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Science in the Supply Chain: Collaboration Opportunities for Advancing Sustainable Agriculture in the United States

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Commentary

Science in the Supply Chain: Collaboration Opportunities for Advancing Sustainable Agriculture in the United States

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Core Ideas

- Sustainability indicators for US agriculture demonstrate improvement since 1980.
- Emerging multi-stakeholder initiatives are seeking to drive further improvement.
- Collaboration with the scientific community is key to achieving improvements.

Abstract: Consumers and corporations are increasingly interested in understanding the sustainability of agricultural supply chains and reducing the environmental impacts of food, fiber, feed, and fuel production. This emerging need to quantify environmental impacts from agricultural production creates an opportunity for collaboration with the scientific community. Without such collaboration, sustainability efforts risk failure by adopting unrealistic goals or misguided approaches. This commentary explores the role of science in Field to Market, a nonprofit organization developing a sustainability program for US commodity crops, and highlights opportunities to address emerging science challenges. We evaluate changes over the past 35 years in key environmental impacts of crop production used to inform land managers as well as companies that are committed to improvements. Achieving improvements will only be possible if three key gaps are addressed regarding available simulation models and data, scale of implementation and uncertainty, and effectiveness of conservation practices. Filling these gaps presents an opportunity for dialogue between scientists, farmers, and private-sector stakeholders to advance scientific knowledge and promote the common objective of sustainable agriculture.

A DEFINING CHALLENGE for society over the next half century will be to produce more food with lower environmental impact, under more variable climatic conditions (Godfray et al., 2010; Smith et al., 2013). Agricultural production must be made more sustainable to minimize negative impacts on the world's soils, water resources and biodiversity (Cassman et al., 2003; Robertson, 2015). Recently, environmental concerns and consumer demand have led some companies that source agricultural commodities for consumer products to invest in strategies to ensure the long-term supply of sustainably produced ingredients, as well as respond to consumer demand for greater transparency and accountability in how products are produced (Nielsen, 2014). This demand has led to the setting of corporate sustainability goals that are leading companies to directly connect with farmers to improve the sustainability and resilience of crop supplies (Macfadyen et al., 2015).

The first step for a company that commits to sustainable commodity sourcing for its products is to understand where the commodities are produced, what the current production practices are and why, and what improvements can be made and how. In the United States, Field to Market arose as a multi-stakeholder platform to connect such consumer-facing retail companies to intermediary supply companies (e.g., agribusinesses), farmers, and relevant nongovernmental organizations (NGOs), government agencies, and universities. Field to Market is coordinating efforts among more than 120 member organizations to develop a pre-competitive sustainability program that functions for all sectors of the supply chain and specifically accounts for the farmer perspective in tools and objectives. Connecting through the supply chain provides direct links between farmers of commodities and the brands that use their crops than has typically been possible, enabling farmers to communicate their sustainability efforts and

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Abbreviations: ASABE, American Society of Agricultural and Biological Engineers; GHG, greenhouse gas; NGO, nongovernmental organization.

challenges. It also opens a path for public-facing brands to connect to their supplying farmers, communicate their goals around sustainability, and invest in solutions in a manner that is productive for farmers.

Thus, rather than focusing on which practices are adopted, Field to Market has focused on the environmental impacts, or outcomes, of production; all member organizations have agreed that outcomes are the most important determinant of sustainability. Practice-based approaches exist and are generally simpler to implement; however, there is evidence that they do not necessarily contribute to environmental improvements (Bizikova, 2016). Outcomes are more scientifically challenging to measure and monitor at both the individual field scale and at regional scale. Field to Market follows the guidelines for outcomes-based sustainable agriculture established by the American Society of Agricultural and Biological Engineers (ASABE) (standard S629; ASABE, 2016). This framework emphasizes multi-stakeholder planning for setting goals and a technology-neutral, transparent approach grounded in science to establish sustainability indicators. Progress toward continuous improvement of the sustainability indicators is then measured by field-scale metrics.

