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TECHNICAL REPORT

Special Section: The USDA LTAR Common Experiment—Research to Support a Sustainable and Resilient Agriculture

The LTAR Cropland Common Experiment at the Kellogg Biological Station

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Abstract

The Kellogg Biological Station Long-term Agroecosystem Research site (KBS LTAR) joined the national LTAR network in 2015 to represent a northeast portion of the North Central Region, extending across 76,000 km^2 of southern Michigan and northern Indiana. Regional cropping systems are dominated by corn (*Zea mays*)–soybean (*Glycine max*) rotations managed with conventional tillage, industry-average rates of fertilizer and pesticide inputs uniformly applied, few cover crops, and little

Abbreviations: ACSE, Aspirational Cropping System Experiment; ASP, aspirational; BAU, business as usual; KBS, Kellogg Biological Station; LTAR, Long-Term Agroecosystem Research; NGO, non-governmental organization.

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animal integration. In 2020, KBS LTAR initiated the Aspirational Cropping System Experiment as part of the LTAR Common Experiment, a co-production model wherein stakeholders and researchers collaborate to advance transformative change in agriculture. The Aspirational (ASP) cropping system treatment, designed by a team of agronomists, farmers, scientists, and other stakeholders, is a five-crop rotation of corn, soybean, winter wheat (*Triticum aestivum*), winter canola (*Brassicus napus*), and a diverse forage mix. All phases are managed with continuous no-till, variable rate fertilizer inputs, and integrated pest management to provide benefits related to economic returns, water quality, greenhouse gas mitigation, soil health, biodiversity, and social well-being. Cover crops follow corn and winter wheat, with fall-planted crops in the rotation providing winter cover in other years. The experiment is replicated with all rotation phases at both the plot and field scales and with perennial prairie strips in consistently low-producing areas of ASP fields. The prevailing practice (or Business as usual [BAU]) treatment mirrors regional prevailing practices as revealed by farmer surveys. Stakeholders and researchers evaluate the success of the ASP and BAU systems annually and implement management changes on a 5-year cycle.

Plain Language Summary
The Long-term Agroecosystem Experiment at the Kellogg Biological Station (KBS LTAR) investigates the long-term sustainability of row crop systems suitable for the upper Midwest U.S. An Aspirational Cropping System Experiment tests the ability of available knowledge and technology to deliver a wider suite of ecosystem services than those practices currently prevailing in the region. The experiment is multidisciplinary, testing questions related to agronomic production, environmental performance, and social outcomes. Results will inform our ability to design climate resilient, conservation-oriented cropping systems that also provide high and stable yields and economic returns.

1 | REGIONAL CONTEXT

The Kellogg Biological Station Long-Term Agroecosystem Research site (KBS LTAR), part of Michigan State University's W. K. Kellogg Biological Station, is located in southwest Michigan (42° 24′N, 85° 23′W) and represents a region that stretches from mid-Michigan to northern Indiana based on production, environmental, and economic similarities (Bean et al., 2021). The region covers 76,000 km^2 (19 million acres) (NRCS, 2022) and shares a southern border with the Eastern Corn Belt (ECB) LTAR. Rural prosperity boundaries (101,000 km^2) extend the KBS region farther into mid-Michigan and southwest past Chicago (Bean et al., 2021; Figure 1).

About three-fourths of the KBS LTAR region is in farmland, with about half of this farmland in crops (NRCS, 2022). Major commodities (NASS, 2024) include corn (36% of Michigan cropland; 977,000 ha), soybean (34%; 951,000 ha), forage (14%; 39,000 ha), and winter wheat (7%; 186,000 ha), with most of the remainder in edible beans (*Phaseolus vulgaris*), sugar beets (*Beta vulgaris*), and potatoes (*Solanum tuberosum*). Dairy, poultry, swine, and other livestock are also major parts of the regional farm economy, as are horticultural crops especially in areas adjacent to Lake Michigan. On average, farms include 82 ha (200 acres) of cultivated cropland. About 13% of corn and 6% of soybean cropland is irrigated.

