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The LTAR Cropland Common Experiment at Central Mississippi River Basin

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Abstract

The Central Mississippi River Basin (CMRB) Common Experiment, with its marginal soils and southern Corn Belt climate, is an ideal location for evaluating progress toward environmental, productivity, and climatic adaptation goals. Sustainable production with conventional row-crop systems is more challenging than in the upper Corn Belt, making evaluation and adoption of alternative farming practices crucial. This Common Experiment has a hydrologically restrictive layer causing reduced plant available water capacity in the root zone. The CMRB site joined the Long-Term Agroecosystem Research Network in 2011 with the Cropland Common Experiment established in 2015. The Common Experiment contrasts prevailing and alternative practices at plot and field scale. Improvement of the soil ecosystem is key, as it underpins other objectives, including reduced nutrient losses, increased soil water holding capacity, and yield stability.

1 | THE REGIONAL CONTEXT

This paper provides a description of the Cropland Common Experiment at the Central Mississippi River Basin (CMRB) Long-Term Agroecosystem Research (LTAR) Network site. The Common Experiment in northeast Missouri is part of the Glaciated Plains Division and encompasses the Heartland Farm Resources Region 1 (USDA Economic Research Service) and the Central Claypan Area (NRCS Major Land Resource Area; MLRA113). This MLRA, spanning approximately 3 million ha in northeast Missouri and southern Illinois, comprises soils with a hydrologically restrictive layer termed "claypan" (USDA NRCS, 2022). The CMRB Common Experiment represents not only MLRA 113 but also soils with similar hydrologic constraints such as MLRA 112 in western Missouri and eastern Kansas (Figure 1; Bean et al., 2021). The CMRB has a constituency area of approximately 9 million ha of cropland with a high representativeness for the region (Kumar et al., 2023). The area represented is smaller than most other LTAR experiments within the Corn Belt but presents a unique set of conditions that challenge simultaneously achieving sustainability, productivity, and environmental health.

Abbreviations: ALT, alternative; CMRB, Central Mississippi River Basin; GCEW, Goodwater Creek Experimental Watershed; GDD, growing degree days; HUC, hydrologic unit code; LTAR, Long-Term Agroecosystem Research; MLRA, Major Land Resource Area; T_{max}, maximum temperature.

Hydrologically, the site falls within the Goodwater Creek Experimental Watershed (GCEW) in the Salt River Basin. Water flows northeast from GCEW, a hydrologic unit code (HUC) 12 watershed, to the Missouri River watershed (HUC 10) and finally into the Upper Mississippi River watershed (HUC 07) before exiting the state toward the Gulf of

Mexico. While the plant available water capacity ranges from 0.30 to 0.35 mm mm^{-1} in the 20- to 30-cm topsoil layer above the claypan, it ranges from 0.20 to 0.25 mm mm^{-1} at and below the claypan because of the high wilting point of clay (Mudgal et al., 2010). This claypan results in a root-zone with low plant available water capacity overall and increased risk of water stress. In spite of this, <2% of cropland is irrigated because of the high mineral content of the water and limited access to high-quality aquifers. The topography is flat to gently rolling with slopes of mostly 0%–3%. Although there is minimal slope, MLRA 113 has the highest estimated cropland soil erosion rates in Missouri (Willett et al., 2012). The offsite movement of soil, nutrients, and pesticides is associated with surface runoff controlled by precipitation intensity and poor soil infiltration (0.001–0.1 mm h^{-1}) at and below the claypan (Baffaut et al., 2015; Conway et al., 2017; Lerch, Kitchen, et al., 2015; Mudgal et al., 2010). Regional streams are fed by a glacial aquifer and are considered slightly to moderately ecologically impaired from surface runoff and nitrate-nitrogen (NO_3-N) pollution (Belitz et al., 2022; Lerch, Baffaut, et al., 2015; Kitchen et al., 2015).