Following the ASABE approach, Field to Market defines sustainability as continuous improvement in eight key environmental outcomes selected through a multi-stakeholder process as mutually agreed on goals: biodiversity, energy use, greenhouse gas emissions, irrigation water use, land use, soil erosion, soil carbon, and water quality. Here, we present Field to Market's assessment of long-term national trends for these environmental outcomes and discuss challenges encountered in developing science-based models for field-scale metrics (Field to Market, 2016). Our purposes are to highlight the science and knowledge gaps that must be addressed to ensure effectiveness of this program. We identify three key areas that require close collaboration with the scientific community: improved representation of complex environmental systems in simulation models, better understanding of environmental impacts across scales, and clear guidance on how management practices influence environmental outcomes. Bridging these gaps presents opportunities to simultaneously advance scientific knowledge and sustainable agricultural systems.

National-Level Indicators of Environmental Outcomes

To evaluate the change over time in environmental outcomes associated with commodity crop production in the United States, we calculated indicators from 1980 to 2015 using publicly available USDA surveys of farm land, production, and practices (USDA-NASS, 2014, 2016a,b; USDA, 2015) for nine crops: barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), cotton (*Gossypium hirsutum L.*), peanut (*Arachis hypogaea* L.), potato (*Solanum tuberosum* L.), rice (*Oryza sativa* L.), soybean [*Glycine max* (L.) Merr.], sugar beet (*Beta vulgaris* L.), and wheat (*Triticum aestivum* L.) (Table 1). Impacts were calculated per unit of production for land use, water use, energy use, and greenhouse gas (GHG) emissions (Fig. 1a–d). Impacts per hectare were calculated for soil erosion, water use, energy use, and GHG emissions (Fig. 2a–d). We did not develop national-scale, crop-specific indicators for more complex environmental outcomes in the program—biodiversity, soil carbon, and water quality. The indicator calculations, results, and discussion of the state of understanding are fully documented in Field to Market (2016).

Results from the efficiency indicators illustrate improvements in land, water, and energy efficiency (Fig. 1a–c) over time. Less of each resource was required per unit of production in 2015 than in 1980. Greenhouse gas emissions also decreased per unit of production over time (Fig. 1d). To understand the extent to which these trends are driven by increased crop yield, we also consider the indicators on a per hectare basis. There, we observe overall reductions in soil erosion per hectare since 1980 (Fig. 2a), with the exception of sugar beet and peanut production. Some crops also demonstrate improvement in irrigation water use per hectare, particularly cotton, rice, peanut, and sugar beet (Fig. 2b). Energy use and GHG emissions per hectare (Fig. 2c–d) show mixed trend results. Although the trend of change over the past 35 years is clear, we note that for many crops and indicators, the greatest improvements occurred early in the time period considered, with generally slower improvement since 2000 (Field to Market, 2016).

Table 1. Year 2000 values for each crop and indicator. Trends in Fig. 1 and 2 **are based on normalized data with year 2000 = 1.**

Crop	Per unit production				Per unit area			
	Land use	Irrigation water use	Energy use	GHG† emissions	Soil erosion	Irrigation water use	Energy use	GHG emissions
	ha kg^{-1}	m^3 kg^{-1}	kJ kg^{-1}	kg CO_2e kg^{-1}	t ha^{-1}	m^3 ha^{-1}	GJ ha^{-1}	kg CO_2e ha^{-1}
Barley	0.00030	1.79	3446	0.34	2.1	779	1.66	164
Corn	0.00012	0.90	1975	0.23	1.7	599	2.74	323
Cotton	0.00139	9.94	21885	2.00	3.6	605	2.14	196
Peanut	0.00042	3.56	5708	0.44	3.8	489	2.23	172
Potato	0.00002	0.13	1565	0.14	3.8	899	10.67	942
Rice	0.00014	1.01	4732	2.05	0.7	1152	5.42	2344
Soybean	0.00040	2.86	1913	0.15	1.7	400	0.78	61
Sugar beet	0.00004	0.73	824	0.08	3.5	1289	3.78	352
Wheat	0.00042	2.17	3622	0.39	1.9	719	1.42	154

† GHG, greenhouse gas; CO_2e, carbon dioxide equivalent.

Improvements on a per hectare basis likely reflect technology adoption that includes reduced tillage practices and more efficient irrigation equipment and crop management practices. The strong improvements in irrigation water use efficiency for cotton, for example, are a combination of several factors. While yields have increased due to both genetic and management improvements (Bauer, 2015; Constable and Bange, 2015), cotton growers have also been transitioning to more efficient water delivery systems and more sophisticated irrigation scheduling methods such as in-field soil moisture sensors (Daystar et al., 2017). The combined impacts result in greater water use efficiency on both indicators.