1.1 | Prevailing practices

Prevailing agricultural practices are similar to those in nearby states, as assessed by data from Ag Census (NASS, 2024), ARMS (Economic Research Service [ERS], 2016), and the MSU Panel Farmer Survey (Guo, Marquart-Pyatt, & Robertson, 2023). The region's dominant cropping system is a

2-year corn–soybean rotation, found on 64% of cropland acres in 2019; this compares to adjacent state averages of 93% (Illinois), 92% (Indiana), and 82% (Ohio) (NASS, 2019). Continuous corn represents 6% of cropland acreage, and the remaining 30% is planted to rotations that include winter wheat, dry beans, sugar beets, and potatoes, reflecting Michigan's high crop diversity.

Most fields in the region are managed using conventional tillage, including moldboard and chisel plowing (less than 15% and 30% of surface residue remaining, respectively) and chisel plowing (15%–30% remaining). In 2017, no-till was employed on 13% of corn and 31% of soybean acreage (Guo, Marquart-Pyatt, & Robertson, 2023) but rarely continuously (Claassen et al., 2018; Guo, Marquart-Pyatt, & Robertson, 2023).

Likewise, a modest proportion of regional field crops is planted to cover crops—10%–27% over the period 2016–2018, though more than in neighboring states (4%–9% Illinois, 8%–18% Indiana, and 10%–22% Ohio) (Guo, Marquart-Pyatt, & Robertson, 2023; Guo, Marquart-Pyatt, Beethem, et al., 2023) as compared to national adoption rates of ∼5% (Wallander et al., 2021).

Prevailing fertility management practices are more difficult to discern. Synthetic nitrogen on corn is mostly broadcast as granular urea or injected between rows as urea ammonium nitrate (UAN) solutions (K. Steinke and J. Stegink, personal communications, 2024). Nitrogen stabilizers like urease and nitrification inhibitors are not widely used. Most farmers apply nitrogen at rates recommended by agronomists employed by seed and fertilizer retailers (Stuart et al., 2018). Manure is available for farms close to confined animal facilities; ∼290,000 ha (714,000 acres) received manure in 2022 (NASS, 2024). The majority of farms rely on synthetic nitrogen and commercial mineral sources of phosphorus, potassium, lime, and micronutrients.

1.2 | Climate

KBS has a humid, continental, and temperate climate (Robertson & Hamilton, 2015; Figure 2). Average annual precipitation (1991–2020) is 926 mm year^{-1} (Hsieh et al., 2024), with ∼1.3 m of snowfall on average (NCDC, 2012). Winter precipitation is lower than in other seasons (17% vs. 26%–30% for others). Summer precipitation (June through August; 1990–2020) averages 282 mm year^{-1}. For June, July, and August, potential evapotranspiration exceeds precipitation (Crum et al., 1990; Hamilton, 2015). Evapotranspiration typically returns ∼59% (± 6 SD) of precipitation to the atmosphere annually (Hamilton et al., 2018); ∼24% drains to groundwater and thence, together with ∼8% lost as runoff (Hamilton, 2015), drains to the Kalamazoo River, Lake Michigan, the St. Lawrence Seaway, and the North Atlantic.

Core Ideas

- The Kellogg Biological Station (KBS) LTAR Site is located in southwest Michigan, representing a 76,000 km^2 region.
- Prevailing practices in the region include corn–soybean rotations with conventional tillage and uniform inputs.
- Stakeholders and researchers co-produced the KBS Aspirational Cropping System Experiment (ACSE).
- The ACSE includes a five-crop rotation designed to optimize stable economic returns and environmental performance.
- Site information including researcher access is available at https://ltar.kbs.msu.edu.

Mean annual temperature at KBS is 9.2˚C, with monthly means (1991–2020) ranging from −4.4˚C in January to 21.8˚C in July (Hsieh et al., 2024). Both mean annual temperature and precipitation have increased in recent decades (Figure 2A,B) as has average growing season length: two additional weeks of frost-free days since 1979 (Crimmins et al., 2023). The Walter–Leith climate diagram (Figure 2D) illustrates these seasonal patterns.

Although there are no apparent trends in drought severity or excessive rainfall (Figure 2C), precipitation is becoming more variable, with longer periods between growing season rainfall events (Pryor et al., 2014), creating small "micro-droughts" with greater rainfall deficits during crop development, sometimes coinciding with heat waves. Likewise, the frequency of winter freeze-thaw cycles is increasing, leading to less snow cover and more frequent soil freeze-thaw cycles (Ruan & Robertson, 2017).

