5-2022

Cultivating Agrobiodiversity in the U.S.: Barriers and Bridges at Multiple Scales

Kaitlyn A. Spangler
Utah State University

CULTIVATING AGROBIODIVERSITY IN THE U.S.: BARRIERS AND BRIDGES AT MULTIPLE SCALES

by

Kaitlyn A. Spangler

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Environment and Society

Approved:

Emily K. Burchfield, Ph.D. Co-major Professor	Claudia Radel, Ph.D. Co-major Professor
Roslynn Brain McCann, Ph.D. Committee Member	Matt Yost, Ph.D. Committee Member
Douglas Jackson-Smith, Ph.D. Committee Member	D. Richard Cutler, Ph.D. Interim Vice Provost for Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2022

ABSTRACT

Cultivating Agrobiodiversity in the U.S.: Barriers and Bridges at Multiple Scales

by

Kaitlyn A. Spangler, Doctor of Philosophy

Utah State University, 2022

Major Professors: Drs. Emily K. Burchfield and Claudia Radel
Department: Environment and Society

Agricultural landscapes in the United States (U.S.) are becoming drastically simplified and commodified, causing concern for biodiversity loss, environmental degradation, and widening socioeconomic injustices upon which U.S. agriculture has been built. There is an urgent need to understand and identify pathways toward diversifying agricultural systems and increasing agrobiodiversity writ large. This dissertation addresses this need through three mixed-methods and multiscale studies. The first study uses national open-access datasets spanning several decades to broadly assess past and current agricultural landscapes across the U.S. I show that U.S. agriculture has gradually trended toward an intensely regulated and specialized system: crop production is heavily concentrated in certain areas, and crop diversity is declining. Meanwhile, federal agricultural policy is increasing in scope and influence while disincentivizing diversification. In the second study, I use random forest (RF) permutation variable importance measures to compare the factors most predictive of county-level crop diversity across nine U.S. regions and elucidate path dependencies of agricultural landscapes that (dis)incentivize crop diversification at the regional scale. Results show that climate, land use norms, and farm inputs are consistently the most important categories for predicting agricultural diversity across regions; however, intra-regional variability exists, presenting regionally specific path dependencies that inhibit crop diversification. The third and final study explores barriers and bridges to crop diversification for current farmers in the Magic Valley of southern Idaho – a region with quantitatively high agricultural diversity. I conducted and analyzed farmer and key informant in-depth interviews to gauge what farmers are currently doing to manage crop diversity (the present) and how they imagine alternative landscapes (the imaginary). We found that farmers in the Magic Valley have established a regionally diversified landscape relying primarily on temporal diversification strategies. Further, daily challenges and structural constraints make experimenting with and imagining alternative landscapes not only difficult but unlikely and even "dangerous" to dream of. Collectively, these three chapters provide a mixed method, multiscale view of how and why U.S. agriculture landscapes simplify or diversify, as well as the barriers and bridges to agricultural diversification.

(238 pages)

PUBLIC ABSTRACT

Cultivating Agrobiodiversity in the U.S.: Barriers and Bridges at Multiple Scales

Kaitlyn A. Spangler

The diversity of crops grown in the United States (U.S.) is declining, causing agricultural landscapes to become more and more simplified. This trend is concerning for the loss of important plant, insect, and animal species, as well as the pollution and degradation of our environment. Through three separate but related studies, this dissertation addresses the need to increase the diversity of these agricultural landscapes in the U.S., particularly through diversifying the type and number of crops grown. The first study uses multiple, openly accessible datasets related to agricultural land use and policies to document and visualize change over recent decades. Through this, I show that U.S. agriculture has gradually become more specialized in the crops grown, crop production is heavily concentrated in certain areas, and crop diversity is continuing to decline. Meanwhile, federal agricultural policy, while having become more influential over how U.S. agriculture operates, incentivizes this specialization. The second study uses nonlinear statistical modeling to identify and compare social, political, and ecological factors that best predict crop diversity across nine regions in the U.S. Factors of climate, prior land use, and farm inputs best predict diversity across regions, but regions show key differences in how factors are important, indicating that patterns at the regional scale constrain and enable further diversification. Finally, the third study relied on interviews with farmers and key informants in southern Idaho's Magic Valley – a cluster of eight counties that is known to be agriculturally diverse. Interviews gauge what farmers are currently doing to manage crop diversity (the present) and how they imagine alternative landscapes (the imaginary). We found that farmers in the Magic Valley manage current diversity mainly through cover cropping and diverse crop rotations, but daily struggles and political barriers make experimenting with and imagining alternative landscapes difficult and unlikely to occur. Together, these three studies provide an integrated view of how and why U.S. agriculture landscapes simplify or diversify, as well as the barriers and bridges such pathways of diversification.

ACKNOWLEDGMENTS

First and foremost, the utmost gratitude goes to my advisors, Drs. Emily Burchfield and Claudia Radel. You have shown me the type of mentorship and support that values me *equally* and *lovingly* as a person and a professional. For that, I am forever grateful; I can only hope to carry that on in my own career because it really is where the magic happens. To my committee members, Drs. Roslynn Brain McCann, Douglas Jackson-Smith, and Matt Yost: thank you for helping me think critically and for pushing my research to greater heights. To my lab mate, confidant, R genius, and dear friend, Britta Schumacher: I truly and deeply could not have done this without you. To my statistical mentor, Dr. Brennan Bean: thank you for your painstaking patience and care in explaining your mathematical wizardry to me. To the folks in the Magic Valley who took the time out of their busy schedules to chat with me: what an indescribable gift to hear your stories. Finally, to my partner, Dylan, my parents, sister, and friends who held me, listened to me, assured me, and cheered me on every step of the way: your love and light are what keeps me going, always. And to my dog, Aspen: thank you for the sweet cuddles and kisses.

Kaitlyn A. Spangler

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1. Background

In the United States (U.S.), the Green Revolution has ultimately failed to meet food production demands of a growing global population *safely* and *sustainably* (Altieri & Nicholls, 2009; Gleissman, 2015). Although modern agriculture is becoming increasingly productive (ERS, 2019; Pellegrini & Fernández, 2018; Ramankutty et al., 2018; Reganold et al., 2011), this productivity has come at the cost of ecological health and sustainability, as well as social justice (Anderson et al., 2019; Spangler et al., 2020). Corporate power and consolidation are rising in the agri-food sector, whereby corporate entities are gaining more control over global agricultural markets and political lobbying. Meanwhile, socioeconomic inequities are widening, and environmental degradation is intensifying (Clapp & Purugganan, 2020). Agricultural production has become increasingly specialized for a decreasing number of crop species (Aguilar et al., 2015; Auch et al., 2018; Baines, 2015), and large-scale farm consolidation is driving out smaller-scale operations (MacDonald & Hoppe, 2017; Paul et al., 2004). This consolidation has led to agglomeration and intensification of commodity production, resulting in simplified agricultural landscapes reliant on external chemical inputs (Aguilar et al., 2015; Brown & Schulte, 2011; Landis, 2017; Meehan et al., 2011; Nassauer, 2010; Spangler et al., 2020).

Such simplification, while aiming to boost yields and maximize production efficiency, is associated with extensive negative socioecological impacts. These include reduced pollinator diversity and soil water retention, the degradation of natural pest control, and less nutrient cycling which can lead to a significant reduction in crop yield

(Grab et al., 2018; Guzman et al., 2019; Hass et al., 2018; King & Hofmockel, 2017; Kremen & Miles, 2012; Meehan et al., 2011). Furthermore, the corporate and governmental institutions that promote landscape simplification reinforce structural inequities to uphold such control. These include barriers to accessing high quality land for Black, Indigenous, and other farmers of color, failing to protect food and farmworkers, and minimizing support for native and heirloom seed networks (Ayazi & Elsheikh, 2015). Given such dire concerns, systems-level change that promotes synergies between people and their environment, such as increasing *agrobiodiversity*, have become urgent (Kremen & Merenlender, 2018; Prokopy et al., 2020).

Agrobiodiversity refers broadly to the "diversity of food and agriculture systems." It encompasses multiple levels, from food and crop inter- and intraspecies diversity (e.g., domesticated plants), and biodiversity associated with food and crops (e.g. pollinators), to the different knowledges, skills, identities, and institutions that manage and affect such diversity (e.g. seed networks or federal subsidies) (K. S. Zimmerer et al., 2019). As Kremen et al. (2012, p. 44) stated, "a farming system is diversified when it intentionally includes functional biodiversity (or biodiversity that promotes *specific* functions of organisms) at multiple spatial and/or temporal scales through practices developed via traditional and/or agroecological scientific knowledge." The noted benefits of agrobiodiversity are grounded in the harnessing of ecosystem services (ES) – benefits humans receive freely from the environment (Zhang et al., 2007). Harnessing ES to and from agriculture can help working landscapes serve several functions (or achieve *multifunctionality*) for food and fiber provision to occur in tandem with (rather than at the cost of) greater socioecological wellbeing (Rodríguez-Loinaz et al., 2015).

At the field-scale, one mechanism of increasing agrobiodiversity that farmers can implement in the short-term is crop diversification. On-farm crop diversification encompasses both temporal and spatial diversity. Temporal diversity can be achieved through a schedule that spans months or years, whereby a snapshot in time may not illustrate the diversity of crop and non-crop land uses. Temporal diversification practices include diverse crop rotations (Davis et al., 2012) or cover cropping (L. W. Bell et al., 2014; Schipanski et al., 2014). Spatial diversity is measurable at a given place in time and enacted through a wide-ranging suite of practices: intercropping or polycropping (Daryanto et al., 2020; Mead & Wiley, 1980), buffer strips, riparian corridors, and hedgerows (Kremen et al., 2012), or creating wildlife habitat patches within and across plots (Pywell et al., 2015). Accumulating evidence exhibits a strong positive association between such diversification and ES provisioning, broadly. Such benefits include improved crop yields (Burchfield et al., 2019; Gaudin et al., 2015; Pywell et al., 2015; Schulte et al., 2017; R. G. Smith et al., 2008), decreased yield volatility over time (Abson et al., 2013; Di Falco & Perrings, 2005; Li et al., 2019), improved pest management (Bommarco et al., 2013; Chaplin-Kramer et al., 2011), improved soil health (Albizua et al., 2015; Berendsen et al., 2012; Ghimire et al., 2018; McDaniel et al., 2014; Postma et al., 2008), increased pollinator diversity (Guzman et al., 2019; Hass et al., 2018; Schulte et al., 2017; Tscharntke et al., 2005), and overall greater productivity than industrial operations based on output per acre (Kremen & Miles, 2012; Virginia et al., 2018).

However, the field-scale is delineated by political and economic boundaries that do not represent the ecological functioning of agricultural landscapes, and the relationship between crop diversification and ES provisioning *beyond the field scale* remains underexplored (Abson et al., 2013; Birkhofer et al., 2018; Duarte et al., 2018). For simplicity, the use of the term landscape here within implies any spatial scale beyond the field, ranging from the aggregation of multiple neighboring plots to the extent of a county boundary. Yet, the agricultural “landscape” is an imprecise concept; a landscape can be defined by varying spatial extents of varying units (i.e., from the micro-, meso-, to macroscales), which affects the ecological processes being observed and measured (Martin et al., 2020; Serafini et al., 2019; Turner et al., 1989).

Crop diversification at landscape scales requires a broader scope of assessment and implementation, as well as the intentional definition of a landscape using social, political, or ecological boundaries. Agricultural land managed beyond the field scale can counteract the often unintended and harmful implications of how farmer decision-making aggregates (Benton, 2012). This aggregation can lead to the “tyranny of small decisions” (Odum, 1982), whereby small, independent decisions can lead to an outcome simply through the accumulation of these choices rather than assessing the goal holistically. Furthermore, the surrounding landscape of a farm holds strong influence on how the ecosystem there within operates, particularly the regional pool of crop and non-crop species and associated habitat, referred to as “landscape effect” (Benton, 2012). Overarchingly, achieving and managing diverse, multifunctional landscapes can promote landscapes whereby wildlife and ES to and from agriculture disperse freely and beneficially (Kremen & Merenlender, 2018; Zhang et al., 2007). Thus, within these landscapes, maximizing production cannot always take precedent over other sociological needs and tradeoffs (Kremen & Merenlender, 2018), promoting greater resilience to shocks and stressors and less volatility of outputs and economic returns (Abson et al., 2013; Di Falco & Chavas, 2008). Given these benefits and challenges, a deeper understanding of the barriers and bridges to crop diversification *across scales* is needed (Duarte et al., 2018; Kremen & Merenlender, 2018; Swift et al., 2004).

This research project aims to broadly assess these barriers and bridges to crop diversification. Given the urgent social and environmental concerns associated with U.S. landscape simplification, as well as the gaps in understanding crop diversification and ES provisioning across scales, there is a need to understand *how* and *why* landscapes become (or do not become) more diverse. The project integrates qualitative and quantitative data from the micro- to macroscale to theoretically, methodologically, and practically advance our understanding of how to enhance agrobiodiversity across the U.S. agri-food system.

2. Theoretical Framework

This research draws on the established fields of political ecology (PE) and agroecology and how they converge into an emerging framework of political agroecology. I first explain how PE has conceptualized and contested scale and socioenvironmental change. Then, I expound on agroecology and its multiple definitions across disciplines. Finally, I integrate these two theories through the lens of political agroecology and discuss how it applies to this research project.

2.1 Political Ecology

In its most basic sense, despite multiple divergent applications and definitions, political ecology (PE) is an approach that assesses socioenvironmental change through its interaction with political systems and processes. Since its inception in 1972, PE and other related geographic fields have grappled with the role of scale in understanding the dynamics of a political economy of socioenvironmental change (Wolf, 1972). Influenced by Marxist agrarian studies, Blaikie and Brookfield (1987) first argued that the relationship between social and environmental factors must be interpreted and understood through the overlap of local, regional, and global scales. Concepts of global and local are important ways of interpreting the multiple levels at which environmental phenomena are both perceived and experienced, in “totality” and in “particularity” (Gibson et al., 2000). “Chains of explanation” help link local processes to broader political and economic forces through four essential scales: 1) individual land managers, 2) the local community, 3) the state, and 4) the international economy (Blaikie & Brookfield, 1987, p. 27). This argument helped legitimize the need for geographers to assess environmental degradation and change through absolute (e.g., state, county, or district boundaries), relative (e.g. perceptions of space and distance), and conceptual (global vs. local) scales (Bassett & Peimer, 2015; Gibson et al., 2000; Perreault et al., 2015; Rocheleau, 2008; K. Zimmerer & Thomas Bassett, 2003).

Several scholars expound that the *production* of scale affects the ways that ecological change is framed – a disruption, transformation, evolution, etc. – and thus makes such production inherently political (Rangan & Kull, 2009). The ‘politics of scale’ has been theorized and extended throughout the geographic literature (e.g., Swyngedouw 1997; N. Smith 1992) as “scale is socially constructed, historically contingent, and politically contested” (72, pg. 399). Scale is an outcome of power relations, decisions, and processes; in other words, it is not an accident (N. Smith, 1984; Swyngedouw, 1997;

Turner et al., 1989). As Rangan and Kull (2009) describe, it is "produced by combining space, time, and power into different forms, functions, measures, symbols, and sensibilities, and is used to articulate relations, controls, and representations of social and biophysical landscapes" (pgs. 36-37). Such production can be understood through 1) spatial practices (routine interactions and activities), 2) representations of space (organization of spatial practices by powerful actors), and 3) representational space (interpretation of socioecological processes). Constructing scale is inextricably intertwined in political processes (e.g., capitalist production and consumption) and is redefined through everyday spaces and livelihoods, not abstract inevitable forces (Brenner, 2001; Marston, 2000; McCarthy, 2005). The politics of scalar production are particularly relevant to understanding the dynamics of agri-food systems, namely how decentralized land management approaches throughout the U.S. influence (and limit) the design, interpretation, and coordination of agricultural landscapes (Moragues-Faus & Marsden, 2017).

2.2 Agroecology

Defining agroecology is an ongoing topic of research and debate. Brym and Reeve (2016) identify agroecology as 1) a scientific research approach, 2) a design approach, 3) an agricultural practice grounded in sustainability, and 4) a socio-political movement. These definitions converge on the notion that sustainable and resilient agricultural systems must provide sufficient food, fiber, fuel, and feed by "increasing the productivity of heritage agroecosystems" (Ferguson & Lovell, 2014, p. 270), while minimizing external inputs and maximizing ecological health and social equity. In its most practical application, agroecology is a suite of practices and an agricultural approach that replaces external inputs with natural, ecological processes to enhance ES to and from agriculture (Altieri & Nicholls, 2009; Zhang et al., 2007). Principles for such practice include 1) enhancing the recycling of biomass and functional biodiversity, 2) optimizing soil health and managing soil organic matter, 3) minimizing resource loss, such as energy, water, nutrients, and genetic diversity, and 4) increasing species and genetic diversity across the landscape (Altieri, 1999; Altieri & Nicholls, 2009). These practices and principles are based on the knowledges widely held by smallholder (or peasant) farmers, family farms, and Indigenous peoples for centuries (Altieri & Nicholls, 2009; Kerr, 2014).

A growing body of literature, researchers, practitioners, and farmers are calling for an expansion of this suite of practices to encompass transformations across the entirety of the agri-food system (M. M. Bell & Bellon, 2018; Dalgaard et al., 2003; Francis et al., 2003). Agroecology is, by definition, an approach that is knowledge-based and requires comparably low technological and monetary inputs compared to conventional methods (Kremen et al., 2012). Therefore, it is a particularly adept approach at being accessible to most farmers and supporting and uplifting farmer knowledge networks and social movements (Altieri, 2002; Kremen & Merenlender, 2018). The challenges of the current U.S. agricultural system emphasize the need to intertwine biodiversity conservation and agriculture throughout a landscape – referred to as "working lands conservation" (Kremen & Merenlender, 2018). Agroecology supports the notion that change at *both* incremental (within the existing agricultural framework) and transformative levels (against the existing agricultural framework) is necessary (National Research Council, 2010; Spangler et al., 2020). This search for pathways of incremental and transformative change has been expanded upon through the integrated, systems-level framework of political agroecology.

2.3 Political Agroecology

Political agroecology is an ideological framework grounded in the need for an entirely different agri-food system (or *regime*). The flow of energy within human systems is dictated by institutional and political factors, often resulting in asymmetrical distributions of material goods, information, and other resources (González de Molina et al., 2019). Current inequitable patterns of production, appropriation, consumption, and excretion within the global and U.S. regime emphasize the importance of a more critical narrative to examine institutions and actors *across scale* (Clapp & Purugganan, 2020). While farmer attitudes and decision-making processes can enact significant localized changes, the community, regional, national, and international scales can advance landscape-level changes or institutional policy shifts (Gonzalez De Molina, 2013; Moragues-Faus & Marsden, 2017). Thus, a multiscalar lens, as developed through PE, is crucial to identifying realistic and meaningful pathways toward socially just and agrobiodiverse systems (Mang & Reed, 2012).

Agents cannot be divorced from their social, political, and economic contexts, and this contextual variability may enable or inhibit how farmers, and, collectively households and communities, choose and enact diversification strategies. Agroecological practices originate from small-scale, peasant agricultural systems where labor is more affordable and reciprocity and collectivism are culturally valued (Altieri, 1999; Ferguson & Lovell, 2017). In the U.S., farmers invest time, money, labor, and value into building large-scale commercial operations that are both supported and encouraged by federal policies and technological advancements (Iles & Marsh, 2012; Kremen & Merenlender, 2018; Spangler et al., 2020). This contributes to “lock-ins” or “path dependencies” that sometimes inhibit transformative potential, putting agroecological alternatives at disadvantage with respect to market competition and labor productivity (Barnett et al., 2015; Ferguson & Lovell, 2017; Horlings & Marsden, 2011). Furthermore, farmers often have to make decisions with great uncertainty and imperfect information, rather than on calculated risks, as they balance business, family, and other complicating factors (Findlater et al., 2019). They balance their notions of a “good farmer” with competing conservationist and productivist identities (Eitzinger et al., 2018; McGuire et al., 2013; Roesch-McNally et al., 2018), as well as familial values (Valliant et al., 2017), political beliefs (Jarosz, 2011), and economic or logistical constraints (Emerton & Snyder, 2018). Given these multiple constraints among others, small-scale farmers cannot solely be blamed for the inability to out-compete corporate commodity producers (Ferguson & Lovell, 2017), and large-scale commodity producers are not solely responsible for the “lock-ins” of landscape simplification (Yoshida et al., 2018).

Within the political agroecology framework, strengthening our understanding of how agroecological diversification can be scaled *across* landscapes, aggregate against “lock-ins”, and support landscapes of alternative possibilities remains crucial yet underdeveloped. Agroecological design of landscapes beyond the field scale calls for contextualized solutions, or “designing from place” (Mang & Reed, 2012), promoting the need to manage for multifunctionality (Hobbs et al., 2014; Jordan & Warner, 2010; Renting et al., 2009). However, this process is complicated by the elusiveness of which political, ecological, or social borders define a landscape. The conceptualization and definition of a landscape is inconsistent across space and time, thus making the people and institutions who could manage for multifunctionality unclear. Furthermore, landscapes are common-pool resources; ES flow across property boundaries and farm plots, and costs of diversification may not be evenly spread over those who reap the benefits (Ostrom, 1990; Zhang et al., 2007). Landscapes also integrate challenges and benefits related to farm size, land ownership and tenancy, local policies, and regionally specific cropping rotations, to name a few (Plexida et al., 2014). Assessing processes of diversification from the macro to microscale can help elucidate realistic pathways to a more sustainable and equitable food future.