The main conclusion from this long-term analysis is that in comparison to 1980, more food, fiber, and feed are being produced with fewer resources. This improvement has been driven primarily by higher crop yields through plant genetics and breeding, as well as management changes such as increased seeding densities (Grassini et al., 2014). When considering how likely these trends are to continue, however, there are two main concerns. First, yield improvements in some regions may now be approaching a biophysical ceiling for current crop varieties as determined by climate and soil properties (Grassini et al., 2013), in some areas reaching 80% of their biophysical potential, considered the highest practical and profitable yield level that can be achieved (Cassman, 1999; Lobell et al., 2009; van Ittersum et al., 2013). Additionally, aggregate improvements in efficiency on a per-unit of production basis may be outweighed by increases in production. For GHGs, for example, it is the total (absolute) load emitted to the atmosphere that determines the environmental impact.

Findings from these national indicators are also subject to important limitations. They rely on the scope of practices and the timeline for USDA management surveys. The periodic nature of the data collected means that in some instances, such as the 2012 Natural Resources Inventory (USDA-NRCS, 2015), surveys coincided with extreme weather events that also influenced producer decisions. Thus, any individual year reflects unique circumstances as well as previous trends (including hysteresis). Nevertheless, by considering the long-term trend with a consistent approach, we can reasonably assess the direction of change and the opportunities for further improvement.