1.3 | Soils and historical land cover

Soils at KBS formed from glacial outwash and loess from regional outwash plains (Luehmann et al., 2016) following retreat of the Wisconsin glaciation ∼18,000 years ago. Predominant soils around KBS are well-drained Alfisols; KBS LTAR experiments are under Typic Hapludalfs, co-mingled Kalamazoo and Oshtemo series loams and sandy loams (Crum & Collins, 1995; Mokma & Doolittle, 1993). LTAR experimental sites are on a fairly level outwash plain with highly permeable soils, and thus the main pathway of water movement off the fields besides evapotranspiration is infiltration and percolation to a water table that lies ∼15 m beneath the surface.

FIGURE 1 Location of Kellogg Biological Station Long-Term Agroecosystem Research (KBS LTAR) within its larger production region. Dashed line indicates regional boundaries for rural prosperity based on farm income. Graphic extracted from Bean et al. (2021).

Pre-European settlement vegetation in the region was a mixture of eastern deciduous forests, oak savannas, and prairie grasslands (Chapman & Brewer, 2008; Gross & Emery, 2007; Transeau, 1935). Fires were likely frequent in the region from 8000 BP, actively promoted from 700 CE by Native Americans. About 15% of soil carbon in late successional forests at KBS is of pyrogenic origin (Córdova et al., 2024).

Permanent agriculture in the area dates from at least 1670 CE, and included crops of corn, dry beans (*Phaseolus vulgaris* L.), cucurbits like squash and pumpkin (*Cucurbita* spp.), and sunflower (*Helianthus annuus* L.). Widespread deforestation began with European settlement in the 1820s as the Potawatomi tribes were forced onto reservations and land was cleared mainly for small grains and hay. Rudy et al. (2008) describe six agrarian transition periods for the region subsequent to this, leading to today's globalization era.

1.4 | Major agronomic challenges in the region

Production challenges identified by farmers (Guo, Marquart-Pyatt, & Robertson, 2023) include rising land and input costs against volatile crop prices that threaten long-term profitability. Increasingly variable weather compresses the number of springtime days that fields are dry enough to be workable, and longer periods between rainfall events introduces more frequent periods of crop water stress (Pryor et al., 2014). Herbicide-resistant weeds create a need for herbicides more effective than glyphosate, more frequent tillage, and other strategies (Owen, 2016). Inefficient crop nutrient use, coupled with weather-driven losses and farmers' tendencies to minimize perceived risk, leads to over-fertilization (Houser, 2022) that reduces ground- and surface-water quality and enhances nitrous oxide (N_2O) emissions. Soil health is challenged by low crop diversity, tillage that oxidizes soil carbon, and the low frequency of cover and forage crops.

2 | THE KBS LTAR ACSE

The KBS LTAR ACSE (https://ltar.kbs.msu.edu) is part of the LTAR Common Experiment (Liebig et al., 2024), and contrasts a prevailing practices system (locally known as the Business as usual or BAU system) against an Aspirational (ASP) system designed to deliver economic prosperity and conservation benefits such as soil health, greenhouse gas mitigation, biodiversity, and clean water. The ASP system was co-designed by stakeholders and researchers in a series of workshops initiated in 2021 after a visioning symposium (Robertson et al., 2021) that invited speakers to imagine a desired agriculture of the future.

Follow-on focus groups prioritized the following desired outcomes for future farming systems:

- stable profitability, or return on investment, as a key element of economic sustainability;
- soil health, as it contributes to sustained soil fertility and the maintenance of water quality;
- greenhouse gas mitigation, including soil carbon sequestration and abated soil N_2O emissions; and
- biodiversity conservation, especially for pollinators, biocontrol agents, and other beneficial insects.

Social outcomes such as family well-being and rural prosperity will emerge from scaling success at the level of individual fields and farms.

