecosystems and several sub-treatments in Arkansas.

ecosystems can also help recognize early signs of disturbances in natural and cropping systems, aid in developing approaches that favor soil C sequestration and reducing soil-C losses.

A healthy soil is characterized by soil respiration that follows a relatively stable temporal trend. Ensuring the sustainability of agricultural soils in Arkansas can be facilitated through further scientific research focused on soil respiration as an indicator of soil health. Additionally, further research must be conducted in deciduous and coniferous forest systems to capture additional major ecosystems and managed environment in Arkansas. Building a baseline data set for various land management practices in a variety of ecosystems may become extremely important in helping landowners know the value of their climate assets, such as soil carbon and greenhouse gas emissions, that could be traded with other industries.

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