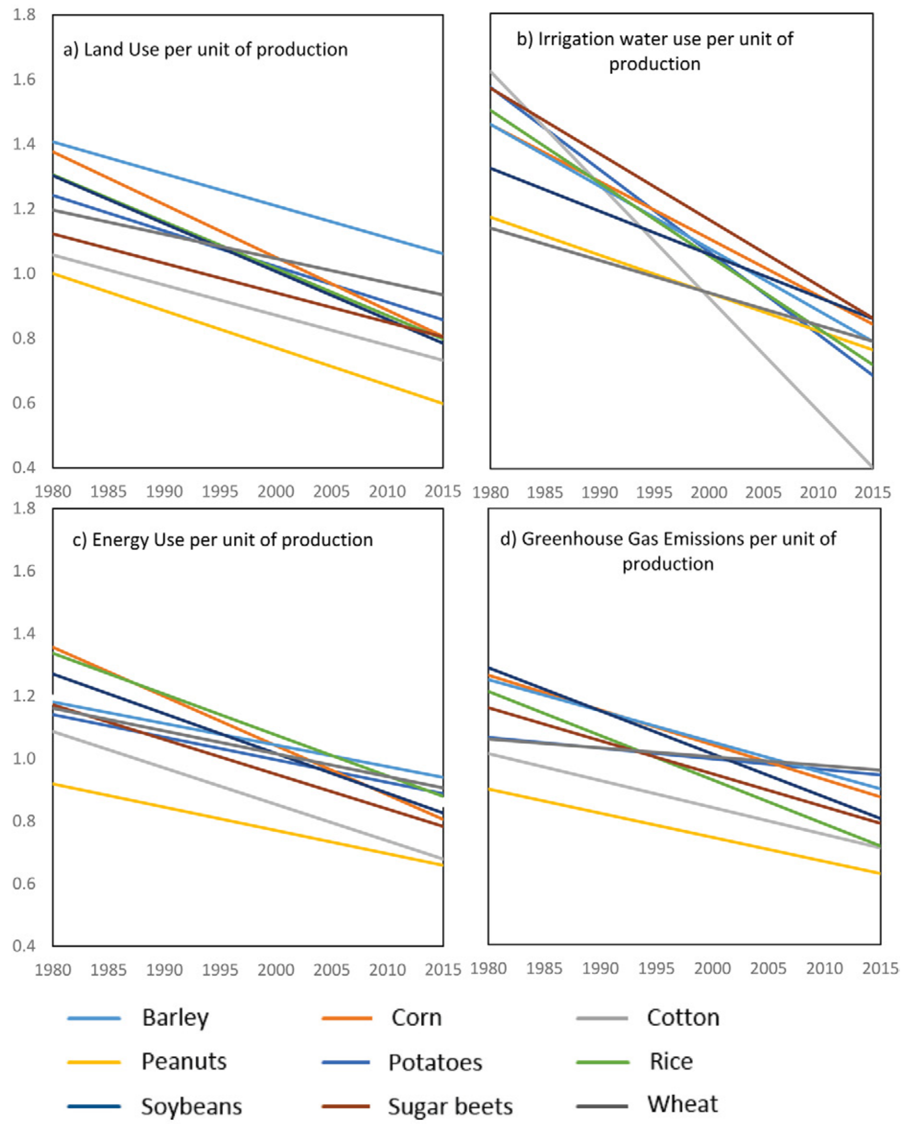

Fig. 1. Linear trend lines for nine commodities, fit to the resource use per unit of crop production for (a) land use, (b) irrigation water use, (c) energy use, and (d) greenhouse gas emissions. Linear trend lines fit with data normalized to year 2000 = 1. Values in year 2000 are presented in Table 1.

Measurement of Field-Scale Environmental Outcomes

The national indicators provide important feedback for decision makers at a regional scale to help identify where such trends are improving, plateauing, or worsening and indicate where new investments in technology or outreach are needed. However, they are of limited use to land managers developing strategies for field-scale operations. Field to Market has therefore adopted field-scale metrics for measuring the same environmental outcomes. These metrics rely on data inputs specific to each field, and methods of calculation vary. The land use, irrigation water use, energy use and GHG emissions metrics are calculated with equations that range from simple to complex, whereas soil erosion is calculated using field-scale simulation models (USDA-ARS, 2016). Metrics for water quality, soil carbon, and biodiversity are