Focus groups also identified the following key design elements most likely to deliver prioritized outcomes:

- high crop diversity, that is, long rotations of 4–7 years to include large grain, small grain, oil seed, and mixed-species forage and cover crops;
- high circularity, that is, nutrient cycles as self-contained as possible to reduce the need for inputs and to minimize losses;
- year-round plant cover using fall-planted crops, cover crops, and perennial forage crops;
- continuous no-till to avoid episodic carbon and soil loss;
- precision agriculture technologies to identify sub-field areas for tailored inputs;
- prairie strips (perennial grasses and forbs) on consistently low productivity sub-field areas; and

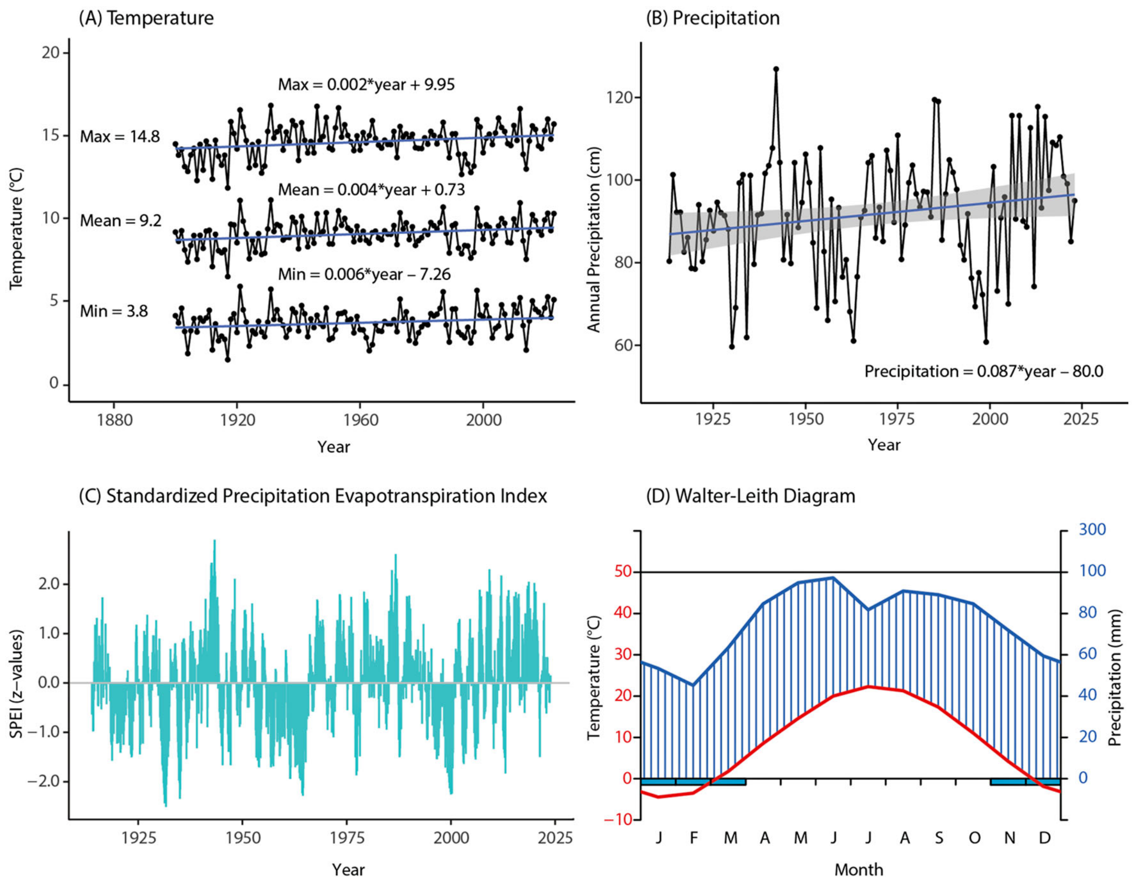

FIGURE 2 Long-term trends at the Kellogg Biological Station (KBS) for (A) mean annual air temperature, (B) mean annual precipitation, (C) mean annual drought severity (Standardized Precipitation Evapotranspiration Index [SPEI]), and (D) the Walter–Leith climate diagram for the period 1913–2023. A negative SPEI indicates water deficit conditions. From Hsieh et al. (2024).

- livestock for grazing forage or cover crops and as a source of composted manure.

A systems design team composed of farmers, crop advisers, and agricultural scientists then used their collective knowledge to design an ASP system as responsive as possible to prioritize outcomes and design elements.