3. Overview of Dissertation

This research aims to address the need for multiscale, integrative research within a political agroecological framework. Figure 1-1 outlines how Chapters II, III, and IV are positioned at different scales, from the macro to micro, to assess barriers and bridges to agricultural diversification. Scaling up from the plot to region indicate the negotiable, or political, boundaries that define and are defined by the socioecological processes therewithin. Identifying and understanding these barriers and bridges, as well as the negotiations of boundaries beyond the field scale, can help advance toward increased crop diversity at the plot and farm level, design multifunctional landscapes, and counteract systemic lock-ins. These pathways of change can help achieve increased agrobiodiversity across multiple scales.

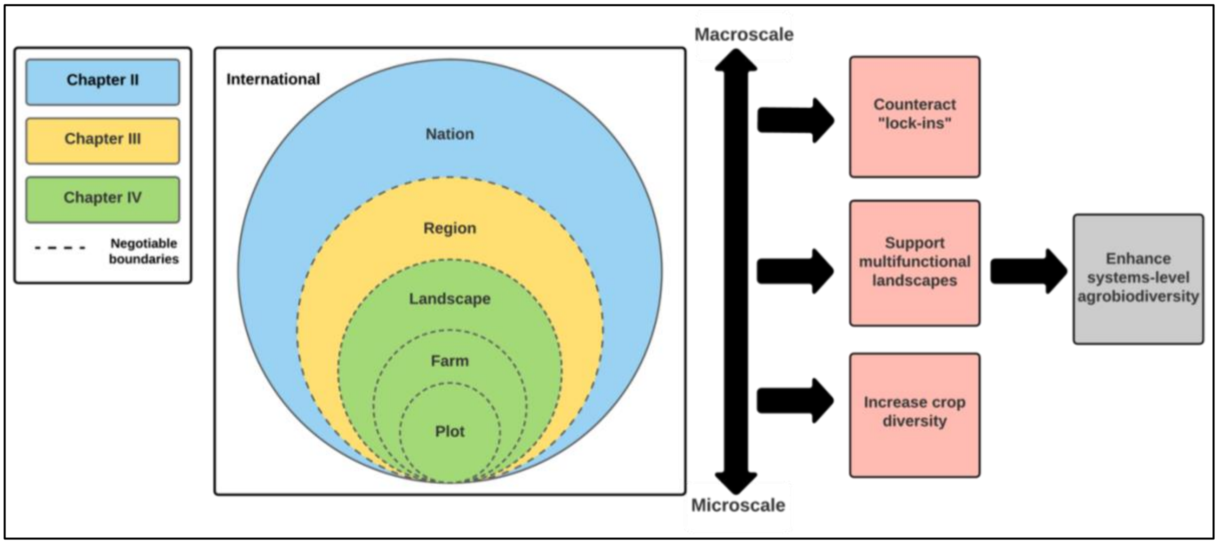


Figure 1-1: Scales and pathways of agricultural diversification in study

Chapter II provides a broad understanding of how and why national agricultural land use and policy have changed over recent decades across the U.S. Processes of farmland consolidation through the growth of larger farms, specialization of commodity production, and an expanding scope of the Farm Bill illustrate systemic drivers of current U.S. agricultural systems. Identifying these trends and drivers helps contextualize regional lock-ins and farmer decision-making.

Chapter III identifies regional factors associated with agricultural diversity, as well as how these factors vary across regions. This analysis provides a framework to situate in-depth qualitative insight of farmer livelihoods with broader socioecological dynamics. It also elucidates regional dynamics that may lock in certain agricultural land uses, markets, and social norms, providing a mesoscale connection between the macro- and microscale factors of agricultural diversification.

Chapter IV builds upon Chapter III by utilizing this regional understanding of agricultural diversity to uncover the barriers and bridges to agricultural diversification more deeply through farmers' perceptions and experiences in the Magic Valley of Idaho. Using in-depth and mixed qualitative methodologies provides nuanced, localized insight into the tradeoffs of managing for agricultural diversity. These insights, in tandem with Chapters II and III, provide robust insight into how and why landscapes across the U.S. are (or are not) diversifying.

References

Abson, D. J., Fraser, E. D., & Benton, T. G. (2013). Landscape diversity and the resilience of agricultural returns: A portfolio analysis of land-use patterns and economic returns from lowland agriculture. *Agriculture & Food Security*, *2*(1), 2. https://doi.org/10.1186/2048-7010-2-2

Aguilar, J., Gramig, G. G., Hendrickson, J. R., Archer, D. W., Forcella, F., & Liebig, M. A. (2015). Crop species diversity changes in the United States: 1978–2012. *PLOS ONE*, *10*(8), e0136580. https://doi.org/10.1371/journal.pone.0136580

Albizua, A., Williams, A., Hedlund, K., & Pascual, U. (2015). Crop rotations including ley and manure can promote ecosystem services in conventional farming systems. *Applied Soil Ecology*, *95*, 54–61. https://doi.org/10.1016/j.apsoil.2015.06.003

Altieri, M. A. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture, Ecosystems and Environment*, *74*(1999), 19–31.

Altieri, M. A. (2002). Agroecology: The science of natural resource management for poor farmers in marginal environments. *Agriculture, Ecosystems & Environment*, *93*(1–3), 1–24. https://doi.org/10.1016/S0167-8809(02)00085-3

Altieri, M. A., & Nicholls, C. I. (2009). Agroecology, small farms, and food sovereignty. *Monthly Review*, *61*(3), 102. https://doi.org/10.14452/MR-061-03-2009-07_8

Anderson, C. R., Bruil, J., Chappell, M. J., Kiss, C., & Pimbert, M. P. (2019). From Transition to Domains of Transformation: Getting to Sustainable and Just Food Systems through Agroecology. *Sustainability*, *11*(19), 5272. https://doi.org/10.3390/su11195272

Auch, R. F., Xian, G., Laingen, C. R., Sayler, K. L., & Reker, R. R. (2018). Human drivers, biophysical changes, and climatic variation affecting contemporary cropping proportions in the northern prairie of the U.S. *Journal of Land Use Science, 13*(1–2), 32–58. https://doi.org/10.1080/1747423X.2017.1413433

Ayazi, H., & Elsheikh, E. (2015). *The Farm Bill: Corporate Power and Structural Racialization in the United States Food System* (p. 92). Haas Institute for a Fair and Inclusive Society at the University of California Berkeley. https://belonging.berkeley.edu/global-justice/glocal-food-systems/farm-bill-report-corporate-power-and-structural-racialization-us-food-system

Baines, J. (2015). Fuel, feed and the corporate restructuring of the food regime. *The Journal of Peasant Studies*, *42*(2), 295–321. https://doi.org/10.1080/03066150.2014.970534

Barnett, J., Evans, L. S., Gross, C., Kiem, A. S., Kingsford, R. T., Palutikof, J. P., Pickering, C. M., & Smithers, S. G. (2015). From barriers to limits to climate change adaptation: Path dependency and the speed of change. *Ecology and Society*, *20*(3), art5. https://doi.org/10.5751/ES-07698-200305

Bassett, T. J., & Peimer, A. W. (2015). Political ecological perspectives on socioecological relations. *Natures Sciences Sociétés*, *23*(2), 157–165. https://doi.org/10.1051/nss/2015029

Bell, L. W., Moore, A. D., & Kirkegaard, J. A. (2014). Evolution in crop–livestock integration systems that improve farm productivity and environmental performance in Australia. *European Journal of Agronomy*, *57*, 10–20. https://doi.org/10.1016/j.eja.2013.04.007

Bell, M. M., & Bellon, S. (2018). Generalization without universalization: Towards an agroecology theory. *Agroecology and Sustainable Food Systems*, *42*(6), 605–611. https://doi.org/10.1080/21683565.2018.1432003

Benton, T. G. (2012). Managing agricultural landscapes for production of multiple services: The policy challenge. *PAGRI*, *1*(12), 12.

Berendsen, R. L., Pieterse, C. M. J., & Bakker, P. A. H. M. (2012). The rhizosphere microbiome and plant health. *Trends in Plant Science*, *17*(8), 478–486. https://doi.org/10.1016/j.tplants.2012.04.001

Birkhofer, K., Andersson, G. K. S., Bengtsson, J., Bommarco, R., Dänhardt, J., Ekbom, B., Ekroos, J., Hahn, T., Hedlund, K., Jönsson, A. M., Lindborg, R., Olsson, O., Rader, R., Rusch, A., Stjernman, M., Williams, A., & Smith, H. G. (2018). Relationships between multiple biodiversity components and ecosystem services along a landscape complexity gradient. *Biological Conservation*, *218*, 247–253. https://doi.org/10.1016/j.biocon.2017.12.027

Blaikie, P., & Brookfield, H. (1987). *Land degradation and society*. Routledge.

Bommarco, R., Kleijn, D., & Potts, S. G. (2013). Ecological intensification: Harnessing ecosystem services for food security. *Trends in Ecology & Evolution*, *28*(4), 230–238. https://doi.org/10.1016/j.tree.2012.10.012

Brenner, N. (2001). The limits to scale? Methodological reflections on scalar structuration. *Progress in Human Geography*, *25*(4), 591–614. https://doi.org/10.1191/030913201682688959

Brown, P. W., & Schulte, L. A. (2011). Agricultural landscape change (1937–2002) in three townships in Iowa, USA. *Landscape and Urban Planning*, *100*(3), 202–212. https://doi.org/10.1016/j.landurbplan.2010.12.007

Brym, Z. T., & Reeve, J. R. (2016). Agroecological principles from a bibliographic analysis of the term agroecology. In E. Lichtfouse (Ed.), *Sustainable Agriculture Reviews* (Vol. 19, pp. 203–231). Springer International Publishing. https://doi.org/10.1007/978-3-319-26777-7_5

Burchfield, E. K., Nelson, K. S., & Spangler, K. (2019). The impact of agricultural landscape diversification on U.S. crop production. *Agriculture, Ecosystems & Environment*, *285*, 106615. https://doi.org/10.1016/j.agee.2019.106615

Chaplin-Kramer, R., O'Rourke, M. E., Blitzer, E. J., & Kremen, C. (2011). A meta-analysis of crop pest and natural enemy response to landscape complexity: Pest and natural enemy response to landscape complexity. *Ecology Letters*, *14*(9), 922–932. https://doi.org/10.1111/j.1461-0248.2011.01642.x

Clapp, J., & Purugganan, J. (2020). Contextualizing corporate control in the agrifood and extractive sectors. *Globalizations*, *17*(7), 1265–1275. https://doi.org/10.1080/14747731.2020.1783814

Dalgaard, T., Hutchings, N. J., & Porter, J. R. (2003). Agroecology, scaling and interdisciplinarity. *Agriculture, Ecosystems & Environment*, *100*(1), 39–51. https://doi.org/10.1016/S0167-8809(03)00152-X

Daryanto, S., Fu, B., Zhao, W., Wang, S., Jacinthe, P.-A., & Wang, L. (2020). Ecosystem service provision of grain legume and cereal intercropping in Africa. *Agricultural Systems*, *178*, 102761. https://doi.org/10.1016/j.agsy.2019.102761

Davis, A. S., Hill, J. D., Chase, C. A., Johanns, A. M., & Liebman, M. (2012). Increasing Cropping System Diversity Balances Productivity, Profitability and Environmental Health. *PLoS ONE*, *7*(10), e47149. https://doi.org/10.1371/journal.pone.0047149

Di Falco, S., & Chavas, J.-P. (2008). Rainfall Shocks, Resilience, and the Effects of Crop Biodiversity on Agroecosystem Productivity. *Land Economics*, *84*(1), 83–96. https://doi.org/10.3368/le.84.1.83

Di Falco, S., & Perrings, C. (2005). Crop biodiversity, risk management and the implications of agricultural assistance. *Ecological Economics*, *55*(4), 459–466. https://doi.org/10.1016/j.ecolecon.2004.12.005

Duarte, G. T., Santos, P. M., Cornelissen, T. G., Ribeiro, M. C., & Paglia, A. P. (2018). The effects of landscape patterns on ecosystem services: Meta-analyses of landscape services. *Landscape Ecology*, *33*(8), 1247–1257. https://doi.org/10.1007/s10980-018-0673-5

Eitzinger, A., Binder, C. R., & Meyer, M. A. (2018). Risk perception and decision-making: Do farmers consider risks from climate change? *Climatic Change*, *151*(3–4), 507–524. https://doi.org/10.1007/s10584-018-2320-1

Emerton, L., & Snyder, K. A. (2018). Rethinking sustainable land management planning: Understanding the social and economic drivers of farmer decision-making in Africa. *Land Use Policy*, *79*, 684–694. https://doi.org/10.1016/j.landusepol.2018.08.041

ERS. (2019). *Agricultural Productivity in the U.S.* USDA Economic Research Service. https://www.ers.usda.gov/data-products/agricultural-productivity-in-the-us/

Ferguson, R. S., & Lovell, S. T. (2014). Permaculture for agroecology: Design, movement, practice, and worldview. A review. *Agronomy for Sustainable Development*, *34*(2), 251–274. https://doi.org/10.1007/s13593-013-0181-6

Ferguson, R. S., & Lovell, S. T. (2017). Diversification and labor productivity on US permaculture farms. *Renewable Agriculture and Food Systems*, *34*(04), 326–337. https://doi.org/10.1017/S1742170517000497

Findlater, K. M., Satterfield, T., & Kandlikar, M. (2019). Farmers' Risk-Based Decision Making Under Pervasive Uncertainty: Cognitive Thresholds and Hazy Hedging. *Risk Analysis*, *39*(8), 1755–1770. https://doi.org/10.1111/risa.13290

Francis, C., Lieblein, G., Gliessman, S., Breland, T. A., Creamer, N., Harwood, R., Salomonsson, L., Helenius, J., Rickerl, D., Salvador, R., Wiedenhoeft, M., Simmons, S., Allen, P., Altieri, M., Flora, C., & Poincelot, R. (2003). Agroecology: The Ecology of Food Systems. *Journal of Sustainable Agriculture*, *22*(3), 99–118. https://doi.org/10.1300/J064v22n03_10

Gaudin, A. C. M., Tolhurst, T. N., Ker, A. P., Janovicek, K., Tortora, C., Martin, R. C., & Deen, W. (2015). Increasing crop diversity mitigates weather variations and improves yield stability. *PLOS ONE*, *10*(2), e0113261. https://doi.org/10.1371/journal.pone.0113261

Ghimire, R., Machado, S., & Bista, P. (2018). Decline in soil organic carbon and nitrogen limits yield in wheat-fallow systems. *Plant and Soil*, *422*(1–2), 423–435. https://doi.org/10.1007/s11104-017-3470-z

Gibson, C. C., Ostrom, E., & Ahn, T. K. (2000). The concept of scale and the human dimensions of global change: A survey. *Ecological Economics*, *32*(2), 217–239. https://doi.org/10.1016/S0921-8009(99)00092-0

Gleissman, S. (2015). *Agroecology: The ecology of sustainable food systems* (3rd ed.). CRC Press.

Gonzalez De Molina, M. (2013). Agroecology and Politics. How To Get Sustainability? About the Necessity for a Political Agroecology. *Agroecology and Sustainable Food Systems*, *37*(1), 16.

González de Molina, M., Petersen, P. F., Peña, F. G., & Caporal, F. R. (2019). *Political Agroecology: Advancing the Transition to Sustainable Food Systems*. CRC Press. https://doi.org/10.1201/9780429428821

Grab, H., Danforth, B., Poveda, K., & Loeb, G. (2018). Landscape simplification reduces classical biological control and crop yield. *Ecological Applications*, *28*(2), 348–355. https://doi.org/10.1002/eap.1651

Guzman, A., Chase, M., & Kremen, C. (2019). On-Farm Diversification in an Agriculturally-Dominated Landscape Positively Influences Specialist Pollinators.

Frontiers in Sustainable Food Systems, *3*, 87. https://doi.org/10.3389/fsufs.2019.00087

Hass, A. L., Kormann, U. G., Tscharntke, T., Clough, Y., Baillod, A. B., Sirami, C., Fahrig, L., Martin, J.-L., Baudry, J., Bertrand, C., Bosch, J., Brotons, L., Burel, F., Georges, R., Giralt, D., Marcos-García, M. Á., Ricarte, A., Siriwardena, G., & Batáry, P. (2018). Landscape configurational heterogeneity by small-scale agriculture, not crop diversity, maintains pollinators and plant reproduction in western Europe. *Proceedings of the Royal Society B: Biological Sciences*, *285*(1872), 20172242. https://doi.org/10.1098/rspb.2017.2242

Hobbs, R. J., Higgs, E., Hall, C. M., Bridgewater, P., Chapin, F. S., Ellis, E. C., Ewel, J. J., Hallett, L. M., Harris, J., Hulvey, K. B., Jackson, S. T., Kennedy, P. L., Kueffer, C., Lach, L., Lantz, T. C., Lugo, A. E., Mascaro, J., Murphy, S. D., Nelson, C. R., … Yung, L. (2014). Managing the whole landscape: Historical, hybrid, and novel ecosystems. *Frontiers in Ecology and the Environment*, *12*(10), 557–564. https://doi.org/10.1890/130300

Horlings, L. G., & Marsden, T. K. (2011). Towards the real green revolution? Exploring the conceptual dimensions of a new ecological modernisation of agriculture that could ‘feed the world.’ *Global Environmental Change*, *21*(2), 441–452. https://doi.org/10.1016/j.gloenvcha.2011.01.004

Iles, A., & Marsh, R. (2012). Nurturing Diversified Farming Systems in Industrialized Countries: How Public Policy Can Contribute. *Ecology and Society*, *17*(4), art42. https://doi.org/10.5751/ES-05041-170442

Jarosz, L. (2011). Nourishing women: Toward a feminist political ecology of community supported agriculture in the United States. *Gender, Place & Culture*, *18*(3), 307–326. https://doi.org/10.1080/0966369X.2011.565871

Jordan, N., & Warner, K. D. (2010). Enhancing the multifunctionality of US agriculture. *BioScience*, *60*(1), 60–66. https://doi.org/10.1525/bio.2010.60.1.10

Kerr, R. B. (2014). Lost and Found Crops: Agrobiodiversity, Indigenous Knowledge, and a Feminist Political Ecology of Sorghum and Finger Millet in Northern Malawi. *Annals of the Association of American Geographers*, *104*(3), 577–593. https://doi.org/10.1080/00045608.2014.892346

King, A. E., & Hofmockel, K. S. (2017). Diversified cropping systems support greater microbial cycling and retention of carbon and nitrogen. *Agriculture, Ecosystems & Environment*, *240*, 66–76. https://doi.org/10.1016/j.agee.2017.01.040

Kremen, C., Iles, A., & Bacon, C. (2012). Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture. *Ecology and Society*, *17*(4). https://doi.org/10.5751/ES-05103-170444

Kremen, C., & Merenlender, A. M. (2018). Landscapes that work for biodiversity and people. *Science*, *362*(6412), eaau6020. https://doi.org/10.1126/science.aau6020

Kremen, C., & Miles, A. (2012). Ecosystem Services in Biologically Diversified versus Conventional Farming Systems: Benefits, Externalities, and Trade-Offs. *Ecology and Society*, *17*(4). https://doi.org/10.5751/ES-05035-170440

Landis, D. A. (2017). Designing agricultural landscapes for biodiversity-based ecosystem services. *Basic and Applied Ecology*, *18*, 1–12. https://doi.org/10.1016/j.baae.2016.07.005

Li, M., Peterson, C. A., Tautges, N. E., Scow, K. M., & Gaudin, A. C. M. (2019). Yields and resilience outcomes of organic, cover crop, and conventional practices in a Mediterranean climate. *Scientific Reports*, *9*(1), 12283. https://doi.org/10.1038/s41598-019-48747-4

MacDonald, J. M., & Hoppe, R. A. (2017). *Large family farms continue to dominate U.S. agricultural production* (Amber Waves, p. 6) [Statistic: Farm Economy]. Economic Research Service.

Mang, P., & Reed, B. (2012). Designing from place: A regenerative framework and methodology. *Building Research & Information*, *40*(1), 23–38. https://doi.org/10.1080/09613218.2012.621341

Marston, S. A. (2000). The social construction of scale. *Progress in Human Geography*, *24*(2), 24.

Martin, A. E., Collins, S. J., Crowe, S., Girard, J., Naujokaitis-Lewis, I., Smith, A. C., Lindsay, K., Mitchell, S., & Fahrig, L. (2020). *Effects of farmland heterogeneity on biodiversity are similar to—Or even larger than—The effects of farming practices*. 13.