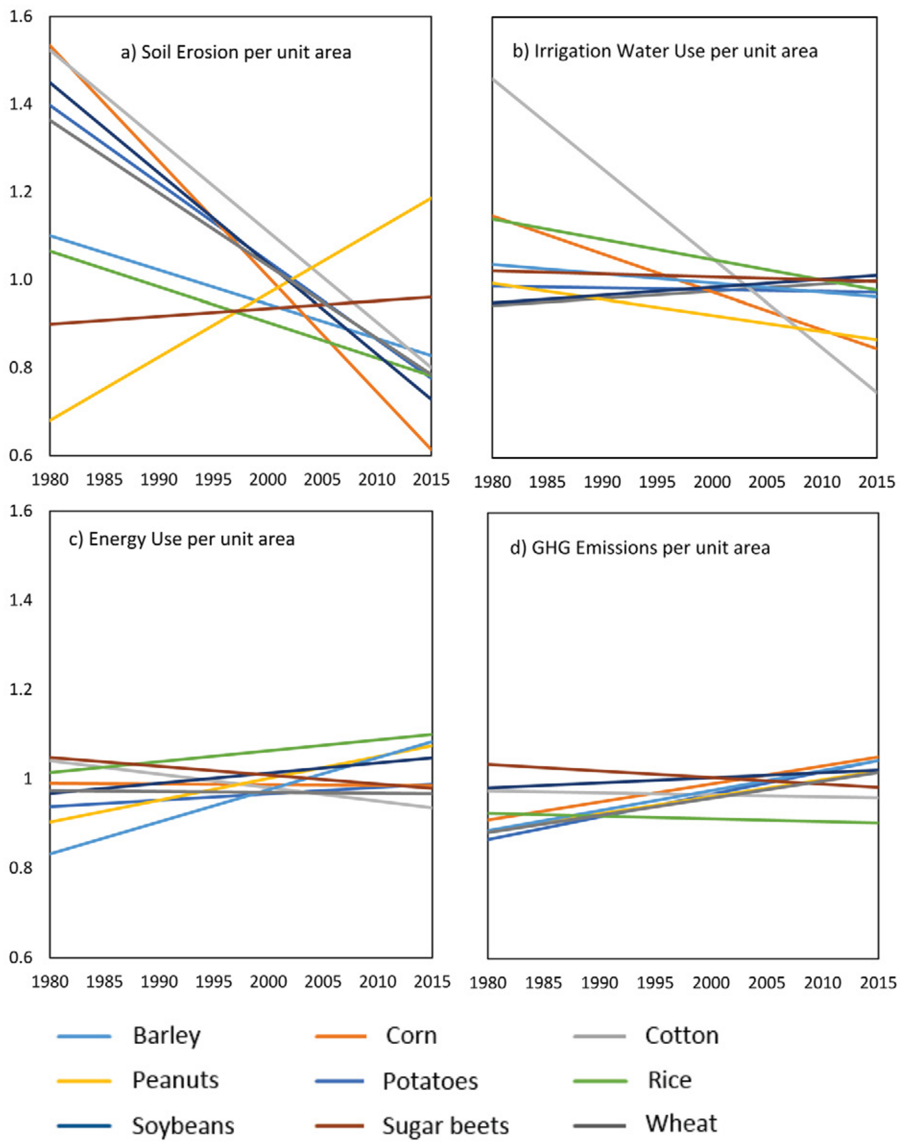

Fig. 2. Linear trend lines for nine commodities, fit to the resource use per unit of area for (a) soil erosion, (b) irrigation water use, (c) energy use, and (d) greenhouse gas (GHG) emissions. Linear trend lines fit with data normalized to year 2000 = 1. Values in year 2000 are presented in Table 1.

calculated with practice-based indices of performance that reflect a likelihood of environmental impact based on practice adoption and limited information on environmental conditions, such as soil properties and climate zones (e.g., the USDA Water Quality Index) (Franzluebbers et al., 2011; Lal and McKinney, 2012; Kome et al., 2013).

These metrics are deployed through the Fieldprint Platform tools, with approximately 2.5 million acres (1.0 million ha) of commodity cropland evaluated for the 2016 growing season. Field to Market encourages long-term monitoring of individual field performance for continuous improvements over multiple years. Farmers are typically engaged to use the Fieldprint Platform by supply chain partners, often originating from brands and retail companies, to collect data, provide technical assistance and other motivations, and catalyze improvements among the farmers contributing to their commodity supply. More information on how the program is designed and operates, and specific examples, is available from the Field to Market website (www.fieldtomarket.org).

The metric calculations in the Fieldprint Platform are all appropriate to the purpose but by necessity are simplifications of complex processes. All metrics are evaluated for revision on the basis of user feedback and scientific understanding at least once every 3 years. A metrics committee of elected member representatives leads this revision process and is responsible for identifying and reaching out to appropriate scientific experts. This collaboration with the scientific community is critical to ensure that the program incorporates the most appropriate advances in sustainability tool development and scientific understanding in metric revisions. Currently, this process involves engaging scientists from member universities, NGOs, and the USDA and in some instances can involve broader engagement of the scientific community (Snyder, 2015) and specific contracts for meta-analyses or model applications. Beyond engaging scientists in direct evaluation of metrics, such metric improvements over the long term may increasingly depend on the development and availability of models capable of accurately simulating both complex biophysical and biogeochemical processes, including fate of applied nutrients (Davidson et al., 2016) and the dynamics of soil carbon (Paustian et al., 2016), and management practices that influence these processes.

The issue of water quality related to agricultural practices is a key example of the challenge of complexity. Despite research at watershed scales demonstrating that losses of nutrients, sediment, and chemicals from farm fields can be minimized and avoided when conservation practices are adopted (USDA-NRCS, 2016), assessments of in-stream water quality have not identified noticeable improvement even where such conservation practices are widely adopted (Dubrovsky et al., 2010; Murphy et al., 2013). Some watershed-scale evidence indicates that improved efficiency of nutrient use has reduced nitrate loading in streams (García et al., 2016; McIsaac et al., 2016), but quantifying the contribution from an individual field remains challenging without expensive and logistically demanding monitoring efforts. Such efforts are complicated by the lag effect of water quality response to changing practices (Meals et al., 2010; Van Meter et al., 2016). Emerging tools are focusing on characterizing the effectiveness of practices in combination with modeling of hydrologic processes

(Tomer et al., 2015). Development of accounting systems for practices can improve assessment of individual field water quality outcomes. However, the water quality simulation models currently available are designed for watershed-scale assessment. Bridging this gap to develop a robust field-scale water quality tool for direct farmer engagement remains a priority for Field to Market.