The resulting ASP system (summarized in Table 1) is a five-crop rotation in the sequence corn, soybean, winter wheat, winter canola (*Brassicus napus*), and a forage mix consisting of alfalfa (*Medicago sativa*), red clover (*Trifolium pratense*), chicory (*Cichorium intybus*), and annual ryegrass (*Lolium multiflorum*) to be either grazed or harvested for off-site livestock consumption. This sequence of spring-planted, fall-planted, and perennial crops allows for optimal integration of cover crops, described below. Crop varieties are genetically modified where advantageous. All phases are managed with continuous (permanent) no-till, precision fertilizer inputs, and integrated pest management based on frequent scouting. Manure is added prior to corn together with synthetic N, which is also added to other crops except soybean. At the field scale nitrogen is applied by subfield productivity zones as defined by yield monitor patterns for the prior 6+ years.

Cover crops in the ASP system are planted following corn and winter wheat. Crimson clover (*Trifolium incarnatum*), dwarf essex rapeseed (*B. napus*), and radish (*Raphanus raphanistrum*) are together interseeded into corn followed by cereal rye (*Secale cereale*) after harvest. Cover crops following winter wheat include a mixture of sorghum sudan grass (*Sorghum bicolor* × *drummondii*), pearl millet (*Pennisetum glaucum*), and sun hemp (*Crotalaria juncea*). Prairie strips are composed of a 22-species mix of native grasses and forbs (Table S1).

The BAU system (Table 1) is a corn–soybean rotation that is chisel plowed in the fall or spring followed by secondary tillage pre-plant. There are no cover crops in the BAU system, and nitrogen fertilizer (granular urea) is spread in the spring followed by liquid nitrogen (urea-ammonium-nitrate) injected at planting and after corn emergence.

Elements of the BAU and ASP systems are evaluated every 5 years for major adjustments. BAU system adjustments are made as prevailing practices change, with minor adjustments informed by commercial crop advisers and major adjustments

TABLE 1 Summary of Kellogg Biological Station Long-term Agroecosystem Research (KBS LTAR) Aspirational Cropping System Experiment (ACSE) treatments.

Management	Business as usual	Aspirational
Crop rotation	Corn–soybean	Corn–soybean–winter wheat–winter canola–diverse perennial forage
Crop genetics	High-yielding corporate varieties with genetic modifications; fungicide and insecticide seed treatments	Corporate and public varieties targeting system suitability with genetic modifications for corn and soybeans; fungicide seed treatment on corn, wheat & canola; insecticide seed treatment on corn only
Planting	Agronomic optimum flat seeding rates when soil conditions allow, starting in mid-April for both crops	Variable seeding rates based on yield and soil maps; planting dates determined by soil conditions as well as cover crop termination timing
Tillage	Chisel plow & soil finish	None – continuous permanent no-till
Cover crops	None	Grass & brassica after corn; grass & legume after wheat; legume, grass & forb after canola
Fertility	Agronomic optimum flat rates of nitrogen; phosphorus and potassium based on soil tests and crop removal; sulfur and micronutrients mixed with nitrogen fertilizer	Variable rate nitrogen based on MRTN and credits for manure, soil health, and legume cover crops; variable rate phosphorus and potassium based on grid soil sampling; banded phosphorus within or near rows; sulfur and micronutrients mixed with nitrogen fertilizer
Pest management	Scheduled herbicide, insecticide, and fungicide applications	Integrated pest management utilizing scouting and pest forecasting models
Livestock integration	None	Cover crops harvested for forage; straw harvested for bedding; manure composted and returned to fields prior to corn planting
Conservation plantings	None	Prairie strips planted in low-yielding marginal areas of fields
Irrigation or drainage	None	None

informed by survey data from USDA and the MSU Panel Farmer Survey. Changes to ASP system management will be adjusted on the same schedule. The experiment will thus be adaptive and dynamic—changing with markets, climate, and technology.

2.1 | Experimental design for the ACSE

The KBS ACSE is a single-factor experiment laid out at both plot and field scales in a randomized complete block design with all rotation phases present in order to readily separate treatment effects from year-to-year differences in climate and other environmental factors. At the plot scale the two treatments are replicated in four blocks, resulting in eight BAU plots (2 rotation phases × 4 blocks) and 20 ASP plots (5 rotation phases × 4 blocks). Plot size (Figure 3) precludes prairie strips, so four additional plots are planted to prairie strip species. Microplots in each plot are available for nested experiments.