Prior to plowing 150 years ago, this region was predominantly tallgrass prairie and wooded riparian forest along river corridors. Today, the land is primarily in grain row-crop systems and pasture with forest in riparian buffers and areas not suitable for crop or livestock production. Currently, 44% of the Salt River Basin is used for grain crops and 33% for pasture; the land under grain crop production receives over 85% of fertilizer inputs for the region (Lerch et al., 2008; Lerch, Kitchen, et al., 2015). This region is unique within the Corn Belt because of its diverse landscapes and variety of cropping systems. Predominant cash crops include soybean (*Glycine max*), maize (*Zea mays*), and winter wheat (*Triticum aestivum*) with other minor crops including grain sorghum (*Sorghum bicolor*), alfalfa (*Medicago sativa*), and oats (*Avena sativa*). The statewide cropped area is approximately 5.5 million ha and comprises soybean (~45%), maize (~30%), and winter wheat (~5%) (USDA NASS, 2024a).

In contrast to much of the Corn Belt, farmers in this region have achieved higher profitability and consistent yields with soybean; thus, soybean has been used more frequently in crop rotations than maize (Conway et al., 2020; Yost et al., 2017, 2019). The indeterminate growth habit of soybean results in an extended period of flowering and seed set offering greater yield stability. However, maize is becoming more utilized in the crop rotation. Since 1990, acreage planted to soybean has increased by an average of 0.5% each year and maize by 2% (USDA NASS, 2024b). Winter wheat and grain sorghum acreage has decreased substantially in the same period. Winter wheat, grown here more often than in the upper Corn Belt, is seeded following the harvest of warm-season cash crops, generally soybean. On pastures, the forage is primarily tall fescue (*Festuca arundinacea* Schreb.), a cool-season grass.

Core Ideas

- The Central Mississippi River Basin Common Experiment has a southern Corn Belt climate and soils with a hydrologically restrictive layer unique among Long-Term Agroecosystem Research sites.
- Improvements to the soil ecosystem are necessary to achieve production, environmental, and climate goals for this region.
- Yield stability is a key metric for farmers in this region due to high temporal and spatial yield variability.
- The capacity for improved environmental indicators here may be particularly valuable for guiding expectations in areas with less challenging soils.

Cover crops are grown on up to 10% of Missouri agricultural land (NASA, 2022; Zhou et al., 2022). Conservation practices like no-tillage, cover crops, and crop rotation diversification are more profitable here compared to other regions (Conway et al., 2020). Minimizing soil erosion is a major concern to preserve existing topsoil and improve soil quality (Veum et al., 2015).

Soil in this region originates from sedimentary bedrock, layers of moderately dissected glacial tills, and soil profiles formed in till, pedisediments, and loess (Sadler, Lerch, et al., 2015). Over time, illuviated clay developed an argillic (claypan) horizon with 450–650 g kg^{-1} smectitic clay (Baffaut et al., 2015; Kitchen et al., 2015). Key soil features include loess thickness, smectitic clay mineralogy, and depths to the argillic horizon and a paleosol (Sadler, Lerch, et al., 2015).

Plowing of the native prairie and subsequent cultivation has resulted, on average, in the loss of half of the original topsoil. Ongoing erosion and redeposition of topsoil within fields has caused extreme within-field variation in topsoil depth as high as 0–100 cm (Kitchen et al., 1999). Typically, the topsoil depth on summits is moderate (~35 cm), less on backslopes (<10 cm), and deepest at footslopes (>50 cm) (Kitchen et al., 2015; Myers et al., 2007). The claypan limits root development with the highest root density above the claypan (Myers et al., 2007).

1.1 | Climate in this region

This region is at the intersection of air masses and moisture coming from the Gulf of Mexico, Great Plains, and Canada; Gulf of Mexico patterns are becoming more dominant due to climate change (Knight et al., 2008; Winkler et al., 2014). The CMRB is the warmest LTAR site within the Corn Belt with winters having a less distinct freeze-thaw pattern.