McCarthy, J. (2005). Scale, Sovereignty, and Strategy in Environmental Governance. *Antipode*, *37*(4), 731–753. https://doi.org/10.1111/j.0066-4812.2005.00523.x

McDaniel, M. D., Tiemann, L. K., & Grandy, A. S. (2014). Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. *Ecological Applications*, *24*(3), 560–570. https://doi.org/10.1890/13-0616.1

McGuire, J., Morton, L. W., & Cast, A. D. (2013). Reconstructing the good farmer identity: Shifts in farmer identities and farm management practices to improve water quality. *Agriculture and Human Values, 30*(1), 57–69. https://doi.org/10.1007/s10460-012-9381-y

Mead, R., & Wiley, R. (1980). The concept of a "Land Equivalent Ratio" and advantages in yields from intercropping. *Experimental Agriculture*, *16*(3), 217–228. https://doi.org/doi:10.1017/S0014479700010978

Meehan, T. D., Werling, B. P., Landis, D. A., & Gratton, C. (2011). Agricultural landscape simplification and insecticide use in the Midwestern United States. *Proceedings of the National Academy of Sciences*, *108*(28), 11500–11505. https://doi.org/10.1073/pnas.1100751108

Moragues-Faus, A., & Marsden, T. (2017). The political ecology of food: Carving 'spaces of possibility' in a new research agenda. *Journal of Rural Studies*, *55*, 275–288. https://doi.org/10.1016/j.jrurstud.2017.08.016

Nassauer, J. I. (2010). Rural landscape change as a product of US federal policy. In J. Primdahl & S. Swaffield (Eds.), *Globalisation and Agricultural Landscapes* (pp. 185–200). Cambridge University Press. https://doi.org/10.1017/CBO9780511844928.011

National Research Council. (2010). *Toward sustainable agricultural systems in the 21st century*. The National Academies Press.

Neumann, R. P. (2009). Political ecology: Theorizing scale. *Progress in Human Geography*, *33*(3), 398–406. https://doi.org/10.1177/0309132508096353

Odum, W. E. (1982). Environmental degradataion and the tyranny of small decisions. *BioScience*, *32*(9), 728–729.

Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge University Press.

Paul, C. M., Nehring, R., Banker, D., & Somwaru, A. (2004). Scale economies and efficiency in U.S. agriculture: Are traditional farms history? *Journal of Productivity Analysis*, *22*(3), 22.

Pellegrini, P., & Fernández, R. J. (2018). Crop intensification, land use, and on-farm energy-use efficiency during the worldwide spread of the green revolution. *Proceedings of the National Academy of Sciences*, *115*(10), 2335–2340. https://doi.org/10.1073/pnas.1717072115

Perreault, T., Bridge, G., & McCarthy, J. (2015). *The Routledge Handbook of Political Ecology* (1st Edition). Routledge.

Plexida, S. G., Sfougaris, A. I., Ispikoudis, I. P., & Papanastasis, V. P. (2014). Selecting landscape metrics as indicators of spatial heterogeneity—A comparison among Greek landscapes. *International Journal of Applied Earth Observation and Geoinformation*, *26*, 26–35. https://doi.org/10.1016/j.jag.2013.05.001

Postma, J., Schilder, M. T., Bloem, J., & van Leeuwen-Haagsma, W. K. (2008). Soil suppressiveness and functional diversity of the soil microflora in organic farming systems. *Soil Biology and Biochemistry*, *40*(9), 2394–2406. https://doi.org/10.1016/j.soilbio.2008.05.023

Prokopy, L. S., Gramig, B. M., Bower, A., Church, S. P., Ellison, B., Gassman, P. W., Genskow, K., Gucker, D., Hallett, S. G., Hill, J., Hunt, N., Johnson, K. A., Kaplan, I., Kelleher, J. P., Kok, H., Komp, M., Lammers, P., LaRose, S., Liebman, M., … Ulrich-Schad, J. D. (2020). The urgency of transforming the Midwestern U.S. landscape into more than corn and soybean. *Agriculture and Human Values*, *37*(3), 537–539. https://doi.org/10.1007/s10460-020-10077-x

Pywell, R. F., Heard, M. S., Woodcock, B. A., Hinsley, S., Ridding, L., Nowakowski, M., & Bullock, J. M. (2015). Wildlife-friendly farming increases crop yield: Evidence for ecological intensification. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1816), 20151740. https://doi.org/10.1098/rspb.2015.1740

Ramankutty, N., Mehrabi, Z., Waha, K., Jarvis, L., Kremen, C., Herrero, M., & Rieseberg, L. H. (2018). Trends in global agricultural land use: Implications for environmental health and food security. *Annual Review of Plant Biology*, *69*(1), 789–815. https://doi.org/10.1146/annurev-arplant-042817-040256

Rangan, H., & Kull, C. A. (2009). What makes ecology `political'?: Rethinking `scale' in political ecology. *Progress in Human Geography*, *33*(1), 28–45. https://doi.org/10.1177/0309132508090215

Reganold, J. P., Jackson-Smith, D., Batie, S. S., Harwood, R. R., Kornegay, J. L., Bucks, D., Flora, C. B., Hanson, J. C., Jury, W. A., Meyer, D., Schumacher, A., Sehmsdorf, H., Shennan, C., Thrupp, L. A., & Willis, P. (2011). Transforming U.S. Agriculture. *Science*, *332*(6030), 670–671. https://doi.org/10.1126/science.1202462

Renting, H., Rossing, W. A. H., Groot, J. C. J., Van der Ploeg, J. D., Laurent, C., Perraud, D., Stobbelaar, D. J., & Van Ittersum, M. K. (2009). Exploring multifunctional agriculture. A review of conceptual approaches and prospects for an integrative transitional framework. *Journal of Environmental Management*, *90*, S112–S123. https://doi.org/10.1016/j.jenvman.2008.11.014

Rocheleau, D. E. (2008). Political ecology in the key of policy: From chains of explanation to webs of relation. *Geoforum*, *39*(2), 716–727. https://doi.org/10.1016/j.geoforum.2007.02.005

Rodríguez-Loinaz, G., Alday, J. G., & Onaindia, M. (2015). Multiple ecosystem services landscape index: A tool for multifunctional landscapes conservation. *Journal of Environmental Management*, *147*, 152–163. https://doi.org/10.1016/j.jenvman.2014.09.001

Roesch-McNally, G., Arbuckle, J. G., & Tyndall, J. C. (2018). Soil as Social-Ecological Feedback: Examining the “Ethic” of Soil Stewardship among Corn Belt Farmers. *Rural Sociology*, *83*(1), 145–173. https://doi.org/10.1111/ruso.12167

Schipanski, M. E., Barbercheck, M., Douglas, M. R., Finney, D. M., Haider, K., Kaye, J. P., Kemanian, A. R., Mortensen, D. A., Ryan, M. R., Tooker, J., & White, C. (2014). A framework for evaluating ecosystem services provided by cover crops in agroecosystems. *Agricultural Systems*, *125*, 12–22. https://doi.org/10.1016/j.agsy.2013.11.004

Schulte, L. A., Niemi, J., Helmers, M. J., Liebman, M., Arbuckle, J. G., James, D. E., Kolka, R. K., O’Neal, M. E., Tomer, M. D., Tyndall, J. C., Asbjornsen, H., Drobney, P., Neal, J., Van Ryswyk, G., & Witte, C. (2017). Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn–soybean croplands. *Proceedings of the National Academy of Sciences*, *114*(42), 11247–11252. https://doi.org/10.1073/pnas.1620229114

Serafini, V. N., Priotto, J. W., & Gomez, M. D. (2019). Effects of agroecosystem landscape complexity on small mammals: A multi-species approach at different spatial scales. *Landscape Ecology*, *34*(5), 1117–1129. https://doi.org/10.1007/s10980-019-00825-8

Smith, N. (1984). *Uneven Development: Nature, Capital, and the Production of Space*. Basil Blackwell.

Smith, N. (1992). Geography, difference and the politics of scale. In J. Doherty, E. Graham, & M. Malek (Eds.), *Postmodernism and the social sciences* (pp. 57–79). Macmillan.

Smith, R. G., Gross, K. L., & Robertson, G. P. (2008). Effects of crop diversity on agroecosystem function: Crop yield response. *Ecosystems*, *11*(3), 355–366. https://doi.org/10.1007/s10021-008-9124-5

Spangler, K., Burchfield, E. K., & Schumacher, B. (2020). Past and Current Dynamics of U.S. Agricultural Land Use and Policy. *Frontiers in Sustainable Food Systems*, *4*(98), 21. https://doi.org/10.3389/fsufs.2020.00098

Swift, M. J., Izac, A.-M. N., & van Noordwijk, M. (2004). Biodiversity and ecosystem services in agricultural landscapes—Are we asking the right questions? *Agriculture, Ecosystems & Environment*, *104*(1), 113–134. https://doi.org/10.1016/j.agee.2004.01.013

Swyngedouw, E. (1997). Neither global nor local: "glocalization" and the politics of scale. In K. Cox (Ed.), *Spaces of globalization: Reasserting the power of the local* (pp. 137–166). Guilford.

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. *Ecology Letters*, *8*(8), 857–874. https://doi.org/10.1111/j.1461-0248.2005.00782.x

Turner, M. G., O'Neill, R. V., Gardner, R. H., & Milne, B. T. (1989). Effects of changing spatial scale on the analysis of landscape pattern. *Landscape Ecology*, *3*(3–4), 153–162. https://doi.org/10.1007/BF00131534

Valliant, J. C. D., Farmer, J. R., Dickinson, S. L., Bruce, A. B., & Robinson, J. M. (2017). Family as a catalyst in farms' diversifying agricultural products: A mixed methods analysis of diversified and non-diversified farms in Indiana, Michigan and Ohio. *Journal of Rural Studies*, *55*, 303–315. https://doi.org/10.1016/j.jrurstud.2017.08.017

Virginia, A., Zamora, M., Barbera, A., Castro-Franco, M., Domenech, M., De Gerónimo, E., & Costa, J. L. (2018). Industrial agriculture and agroecological transition systems: A comparative analysis of productivity results, organic matter and glyphosate in soil. *Agricultural Systems*, *167*, 103–112. https://doi.org/10.1016/j.agsy.2018.09.005

Wolf, E. (1972). Ownership and Political Ecology. *Anthropological Quarterly*, *45*(3), 201. https://doi.org/10.2307/3316532

Yoshida, Y., Flint, C. G., & Dolan, M. K. (2018). Farming between love and money: US Midwestern farmers' human–nature relationships and impacts on watershed conservation. *Journal of Environmental Planning and Management*, *61*(5–6), 1033–1050. https://doi.org/10.1080/09640568.2017.1327423

Zhang, W., Ricketts, T. H., Kremen, C., Carney, K., & Swinton, S. M. (2007). Ecosystem services and dis-services to agriculture. *Ecological Economics*, *64*(2), 253–260. https://doi.org/10.1016/j.ecolecon.2007.02.024

Zimmerer, K. S., de Haan, S., Jones, A. D., Creed-Kanashiro, H., Tello, M., Carrasco, M., Meza, K., Plasencia Amaya, F., Cruz-Garcia, G. S., Tubbeh, R., & Jiménez Olivencia, Y. (2019). The biodiversity of food and agriculture (Agrobiodiversity) in the anthropocene: Research advances and conceptual framework. *Anthropocene*, *25*, 100192. https://doi.org/10.1016/j.ancene.2019.100192

Zimmerer, K. & Thomas Bassett (Eds.). (2003). *Political ecology: An integrative approach to geography and environment-development studies*. Guilford.

CHAPTER II

PAST AND CURRENT DYNAMICS OF U.S. AGRICULTURAL LAND USE AND POLICY[1,2]

Abstract

Over the past century, agricultural land use in the United States has seen drastic shifts to support increasing demand for food and commodities; in many regions, this has resulted in highly simplified agricultural landscapes. Surmounting evidence exhibits the negative impacts of this simplification on the long-term provisioning of necessary ecosystem services to and from agriculture. However, transitions toward alternative systems often occur at a small scale, rather than at a systemic level. Within the National Research Council's (NRC) sustainable agricultural systems framework, we utilize national open-source datasets spanning several decades to broadly assess past and current agricultural landscapes across the U.S. We integrate and analyze agricultural land use and land cover data with policy data to address two main objectives: (1) Document and visualize changes over recent decades in cropland conversion, agricultural productivity, and crop composition across the U.S.; and (2) identify broad policy changes of the U.S. Farm Bills from 1933 to 2018 associated with these land use trends. We show that U.S. agriculture has gradually trended toward an intensely regulated and specialized system.

---

[1] This paper has been published by *Frontiers in Sustainable Food Systems* with co-authors Emily Burchfield and Britta Schumacher. It can be accessed at the following citation: "Spangler, K., Burchfield, E., & Schumacher, B. 2020. Past and current dynamics of U.S. agricultural land use and policy. *Frontiers in Sustainable Food Systems*, *4*(98), 21. https://doi.org/10.3389/fsufs.2020.00098"

[2] This research was supported by funds from EB's start-up funds from the Department of Environment and Society at Utah State University (USU), USU's Climate Adaptation Science Program through the National Science Foundation under Grant No. 1633756, and the Utah Agricultural Experiment Station under Grant No. UTA01422.

Crop production is heavily concentrated in certain areas, larger farms are getting larger, while the number of smaller operations is decreasing, and crop diversity is declining. Meanwhile, federal agricultural policy is increasing in scope and influence. Through these data-driven insights, we argue that incremental and transformative pathways of change are needed to support alternative production practices, incentivize diversified landscapes, and promote innovation toward more sustainable agricultural systems across multiple scales.

1. Introduction

Agriculture has drastically transformed Earth's surface over the last century. Concerns arise in the ability of the global agri-food system to meet current and future food demands while maintaining biological diversity and conservation needs. Globally, since the 1960s, the large-scale demand and movement of commercial crops grown in intensive management systems has increased, contributing to a narrowing of crop species and genetic diversity worldwide (Harlan, 1975; Heal et al., 2004; Khoury et al., 2014). Surmounting evidence illustrates the negative ecological impacts of this shift, largely due to intensive annual crop production and landscape simplification (Pimentel et al., 1995; Tilman, 1999; Horrigan et al., 2002; Robinson and Sutherland, 2002; Benton et al., 2003; Bianchi et al., 2006). Simplified agricultural landscapes are associated with the degradation of key ecosystem services (ES)—or the benefits humans receive freely from the environment—that are essential to agricultural production, such as soil fertility, nutrient cycling, and genetic biodiversity, as well as regulating services including soil retention, pollination, natural pest control, and water purification (Tscharntke et al., 2005, 2012; Hendrickx et al., 2007; Meehan et al., 2011; Bommarco et al., 2013; McDaniel et al., 2014; Landis, 2017). ES generated by agricultural systems are primarily acquired through provisioning services, i.e., food, fiber, and fuel production, but also through cultural services, such as enhancing landscape aesthetics, building social networks, and market participation, and other services, such as wildlife habitat preservation; these mechanisms feed back into supporting and regulating services. Ecological functions that *disrupt* agricultural production (referred to as *disservices*), such as competition for water or crop damage from natural predators and pests, may further contribute to disservices generated from agriculture, including nutrient runoff or habitat loss (Rabalais et al., 2002; Zhang et al., 2007; Hillier et al., 2009; Cardinale et al., 2012; Hooper et al., 2012). Managing agriculture to optimize ecosystem health and the provisioning of key ES for agriculture while minimizing disservices can increase the stability and quantity of production over time, decrease need for external inputs, and increase ES delivery to the broader ecosystem (Cassman, 1999; Tscharntke et al., 2005; Bommarco et al., 2013, 2018; Pywell et al., 2015; Burchfield et al., 2019).

Recent calls for transformations in our agricultural landscapes emphasize the importance of agricultural systems that boost ES for agriculture through practices that are environmentally, economically, and socially beneficial while also maintaining or increasing productivity (Reganold et al., 2011). The National Research Council's (NRC) Committee on Twenty First Century Systems Agriculture (NRC, 2010) defined several objectives for sustainable agricultural systems. First and foremost, agricultural sustainability is defined within four main themes: (1) Satisfy human food, feed, and fiber needs and contribute to biofuel needs; (2) enhance environmental quality and the resource base; (3) sustain the economic viability of agriculture; and (4) enhance the quality of life for farmers, farm workers, and society as a whole. These main objectives of sustainability align with NRC's "systems agriculture" approach to understanding the interactions among actors and components of the system as a whole, rather than the function of each component separately. The NRC further identified three main qualities of system's robustness to use as considerations for systems moving toward sustainability. Robustness encompasses resistance (ability to withstand shocks), resilience (capacity to absorb shocks and stressors over time), and adaptability (ability to make necessary systemic changes in response to long-term environmental changes).

Identifying pathways toward sustainable change cannot be viewed through a dichotomous conventional-sustainable lens but rather contextualized within social, political, economic, and ecological drivers. As the NRC states, "The committee's definition of sustainable farming does not accept a sharp dichotomy between conventional and sustainable farming systems, not only because farming enterprises reflect many combinations of farming practices, organization forms, and management strategies, but also because all types of systems can potentially contribute to achieving various sustainability goals and objectives" (2010, p. 37). Although poorly defined across disciplines, agroecology has long presented viable alternatives to industrial agricultural practices (Francis et al., 2003). Rather than focusing on certain agroecological on-farm practices, we ground this paper in the broad definition from Brym and Reeve (2016, p. 214): agroecology is a "field of study motivated to understand ecological, evolutionary, and socioeconomic principles and use them in an improvement process that sustains food production, conserves resources, and maintains social equality." This definition aligns with calls from the NRC to move toward greater sustainability through several pathways of change, either incremental or transformative. Incremental change can gradually increase and support the adoption of current conservation practices to make them more widespread within conventional systems, as well as also support research for the economic viability of such practices. Transformative change would support broader, systemic shifts from conventional and agroecological approaches through establishing new markets and supporting ecologically based management (e.g., organic, mixed systems) (NRC, 2010).

We build upon prior research that has attempted to assess and interpret changes in U.S. agricultural systems over time. Several studies have focused on land use change within specific regions of the U.S., such as agricultural land cover loss due to competing development demands in the Eastern U.S. (Drummond and Loveland, 2010; Sayler et al., 2016) or cropland concentration due to high soil quality in the South (Hart, 1978). A large number of studies have shown how the Corn Belt has intensified agricultural land toward specialized commodity production over time due to favorable climatic conditions, high quality land, and political incentives (Hart, 1986, 1991, 2001, 2004; Hudson, 1994; Drummond et al., 2012; Auch and Karstensen, 2015; Laingen, 2017). Other studies discuss trends of fluctuating conversion from grassland and marginal cropland to intensive commodity and biofuel production in the Great Plains, driven by enrollment in federal conservation programs, technological advances, improved management practices, and increased precipitation (Drummond et al., 2012; Wright and Wimberly, 2013; Reitsma et al., 2015; Taylor et al., 2015; Auch et al., 2018). However, these studies are limited in geographic scope and do not contextualize such trends in the national aggregate. Research with a broad U.S. focus are either outdated (Hudson, 1994; Hart, 2001; Cozen, 2010) or fail to discuss political drivers and environmental implications within an agroecological framework (Sleeter et al., 2013; Sohl et al., 2016; Auch et al., 2018; Hudson and Laingen, 2018). Other recent research has attempted to project recent land cover datasets farther back in time to assess historical land use trends (e.g., Arora and Wolter, 2018) but do not extend past the 1980s and emphasize the need to understand current land use trends through historical processes. Given the trajectory of U.S. federal agricultural policy, land use changes prior to the 1970s and 1980s are important in understanding how current trends were established and are reinforced. Data-driven research can help identify trends within and across agricultural systems to better inform the prioritization of sustainability objectives.

This paper serves as a high-level overview of how agricultural land use and policy drivers have changed at a national level over the past half century. Rather than attempting to evaluate the current state of sustainability of the U.S. agricultural system, this data-driven narrative serves two main objectives: (1) to clarify the magnitude and extent of large-scale agricultural landscape transformations, as well as the changes in policy structure, and (2) provide a framework to interpret and assess sustainable pathways for future agricultural change at the national scale. After discussing the methods, we present data trends and figures and contextualize these findings in the discussion section. We conclude with recommendations of national-level factors to consider within transitions toward more sustainable agriculture systems.

2. Methods

We utilized open-source datasets and open-source programming software to visualize policy, land use, and agricultural production changes. The majority of these data are focused on the county scale, as it is the finest resolution at which farm-level data is aggregated in the U.S. Using county-level data enabled us to understand, visualize, and interpret the spatial and temporal complexities of national agricultural trends. Through such visualizations, we illustrated trends in cropland transitions, crop composition, and the policy structure of the Farm Bills.

2.1 Datasets

Various multiscale datasets were synthesized and merged into a panel dataset (Table 2-1). Crop acreage, farm size, and chemical inputs were obtained through the National Agricultural Statistics Service (NASS) (USDA NASS, 2019c), whereby the county-year scale is the highest resolution available. The NASS database presents data both from the U.S. Census of Agriculture and a variety of national agricultural surveys administered by the USDA. USDA surveys are administered at the county and state scale annually with foci such as crop/stocks to measure crop acreage and yield, farm labor, crop prices and markets, and more specific topics, such as milk or broiler production. For some surveys, data are available from the mid-1800s to present day. The NASS QuickStats interface provides all of this survey information but does not indicate which survey the data are from or clearly define the cutoff of *who* counts in the surveys; additionally, the sampling strategy is determined by each state. Openly available from 1997 onward, the Census is conducted every 5 years and is administered to all farms and ranches (in rural or urban settings) producing and potentially selling at least $1,000 of their products. The Census is the only source of detailed county-level agricultural data that is collected, tabulated, and published using a uniform set of definitions and methodology. Thus, the Census is considered the most complete count and measurement of U.S. farms, operators, and ranches in the U.S. Though the combination of these data is limited in its generalizability given its inconsistency of data collection measures, it provides the most comprehensive, open-source record of historical U.S. agricultural data.