Each treatment is also replicated at the field scale (Figure 4) in order to detect the influence of spatial variability on desired outcomes, to observe effects on mobile taxa like birds and insects, and to examine the effects of prairie strips (Kemmerling et al., 2022; Kravchenko et al., 2017; Robertson et al., 2007). Fourteen fields (four BAU and 10 ASP) with areas ranging from 5 to 14 ha are managed as at the plot scale with two exceptions. First, ASP fields include 30-m-wide prairie strips, which cover from 5% to 18% of any given field, placed in low-productivity subfield areas. Second, nitrogen is precision-applied by productivity zone. Sampling frequency and protocols are identical for each field, but not conducted as intensively as at the plot scale. Management practices are detailed in Supporting Information and available at the KBS LTAR website (https://www.canr.msu.edu/ltar/).

2.2 | Measurements

Field measurements in the ACSE began in 2022 and align with LTAR network production, socioeconomic, and environmental indicators (Liebig et al., 2024; Spiegal et al., 2018). Measurements are shown in Table S2 and follow protocols used across all LTAR cropland sites, with results uploaded to local and LTAR network databases. Economic measures include yield, crop quality, input costs, and, for crops not commonly grown in the area, market identification. Environmental measures include soil health, biodiversity

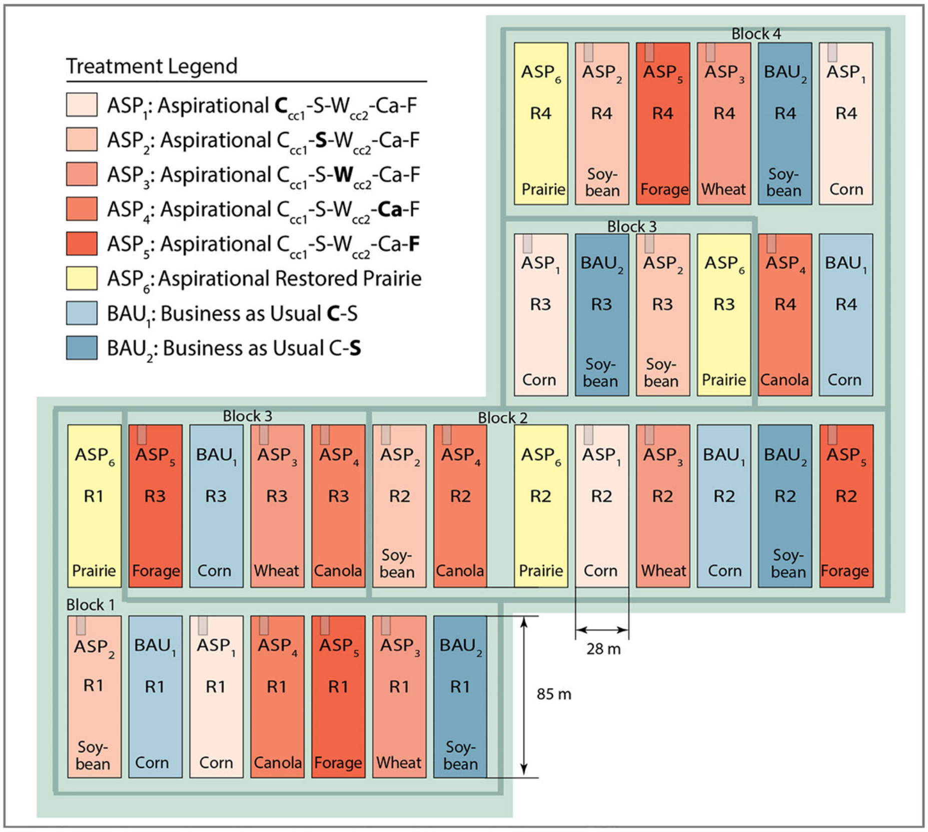

FIGURE 3 Layout of the Kellogg Biological Station Long-Term Agroecosystem Research (KBS LTAR) Aspirational Cropping System Experiment (ACSE). Business-as-usual (BAU or prevailing practice) treatment plots are in blue, Aspirational (ASP) treatment plots are in red, with restored prairie in yellow. Crop names are for the 2022 base year (C, corn; S, soybeans; W, winter wheat; Ca, canola; F, forage; cc, cover crop). Subscripts denote rotation entry points, for example, ASP$_1$ started with corn, ASP$_2$ started with soybean, etc., such that every entry point is present every year.