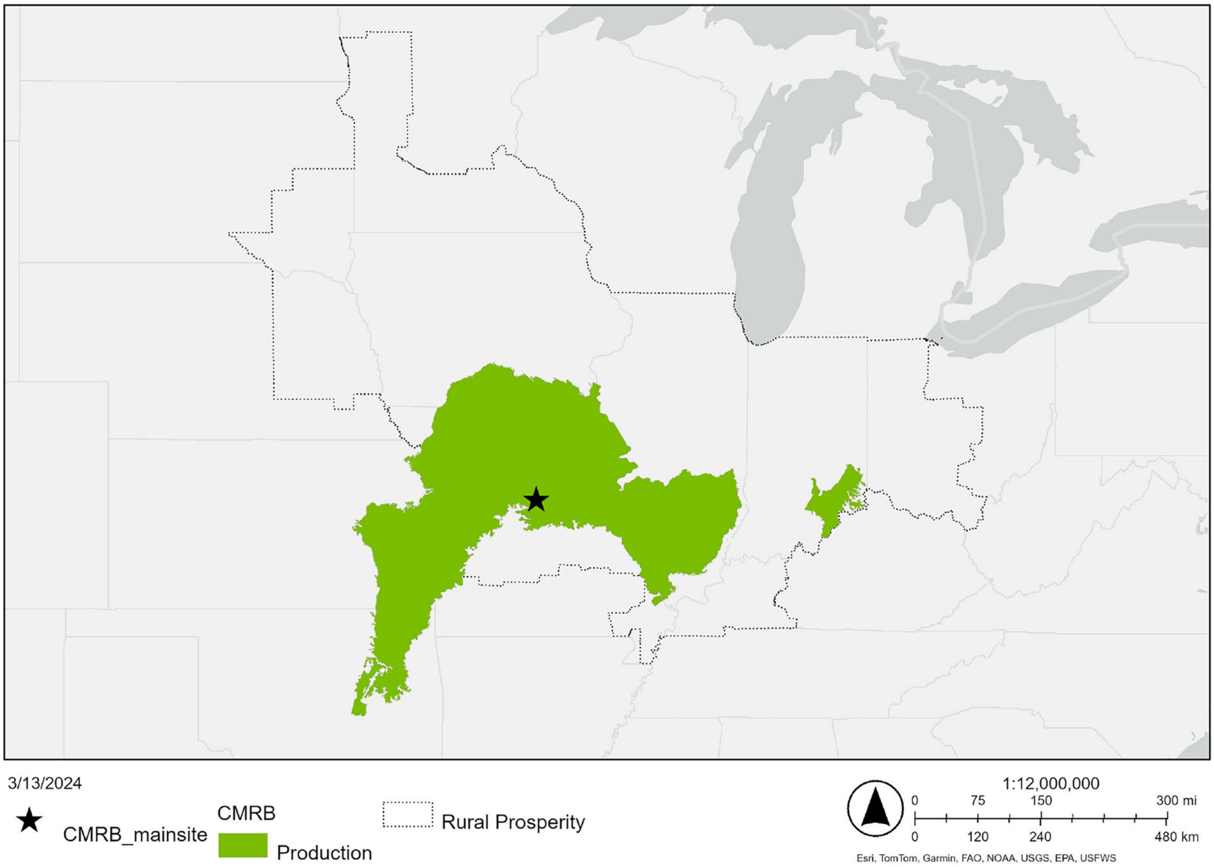

FIGURE 1 The Central Mississippi River Basin (CMRB) Common Experiment as part of the USDA Long-Term Agroecosystem Research Network. The filled area is the production region with the dotted outline denoting the economic region (Bean et al., 2021).

All months have mean maximum daily temperatures above freezing, allowing water flow and evaporation in winter (Table S1) (Schreiner-McGraw et al., 2023) and relatively short periods of snow and ice coverage (Sadler, Sudduth, et al., 2015). The frost-free growing season extends from April 8 to October 25 (day of year 98 and 298, respectively) totaling 200 days and 2060 growing degree days (GDD; ˚C) (Abendroth et al., 2019). Mean annual precipitation in catchments surrounding CMRB has ranged from 966 to 1049 mm (Baffaut, Ghidey, et al., 2020). Although median precipitation is near 1000 mm, it varied over a 30-year period (1993–3023) from 752 mm (2007) to 1580 mm (2008). Most precipitation occurs from April to June (34%) and July to September (30%), with drier conditions in fall (20%) and winter (16%) months (Sadler, Sudduth, et al., 2015). Annually, about 65% of precipitation is lost to evapotranspiration (~650 mm), 30% to surface and subsurface flow, and the remainder to percolation (Baffaut, Baker, et al., 2020).