Table 2-1: Datasets used to visualize crop composition, acreage, productivity, and policy changes

Variable	Spatial resolution	Temporal resolution	Duration	Source
Crop acreage	County/National	Annual	1920-2019	USDA NASS Survey
Major land use	State	Every 5 years	1945-2012	ERS MLU
Average farm size	County	Every 5 years	1997-2017	USDA Census of Agriculture
Agricultural inputs	County	Every 5 years	1997-2017	USDA Census of Agriculture
Agricultural land cover	County	Every 10 years	1974-2012	NWALT
Farm Bill	National	Every 5 years	1933-2018	National Ag. Law Center

There are few land cover datasets that cover the entire U.S. and also extend decades back in time. Given its moderate spatial and temporal resolution, we utilized the National Wall-to-Wall Anthropogenic Land Use Trends (NWALT) dataset created by the U.S. Geological Survey (USGS) (Falcone, 2015). It uses the 2011 National Land Cover Database (NLCD) (Homer et al., 2015) as a base grid and other USGS and USDA historical imagery and datasets to map land use farther back in time with similar accuracy. NWALT classifications agreed with NLCD land use classifications from 2001-2011 with at least 94% accuracy and agreed with over 99.5% of county-level cropland changes from the USDA Census of Agriculture (Falcone, 2015). This dataset contains five 60-meter (m) resolution raster datasets from the years 1974, 1982, 1992, 2002, and 2012 of land use across the coterminous U.S, extending farther back in time than most other land cover datasets. However, some of the underlying data may span several years rather than an exact snapshot in time (Falcone, 2015); therefore, NWALT can be used for assessing broad temporal trends. We computed agricultural land as a percentage of overall county land to match the spatial resolution of NASS data. Agricultural land pixels are differentiated in this dataset by cultivated crop production and pasture/hay production based on 2011 NLCD classifications. Agricultural infrastructure, such as farm roads, are not included in these classifications.

The USDA's Economic Research Service (ERS) Major Land Uses (MLU) series has been collected every 5 years beginning in 1945, coinciding with the Census of Agriculture. As such, the ERS MLU is the longest running, most comprehensive accounting of all major land uses in the U.S. The dataset provides acreage across six land use categories (cropland, grassland pasture and range, forest-use land, special-use areas, urban areas, and miscellaneous other land) at both regional (Pacific, Mountain, Southern Plains, etc.) and state scales, compiled by reconciling several data sources. Thus, despite the ERS's use of standardized procedures to measure land use (Barnard and Hexem, 1988), there is a degree of uncertainty introduced by making comparisons through time. For this dataset, cropland includes cropland used for crops (harvested, crop failure, and cultivated summer fallow), cropland used for pasture (considered to be in long term rotation), and cropland idled. Grassland, pasture and range includes grassland and other non-forested pasture and range in farms, as well as estimates for open and non-forested grazing lands not in farms. Special use areas include rural transportation, rural parks and wildlife, defense and industrial areas, and miscellaneous farmland (farmsteads, farm roads and lanes, and misc. farmland). Urban areas include densely populated urbanized areas of 2,500 to 50,000 people or more, and forested areas including forest cover of grazed (commercial use) and non-grazed forest. We utilized this dataset to track trends in cropland conversion in comparison to other ERS MLUs between 1945 and 2012 (Bigelow and Borchers, 2017).

Finally, the U.S. Farm Bill (FB) policy documents from 1933 to 2018 are openly available through the National Agricultural Law Center (2019). While not the *only* important agricultural policy in recent U.S. history, the FB has played a key role in how, where, why, and what type of food is produced at a national scale. Over time, it has grown in size to encompass nearly all aspects of food production. These policy documents have changed in structure, starting with a 25-page document in 1933 encompassing two main topics: (1) agricultural adjustment and (2) agricultural credit, and becoming a 529-page document in 2018, encompassing 12 specific "Titles" ranging from Commodities to Nutrition to Rural Development. Within these Titles are statutes and funding programs that largely define the broader policy structure within which agricultural land use decisions are made.

2.2 Data Exploration

Using exploratory mapping and data mining techniques in R (version 3.6.3) (R Core Team, 2020), we selected variables of interest and assessed their spatiotemporal consistency and availability. This included plotting variables over time at county, state, and national scales to determine data reliability and representativeness, noting when and how representation changed across scales We focused on county-level data whenever possible as the most interpretable scale of agricultural landscape change. Particularly for

NASS data, availability is variable by county, state, and year based on changing federal data collection, reporting procedures, and data privacy concerns; there are noted inconsistencies *across* USDA datasets as well (Hart, 2001; Arora and Wolter, 2018). Nonetheless, land use science and spatial modeling communities have acknowledged and accepted the need to use data at multiple scales given a lack of other alternatives (Rindfuss et al., 2004; Auch et al., 2018). Ultimately, we focused on six main variables of interest: (1) acres planted (by crop, per county and nationally), (2) percent planted (by crop, per county), (3) average acres per farm operation (per county), (4) percent crop and pastureland (per county), (5) cropland acreage (as a proportion of national acreage), and (6) agricultural input use (per county).

Given the changing structure and purpose of federal FB policies, we conducted a broad content analysis of the FB documents as a systematic way of capturing the frequency and content of textual data of the FBs from 1933 to 2018 (Krippendorf, 2004). With the qualitative coding software ATLAS.ti, we utilized a predetermined coding scheme to identify two major themes in each FB: (1) the number of distinct crops and (2) the stated purpose. These codes aimed to operationalize the scope and purpose of the FB as it relates to commodity production. Coding was limited to Titles, programs, and definitions that directly defined commodity crops, stipulated support and subsidies for their production, and promoted commodity markets; these included commodity programs, trade, agricultural marketing, credit, and crop insurance but excluded nutrition, conservation, forestry, research, etc. While excluded Titles do play a role in commodity production and land use, we explicitly focused on those that drive and regulate the composition of crops produced. Further, commodity definitions in the FB are defined within the commodity programs, and other Titles, such as conservation, are based upon these prior definitions. We contextualized these results within academic and gray literature.

3. Results

The results of this data synthesis are organized by three main themes. The first theme is land use which includes cropland, farm size, and productivity by visualizing trends in location of agricultural land, regional farm size variation, and how these changes relate to increased productivity of U.S. agriculture. The second theme is crop composition, including the composition of crops and how their relative acreage varies across space and has changed through time. The third theme is policy, presenting data to contextualize the overarching FB policy structure, how it has changed, and how it affects the first and second themes.

Changes are referenced within the regional specifications of the USDA ERSs Farm Resource Regions (FRRs) (Figure 2-1). These regions portray the geographic distribution of and specialization within the production of U.S. farm commodities (ERS, 2000). FRRs aggregate areas with similar types of farms, commodities, soil, physiographic, and climate characteristics nationally to contrast with the state and county boundaries (that are often political rather than biophysical borders) used to visualize data trends. We utilized these regions to further understand and contextualize trends across themes.

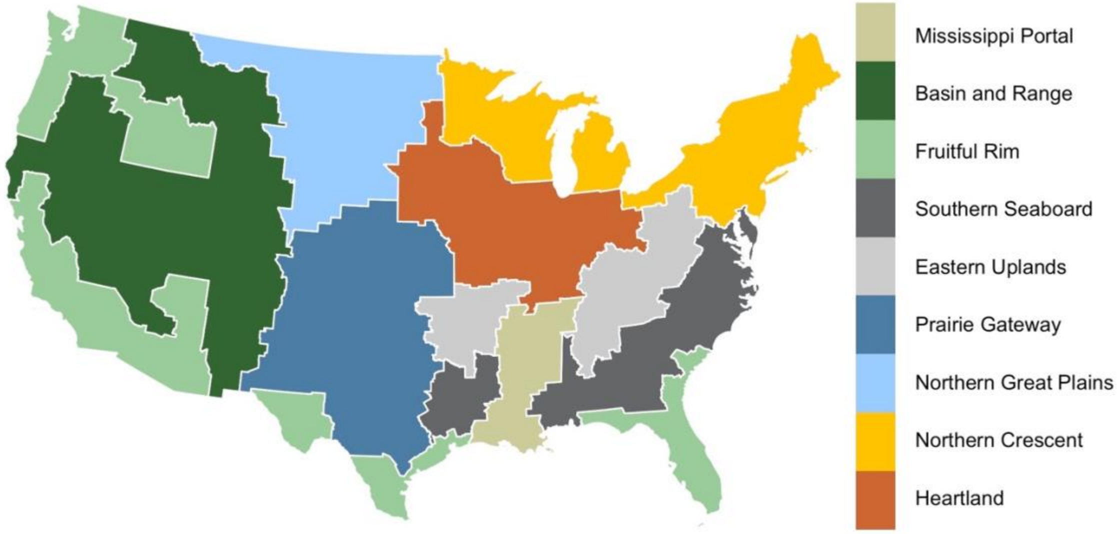


Figure 2-1: Farm Resource Regions (FRRs) across the U.S., determined by crop production type, amount, and value

3.1 Cropland, Farm Size, and Productivity

U.S. cropland has changed in both amount and type over recent decades. From 1945 to 2012, cropland as a proportion of total land use decreased; meanwhile urban and special use areas increased (Figure 2-2). As seen in Figure 2-2, there was a slight decrease from 23.7% of the national share of land use in 1945 to 20.7% in 2012 (3% decrease). Comparatively, urban areas increased from 0.8% of the national share in 1945 to 3.7% in 2012. Special-use areas increased from 4.5% in 1945 to 8.9% in 2012. Grassland, pasture and range decreased by 0.03%. Forest-use decreased from 31.6 to 28.5%. Miscellaneous land uses decreased from 4.9 to 3.6%. However, both the ERS MLU and NWALT data confirm that cropland as a percentage of national land has decreased by 3% just since the 1970s. Therefore, this decline primarily occurred within the past four decades.

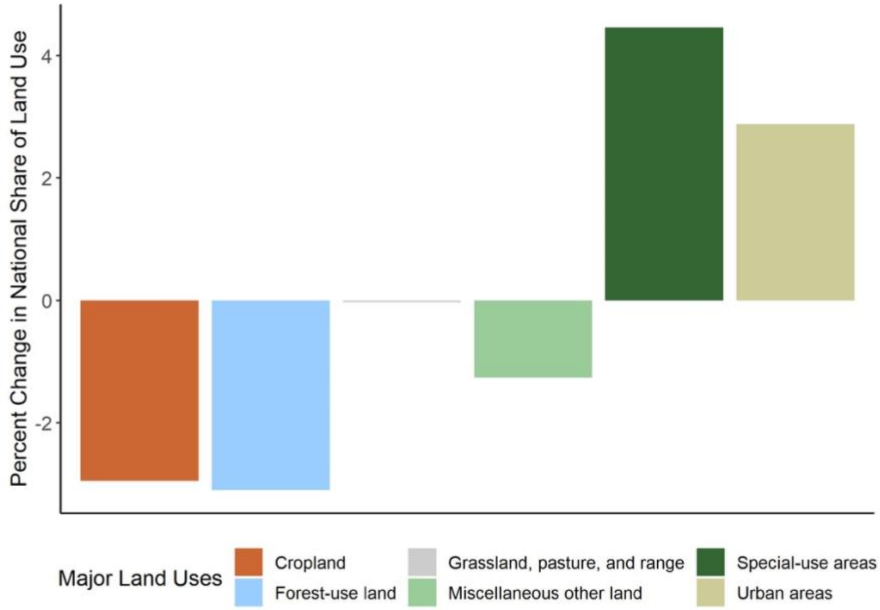


Figure 2-2: Percent change in the national share of land use across the ERS Major Land Use categories between 1945 and 2012. DATA: ERS MLU

Further, crops are grown in fairly concentrated regions, and there are no obvious changes in *location* of cropland. According to the NWALT data, counties where cropland is dominant have remained consistent over the past few decades without dramatic conversion of other land uses to cropland (see Appendix A, SI Figure 1); by “dominant,” we mean that cropland accounts for most of the land use in a county. Though dominance does not tell the full story of a commodity (i.e., it does not demonstrate which counties are the most *productive*), it is an important metric in understanding the composition of U.S. agricultural landscapes. As Figure 2-3 illustrates, some counties, e.g., in the Heartland region, are almost entirely covered by cropland (nearly 100%), while others, e.g., in the Basin and Range region, produce few, if any, crops. Figure 2-3 also illustrates where cropland is most prevalent by county. The Southern Seaboard and the Fruitful Rim of California and the Pacific Northwest demonstrate clear intra-regional agricultural clustering, whereby crop production is concentrated in a select few counties. The midwestern Heartland and Mississippi Portal regions are dominated by cropland compared to the rest of the country; these areas of cropland dominance align with spatial trends in harvested acres for corn, soy, and wheat (see Appendix A, SI Figures 2-4).

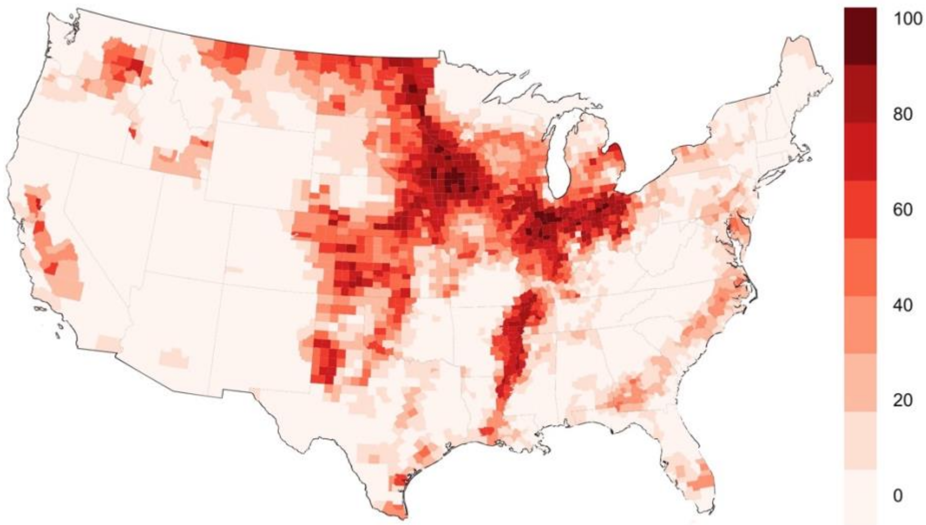


Figure 2-3: Percent cropland by county in 2012. Data: NWALT

Pasture and land in hay production also demonstrate patterns of clustering. The proportion of land devoted to hay and pasture in the U.S. has decreased by 13.8% from the 1970s to 2012 (according to NWALT data), which is a larger change than the decrease in cropland (−2%). Furthermore, according to the ERS MLU data, grassland pasture and range have only lost 0.08% of its share of total land use between 1945 and 2012. Areas within the Heartland, Eastern Uplands, and Prairie Gateway regions exhibit high proportions of pasture and hay (Figure 2-4), whereby some counties are 50 to 70% covered by such production. However, these areas of landscape dominance do not necessarily produce the highest yields or relative yields (yield/harvested acre) in the U.S. For instance, clusters of counties in the West Coast portion of the Fruitful Rim harvest more hay per acre than any county in the Heartland (see Appendix A, SI Figure 5).

Pasture-dominant areas do not appear to overlap with crop-dominant areas, indicating divergent specialization in intensive crop and pastureland.

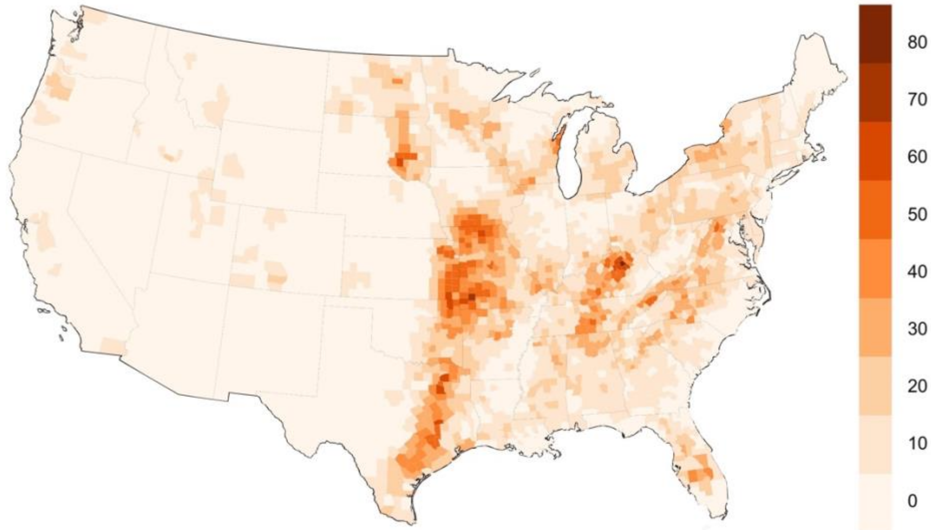


Figure 2-4: Percent pasture and hay land by county in 2012. Data: NWALT

Farm size has been changing alongside the concentration of national agricultural land. The total number of farms has declined over time. In 2018, the USDA estimated 2 million farms nationally, which is 12,800 farms less than the estimate for 2017 (USDA NASS, 2019b). In 2011, the estimate was nearly 2.13 million; over 8 years, there was a 4.7% decrease in the number of farms nationally (USDA NASS, 2019b). The peak number of farms in the U.S. was in 1935 at 6.8 million farms, but this number has steadily decreased since then (Hoppe, 2014). Meanwhile, highly productive industrial farms have expanded in size while midsize farms continue to decrease in number. For example, of all agricultural land in the U.S. in 2018, 40.8% is operated by large-scale farms that earn sales of $500,000 or more, but these large operations comprise merely 7.5% of all total *number* of farms; farms that earn less than $100,000 comprise 30.1% of all farmland but comprise 81.5% of all farms (USDA NASS, 2019b). Thus, significantly fewer large-scale family and commercial farms operate a greater proportion of cropland.

Given this shift, total average farm size has not changed much in recent decades. According to the Census of Agriculture, the national average farm size changed from 440 acres in 1982, to 491 acres in 1992, to 433 acres in 2012, and 443 in 2019 (USDA, 1982, 1992; USDA NASS, 2019b). Therefore, average farm size has remained relatively stable due to a disproportionately greater number of smaller farms and larger farms increasing in size (Hoppe, 2014; MacDonald and Hoppe, 2017).

Regional differences of farm size further affect these averages. As seen in Figure 2-5, the largest farms are found in the Northern Great Plains [median = 1,505 acres, mean = 2,135 acres, standard deviation (SD) = 1,528 acres] and Basin and Range Regions (median = 783 acres, mean = 1,369 acres, SD = 1,516 acres), while the smallest farms are found in the Eastern Uplands (median = 148 acres, mean = 165 acres, SD = 77 acres) and Northern Crescent Regions (median = 161 acres, mean = 168 acres, SD = 80 acres). However, most regions have several outlier counties that exhibit average county farm sizes significantly beyond the regional mean. In particular, counties in the Basin and Range (median = 783 acres, mean = 1,368 acres, SD = 1,515 acres), Fruitful Rim (median = 271 acres, mean = 1,145 acres, SD = 3,756 acres), and Prairie Gateway (median = 817 acres, mean = 1,143 acres, SD = 1,186 acres) exhibit a wide range of average farm sizes; some counties in these regions average well over 5,000 acres per operation. Since most pasture and hay production occurs within the Prairie Gateway (Figure 2-4), these data show that such production in certain counties comprises much larger farms than the rest of the region. Contrastingly, regions such as the Eastern

Uplands, Heartland, Northern Crescent, and Southern Seaboard exhibit outliers noticeably closer to the regional median. Given that the majority of cropland falls within the Heartland region (Figure 2-3), these data demonstrate that most of these farms are similar in size and are not the largest on average at a national scale (median = 319 acres, mean = 343 acres, SD = 155 acres).