Science and Supply Chain Collaborations for Sustainability

It is increasingly recognized that voluntary adoption of conservation practices is best encouraged by both documenting environmental outcomes from agriculture and incentivizing practice change (Baumgart-Getz et al., 2012; Osmond et al., 2012; Shortle et al., 2012; Zhang et al., 2015). The more robust our understanding of the science becomes, the greater the potential for changes that significantly improve environmental outcomes at local, regional, and national levels. Collaboration is vital for advancing scientific understanding, implementing effective change at a broad scale for US agriculture, and using insights from such changes to enhance and inform research needs and insights. We identify three key areas for collaboration:

- Improving the representation of complex environmental systems in simulation models for field-level feedback.
- Understanding of environmental impacts across scales, and quantification and communication of uncertainty at relevant scales.
- Improving understanding of how agricultural practices influence environmental outcomes at and beyond the field scale.

The first key area concerns simulation models—valuable research tools that provide reliable results when calibrated and provided with adequate data (Grassini et al., 2015; Basso et al., 2016). However, simulation model application as farmer-applied tools requires a different perspective from research use, in particular, determining what level of accuracy is "good enough" to use as the basis to recommend management changes to farmers who have real economic costs and production consequences at stake. Recommending changes that are costly or ineffective at improving environmental outcomes can undermine future efforts.

The second key area concerns issues of scale and uncertainty. Connecting individual farmer actions on the field to changes in environmental outcomes at larger scales represents a gap in our current understanding. Robust environmental assessment tools are needed to evaluate these linkages. Developments in data availability and data science provide an opportunity to create such tools (Grassini et al., 2017). Multiscale data frameworks can categorize fields within analog climate–soil groups, evaluate tradeoffs in productivity and environmental performance, and help identify opportunities for sustainability improvements. An analogous framework for rangelands and forestlands has been developed thorough the USDA Ecological Site Descriptions network (Brown and Havstad, 2016). Similar scale issues must be considered in frameworks to understand and quantify the uncertainty of metric results at both field and regional scales to inform land managers of the potential risks and rewards of management changes.

Finally, both modeling and spatial analysis rely on robust scientific understanding of the impacts of conservation practices on environmental outcomes. As complex systems, the environmental outcomes can be expected to vary between fields based on myriad variables; among the less well understood is the variation in response to specific practices. Although approaches such as the USDA Conservation Effects Assessment Program can quantify potential benefits of conservation practices at a large watershed level (Osmond et al., 2012), there are limitations to the scale of simulation of environmental responses to conservation practices at the field scale, as conditions often vary from field to field (Osmond et al., 2015). The supply chain engagement approach has the ability to achieve scale of impact but relies on input and collaboration with the scientific community to ensure that recommendations for management changes lead to real improvements in environmental outcomes.

Improving connections between researchers and the private sector through these three key areas is a promising avenue to convey the importance of sustainability. Several opportunities exist for scientist contributions to the Field to Market program, specifically:

- Direct engagement through university membership and participation in standing committees and technical working groups,
- Contributing specific expertise on metrics through provision of data, meta-analyses, and simulation model development.
- Identifying Field to Market as a collaborating partner in research proposals that aim to improve on the three key areas identified here.

The first two avenues are representative of current activities, and the third is the key to broader collaboration over long-term research projects and model development efforts that will be mutually beneficial to the research community as well as to Field to Market. While we focus specifically on commodity crops in the United States, other programs exist for agricultural products and world regions that likely would similarly benefit from greater collaboration with the scientific community. By collaborating with such efforts, scientists ensure that their findings gain a broader audience for implementation through the agricultural advisors who currently work for a range of organizations. Continuous improvement will remain challenging to achieve, document, and verify without the ability both to measure outcomes and to provide accurate technical guidance on practices that can improve on the outcome measured.

Although some progress has been made in key sustainability indicators at the national level, a gap needs to be filled to enable farmers and the supply chain to actively work toward further improvements in environmental outcomes. Outcomes-based sustainability approaches can only be effective if the science underlying the metrics, indicators, and models used is sound. By setting ambitious goals around complex problems, organizations are pushing the boundaries of what is currently understood and can be represented in existing models. Collaboration is vital to both the advancement of scientific understanding and the implementation of effective changes in cropping system management.

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