Spring, fall, and winter seasons in the Corn Belt are warming at a greater rate than the summer due to a climatological warming hole (Alter et al., 2018; Basso et al., 2021; Partridge et al., 2019). This seasonal difference in warming is undergirded by differences in the magnitude of warming between minimum (T_{min}) and maximum (T_{max}) temperatures. Summer maximum temperatures have decreased in this region since 1950 when assessed as either T_{max} or heat stress degree days (unpublished CMRB data; Abendroth et al., 2019). The region's average annual temperature has risen, currently 12.5˚C at CMRB (Table S1). Precipitation patterns are shifting in seasonality and intensity, which is particularly important given the shallow topsoil and restrictive claypan layer. The decadal (2012–2022) average precipitation is 997 mm with the highest quantity in June (139 mm) and least in February (35 mm) (Table S1). The CMRB experiment is rainfed, and cropping systems must utilize stored precipitation from the soil profile.

1.2 | Major cropping challenges in the region

The primary challenge for crops is the low water-holding capacity of claypan soils. These soils quickly saturate during the spring making field operations challenging and then quickly dry during the growing season without recharge by timely precipitation. Farmers have frequently tilled in the spring for seedbed preparation or to incorporate inputs, but this is undercutting long-term stewardship (Conway et al., 2020). Appropriate management of these marginal soils will become more challenging as climate change results in more rapid transitions between wet and dry periods (Chen & Ford, 2022).

The dominance of summer annual crops results in a fallow period of up to 6 months. While introducing perennials (grasses and legumes) could provide many benefits, this is not a viable option for many (Veum et al., 2015). Therefore, increased year-round coverage with diverse, annual crops is a step forward by promoting deeper roots, better infiltration, increased microbial activity, and greater resilience to climate extremes (Schreiner-McGraw & Baffaut, 2023; Veum et al., 2015). The current fallow period is sufficient for cover crop or winter wheat production, as only ~70% of the frost-free period GDDs are currently used for maize or soybean production (Abendroth et al., 2021).

Optimizing crop fertilization is challenging given the uneven topsoil depth across fields and the acidic soil pH, with topsoil pH below 7 and claypan pH ranging from 4.0 to 4.5 (Myers et al., 2007). As soil acidity increases, the availability of macronutrients and micronutrients to crops decreases (Alam et al., 1999; Marschner, 1991). Considering the varying topsoil depth, phosphorus and potassium fertilizers are more appropriately applied using precision agriculture technology. Highly eroded areas need more phosphorus fertilizer to overcome the sorption caused by high clay content and acidity, but less potassium, as it is supplied in part from the claypan (Conway et al., 2018).

Farmers apply most of their synthetic fertilizers shortly before planting (Scharf et al., 2002). Edge-of-field nitrate-N losses in runoff range from 18 to 36 kg ha^{-1} $year^{-1}$ (Baffaut et al., 2019), while loads of nitrate-N leaving the GCEW range from 2 to 8 kg ha^{-1} $year^{-1}$ (Lerch, Kitchen, et al., 2015). Fall fertilizer applications, especially nitrogen, pose increased environmental risks due to surface runoff and denitrification. Baffaut et al. (2019) and Lerch, Kitchen, et al. (2015) have estimated losses of nitrogen to gaseous forms to 20%–25% and 35% of applied nitrogen, respectively. Mitigating fertilizer losses occurs when fall applications are reduced, fertilizer management approaches are improved, or the fallow period is eliminated. Most of the nitrogen fertilizer (56%–88%) purchased in Missouri is applied to maize followed by winter wheat and grain sorghum (Lerch, Baffaut, et al., 2015). The movement of ammonium-nitrate (NH_4-N) and NO_3-N offsite occurs mainly from January to June due to preplant fertilizer applications during the fallow period and crops not able to utilize nitrogen before it is lost to runoff or leaching. The movement of orthophosphate (PO_4-P) occurs year-round and is associated with erosion events. Unlike other regions, over 90% of nutrient loads are associated with storm events and are not greatly changed by management practices (Kitchen et al., 2015; Lerch, Baffaut, et al., 2015). Nitrate-nitrogen losses predominantly result from denitrification within riparian zones and streambeds (Kitchen et al., 2015). Overall, this region sees nitrate-N stream concentrations <2 mg L^{-1} (Lerch, Kitchen, et al., 2015) and contributes less to hypoxic conditions in the Gulf of Mexico than the artificially drained northern and eastern areas of the Corn Belt (Sadler, Lerch, et al., 2015), or even the well-drained agricultural watersheds in northwest Missouri where median concentrations range from 4 to 8 mg L^{-1} (Lerch, Kitchen, et al., 2015).