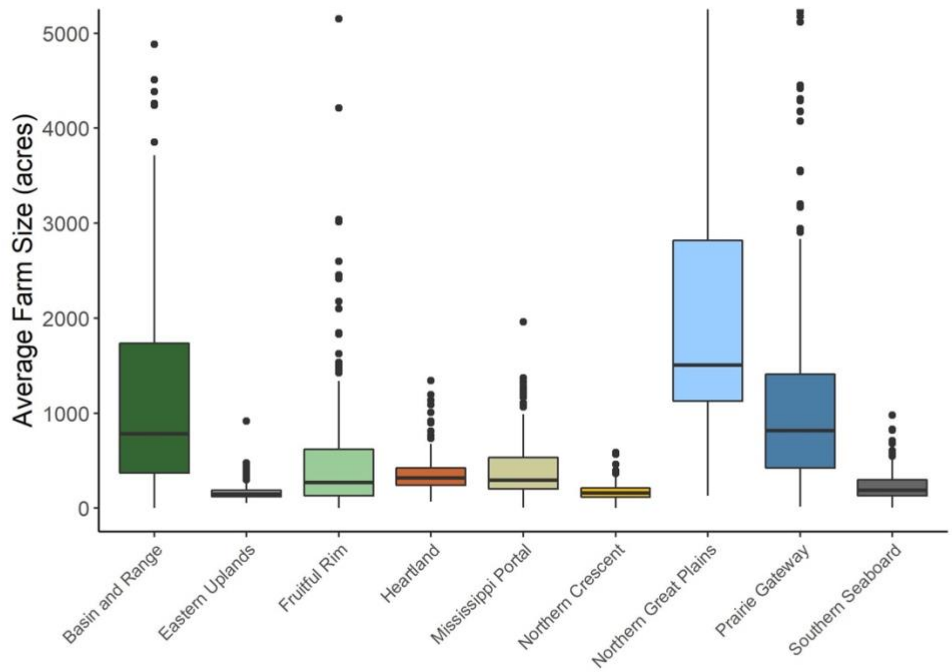


Figure 2-5: Average farm size (acres per operation) by FRR, 2012. Counties with an average farm size > 5,000 acres [n = 46, range = 5,119 to 37,952 acres] were removed from visualization for readability. Data: USDA NASS Survey

Further, Figure 2-6 illustrates the variability in average farm size by county. The largest farms (in acres/operation per county) are found primarily in the western U.S. with a clear distinction between eastern and western counties. This also indicates where the largest farms in the Basin and Range, Prairie Gateway, and Texas portion of the Fruitful Rim regions are located. Farms that average over 10,000 acres are exclusively found in these regions and are clustered together. Most of the average farm sizes in these regions exceed 1,000 acres, if not 5,000 acres. In the Heartland, however, most farms do not exceed an average of 400 acres per operation.

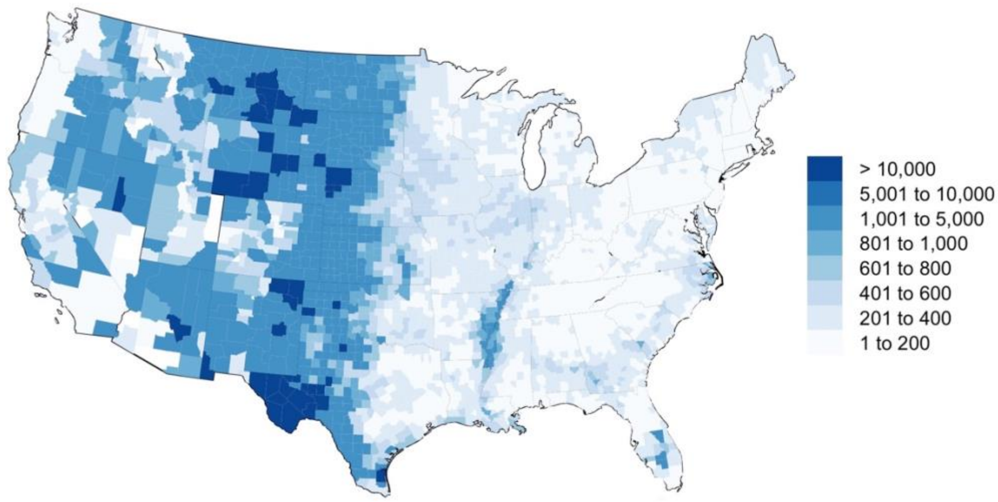


Figure 2-6: Average farm size (acres per operation) by county in 2012. Data: USDA NASS Census of Agriculture

When directly comparing farm size and dominance of agricultural land (including both cropland and hay/pasture production) by county, certain areas exhibit large farm sizes but are not dominated by agricultural production at the county scale. By binning both average farm size by county and percentage agricultural land by county into thirds and pairing each tercile into distinct categories, we visualize the spatial relationship between farm size and agricultural dominance (Figure 2-7). Counties largely in the Heartland, Mississippi Portal, and Northern Great Plains exhibit, on average, medium and large farms with the highest percentage of agricultural land (in teal). Much of the counties in the Basin and Range and Prairie Gateway exhibit large average farm sizes (in acres/operation) and a low percentage of agricultural land (yellow). Counties with relatively small average farm size but a large percentage of the county as agricultural land (dark purple) are scattered throughout the rest of the Heartland, while both low percentage agricultural land and a relatively small average farm size per county (light blue-green) are almost exclusively found in the Southern Seaboard, Northern Crescent, and northwestern Fruitful Rim. These trends reflect the different landscape composition patterns across the country. Greater availability of land in the western U.S. may allow for much larger farms on average for grazing and pasture, but the concentration of these farms is relatively low compared to densely concentrated crop-producing farms across the midwestern U.S.

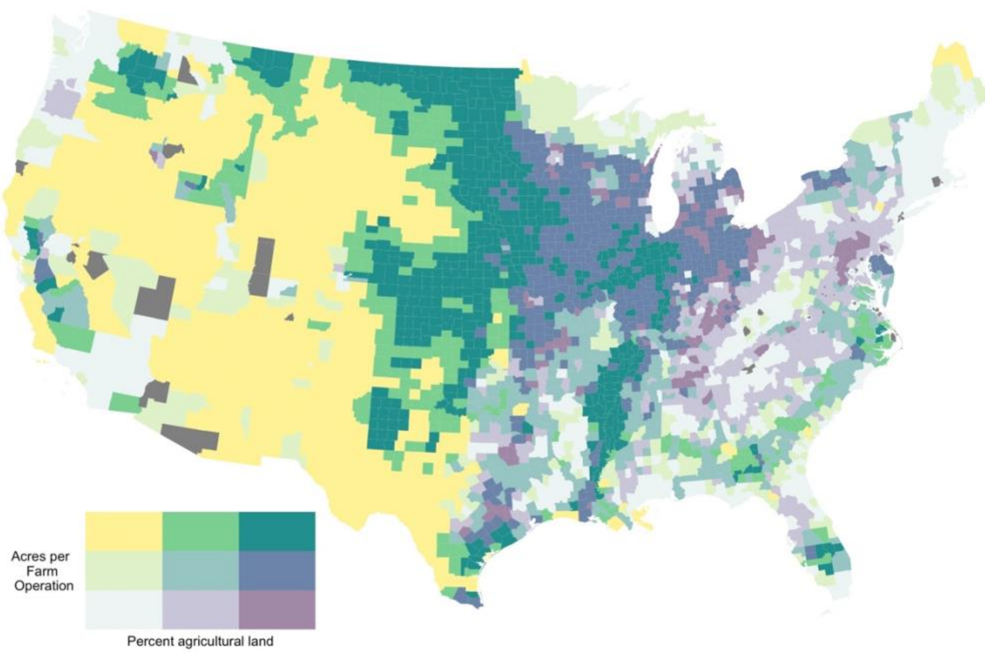


Figure 2-7: Bivariate choropleth constructed by binning county-level average farm size (by acre per operation per county) and percent agricultural land by county (both pasture and crop production) into thirds and pairing each tercile into distinct categories. Yellow indicates counties with large average farm sizes (in acres/operation) and a low percentage of agricultural land. Teal indicates counties with large average farm sizes and a high percentage of agricultural land. Purple indicates counties with a small average farm size but a large percentage of the county as agricultural land. Light blue is both low percentage agricultural land and a small average farm size per county. Dark gray counties indicate missing data. DATA: NWALT and USDA NASS Census of Agriculture

In conjunction with a decrease in national cropland and regional variations of farm size and type, U.S. agriculture has become more productive writ large since the 1970s. Total Factor Productivity (TFP) accounts for all of the land, labor, capital, and material resources employed in farm production and then compares them with the total amount of crop and livestock output. If, for instance, total output grows faster than total inputs, the total productivity of the factors of production (i.e., TFP) is increasing. TFP data is only publicly available at the state level from 1960 through 2004. Based on this data, since 1960, every state reflects an *increase* in TFP; no state or region has become less productive (ERS, 2019a). Farms in the Heartland and the Mississippi Portal have become over 100 to 150 percent more productive (see Appendix A, SI Figure 6). Meanwhile, the Pacific Northwest portion of the Fruitful Rim and Basin and Range reflect TFP gains between 150 and 200 percent. Other areas in the Basin and Range, particularly throughout Colorado, Kansas, Montana, and Texas, have seen lesser gains but are still ~50 to 75 percent more productive than 1960. Productivity gains in the Southern Seaboard and the Northern Crescent reflect around a 100 to 125 percent increase on average. These increases are regionally concentrated to reflect the intensification of agricultural production in certain areas, particularly through increases in external inputs (Figure 2-8).

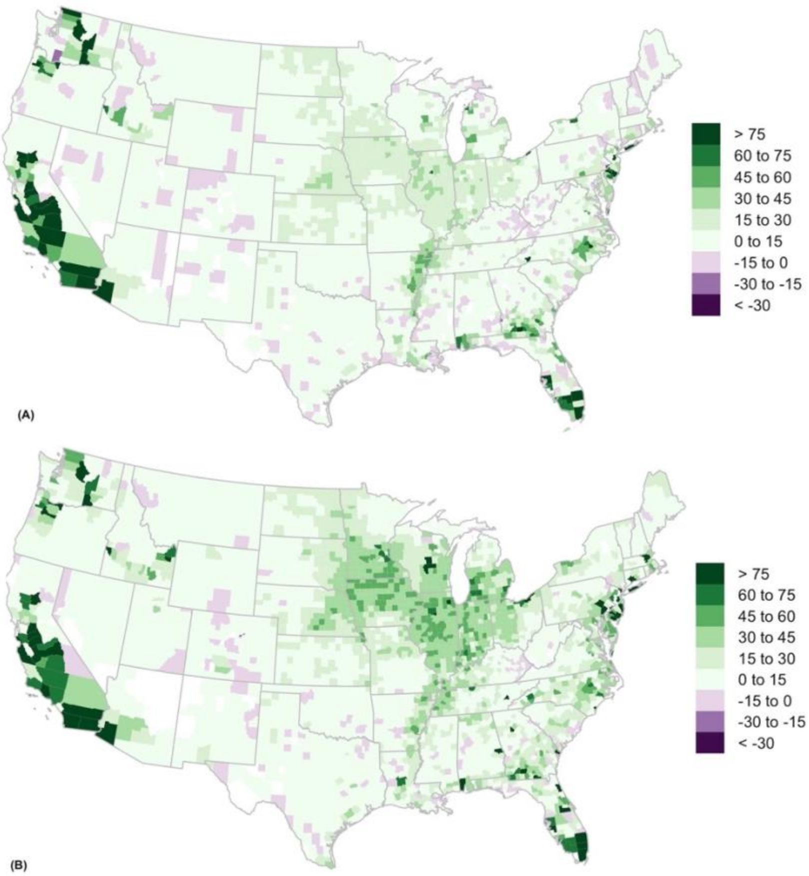


Figure 2-8: Change (in USD) in inputs per operated acre by county between 1997 and 2017 by county 8A) Change (in USD) in chemical expense per operated acre; 8B) Change (in USD) in fertilizer expense per operated acre. 1997 USD values are adjusted for inflation using average consumer price indices (CPI) from January-December 1997 (avg. CPI ~ 160.52) and January-December 2017 (avg. CPI ~ 245.12). DATA: USDA NASS Census of Agriculture

Those same U.S. regions that have realized huge gains in TFP have, at the same time, become more reliant on off-farm inputs like synthetic fertilizers and chemicals. Certain counties in the West Coast portion of the Fruitful Rim and along the Southern Seaboard have increased expenditures on chemicals by, on average, \$30 to over \$75 per acre (Figure 2-8A) and on fertilizers by similar amounts (Figure 2-8B). Areas within the Heartland and Mississippi Portal have largely increased their chemical expenses by \$0 to \$30 per acre (Figure 2-8A) but have increased fertilizer expenses between an average of \$15 to \$45 per acre (Figure 2-8B). These large expenditure changes over the past two decades stand in contrast to places along the Southern Seaboard, within the Basin and Range, and the Prairie Gateway that have maintained spending, only shifting (increased or decreased) by $15 per acre. Again, these regional differences highlight the resource-intensive crop production practices of select U.S. agricultural regions. Overall, the majority (~80%) of counties show increasing use of, and expenditure on, synthetic inputs since 1997; few places (only within certain counties in the west and in the Eastern Uplands) have decreased spending per acre. However, since TFP has increased alongside external input use, this suggests that crop yield is rising faster than input use.

3.2 Crop Composition

Crop composition has seen drastic changes at a national level as agricultural production has become more productive and input intensive. Since 1963, harvested soybean and corn acreage (although complementary for crop rotation) has increased by 76 percent (74 million acres), while acreage for other feed crops such as oats, barley, sorghum, and hay have declined by a combined 50 million acres (Bigelow and Borchers, 2017). Wheat, once the dominant crop in the U.S., comprises the third largest acreage planted of U.S. crops at 46 million (Ash et al., 2018).

Since the 1970s (and preceding that), the composition of crop acreage (total acres planted per crop) across the U.S. has become increasingly specialized. Demonstrated in Figure 2-9, by 2019, total crop acreage of major crops is nearly dominated by corn, soy, and wheat (winter, spring, and durum). In 1925, corn and wheat comprise a majority of the acreage planted with cotton and oats following closely behind; however, the difference in acreage planted for these crops is comparatively small. From the mid-1920s to the 1970s, acreage for cotton, oats, barley, and peanuts gradually decreases; meanwhile, acreage for soybeans rapidly increases, and wheat and corn acreage remain consistently dominant. From the 1970s through 2019, acres planted for corn, soy, and wheat (particularly soy) increase at the same time other major commodities decrease. Steady declines of the planted acreage of sorghum, cotton, barley, and oats become evident as corn and wheat remain consistent, and soy continues to expand. Meanwhile, acreage of peanuts, canola, and rice remain negligible in a national context (see Appendix A, SI Figure 7 for separated crop trends). Therefore, the 1970s era onward was characterized by observable specialization toward certain crops. As of 2019, these crops (corn, soy, and wheat) comprise a total of 210,958,000 planted acres; corn and soy alone cover nearly 166 million. According to the 2017 Census estimates of total cropland in the U.S., corn, soy, and wheat cover 64.7% of harvested cropland acres; corn and soy alone cover 56.6% (USDA NASS, 2019a).

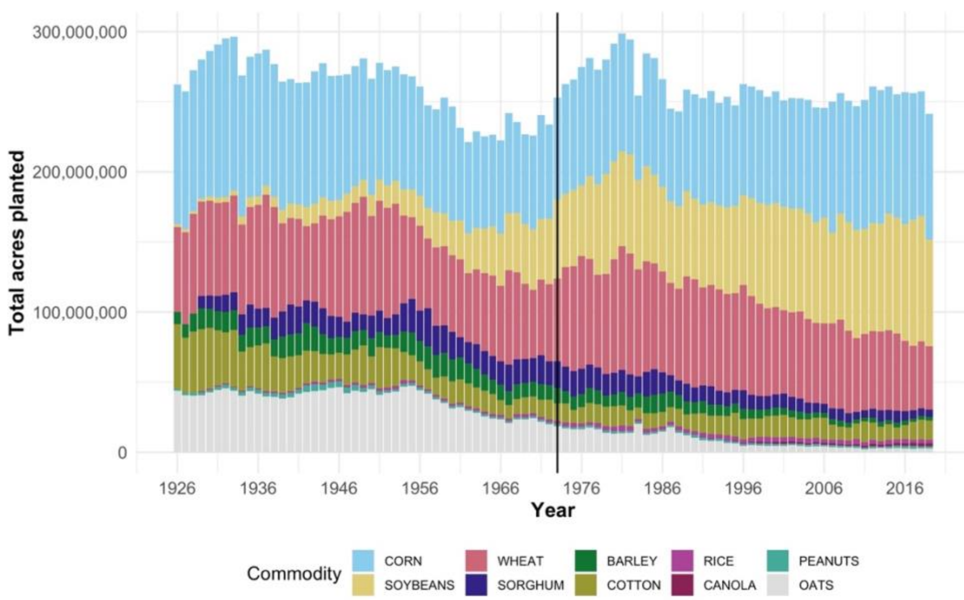


Figure 2-9: Total acres planted of 10 major U.S. crops between 1920 and 2019. Top 10 crops determined by acres planted in 2019. A vertical line at 1973 indicates the passing of the 1973 Farm Bill and marked transition toward crop specialization. DATA: USDA NASS Survey

Although the national trend in planted crop acres is dominated by corn, soybeans, and wheat, regional variability of agricultural land use diversity exists. The Shannon's Diversity Index (SDI) is a measure of evenness and abundance of different land use types as a way of measuring ecological diversity in a given area (Gustafson, 1998; Aguilar et al., 2015). Figure 2-10 illustrates the SDI per 20 km based on agricultural land use categories as defined by the USDA Cropland Data Layer (CDL) database (only available from 2008 to 2018 thus limiting its historical depth to interpret land use trends over time; Arora and Wolter, 2018) and computed by Burchfield et al. (2019). This index provides a measure of crop diversity for 20-kilometer (km) pixels within a given year. Areas of low diversity (light green) are concentrated in the Heartland and Basin and Range regions. Counties of high diversity (dark blue) are concentrated along the Southern Seaboard, Fruitful Rim of California and the Pacific Northwest, and the Northern Great Plans. Thus, certain agriculturally dominant regions, such as the Heartland, are highly specialized and non-diverse, while others, such as the Fruitful Rim of California, are highly diverse. Such variation in agricultural land use diversity emphasizes the different production systems and agroecological contexts in which crops are grown nationally.

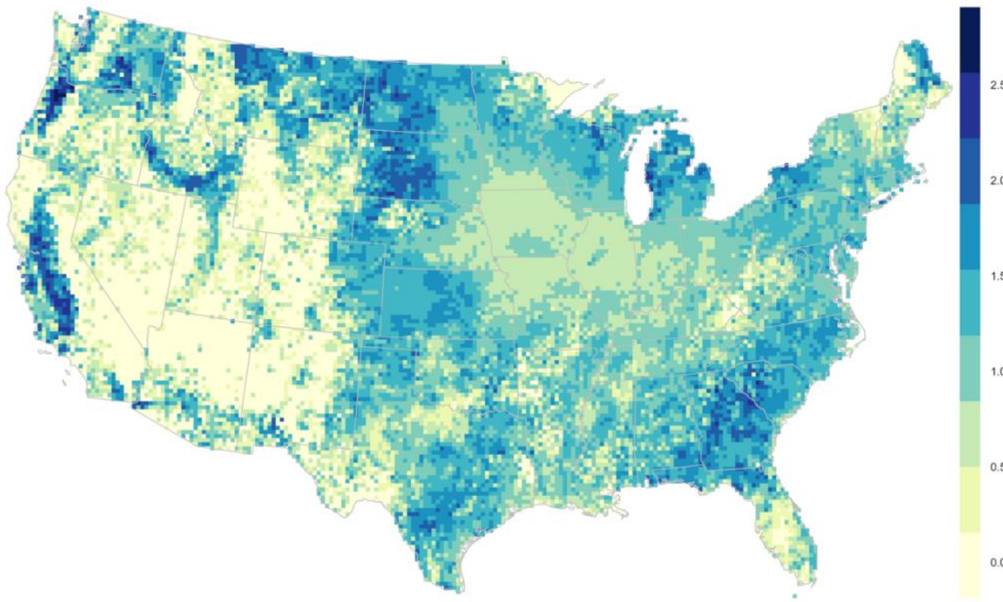


Figure 2-10: Shannon's Diversity Index (SDI) of agricultural land use categories for each 20-km pixel in the U.S. in 2017. Light green indicates counties with a low SDI and dark blue indicates counties with a high SDI. Source: (Burchfield, Nelson, and Spangler 2019)

These trends in crop diversity contextualize where the majority of crops that dominate U.S. crop production (as demonstrated from Figure 2-9) are concentrated. Figure 2-11 illustrates percent of a county cultivated for the two major crops: corn and soybeans. By visualizing the percent of each county cultivated by these crops in the U.S., regional dominance of this commodity production is evident. Dominant counties of 40% or higher of cultivated land for each crop largely fall within the midwestern Heartland region. Further, this region has a comparatively lower SDI value (Figure 2-10) than most other productive regions. Yet, areas along the Mississippi Portal and the Prairie Gateway demonstrate dominance of soybean cultivation *and* a comparatively high SDI value. The location of these dominant landscapes further illustrates how and where crop specialization has occurred and continues to occur.