measures (especially pollinator and nematode taxa), water quality, greenhouse gas fluxes, and soil carbon accretion. Social measures include farmer decisions and their underlying factors, including information sources and values (Beethem et al., 2023; Guo, Marquart-Pyatt, & Robertson, 2023; Guo, Marquart-Pyatt, Beethem, et al., 2023) as determined by surveys and interviews.

3 | OTHER EXPERIMENTS AT KBS LTAR

The LTAR ACSE complements other long-term experiments at KBS. These include in particular the Main Cropping System Experiment of the KBS Long-Term Ecological Research site, in place since 1989 (Robertson & Hamilton, 2015), and the Bioenergy Cropping System Experiment of the Great Lakes Bioenergy Research Center dating from 2009 (Sanford et al., 2016). Both are on similar soils and in close proximity to the ACSE, and described further in Supporting Information.

4 | STAKEHOLDER ENGAGEMENT AT KBS LTAR

KBS LTAR aspires to a co-production model wherein stakeholders and scientists collaborate to advance transformative change in agriculture. Most tangibly, this occurs within the context of the ACSE as described above. Following ACSE establishment, stakeholders and scientists have together identified priority outcomes and metrics. Stakeholder events have included an 80-person on-site metrics workshop in 2022 where demonstrations of measurement technologies preceded group discussions (Guo, Marquart-Pyatt, & Robertson, in press; Guo, personal communication, 2024); a 25-person all-day workshop in 2023 with key stakeholders to refine priorities; and a 100-person stakeholder summit in 2024 where researchers and stakeholders together identified scientific questions of greatest importance to agricultural intensification and regenerative agriculture in the region.

KBS LTAR stakeholders include those with a stake in regional agricultural outcomes, and in particular those with