2 | THE COMMON EXPERIMENT AT CMRB

The Common Experiment focuses on restoring degraded soils for improved functionality, increasing productivity despite a shallow restrictive soil layer, and conserving soil moisture for crop use. To achieve this, we focus on conservation practices that can be implemented by farmers including no-tillage, cover crops, diversified and extended rotations, and precision fertilizer applications; these have already improved soil health, specifically biological soil function, represented by greater soil organic carbon, β-glucosidase activity, microbial biomass C, and mineralizable N (Veum et al., 2015). We are also working to quantify the mechanisms behind changes in soil carbon and whether sequestration is from atmospheric removal, erosion reduction, or a combination (Baffaut, Baker, et al., 2020; Schreiner-McGraw et al., 2024). For farmers to adopt new practices, crop yield stability is crucial. Annual within-field yield variability is sizable with yields differing by as much as 4:1 due to variable topsoil depth (Yost et al., 2016, 2017). Enhancing crop yield stability requires limiting abiotic plant stress from moisture shortages during critical reproductive periods (Hatfield & Prueger, 2015). A key metric of success for these practices is whether premature crop senescence from abiotic stressors is prevented. Our sustainability and resilience strategy depends on intensification of the system with plants growing on the landscape year-round; this is feasible given the warmer climate compared to the upper Corn Belt (Bai et al., 2019; Kleinman et al., 2018; Schreiner-McGraw et al., 2024).

Our location joined the LTAR Network in 2011, with the Common Experiment established in 2015 (Sadler, Lerch, et al., 2015; Spiegal et al., 2018). It is located on a typical upland claypan soil belonging to the Adco-Mexico-Putnam association, with characteristics detailed previously here and in Kitchen et al. (1998). The soil series vary by landscape position with Adco silt loam at summits and Mexico silt loam on backslope and footslopes. The plots and field sites are located 2 km north of Centralia, MO, in Audrain County at an elevation of 260 m.

The Common Experiment utilizes a paired design of two fields with georeferenced subsampling locations and 0.35 ha replicated plots (Figure 2). The fields measure 20 ha