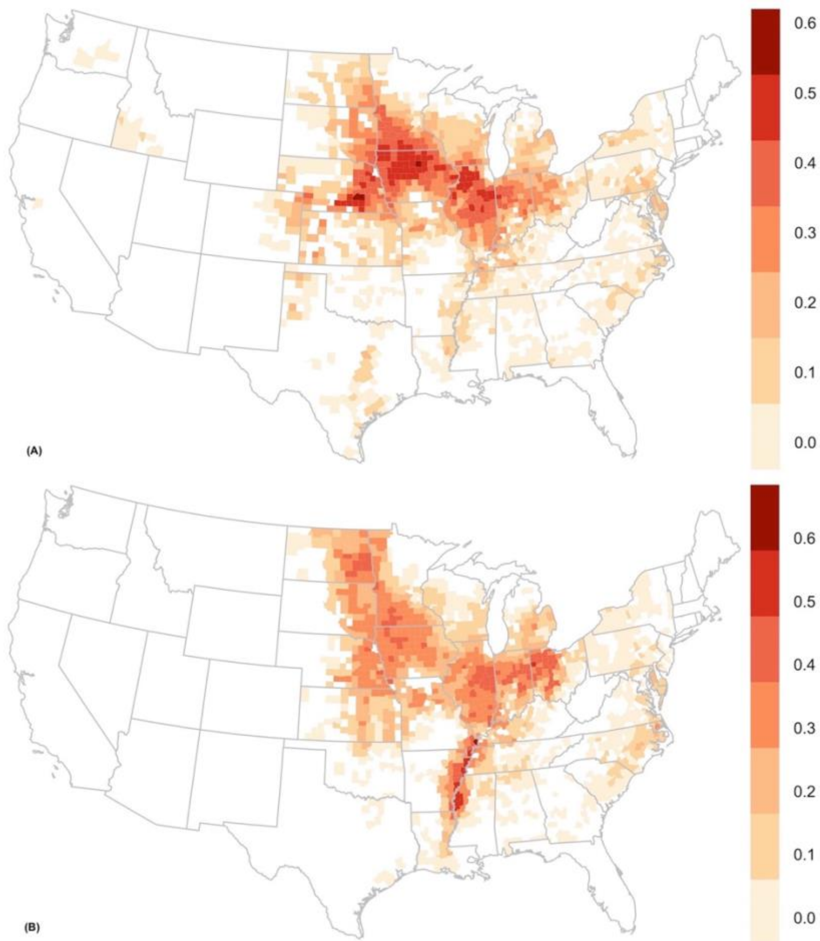


Figure 2-11: 11A) Percent of total county land cultivated with corn in 2017; 11B) Percent of total county land cultivated with soybeans in 2017. DATA: USDA NASS Survey

3.3 Policy Structure

Agricultural land use changes in the U.S. take place within a policy structure that operates at multiple levels, from local zoning laws to national-level subsidy programs. The U.S. Farm Bill (FB) has become what is referred to as an *omnibus* (or all-encompassing) piece of legislation that largely influences how, where, and why food is produced and distributed; these policies cover an increasingly broad suite of programs and purposes. For example, the 1933 FB, titled the Agricultural Adjustment Act of 1933, aimed specifically to provide relief for farmers in debt and increase agricultural revenue. Its stated purpose is as follows:

> "To relieve the existing national economic emergency by increasing agricultural purchasing power, to raise revenue for extraordinary expenses incurred by reason of such emergency, to provide emergency relief with respect to agricultural indebtedness, to provide for the orderly liquidation of joint-stock land banks, and for other purposes." (Agricultural Adjustment Act, 1933)

Thus, it was a reactionary policy to an ongoing economic crisis. The most recent version of the FB passed in 2018, states its purpose as the following:

> "To provide for the reform and continuation of agricultural and other programs of the Department of Agriculture through fiscal year 2023, and for other purposes." (Agricultural Improvement Act, 2018)

This most recent FB reflects a broader purpose than 1933, maintaining and updating the status quo of the U.S. agricultural system. The goal for "reform and continuation of agricultural programs" emphasizes the growing importance of these programs that regulate how the U.S. agri-food system operates. FB programs currently cover a wide variety of "Titles" or topics in the 2018 policy document; these Titles include: (1) Commodities, (2) Conservation, (3) Trade, (4) Nutrition, (5) Credit, (6) Rural Development, (7) Research, Extension, and related matters, (8) Forestry, (9) Energy, (10) Horticulture, (11) Crop Insurance, and (12) Miscellaneous. This 2018 FB proposed a budget for $428 billion for its 5-year life span, of which 76% is dedicated to Nutrition programs such as the Supplemental Nutrition Assistance Program (SNAP), and a mere

9% is dedicated to crop insurance, 7% for commodities, and 7% for conservation (McMinimy et al., 2019). The importance and composition of these Titles has substantially changed over time, ultimately defining and reinforcing the political structure of agricultural production in the U.S (for a more complete list, see McFadden and Hoppe, 2017, Appendix A).

FB programs have historically aimed to improve agricultural productivity and markets by controlling the supply of commodities. The Emergency Feed Grains Act of 1961 replaced market-oriented policies with direct federal government regulation; this put the federal government in greater control over the driving forces of the production (McGranahan et al., 2013). Following that, the well-known era of “fencerow to fencerow” production of the 1970s was defined by increased supply of agricultural commodities that captured economies of scale to combat high production costs. The “Russian Grain Robbery” of the mid-1970s—in which the Soviet government purchased over one fourth of U.S. wheat harvests to increase their own livestock production—challenged domestic demand for commodities, tripled wheat prices, and doubled corn and soy prices. This market spike led to the export of 80% of wheat in the U.S. to the Soviet Union (Luttrell, 1973). The then Secretary of Agriculture, Earl Butz, supported this international trade market as a way of boosting exports to foreign markets. Therefore, to combat the rise in commodity prices for the U.S., he encouraged farmers to increase their production, aiming to create immediate surpluses of commodity crops, particularly corn and soybeans (McGranahan et al., 2013). Although overall cropland cultivated did not immediately increase during this era, corn, soy, and wheat production noticeably expanded while production of other crops (e.g., sorghum, barley, oats) declined (see Figure 9 above, whereby a vertical line at the year 1973 marks this transition). The Agricultural and Food Act of 1981 extended these federal support policies from the 1970s, leading to the 1980s Farm Crisis: the federal government made billions of dollars of payments to farmers growing commodity crops to reduce production, re-adjust commodity prices, and help farmers address rising debt (McGranahan et al., 2013). These federal regulations created incentives for specialized agricultural land use over the past 50 years currently still in effect.

Agricultural land reserve programs have played a role in influencing how and where commodities are produced. From the late 1950s through 1990, the federal government paid farmers to take productive cropland out of production as a means of supply control; this land had to be converted to grassland, trees, or other non-crop purposes (Olson, 2001). The Agricultural Act of 1956 established the Soil Bank Program to set aside 12 million hectares of land from commodity production to be used for wildlife habitat; however, the land enrolled in this early conservation reserve program was already low in productivity. Thus, this type of land reserve program helped regulate the amount of highly productive land used for commodity production by reducing the less productive land competing on the market with more productive land (McGranahan et al., 2013). Meanwhile, in conjunction with technological advances made during the Green Revolution of the 1950s and '60s, productivity of major crops increased on this high-quality land. In 1985, the Conservation Reserve Program (CRP) was established under the Food Security Act of 1985 with aims to reduce soil erosion on highly erodible cropland and reduce off-farm sedimentation, as well as *decrease* commodity surpluses and increase farm income. Further, the "swamp buster" provision was added for environmental protection by disincentivizing farmers from producing agricultural commodities on wetlands after 1985, as this conversion made them ineligible for federal support (Daniels, 1988). While the 1956 Soil Bank Act did not limit the amount of land that could be taken out of production, the 1985 CRP provision limited this amount of land to no more than 25% of a county's total cropland base; this helped minimize large-scale economic impacts on commodity prices and agri-businesses. However, ongoing commodity price support programs have continued to compete with CRP enrollment. Thus, while CRP enrollment has continued since 1985, it has not effectively targeted the most sensitive and erodible land or out-competed other financial incentives for farmers to produce subsidized commodity surpluses (Isik and Yang, 2004; Johnson et al., 2016).

In addition to incentivizing commodity production, FB programs have limited diversification on agricultural lands that are supported by federal subsidies. In the 1985 FB, acreage designated to commodity production was limited by the Acreage Limitation Program (ALP) and Paid Land Diversion Program (PLD); to receive subsidy payments, certain commodities could only be planted on a set amount of acreage. As of the 1996 FB, “production flexibility contracts” (a.k.a. “Freedom to Farm”) replaced ALP and PLD to allow farmers to plant different crops other than previously stipulated commodities to increase planting flexibility while still receiving federal support (Willis and O'Brien, 2002). Producers could plant 100% of their contract acreage to a different crop, including grazing or hay production. However, this flexibility was limited; fruit and vegetable production (other than lentils, mung beans, or dry peas) was prohibited, unless a history of double-cropping fruits or vegetables had been established (ERS, 1996). As of 2002, this planting flexibility was replaced with direct payments to farmers for specific crop types and payment rates, regardless of farmer need (Willis and O'Brien, 2002). By 2014, direct payment subsidies were cut from the FB, replaced by several risk management programs (discussed below), but these recent changes do not undo historical incentives for land use specialization.

Further, commodity support programs are only accessible to certain farmers and favor certain types of production. Historically and at present, these programs are only eligible for established base acres. Base acres are defined as farm-level acreage for certain commodities based on the historical average acreage of that commodity; these are the acres eligible for commodity program payments. Therefore, program payments are determined by what *has been* grown on these base acres rather than what is currently being grown. Base acres were established in the 2002 Farm Bill and reflect planted acreage from 1998 to 2001 until the recent opportunity from the 2014 Farm Bill to re-allocate acres based on 2009 to 2012 planting (Farm Bureau, 2016). However, this reallocation did not allow *new* base acres to be designated—only the *adjustment* of designated acres to different commodities. Since base acres are linked to the farm itself, not the farmer, this omits land recently converted to commodity production to be supported by FB commodity payments (Farm Bureau, 2016). This further incentivizes keeping land previously managed for intensive commodity production in the same type of production.

Thus, farmers with certain acreage could receive payments for wheat production but not currently produce wheat; contrastingly, acreage under current wheat cultivation *without* base acreage designation could not receive program support. In fact, differences in base acres and *actual* average acreage planted for covered commodities are largely observed across the U.S., maligning the risk mitigation potential of Commodity Title programs with risk experienced by farmers (Newton, 2017). These base acreage designations have not been updated in the 2018 FB, but base acres out of commodity production in the past 10 years are now ineligible for program payments; instead, these base acres can be enrolled in conservation programs, such as the Conservation Stewardship Program (Newton, 2017).

Current Titles established under the 2018 FB reflect past influences of federal agricultural policies and reinforce federal support and influence over the U.S. food system. Although all Titles may influence farmer decision-making and agricultural land use in some way, the Commodity, Credit, Trade, and Crop Insurance Titles (designated as “commodity-focused” Titles hereafter) cover many of the programs that serve to directly mitigate risk through insurance, provide financial assistance and disaster relief through loans and subsidies, and influence market demand through international trade regulations. These Titles are major drivers of the types of commodities produced, as well as where, why, and how this production occurs in present day.

Of these commodity-focused titles, the Commodity Title is the arguably the most influential Title for regulating commodity production and influencing farmer decisions. Commodity programs effectively provide support for market fluctuations and risk associated with commodity production, comprising the majority of influence over agricultural land use. Two main programs under this title include the Price Loss Coverage (PLC) program and the Agricultural Risk Coverage (ARC) program and are administered through the Farm Service Agency (FSA). The PLC, based on a certain crop-year price, pays farmers with historical base acres eligible for covered commodities when the market-based effective price falls below the effective reference price—a price determined by the 2014 FB that allows for market fluctuations (ERS, 2019b). ARC pays farmers with historical base acres when the actual yield (distinguished between irrigated and non-irrigated acres) and prices for their county's average per-acre crop year revenue falls below the guaranteed level for each covered commodity. Commodities covered by both of these programs are defined as wheat, oats, barley, corn, grain sorghum, rice, soybeans, sunflower seed, rapeseed, canola, safflower, flaxseed, mustard seed, crambe and sesame seed, dry peas, lentils, small chickpeas, large chickpeas, and peanuts. As of the 2018 FB, farmers can switch between PLC and ARC programs with greater flexibility. Other programs include the Non-insured Crop Disaster Assistance Program (NAP), Non-recourse Marketing Assistance Loan Program (MAL), and the Dairy Margin Coverage Program (DMC). NAP provides risk protection for crops not covered under the Federal Crop Insurance Program. MAL offers farmers short-term loans when market prices are at their lowest (during harvest time) to allow them to wait and sell their commodity when prices improve. Eligible commodities for MAL include wheat, corn, sorghum, barley, oats, upland and extra-long-staple cotton, long- and medium-grain rice, soybeans/other oilseeds, certain pulses, peanuts, sugar, honey, wool, and mohair. DMC offers coverage for dairy producers when the margin between the price of all milk and the average feed price is below a producer-determined threshold to help manage the fluctuations of the dairy market (ERS, 2019b). These programs largely aim to mitigate risk for farmers, as opposed to control supply of commodities.

Other commodity-focused Titles serve different yet complementary purposes. The Crop Insurance Title updates, modifies, and enacts the Federal Crop Insurance Program

(FCIP) whereby farmers can access subsidies to protect against yield, crop revenue, and whole-farm revenue (WFA) losses (Johnson and Monke, 2019). Yield and crop revenue insurance coverage is crop-specific, whereby WFA covers the expected income of an entire farm to support more diversified systems. These insurance products are administered through the Risk Management Agency (RMA) and coverage extends across row crops, livestock, dairy, organic production, other specialty crops, grazing land, etc. (ERS, 2019b). The Trade Title reinforces global markets for U.S. grown crops and largely influences international food prices for U.S. farmers (ERS, 2019b; Johnson and Monke, 2019). Finally, the Credit Title provides direct government loans to farmers and ranchers through the FSA to support beginning, socially disadvantaged, and veteran producers (ERS, 2019b; Johnson and Monke, 2019).

As the structure of each FB has changed over time, the number of crops and commodities included in commodity-focused Titles and programs has increased. Figure 2-12 illustrates the *distinct* number of crops and commodities in such Titles of each FB over time. This numeric measure helps illustrate both the broadening scope of the policy itself, as well as the diversity of crops included within FB programs that aim to support and regulate their production.

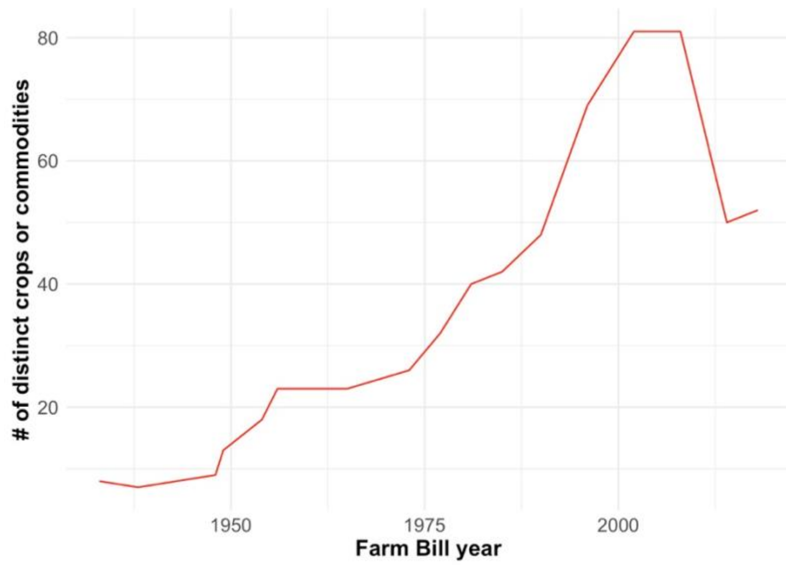


Figure 2-12: Number of distinct crops or commodities included in the Farm Bill Commodities, Trade, Credit, and Crop Insurance Titles (i.e., commodity-focused Titles). DATA: U.S. Farm Bills

The 1933 FB only mentions eight distinct crops and animal products (cotton, wheat, rice, corn, tobacco, hogs, milk, and fruit groves/orchards) in its entire 25 pages, demonstrating its limited and reactionary purpose. Contrastingly, the 2018 FB mentions 52 distinct crops across 529 pages—a product of a gradual expansion in scope and influence over time. The highest number of crops mentioned is 81 in both the 2002 and 2008 FBs. Crops classified as fruits or vegetables were not recognized or mentioned in the documents until the 1980s; crops for biofuel or organic production were not introduced until the late 1980s, as well. Further, while the number of crops and commodities within the FB increased from the 1970s onward, the composition of U.S. crop acreage became increasingly less diverse (as seen in Figure 9 above); these political and ecological changes occurred in tandem, suggesting that the increasing scope of the FB supported such specialization.

4. Discussion

We discuss the implications of these results in the context of recent literature and the concern for transitioning the U.S. agricultural system toward greater sustainability. The discussion is structured to mirror the results section and contextualize the above data trends. We conclude with recommendations within the broader framework of sustainable agricultural transitions and future research.

4.1 Cropland, Farm Size, and Productivity

In recent decades, U.S. agricultural production has reaped the benefits of industrialization and mechanization to support exponential increases in yield of major crops (Reganold et al., 2011; Aguilar et al., 2015; Pellegrini and Fernández, 2018). Although total land area devoted to agriculture is declining nationally (yet expanding globally, see Ramankutty et al., 2018), crop production is heavily concentrated in certain areas. Larger farms are consolidating, and competition for farmland among farmers is increasing (USDA NASS, 2019b). These large-scale farms are comprising more and more of U.S. cropland and are out-competing smaller operations (Paul et al., 2004; MacDonald and Hoppe, 2017); this consolidation is driven by historical patterns of land dispossession and predominantly White landownership (Dunbar-Ortiz, 2014; Ayazi and Elsheikh, 2015; Horst and Marion, 2019), as well as farmers expanding through part-ownership and operating rented land (Hart, 1991). At the same time, larger farms have brought economies of *scale* that boost productivity (Paul et al., 2004) and benefit from economies of size that make it profitable to expand farm size per unit of output (Duffy, 2009). Agglomeration of agricultural production around similar land uses, and crop types reflects the pressure for farms to consolidate input investments, share information, and overcome the scalar thresholds of market competition.

While biophysical differences and political incentives influence regional specialization of crop production (Hart, 1978, 1986, 2001), county-level dominance of cropland in areas such as the Heartland, Basin and Range, and Mississippi Portal signifies the simplification and intensification of agricultural landscapes. The Corn Belt, originating from a landscape of mixed farming and agricultural experimentation, has become highly specialized for surplus commodity production (Hart, 1986; Hudson, 1994). The location of farms and cropland in the Heartland has remained relatively stable over the past several decades, indicating that the highest quality and most productive agricultural lands have stayed in agriculture throughout the region (Hart, 1986, 1991; Drummond et al., 2012). Other regions across the western U.S. have seen fluctuations in amount and location of cropland due to greater climatic, economic, and technological variability, as well as changing FB policies (Hart, 2001; Drummond et al., 2012). National evidence of productivity growth, particularly in the Midwest, indicate that farm consolidation is a substantial factor in the exponential increase of aggregate total factor productivity, alongside technological innovation (Key, 2019).

Technological advances in seed genomics, fertilizers, chemicals, and mechanization have revolutionized agriculture in the U.S., but they have also introduced complicated ecological consequences. The introduction of herbicide-resistant (HR) genetically engineered crops in 1996 made the broad-spectrum application of glyphosate possible. Glyphosate-resistant HR crops have necessarily increased the application rates of herbicides and pesticides, introducing resistance in weed and insect populations;

meanwhile, populations of beneficial species are decreasing (Benbrook, 2012; Pimentel and Burgess, 2014). Innovations in low-cost synthetic fertilizers in the 1950s and ‘60s made integrated crop-livestock farming and nutrient recycling biologically obsolete (Davis et al., 2012). Farmer reliance on synthetic fertilizers has increased due to soil fertility declines, yet evidence suggests that synthetic nitrogen depletes soil organic matter, a key indicator of soil health (Mulvaney et al., 2009). Labor efficiency increased with mechanization, and synthetic fertilizers and chemical inputs became increasingly available; meanwhile, specialization of crop and livestock production became more economically viable and efficient. Agricultural research has enabled corn, soy, and wheat to be highly productive per acre harvested. In the 2017/18 season, corn and soy provided $232 and $287 net returns per acre, respectively, and wheat provided $98 per acre (Ash et al., 2018). Yields of these crops and commodities have seen exponential increases prior to and following the Green Revolution in certain areas (e.g., the Corn Belt) yet have begun to plateau in others (e.g., fringes of the Corn Belt) (Hart, 1986; Ray et al., 2012; Pellegrini and Fernández, 2018). These advances led to increasing economies of scale, captured in the growth of farm size, shifts in farm infrastructure toward specialization, and a rapid decline in the number of farms across the U.S. (Hart, 1986; Dimitri et al., 2005).

Trends in national cropland reflect a “land-sparing” approach—less land used more *intensively* for increasing productivity and specialization—compared to a “land-sharing” approach—more land used more *extensively* to manage greater diversity of land use (Phalan et al., 2014). These different approaches to land management have been hotly debated regarding conservation and long-term sustainability (Fischer et al., 2008, 2014).

As the U.S. trends toward greater specialization in agricultural production, this puts greater pressure on effective biodiversity conservation of non-agricultural land. Furthermore, this specialization holds implications for the sensitivity and resilience of agricultural production within an increasingly uncertain climate (Ortiz-Bobea et al., 2018) and increasing reliance on external mechanization (Rada and Fuglie, 2019). Such changes could increase farmer debt and put greater pressure on rural economies. These implications heighten concern over the long-term management of the ecological health of agricultural land within the context of increasing input use, machinery, and decreasing intra-crop and inter-crop species diversity within and across farms.