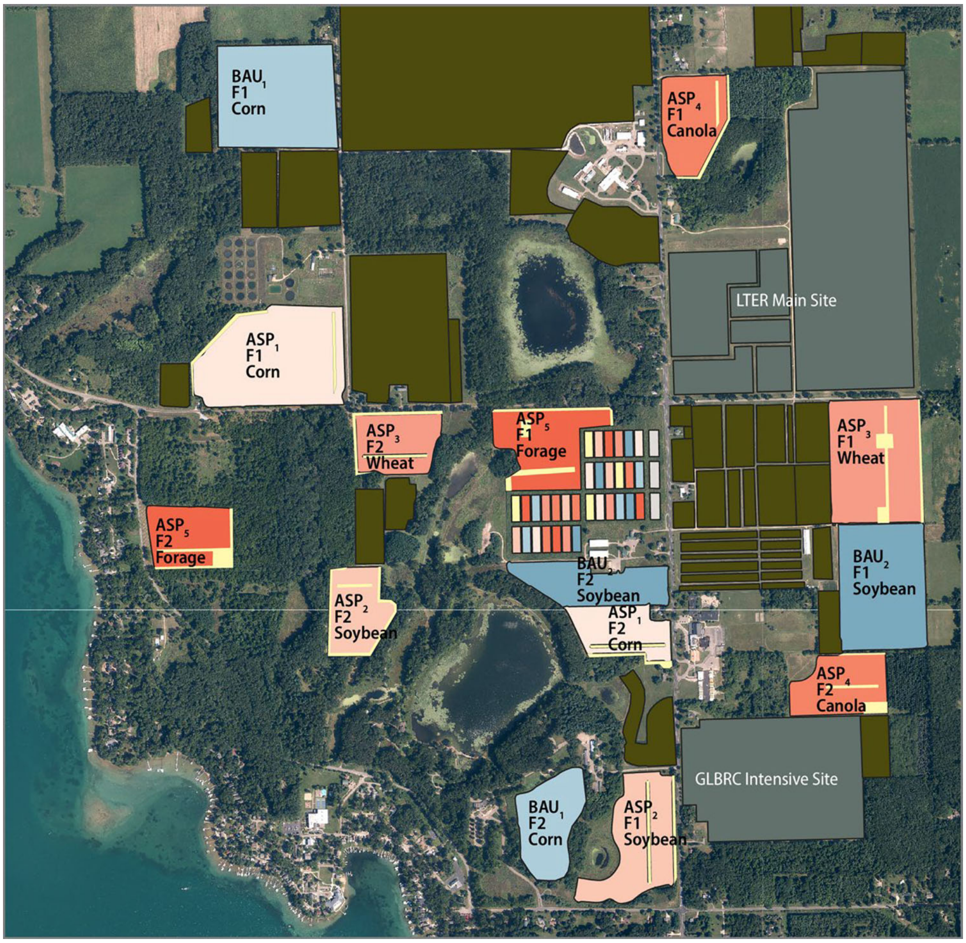

FIGURE 4 Experimental fields of the Kellogg Biological Station Long-Term Agroecosystem Research (KBS LTAR) Aspirational Cropping System Experiment (ACSE). Fields assigned to the Business-as-usual (BAU) or prevailing practice system are in blue and Aspirational (ASP) fields are in red; prairie strips in ASP fields are in yellow. $N = 2$ replicate fields per treatment. Crop names are for the 2022 base year. F1, field replicate 1; F2, field replicate 2. Subscripts denote rotation entry points; every phase is replicated every year.

a professional interest in or capacity to affect outcomes. We have drawn from six primary groups (Guo, Marquart-Pyatt, & Robertson, in press):

- producers both conventional and innovative;
- agricultural professionals including crop advisers, university extension educators, and seed, fertilizer, and crop protection retailers;
- conservationists from non-governmental organizations (NGOs) and the National Resource Conservation Service;
- policy makers and influencers from farm organizations, commodity groups, and state and federal legislatures;
- commodity buyers such as milling companies; and
- public facing retailers such as food processors and distributors.

In 2023, we formed a KBS LTAR Stakeholder Advisory Board, comprised of individuals from commodity groups such as the Corn Marketing Program of Michigan, farmer advocacy groups such as the Michigan Farm Bureau and Michigan Agriculture Advancement, Michigan Department of Natural Resources, MSU Extension, conservation NGOs such as The Nature Conservancy and National Wildlife Federation, county Conservation Districts, a regional crop advising firm, a regional milling company, and four regional farms. The Board has been invaluable for providing feedback and advice and for helping to distill input from the larger group of stakeholders into actionable goals. An early product was the consensus establishment of a shared purpose for KBS LTAR—to bridge the gap between present-day agriculture and the agriculture needed by future generations.

Five key questions emerged from early advisory board discussions:

- What evidence will show the differences and trade-offs between aspirational and business-as-usual treatments?
- What is the return on investment for the BAU and ASP systems, and specific practices within?

- How can a farm be managed for both biodiversity and profitability?
- How do we manage for changing climate including weather extremes?
- How can we ensure that KBS LTAR research reaches everyone it can benefit?

Research priorities are chosen to balance impact, effort, and resources, which include personnel, infrastructure, and funding availabilities.

5 | FUTURE DIRECTION

The early trajectory of KBS LTAR points to a strong potential for substantive impact on regional cropping system practices. Stakeholders are integral to the project and join researchers in a desire to push the boundaries of today's cropping systems toward those that can deliver a better optimized suite of ecosystem services for tomorrow—without compromising high productivity and stable economic returns. Understanding the successes and challenges of the ASP system, including underlying causes and indirect consequences, is a high priority for KBS LTAR, and will require additional experimentation once patterns begin to emerge. Concomitantly, research priorities will evolve—in some cases as questions are answered, in other cases as questions emerge. And although many will take a decade or more to resolve, early insights will be instructive.

Going forward, we expect that on-farm experiments will become an increasingly important way to extend, generalize, and validate results from KBS-based research. A goal of the current 5-year period is to generate the capacity to transfer aspects of our ACSE to regional farm settings. We look forward to the deeper engagement with stakeholders that this will entail.

AUTHOR CONTRIBUTIONS

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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