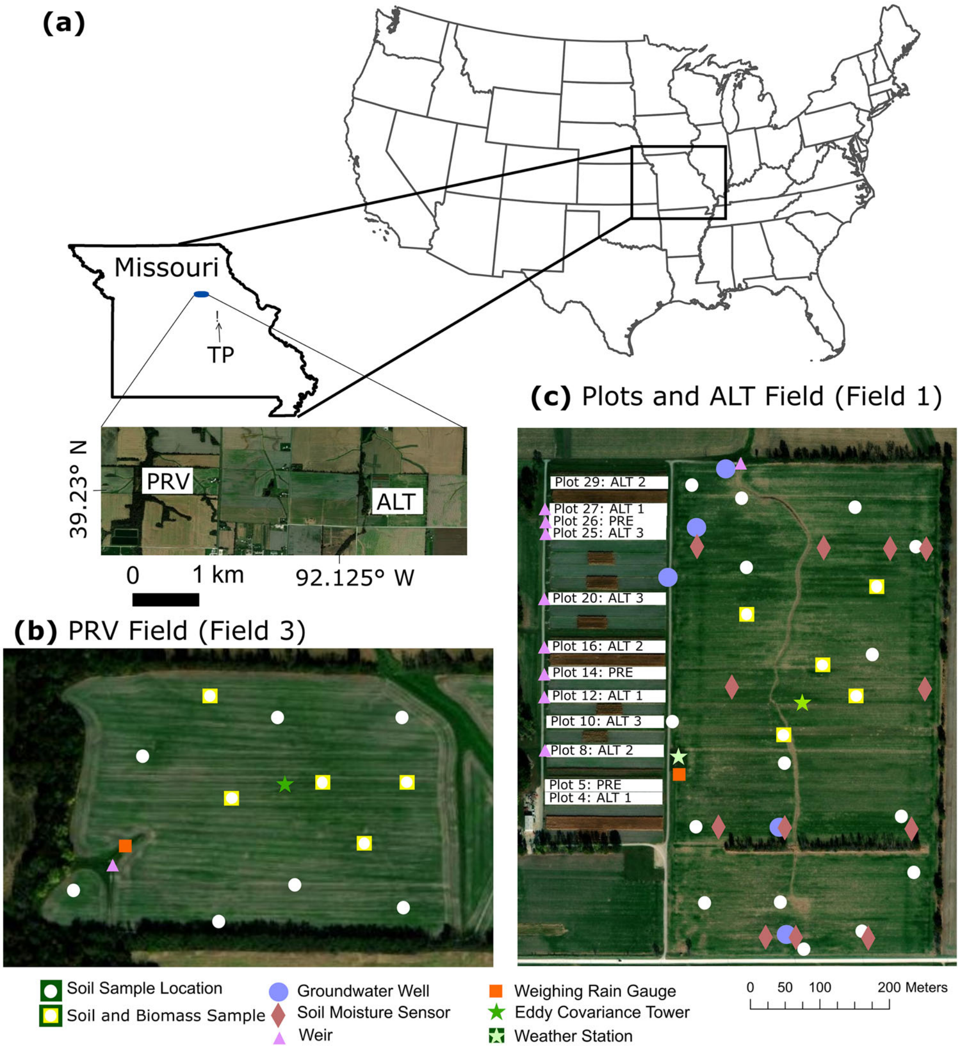

FIGURE 2 Long-Term Agroecosystem Research (LTAR) Central Mississippi River Basin (CMRB) Common Experiment schematic detailing the replicated plots and field sites with prevailing (PRV) and alternative (ALT) practices. The replicated plots have prevailing and alternative practices with three iterations of the alternative (ALT 1, ALT 2, and ALT 3). The 4-year system is defined as ALT 2 while 3-year variants are ALT 1 and ALT 3. The ALT Field has ALT 2 practices.

(prevailing treatment; Field 3) and 35 ha (alternative treatment; Field 1). Replicated plots 18 m wide by 189 m long are located adjacent to Field 1. The plots use a randomized complete block design with three replications. The management system (prevailing or alternative) forms the main plot treatment, and landscape position serves as the split plot treatment. Six plots (two plots per replicate) are considered part of the Common Experiment and represent our signature prevailing and alternative practices. As shown in Figure 2, additional plots provide a benchmark of other alternative practices. The experiments are on land managed under a 5-year renewable lease initiated in 1991 between the landowners and the University of Missouri. USDA-ARS staff and scientists manage Field 1 (alternative practice) and the replicated plots. A local farmer has managed Field 3 (prevailing practice) since 2006; it is located 2.5 km from Field 1 with similar site characteristics. In addition, Tucker Prairie, owned and operated by the University of Missouri and located 33 km southeast of the CMRB site, provides a benchmark for unmanaged ecosystems. This native prairie, untilled with annual prescribed burns since 1958, features over 230 native plant species in 52 families and is dominated by warm-season grasses (Kellar et al., 2015; Kucera, 1956). Tucker Prairie is the closest remaining native, remnant, claypan prairie system featuring the unique hydrologic and soil characteristics of the CMRB's Central Claypan Region (MLRA 113) found on the same soil series (Veum et al., 2014 and references therein); therefore, it serves as the CMRB ecological reference site.

The prevailing practice is a soybean-soybean-maize rotation with minimum tillage and uniform application of nitrogen, phosphorus, and potassium synthetic fertilizer. Nitrogen is generally applied as fall anhydrous or preplant at 200 kg

N ha^{-1}. Phosphorus and potassium application rates will vary based on soil test results; these are generally applied as a granular broadcast preplant. The prevailing field (Field 3) has had minimum tillage from 2002 to 2022. In 2023, the farmer introduced cereal rye (*Secale cereale*) as a cover crop and eliminated tillage; these were the first significant modifications since he began farming this field in 2006.