4.2 Crop Composition

In the U.S., the diversity of agricultural crops cultivated has decreased since the 1970s with wide regional differences. Regions that are most productive for dominant crops (i.e., corn and soybeans) maintain the least crop species diversity. Certain areas, such as Mississippi Portal Region, have maintained higher crop species diversity, whereby other areas, such as the Heartland region, have become largely optimized for a select few crops and commodities through decreasing diversity (Hart, 1986; Aguilar et al., 2015; Baines, 2015; Auch et al., 2018). Similarly, on a global scale, agricultural land has become dominated by a less diverse portfolio of crops (Martin et al., 2019).

Effects of declining crop species diversity raise concerns over the long-term health of agricultural ecosystems, as well as the stability of agricultural economies over time. Crop species diversity can be assessed at an on-farm and landscape level and holds different implications for land management. Increasing crop species diversity at a landscape level through compositional heterogeneity (i.e., the distinct number of crop types across a landscape) may have significant beneficial impacts on yield of major crops like corn and soy (Burchfield et al., 2019). Increasing configurational heterogeneity (i.e., the spatial arrangement of crop types and land uses) can boost pollinators and plant reproduction for small-scale farms (Hass et al., 2018). Further, increasing farm-scale diversity can improve the resilience and stability of agricultural production over time (Abson et al., 2013). Although some U.S. regions are much less diverse than others, maintaining crop diversity at local, national, and global scales is of great importance to achieve and maintain food security for the future (Massawe et al., 2016).

Managing on-farm and landscape-scale crop species diversity comes with a suite of considerations. Assuming that farmers aim to reduce risk in their operations, diverse cropping systems and practices have been positively linked to increased mean income and reduced income variance over time (Di Falco and Perrings, 2003). Crop diversity is known to enhance ecosystem services (ES) such as soil health, pest management, and water quality (Tscharntke et al., 2005, 2012; Hendrickx et al., 2007; Meehan et al., 2011; Bommarco et al., 2013; McDaniel et al., 2014; Landis, 2017), but these ecological benefits must also complement, if not enhance, other benefits for farmer livelihoods. Increasing crop diversity through practices such as crop rotation (over several seasons), intercropping (within one season), non-crop vegetation (such as filter strips or wildlife habitat), or integrated pest management pose challenges and barriers to their adoption; these include learning new management skills, balancing the potential risk on yield of major crops, or accessing appropriate machinery or technology to implement them effectively (Way and van Emden, 2000; Hooper et al., 2005; Pridham and Entz, 2008; NRC, 2010). Furthermore, these incentives and disincentives are filtered through federal agricultural policies that offer competing financial support. Biodiversity management on farms and across landscapes must be contextualized through such overlapping political, ecological, and social constraints.

4.3 Policy Structure

Federal agricultural policy has increased in scope since 1933 and maintains considerable influence. In fact, through this increase, the federal government is the primary source of supplemental income for farmers through subsidy payments (O'Connor, 2012). While the purpose of the FB has changed significantly since 1933, the incentive structure has not, prioritizing commodity production over both conservation practices (Lehner and Rosenberg, 2018) and agricultural diversification, even when the cost of production has exceeded farmer revenue (Hart, 1986). Even though the number of crops indicated in each commodity-focused FB Title has increased, the national crop portfolio has become increasingly less diverse. This misalignment between the diversity of crops regulated or supported by FB programs and the non-diversity of U.S. crop production highlights how policy ultimately promotes specialized commodity production. While environmental concerns arise over such land use trends, the implications of these federal policies are mixed.

Increasing federal control over and support of agricultural production has been debated in recent literature, particularly if and how it may promote or inhibit greater sustainability for both farmer livelihoods and ecological health. Evidence supports that U.S. agricultural subsidies are less accessible to smaller, organic, or diversified farming operations, fail to encourage conservation practices, promote commodity specialization (Bruckner, 2016), and systemically privilege White landowners over marginalized farmers and farmworkers (Dunbar-Ortiz, 2014; Ayazi and Elsheikh, 2015; Minkoff-Zern and Sloat, 2017). While subsidies and financial assistance may help mitigate risk associated with crop diversification for farmers, it has also been shown to *discourage* diversification and support specialized commodity production (Di Falco and Perrings, 2005). Since crop insurance helps mitigate the need for income variation, farmers may rely less on diversifying their farming systems to reduce this risk (O'Donoghue et al., 2009). Growing federal support for risk mitigation programs—such as ARC, PLC, and crop insurance programs—further decouples farmer decision-making from environmental risk. Although crop insurance enrollment does not lead to greater nutrient use through fertilizers and other chemicals (Weber et al., 2016), recent studies have shown that crop insurance increases irrigation withdrawals across the U.S. by motivating farmers to grow more water-intensive crops (Deryugina and Konar, 2017). Furthermore, farmers enrolled in crop insurance were found to experience greater yield sensitivity of corn and soy in extreme heat than those not insured; thus, crop insurance could provide a disincentive to take adaptive measures against climate-related impacts (Annan and Schlenker, 2015).

Despite these limitations, removing or decreasing federal agricultural assistance as an alternative is associated with several tradeoffs. In fact, this reduction may actually support farm consolidation. Large farms can more easily access crop insurance (due to access to greater capital) than small and medium size farms (Bruckner, 2016; Graddy-Lovelace and Diamond, 2017); this reinforces barriers for disadvantaged, small-scale, or aspiring farmers (Calo and De Master, 2016; Rosenberg and Stucki, 2017; Horst and

Marion, 2019). Examples of subsidy reduction outside of the U.S. exhibit mixed results. Subsidy removal in Canada has been associated with increased specialization of production (Bradshaw, 2004), while New Zealand has seen increased farm diversification and off-farm income for farmers (Vitalis, 2007). Some argue that focusing the political debate around agricultural subsidies distracts policymakers from intervening in agricultural markets in necessary yet beneficial ways (Graddy-Lovelace and Diamond, 2017). Therefore, increased agricultural subsidies do not presume to move *away* from agricultural sustainability, but rather the type and incentive of such policies should be questioned.

5. Conclusion

Overarchingly, the U.S. agricultural system has gradually transitioned toward a regulated and specialized system, recognized through consolidation of U.S. farms and the homogenization of crop production. Fewer and fewer farms own more and more land, and these farms continue to produce a select few crops within highly mechanized processes. These changes emphasize productivity and efficiency, despite increasing concern for biodiversity loss. Further, even though the Farm Bill has increased in scope, the underlying structures incentivizing and reinforcing agricultural specialization have not changed.

While we do not attempt to assess the current sustainability of U.S. agriculture within the NRC's definition, historical data trends accentuate the priorities of the production system writ large. Through substantial gains in productivity and specialization of commodities across the U.S., past and current agricultural land use largely reflect two of the sustainability objectives: (1) satisfying human food, feed, fiber, and biofuel needs; and (2) sustaining the economic viability of agriculture. However, the prioritization of sufficient production and its economic viability has come at the cost of the other outlined objectives: (3) enhancing environmental quality and the resource base; and (4) enhancing the quality of life for farmers, farm workers, and society as a whole. Intensive commodity production has concentrated in space and contributes to biodiversity loss and declining agroecosystem health. These systems often fail to promote farming that *harnesses* and *enhances* ES provisioning and are increasing reliance on external inputs instead. Meanwhile agricultural policies are not equally as advantageous or accessible to *all* producers, exacerbating social inequities and disadvantaging new or diverse farmers. The imbalance of these objectives heightens concern over the robustness of the system. Decreasing trends in crop diversity may contribute to decreased resistance and resilience to shocks and stressors associated with a changing climate and changing environments, and the adaptability needed to address urgent changes may be limited by an increasingly regulatory policy structure.

Within the NRC framework of change, *both* incremental and transformative approaches to change are necessary to promote more sustainable agricultural systems. For large-scale landscape transformations to occur, agricultural research and technological innovation must focus on commercial grain producers; this is how the majority of the agricultural land is used. To implement transformative change without destabilizing crop markets would be difficult. However, given how large these agricultural landscapes are, *any* change in their compositional (increased complexity of different land cover types) and configurational (increased complexity of spatial patterning of cover types) heterogeneity can produce important changes in biodiversity for local or global conservation (Fahrig et al., 2011); changes outside of these markets will not have the largest transformative impact. Therefore, incremental approaches could best support technological advancements and innovations already available for land management by building off current research and enhancing adoption for existing conservation alternatives. Transformative change could target restrictive policies—such as updating base acreage designations or reducing barriers for non-White or small-scale farmers—to encourage more flexible and diverse programs that support commodity production. Federal agricultural policy at present fails to effectively *promote* diversification or conservation practices; whether increased or decreased federal support will do so is currently debated. Yet, a more diverse and socially inclusive suite of programs can help support more diverse systems in which these commodities are grown, promoting technological innovations that can reduce the impacts of agricultural landscape simplification. If large farms and corporate entities remain consistently advantaged over small farms and businesses, then alternative agricultural management schemes will be limited.

We have built upon the NRC (2010) report discussing the complicated nature of evaluating sustainability within agricultural systems. By utilizing national-level data to look at trends of land use and policy over time, we inform and update previous research to remain contextually relevant for policy decisions and assess U.S. trends writ large. Agricultural transformations toward sustainability do not fit within the dichotomy of conventional or sustainable systems. Rather, considering drivers and constraints across multiple scales helps identify realistic pathways of change. For a more sustainable future, both incremental and transformative changes are needed to address the proximate and ultimate conditions of the current state of agricultural landscapes. Although crop composition, productivity, and farm consolidation trends vary regionally, agricultural policy is regulated at a federal level. Therefore, we call for federal agricultural policies to more appropriately address the current drivers of on-farm and landscape simplification, as well as the overlapping factors of sustainability from the local to global scale to contextualize the feasibility of agricultural transitions.

References

Abson, D. J., Fraser, E., and Benton, T. G. (2013). Landscape diversity and the resilience of agricultural returns: a portfolio analysis of land-use patterns and economic returns from lowland agriculture. *Agric. Food Secur.* 2:2. doi: 10.1186/2048-7010-2-2

Aguilar, J., Greta, G. G., Hendrickson, J. R., Archer, D. W., Forcella, F., and Liebig, M. A. (2015). Crop species diversity changes in the United States: 1978-2012. *PLoS ONE* 10:e0136580. doi: 10.1371/journal.pone.0136580

Annan, F., and Schlenker, W. (2015). Federal crop insurance and the disincentive to adapt to extreme heat. *Am. Econ. Rev.* 105, 262–266. doi: 10.1257/aer.p20151031

Arora, G., and Wolter, P. (2018). Tracking land cover change along the western edge of the U.S. corn belt from 1984 through 2016 using satellite sensor data: observed trends and contributing factors. *J. Land Use Sci.* 13, 59–80. doi: 10.1080/1747423X.2018.1466001

Ash, M., Bond, J. K., Capehart, T., Childs, N. W., McConnell, M., Meyer, L., et al.

(2018). *An Exploration of Crop Markets: A Deeper Look Into the USDA Crop Baseline Projections*. FDS-18J-01. U.S. Department of Agriculture, Economic Research Service.

Auch, R. F., and Karstensen, K. A. (2015). *Status and Trends of Land Change in the Midwest-South Central United States-1973 to (2000).* U.S. Geological Survey Professional Paper 1794-C. Land Cover Trends (Washington, DC: USGS).

Auch, R. F., Xian, G., Laingen, C. R., Sayler, K. L., and Reker, R. R. (2018). Human drivers, biophysical changes, and climatic variation affecting contemporary cropping proportions in the northern prairie of the U.S. *J. Land Use Sci.* 13, 32–58. doi: 10.1080/1747423X.2017.1413433

Ayazi, H., and Elsheikh, E. (2015). *The Farm Bill: Corporate Power and Structural Racialization in the United States Food System*. Berkeley, CA: Haas Institute for a Fair and Inclusive Society at the University of California Berkeley. Available online at: https://belonging.berkeley.edu/global-justice/glocal-food-systems/farm-bill-report-corporate-power-and-structural-racialization-us-food-system

Baines, J. (2015). Fuel, feed and the corporate restructuring of the food regime. *J. Peasant Stud.* 42, 295–321. doi: 10.1080/03066150.2014.970534

Barnard, C. H., and Hexem, R. (1988). *Major Statistical Series of the U.S. Department of Agriculture: Land Values and Land Use,* AH-671, Vol. 6. US Department of Agriculture, Economic Research Service.

Benbrook, C. M. (2012). Impacts of genetically engineered crops on pesticide use in the U.S. - The first sixteen years. *Environ. Sci. Eur.* 24:24. doi: 10.1186/2190-4715-24-24

Benton, T. G., Vickery, J. A., and Wilson, J. D. (2003). Farmland biodiversity: is habitat heterogeneity the key? *Trends Ecol. Evol.* 18, 182–188. doi: 10.1016/S0169-5347(03)00011-9

Bianchi, F. J. J. A., Booij, C. J. H., and Tscharntke, T. (2006). Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. *Proc. R. Soc. B Biol. Sci.* 273, 1715–1727. doi: 10.1098/rspb.2006.3530

Bigelow, D. P., and Borchers, A. (2017). *Major Uses of Land in the United States (2012)*. EIB-178. U.S. Department of Agriculture, Economic Research Service.

Bommarco, R., Kleijn, D., and Potts, S. G. (2013). Ecological intensification: harnessing ecosystem services for food security. *Trends Ecol. Evol.* 28, 230–238. doi: 10.1016/j.tree.2012.10.012

Bommarco, R., Vico, G., and Hallin, S. (2018). Exploiting ecosystem services in agriculture for increased food security. *Glob. Food Secur.* 17, 57–63. doi: 10.1016/j.gfs.2018.04.001

Bradshaw, B. (2004). Plus c'est la même chose? questioning crop diversification as a response to agricultural deregulation in Saskatchewan, Canada. *J. Rural Stud.* 20, 35–48. doi: 10.1016/S0743-0167(03)00033-0

Bruckner, T. (2016). Agricultural subsidies and farm consolidation. *Am. J. Econ. Sociol.* 75, 623–648. doi: 10.1111/ajes.12151

Brym, Z. T., and Reeve, J. R. (2016). “Agroecological principles from a bibliographic analysis of the term agroecology,” in *Sustainable Agriculture Reviews*, Vol. 19, ed E. Lichtfouse (Cham: Springer International Publishing), 203–231.

Burchfield, E. K., Nelson, K. S., and Spangler, K. A. (2019). The impact of agricultural landscape diversification on U.S. crop production. *Agric. Ecosyst. Environ.* 285:106615. doi: 10.1016/j.agee.2019.106615

Calo, A., and De Master, K. (2016). After the incubator: factors impeding land access along the path from farmworker to proprietor. *J. Agric. Food Syst. Commun. Dev.* 6, 1–17. doi: 10.5304/jafscd.2016.062.018

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., et al. (2012). Biodiversity loss and its impact on humanity. *Nature* 486, 59–67. doi: 10.1038/nature11148

Cassman, K. G. (1999). Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. *Proc. Natl. Acad. Sci. U.S.A.* 96, 5952–5959. doi: 10.1073/pnas.96.11.5952

Cozen, M. (2010). *The Making of the American Landscape. Routledge*. Available online at: https://ebookcentral-proquest-com.dist.lib.usu.edu/lib/usu/detail.action?docID=1702299

Daniels, T. L. (1988). America's conservation reserve program: rural planning or just another subsidy? *J. Rural Stud.* 4, 405–411. doi: 10.1016/0743-0167(88)90008-3

Davis, A. S., Hill, J. D., Chase, C. A., Johanns, A. M., and Liebman, M. (2012). Increasing cropping system diversity balances productivity, profitability and environmental health. *PLoS ONE* 7:e47149. doi: 10.1371/journal.pone.0047149

Deryugina, T., and Konar, M. (2017). Impacts of crop insurance on water withdrawals for irrigation. *Adv. Water Resour.* 110, 437–444. doi:10.1016/j.advwatres.2017.03.013

Di Falco, S., and Perrings, C. (2003). Crop genetic diversity, productivity and stability of agroecosystems. a theoretical and empirical investigation. *Scott. J. Polit. Econ.* 50, 207–216. doi: 10.1111/1467-9485.5002006

Di Falco, S., and Perrings, C. (2005). Crop biodiversity, risk management and the implications of agricultural assistance. *Ecol. Econ.* 55, 459–466. doi: 10.1016/j.ecolecon.2004.12.005

Dimitri, C., Effland, A. B. W., and Conklin, N. C. (2005). *The 20th Century Transformation of U.S. Agriculture and Farm Policy. USDA ERS*. Available online at: http://ageconsearch.umn.edu/bitstream/59390/2/eib3.pdf

Drummond, M. A., Auch, R., Karstensen, K. A., Sayler, K., Taylor, J., and Loveland, T. R. (2012). Land change variability and human-environment dynamics in the United States great plains. *Land Use Policy* 29, 710–723. doi: 10.1016/j.landusepol.2011.11.007

Drummond, M. A., and Loveland, T. R. (2010). Land-use pressure and a transition to forest-cover loss in the Eastern United States. *Bioscience* 60, 286–298. doi: 10.1525/bio.2010.60.4.7

Duffy, M. (2009). Economies of size in production agriculture. *J. Hunger Environ. Nutr.* 4, 375–392. doi: 10.1080/19320240903321292

Dunbar-Ortiz, R. (2014). *An Indigenous Peoples' History of the United States*. Boston, MA: Beacon Press.

ERS (1996). *1996 FAIR Act Frames Farm Policy for 7 Years.* Agricultural Outlook Supplement April (1996). Washington, DC: ERS.

ERS (2000). *Farm Resource Regions. Agricultural Information Bulletin 760*.

Washington, DC: USDA Economic Research Service. Available online at: https://www.ers.usda.gov/webdocs/publications/42298/32489_aib-760_002.pdf?v=42487

ERS (2019a). *Agricultural Productivity in the U.S. USDA Economic Research Service*. Available online at: https://www.ers.usda.gov/data-products/agricultural-productivity-in-the-us/

ERS (2019b). *Agriculture Improvement Act of 2018: Highlights and Implications*. Washington, DC: US Department of Agriculture, Economic Research Service. Available online at: https://www.ers.usda.gov/agriculture-improvement-act-of-2018-highlights-and-implications/

Fahrig, L., Baudry, J., Brotons, L., Burel, F. G., Crist, T. O., Fuller, R. J., et al. (2011). Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. *Ecol. Lett.* 14, 101–112. doi: 10.1111/j.1461-0248.2010.01559.x

Falcone, J. A. (2015). *U.S. Conterminous Wall-to-Wall Anthropogenic Land Use Trends (NWALT), 1974-2012*. U.S. Geological Survey Data Series 948, 33 p. plus appendixes 3-6 as separate files. doi: 10.3133/ds948

Farm Bureau (2016). *Options for Updating Bases and Yields*. Farm Bureau: 2018 Farm Bill. Washington, DC: Farm Bureau. Avaliable online at: https://www.fb.org/files/2018FarmBill/Options_for_Updating_Bases_and_Yields.pdf

Fischer, J., Abson, D. J., Butsic, V., Chappell, M. J., Ekroos, J., Hanspach, J., et al. (2014). Land sparing versus land sharing: moving forward. *Conserv. Lett.* 7, 149–157. doi: 10.1111/conl.12084

Fischer, J., Brosi, B., Daily, G. C., Ehrlich, P. R., Goldman, R., Goldstein, J., et al. (2008). Should agricultural policies encourage land sparing or wildlife-friendly farming? *Front. Ecol. Environ.* 6, 380–385. doi: 10.1890/070019

Francis, C. A., Lieblein, G., Gliessman, S. R., Breland, T. A., Creamer, N., Harwood, R., et al. (2003). Agroecology: the ecology of food systems. *J. Sustain. Agric.* 22, 99–118. doi: 10.1300/J064v22n03_10

Graddy-Lovelace, G., and Diamond, A. (2017). From supply management to agricultural subsidies-and back again? the US farm bill & agrarian inviability. *J. Rural Stud.* 50, 70–83. doi: 10.1016/j.jrurstud.2016.12.007

Gustafson, E. J. (1998). Quantifying landscape spatial pattern: what is the state of the art? *Ecosystems* 1:15. doi: 10.1007/s100219900011

Harlan, J. R. (1975). Our vanishing genetic resources. *Science* 188, 617–621. doi: 10.1126/science.188.4188.617

Hart, J. F. (1978). Cropland concentrations in the South. *Ann. Assoc. Am. Geogr.* 68, 505–517. doi: 10.1111/j.1467-8306.1978.tb01213.x

Hart, J. F. (1986). Change in the corn belt. *Geogr. Rev.* 76:51. doi: 10.2307/214784

Hart, J. F. (1991). Part-ownership and farm enlargement in the Midwest. *Ann. Assoc. Am. Geogr.* 81, 66–79. doi: 10.1111/j.1467-8306.1991.tb01679.x

Hart, J. F. (2001). Half a century of cropland change. *Geogr. Rev.* 91:525. doi: 10.2307/3594739

Hart, J. F. (2004). *The Changing Scale of American Agriculture*. Charlottesville, VA: University of Virginia Press.

Hass, A. L., Kormann, U. G., Tscharntke, T., Clough, Y., Baillod, A. B., Sirami, C., et al.