In contrast, the alternative practice is a 4-year no-tillage cropping system of maize–soybean–winter wheat–hay with a cereal rye cover crop following maize (ALT and ALT 2 in Figure 2). The soybean is planted into the live cereal rye cover crop with the rye crimped following planting. The hay crop, consisting of a mixture of Timothy Grass (*Phleum pratense*) and Medium Red Clover (*Trifolium pratense*), is generally baled and removed three times. This hay crop may have its first cutting during the fall of the sowing year with one to two cuttings the following year and a final cutting potentially the following spring before maize is planted. Maize and wheat receive a base rate of synthetic nitrogen fertilizer followed by a mid-season variable-rate application guided by canopy reflectance sensing. Phosphorus, potassium, and lime (when necessary) are variable-rate applied based on gridded soil test results. This alternative practice had its first significant change in 2019 when it was transitioned from a 3-year system of maize–soybean–winter wheat with cover crops to the current 4-year system. The practice changed from planting a multi-species cover crop following the wheat harvest to sowing the hay crop, which remains in place for 18 months before returning to maize (ALT 2 in Figure 2). The ALT 2 system is our signature ALT treatment, although two additional alternative systems exist in the replicated plots; these are 3-year variants and include maize–soybean–wheat with cover crops (ALT 1) or grain sorghum–soybean–wheat with cover crops (ALT 3).

Plots are oriented with a westward aspect forming three distinct split plots characterized by varying slopes: summit (0%–1% slope), backslope (1%–3% slope), and footslope (<1% slope). These landscape position designations were established from a survey by the Missouri Cooperative Soil Survey in conjunction with topographical and soil electrical conductivity maps (Jung et al., 2005; Kitchen et al., 1998). Topsoil depth averaged 16 cm at the summit, 9 cm at the backslope, and 34 cm at the footslope, with a standard error of 2 cm at each position (Jung et al., 2005). The split plots vary in size with area in between to ensure a clear distinction of beginning and end for each landscape position; minimum split plot size is 18 m by 18 m (0.032 ha).

Surface runoff and water quality are monitored at drainage points on each of the fields and in two out of three plot replicates for each treatment. This is accomplished using edge-of-field monitoring with field weirs and plot flumes with automated samplers (Sadler, Lerch, et al., 2015). To limit contamination from adjacent plots, surface berms are regularly maintained, and in-ground plastic barriers were installed to restrict water and soluble constituent movement.

2.1 | Prior research informed the Common Experiment

Experimentation began at this site in 1971, initially focusing on climatology and hydrology of the watershed (Baffaut et al., 2015), and later expanded to include other disciplines. This prior research (Table S2) served as foundational knowledge in designing the Common Experiment. Research is published and findable under key phrases and abbreviations of Goodwater Creek Experimental Watershed (GCEW), Salt River Basin (SRB), Management Systems Evaluation Areas (MSEA), Agricultural Systems for Environmental Quality (ASEQ), and Conservation Effects Assessment Project (CEAP).

The practices chosen for the Common Experiment were influenced by prior research examining the net economic return across cropping systems, landscape positions, and depth to claypan (Table S2) (Conway et al., 2020). Prior to establishment of the alternative practice, Field 1 was conventionally farmed from 1993 to 2003 with maize–soybean in a tilled system along with uniform fertilizer applications. In 2004, two management zones were established and farmed differently for a decade (until 2014) using precision agriculture (Kitchen et al., 2005). The farming practices were developed with stakeholder input based on four criteria: profitability, erosion susceptibility, surface water quality, and ground water quality (Kitchen et al., 2005). This approach had significant environmental gains compared to previous conventional management including reductions in sediment losses, nitrate-N loss, phosphorus loss, and atrazine runoff, and increased yield stability (Baffaut, Ghidey, et al., 2020; Yost et al., 2017).

The alternative practices used today in the Common Experiment were designed largely from this precision agriculture system in Field 1. While the integration of precision agriculture and conservation practices did not increase profits, crop yields were stabilized (Yost et al., 2017, 2019). Although soybean has been more profitable, maize is included in the alternative practice to utilize herbicides that target hard-to-control weeds in the soybean and wheat phases and because of its increasing use by farmers.

Today, we use the multi-decadal research knowledge to inform and guide interpretations of results when assessing the performance (i.e., productivity, stability, and resiliency) and environmental footprints of different management systems. Because the prevailing and alternative systems differ in length (3 vs. 4 years, respectively), we perform system analysis, avoiding isolated crop comparisons. We measure grain yield, aboveground biomass and nutrient content, water balance, runoff water quality, and changes in soil health indicators, including physical (bulk density and aggregate stability), chemical (pH, nutrients, and electrical conductivity), and biological (organic carbon, mineralizable C and N, total protein, reactive C, microbial biomass, and a suite of enzyme activities) measurements (Veum et al., 2014). This is accomplished using the LTAR Common Experiment protocols for all primary metrics (Abendroth et al., in press) when available and referencing historical data for long-term trends.

We align the prevailing practices on the large plots with the practices selected by the farmer on the prevailing field (Field 3). This requires a flexible management style and frequent communication between parties, but differences can still occur. For example, in the fall of 2022, the farmer planted a cereal rye cover crop late in the fall, which failed to establish. We matched his practice in the replicated plots where the cover crop established successfully. However, the establishment (and subsequent yield) of the maize crop was much poorer in the plots compared to the farmer field. This change by the farmer illustrates two points: (1) plot outcomes can differ from field outcomes even though treatments theoretically match, and (2) as prevailing treatments are altered to include practices from the alternative treatment, the latter must evolve and test new practices. An additional change to our alternative treatment was the inclusion of a hay crop because the cereal rye was not able to substantially increase soil carbon in the soil profile, resulting in a need to perennialize the system.

3 | STAKEHOLDER ENGAGEMENT

Our stakeholder group was selected based on their scope, reach, and expertise including farming, precision agriculture, soil and water conservation, soil health, carbon sequestration, cropping systems, farmer decisions, climate, tools for farm deployment, irrigation, and air quality. The group comprises three Missouri farmers, farmer-focused industry partners, USDA Midwest Climate Hub, agency and nonprofit partners, commodity boards, and academia.

These stakeholders meet with CMRB scientists biannually to discuss research findings, emerging areas of interest, challenges, and ways to advance agricultural science. Previous interactions between scientists and stakeholders were instrumental in defining precision agriculture practices (i.e., 2004–2014) (Kitchen et al., 2005; Yost et al., 2017) and developing the LTAR prevailing practices (i.e., 2015 to present).

4 | FUTURE DIRECTION

Changing precipitation patterns will further challenge farming operations with more intense spring rainfall events and reduced fieldwork days (Gautam et al., 2018; Phung et al., 2019). We are examining ways to minimize field operations and compaction associated with pesticide and fertilizer applications. Precipitation shifts also increase the risk of water stress during critical grain formation periods. We are keenly focused on ways to preserve and store water for plant use to a greater extent. This includes minimizing evaporation with increased surface residues, decreased water consumption due to weed pressure, and potential shifts in timing of operations and eventually, crops grown.

The prevailing practice is more vulnerable to environmental changes (Schreiner-McGraw & Baffaut, 2023). Based on initial data, the lack of year-round cover in the prevailing practice is resulting in a higher likelihood of soil erosion, and water and heat stress during droughts. To avoid mid-summer crop stress, farmers may shift to planting more winter wheat to capitalize on the wetter springs and earlier season growth possible compared to warm-season crops. We are examining crops and systems for the future that spread out field operations and risk beyond the typical spring window. We know the centroid of the Corn Belt continues to shift and expand northwest due to climate change and genetic and management advancements (Wang et al., 2020). Maize remains a popular option in this region, but future feasibility may change as eastern and southern areas retract in acreage. It is plausible that as the climate continues to warm, the alternative system could include four cash-generating crops in 2 years. Currently, 600˚C GDDs per year are not used in conventional maize or soybean production (Abendroth et al., 2021). However, the suitability of this approach will be dependent on balancing heat availability with water availability and storage.

Obtaining water by irrigating from on-farm ponds is a possibility for summer annual crops during periods of moisture shortage. This approach is gaining traction in the upper Corn Belt where excess springtime water is stored and later pumped onto fields (Hay et al., 2021; Willison et al., 2021). However, very limited infrastructure exists in the CMRB region because irrigation has not been common at present and would be cost prohibitive for many. Therefore, an aggressive approach to increase soil organic matter and water holding capacity is more tenable as a first step. We may need to consider incorporating perennial grasses, that can break through and mineralize the claypan layer, for 1 or 2 years and then rotate back to the annual crops.

AUTHOR CONTRIBUTIONS

Lori J. Abendroth: Investigation; writing—original draft; writing—review and editing. **Adam P. Schreiner-McGraw**: Investigation; visualization; writing—review and editing. **Curtis J. Ransom**: Investigation; visualization; writing—review and editing. **Claire Baffaut**: Investigation; writing—review and editing. **Kenneth A. Sudduth**: Investigation; writing—review and editing. **Kristen S. Veum**: Investigation; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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SUPPORTING INFORMATION

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