(2018). Landscape configurational heterogeneity by small-scale agriculture, not crop diversity, maintains pollinators and plant reproduction in Western Europe. *Proc. R. Soc. B Biol. Sci.* 285:20172242. doi: 10.1098/rspb.2017.2242

Heal, G., Walker, B., Levin, S., Arrow, K., Dasgupta, P., Daily, G., et al. (2004). Genetic diversity and interdependent crop choices in agriculture. *Resour. Energ. Econ.* 26, 175–184. doi: 10.1016/j.reseneeco.2003.11.006

Hendrickx, F., Maelfait, J. P., Van Wingerden, W., Schweiger, O., Speelmans, M., Aviron, S., et al. (2007). How landscape structure, land-use intensity and habitat diversity affect components of total arthropod diversity in agricultural landscapes: agricultural factors and arthropod biodiversity. *J. Appl. Ecol.* 44, 340–351. doi: 10.1111/j.1365-2664.2006.01270.x

Hillier, J., Hawes, C., Squire, G., Hilton, A., Wale, S., and Smith, P. (2009). The carbon footprint of food crop production. *Int. J. Agric. Sustain.* 7, 107–118. doi: 10.3763/ijas.2009.0419

Homer, C., Dewitz, J., Yang, L., Jin, S., Danielson, P., Coulston, J. W., et al. (2015). Completion of the 2011 National land cover database for the conterminous United States - representing a decade of land cover change information. *Photogramm. Eng. Remote Sensing* 81, 345–354. doi: 10.14358/PERS.81.5.345

Hooper, D. U., Adair, E. C., Cardinale, B. J., Byrnes, J. E. K., Hungate, B. A., Matulich, K. L., et al. (2012). A global synthesis reveals biodiversity loss as a major driver of ecosystem change. *Nature* 486, 105–108. doi: 10.1038/nature11118

Hooper, D. U., Chapin, F. S., Ewel, J. J, Hector, A., Inchausti, P., Lavorel, S., et al.

(2005). Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecol. Monogr.* 75, 3–35. doi: 10.1890/04-0922

Hoppe, R. A. (2014). *Structure and Finances of US Farms: Family Farm Report, 2014 Edition. Economic Information Bulletin No. (EIB-132)*. Economic Research Service.

Horrigan, L., Lawrence, R. S., and Walker, P. (2002). How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environ. Health Perspect.* 110, 445–456. doi: 10.1289/ehp.02110445

Horst, M., and Marion, A. (2019). Racial, ethnic and gender inequities in farmland ownership and farming in the US. *Agric. Hum. Values* 36, 1–16. doi: 10.1007/s10460-018-9883-3

Hudson, J. C. (1994). *Making the Corn Belt: A Geographical History of Middle-Western Agriculture*. Bloomington, IN: Indiana University Press.

Hudson, J. C., and Laingen, C. R. (2018). *American Farms, American Food: A Geography of Agriculture and Food Production in the United States*. Lanham, MD: Lexington Books.

Isik, M., and Yang, W. (2004). An analysis of the effects of uncertainty and irreversibility on farmer participation in the conservation reserve program. *J. Agric. Resour. Econ.* 29:18. doi: 10.22004/ag.econ.31113

Johnson, K. A., Dalzell, B. J., Donahue, M., Gourevitch, J., Johnson, D. L., Karlovits, G. S., et al. (2016). Conservation Reserve Program (CRP) lands provide ecosystem service benefits that exceed land rental payment costs. *Ecosyst. Serv.* 18, 175–185. doi: 10.1016/j.ecoser.2016.03.004

Johnson, R., and Monke, J. (2019). *What Is the Farm Bill?* CRS Report RS22131. Washington, DC: Congressional Research Service.

Key, N. (2019). Farm size and productivity growth in the United States corn belt. *Food Policy* 84, 186–195. doi: 10.1016/j.foodpol.2018.03.017

Khoury, C. K., Bjorkman, A. D, Dempewolf, H., Ramirez-Villegas, J., Guarino, L., Jarvis, A., et al. (2014). Increasing homogeneity in global food supplies and the implications for food security. *Proc. Natl. Acad. Sci. U.S.A.* 111, 4001–4006. doi: 10.1073/pnas.1313490111

Krippendorf, K. (2004). *Content Analysis: An Introduction to Its Methodology*, 2nd Edn. Thousand Oaks, CA: SAGE Publications, Inc. Available online at: https://www.jstor.org/stable/2288384?origin=crossref

Laingen, C. R. (2017). Creating a dynamic regional model of the US corn belt. *Int. J. Appl.Geospat. Res.* 8, 19–29. doi: 10.4018/IJAGR.2017100102

Landis, D. A. (2017). Designing agricultural landscapes for biodiversity-based ecosystem services. *Basic Appl. Ecol.* 18, 1–12. doi: 10.1016/j.baae.2016.07.005

Lehner, P. H., and Rosenberg, N. A. (2018). Farm bill to help farmers weather climate change. *J. Food Law Policy* 14, 39–54. Available online at: https://ssrn.com/abstract=3219464

Luttrell, C. B. (1973). *The Russian Wheat Deal-Hindsight vs. Foresight*. Federal Reserve Bank of St. Louis 55. doi: 10.20955/r.55.2-9.jiy

MacDonald, J. M., and Hoppe, R. A. (2017). *Large Family Farms Continue to Dominate, US Agricultural Production. Statistic: Farm Economy, Amber Waves*. Washington, DC: Economic Research Service.

Martin, A. R., Cadotte, M. W., Isaac, M. E., Milla, R., Vile, D., and Violle, C. (2019). Regional and global shifts in crop diversity through the anthropocene. *PLoS ONE* 14:e0209788. doi: 10.1371/journal.pone.0209788

Massawe, F., Mayes, S., and Cheng, A. (2016). Crop diversity: an unexploited treasure trove for food security. *Trends Plant Sci.* 21, 365–368. doi: 10.1016/j.tplants.2016.02.006

McDaniel, M. D., Tiemann, L. K., and Grandy, A. S. (2014). Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. *Ecol. Appl.* 24, 560–570. doi: 10.1890/13-0616.1

McFadden, J. R., and Hoppe, R. A. (2017). *The Evolving Distribution Of Payments From Commodity, Conservation, And Federal Crop Insurance Programs*. Economic Information Bulletin Number 184. USDA Economic Research Service.

McGranahan, D. A., Brown, P. W., Schulte, L. A., and Tyndall, J. C. (2013). A historical primer on the US farm bill: supply management and conservation policy. *J. Soil Water Conserv.* 68, 67A−73A. doi: 10.2489/jswc.68.3.67A

McMinimy, M. A., Angadjivand, S., Aussenberg, R. A., Billings, K. C., Bracmort, K., Casey, A. R., et al. (2019). *The 2018 Farm Bill (P.L. 115-334): Summary and Side-by-Side Comparison*. Washington, DC: Congressional Research Service.

Meehan, T. D., Werling, B. P., Landis, D. A., and Gratton, C. (2011). Agricultural landscape simplification and insecticide use in the Midwestern United States. *Proc. Natl. Acad. Sci. U.S.A.* 108, 11500–11505. doi: 10.1073/pnas.1100751108

Minkoff-Zern, L. A., and Sloat, S. (2017). A new era of civil rights? latino immigrant farmers and exclusion at the United States department of agriculture. *Agric. Hum.Values* 34, 631–643. doi: 10.1007/s10460-016-9756-6

Mulvaney, R. L., Khan, S. A., and Ellsworth, T. R. (2009). Synthetic nitrogen fertilizers deplete soil nitrogen: a global dilemma for sustainable cereal production. *J. Environ. Qual.* 38, 2295–2314. doi: 10.2134/jeq2008.0527

National Agricultural Law Center (2019). *United States Farm Bills. National Agricultural Law Center*. Available online at: https://nationalaglawcenter.org/farmbills/

Newton, J. (2017). *Modernizing Base Acres. Market Intel. Farm Bureau*. Available online at: https://www.fb.org/market-intel/modernizing-base-acres

NRC (2010). *Toward Sustainable Agricultural Systems in the 21st Century*. National Research Council of the National Academies. Washington, DC: The National Academies Press.

O'Connor, A. (2012). Fence row to fence row: an examination of federal commodity subsidies. *Kan. J. Law Pub. Policy*. 21, 432–450.

O'Donoghue, E. J., Roberts, M. J., and Key, N. (2009). Did the federal crop insurance reform act alter farm enterprise diversification? *J. Agric. Econ.* 60, 80–104. doi: 10.1111/j.1477-9552.2008.00166.x

Olson, A. (2001). Federal farm programs - past, present and future-will we learn from our mistakes? *Great Plains Nat. Resour. J*. 1:6.

Ortiz-Bobea, A., Knippenberg, E., and Chambers, R. G. (2018). Growing climatic sensitivity of US agriculture linked to technological change and regional specialization. *Sci. Adv.* 4:eaat4343. doi: 10.1126/sciadv.aat4343

Paul, C. M., Nehring, R., Banker, D., and Somwaru, A. (2004). Scale economies and efficiency in US agriculture: are traditional farms history? *J. Product. Anal.* 22:22. doi: 10.1007/s11123-004-7573-1

Pellegrini, P., and Fernández, R. J. (2018). Crop intensification, land use, and on-farm energy-use efficiency during the worldwide spread of the green revolution. *Proc. Natl. Acad. Sci. U.S.A.* 115, 2335–2340. doi: 10.1073/pnas.1717072115

Phalan, B., Green, R., and Balmford, A. (2014). Closing yield gaps: perils and possibilities for biodiversity conservation. *Philos. Trans. R. Soc. B Biol. Sci.* 369:20120285. doi: 10.1098/rstb.2012.0285

Pimentel, D., and Burgess, M. (2014). "Chapter 2: environmental and economic costs of the application of pesticides primarily in the United States," in *Integrated Pest Management*, eds D. Pimentel and R. Peshin (Dordecht: Springer), 47–71.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., et al. (1995). Environmental and economic costs of soil erosion and conservation benefits. *Science* 267, 1117–1123. doi: 10.1126/science.267.5201.1117

Pridham, J. C., and Entz, M. (2008). Intercropping spring wheat with cereal grains, legumes, and oilseeds fails to improve productivity under organic management. *Agron. J.* 100:1436. doi: 10.2134/agronj2007.0227

Pywell, R. F., Heard, M. S., Woodcock, B. A., Hinsley, S., Ridding, L., Nowakowski, M., et al. (2015). Wildlife-friendly farming increases crop yield: evidence for ecological intensification. *Proc. R. Soc. B Biol. Sci.* 282:20151740. doi: 10.1098/rspb.2015.1740

R Core Team (2020). *R: A Language and Environment for Statistical Computing.*

Vienna: R Foundation for Statistical Computing. Available online at: https://www.R-project.org/

Rabalais, N.N., Turner, R.E., and Wiseman, W.J. Jr. (2002). Gulf of Mexico Hypoxia, A.K.A "The Dead Zone." *Ann. Rev. Ecol. Syst.* 33, 235–363. doi: 10.1146/annurev.ecolsys.33.010802.15051

Rada, N. E., and Fuglie, K. O. (2019). New perspectives on farm size and productivity. *Food Policy* 84, 147–152. doi: 10.1016/j.foodpol.2018.03.015

Ramankutty, N., Mehrabi, Z., Waha, K., Jarvis, L., Kremen, C., Herrero, M., et al. (2018). Trends in global agricultural land use: implications for environmental health and food security. *Ann. Rev. Plant Biol.* 69, 789–815. doi: 10.1146/annurev-arplant-042817-040256

Ray, D. K., Ramankutty, N., Mueller, N. D., West, P. C., and Foley, J. A. (2012). Recent patterns of crop yield growth and stagnation. *Nat. Commun*. 3:1293. doi: 10.1038/ncomms2296

Reganold, J. P., Jackson-Smith, D., Batie, S. S., Harwood, R. R., Kornegay, J. L., Bucks, D., et al. (2011). Transforming, US agriculture. *Science* 332, 670–671. doi: 10.1126/science.1202462

Reitsma, K. D., Dunn, B. H., Mishra, U., Clay, S. A., DeSutter, T., and Clay, D. E. (2015). Land-use change impact on soil sustainability in a climate and vegetation transition zone. *Agron. J.* 107, 2363–2372. doi: 10.2134/agronj15.0152

Rindfuss, R. R., Walsh, S. J., Turner, B. L., Fox, J., and Mishra, V. (2004). Developing a science of land change: challenges and methodological issues. *Proc. Natl. Acad. Sci. U.S.A.* 101, 13976–13981. doi: 10.1073/pnas.0401545101

Robinson, R. A., and Sutherland, W. J. (2002). Post-war changes in arable farming and biodiversity in Great Britain. *J. Appl. Ecol*. 39, 157–176. doi: 10.1046/j.1365-2664.2002.00695.x

Rosenberg, N., and Stucki, B. W. (2017). The butz stops here: why the food movement needs to rethink agricultural history. *J. Food. Law. Policy*. 13, 12–25.

Sayler, K. L., Acevedo, W., and Taylor, J. L. (2016). *Status and Trends of Land Change in the Eastern United States-1973 to 2000.* U.S. Geological survey professional paper 1794-D. Land Cover Trends. Washington, DC: USGS.

Sleeter, B. M., Sohl, T. L., Loveland, T. R., Auch, R. F., Acevedo, W., Drummond, M. A., et al. (2013). Land-cover change in the conterminous United States from 1973 to 2000. *Glob. Environ. Change* 23, 733–748. doi: 10.1016/j.gloenvcha.2013.03.006

Sohl, T., Reker, R., Bouchard, M. A., Sayler, K., Dornbierer, J., Wika, S., et al. (2016). Modeled historical land use and land cover for the conterminous United States. *J. Land Use Sci.* 11, 476–499. doi: 10.1080/1747423X.2016.1147619

Taylor, J. L., Acevedo, W., Auch, R. F., and Drummond, M. A. (2015). *Status and Trends of Land Change in the Great Plains of the United States-1973 to (2000).* U.S. Geological Survey Professional Paper 1794-B. Land Cover Trends. Washington, DC: USGS.

Tilman, D. (1999). Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. *Proc. Natl. Acad. Sci. U.S.A.* 96, 5995–6000. doi: 10.1073/pnas.96.11.5995

Tscharntke, T., Clough, Y., Wanger, T. C., Jackson, L., Motzke, I., Perfecto, I., et al.

(2012). Global food security, biodiversity conservation and the future of agricultural intensification. *Biol. Conserv.* 151, 53–59. doi: 10.1016/j.biocon.2012.01.068

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., and Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity - ecosystem service management. *Ecol. Lett.* 8, 857–874. doi: 10.1111/j.1461-0248.2005.00782.x

USDA (1982). *1982 Census Publications. USDA Census of Agriculture Historical Archive*. Avaliable online at: http://usda.mannlib.cornell.edu/usda/AgCensusImages/1982/01/51/121/Table-01.pdf

USDA (1992). *1992 Census Publications. USDA Census of Agriculture Historical Archive*. Avaliable online at: http://usda.mannlib.cornell.edu/usda/AgCensusImages/1992/01/51/1575/Table-06.pdf

USDA NASS (2019a). *2017 Census of Agriculture Report: United States Summary and State Data. AC-17-A-51. Geography Area Series, Part 51*. Washington, DC: United States Department of Agriculture.

USDA NASS (2019b). *Farms and Land in Farms: 2018 Summary*. USDA.

USDA NASS (2019c). *USDA National Agricultural Statistics Service Quick Stats*. Available online at: https://quickstats.nass.usda.gov/

Vitalis, V. (2007). Agricultural subsidy reform and its implications for sustainable development: the New Zealand experience. *Environ. Sci.* 4, 21–40. doi: 10.1080/15693430601108086

Way, M. J., and van Emden, H. F. (2000). Integrated pest management in practice – pathways towards successful application. *Crop Prot.* 19, 81–103. doi: 10.1016/S0261-2194(99)00098-8

Weber, J. G., Key, N., and O'Donoghue, E. (2016). Does federal crop insurance make environmental externalities from agriculture worse? *J. Assoc. Environ. Resour. Econ.* 3, 707–742. doi: 10.1086/687549

Willis, B., and O'Brien, D. (2002). *Summary and Evolution of U.S. Farm Bill Commodity Titles*. Fayetteville, AK: National Ag Law Center.

Wright, C. K., and Wimberly, M. C. (2013). Recent land use change in the western corn belt threatens grasslands and wetlands. *Proc. Natl. Acad. Sci. U.S.A.* 110, 4134–4139. doi: 10.1073/pnas.1215404110

Zhang, W., Ricketts, T. H., Kremen, C., Carney, K., and Swinton, S. M. (2007). Ecosystem services and dis-services to agriculture. *Ecol. Econ.* 64, 253–260. doi: 10.1016/j.ecolecon.2007.02.024

CHAPTER III

PATH DEPENDENCIES IN U.S. AGRICULTURE: REGIONAL FACTORS OF DIVERSIFICATION[3,4]

Abstract

Concerns of declining agrobiodiversity and widening socioeconomic inequities in United States (U.S.) agriculture highlight the critical need for systemic change. Despite surmounting evidence of the field and landscape scale benefits of diversifying agricultural systems, path dependencies of U.S. agriculture present barriers to such diversification pathways. This study aims to elucidate path dependencies of agricultural landscapes that (dis)incentivize crop diversification at the regional scale through two main research questions: 1) what are the biophysical and socioecological factors most predictive of agricultural diversity across the U.S.; and 2) how do these factors vary regionally? Using a novel panel dataset constructed from several open-source databases, we use random forest (RF) permutation variable importance measures to identify and compare the factors most predictive of county-level crop diversity across nine U.S. regions. Our results show that climate, land use norms, and farm inputs are consistently the most important categories for predicting agricultural diversity across regions; however, variability exists in the relative regional importance of variables within these

---

[3] This paper is currently under review at *Agriculture, Ecosystems, and Environment*. Co-authors include Britta Schumacher, Brennan Bean, and Emily Burchfield.

[4] This research was supported, in part, by the National Science Foundation under Grant No. 1633756 and by United States Department of Agriculture (USDA) National Institute of Food and Agriculture Grant No. 2020-67019-31157. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the USDA.

categories. Thus, factors most strongly predictive of agricultural diversity across U.S. landscapes operate distinctly at a regional level, emphasizing the need to consider multiple scales of influence. These distinct regional relationships contribute to path dependencies that present resistance to enhancing agrobiodiversity. Imagining alternative, diversified agricultural systems – an increasingly urgent necessity in the face of a changing climate and widening sociopolitical inequity – requires a fundamental shift away from regional pathways that lock farmers and farmworkers into maladaptive systems.

1. Introduction

In the United States (U.S.), the Green Revolution is failing to safely and sustainably meet the food production demands of a growing global population (Altieri and Nicholls, 2009; Gleissman, 2015). Although modern agriculture is becoming increasingly productive (ERS, 2019; Key, 2019; Pellegrini and Fernández, 2018; Ramankutty et al., 2018; Reganold et al., 2011), this productivity has come at the cost of ecological health and the wellbeing of farmers, farmworkers, and rural communities writ large (Aizen et al., 2019; Anderson et al., 2019; Benton, 2012; Petersen-Rockney et al., 2021; Prokopy et al., 2020; Spangler et al., 2020; Thaler et al., 2021). Corporate power and consolidation are rising in the agri-food sector, extending corporate influence and control over global agricultural markets and political lobbying (Clapp, 2018; Clapp and Purugganan, 2020). These forces are reducing farmer autonomy (Hendrickson et al., 2020), and reinforcing agricultural policies built upon socioeconomic inequity and injustice (Fagundes et al., 2019; Graddy-Lovelace, 2017; Hauter, 2012).

At the same time, agricultural production has become increasingly specialized for a decreasing number of crop species (Aguilar et al., 2015; Aizen et al., 2019; Auch et al., 2018; Baines, 2015), and large-scale farm consolidation is driving out smaller-scale operations (MacDonald and Hoppe, 2017; Paul et al., 2004). This consolidation has led to the agglomeration and intensification of commodity production, resulting in simplified agricultural landscapes and concomitant biodiversity loss (Grab et al., 2018; Nassauer, 2010; Tscharntke et al., 2005). Moreover, these simplified landscapes are heavily reliant on external chemical and financial inputs and less resilient to uncertainty and change (Kremen and Merenlender, 2018; Landis, 2017; Meehan et al., 2011; Spangler et al., 2020).

Given these urgent concerns, there is a critical need for systemic change in U.S. agriculture. One crucial area for change is a shift away from simplified commodity agriculture by increasing the agrobiodiversity of our agricultural landscapes. Agrobiodiversity refers broadly to the diversity of food and agricultural systems (Zimmerer et al., 2019). As Kremen et al. (2012, p. 44) states, "a farming system is diversified when it intentionally includes functional biodiversity at multiple spatial and/or temporal scales through practices developed via traditional and/or agroecological scientific knowledge." Increasing agrobiodiversity promotes greater multifunctionality – or multiple beneficial functions beyond food and fiber production – throughout the U.S. agri-food system to support mechanisms that "(re-)link agriculture to society at large through a far wider range of interrelations than just large commodity markets" (van der Ploeg et al., 2009, p. S130).

One short term mechanism for increasing agrobiodiversity is crop diversification. Crop diversification includes temporal and spatial diversification practices that increase the number and type of crops grown in an area at any point in time and over several years. Prior research at the field scale strongly supports the benefits of greater crop diversity, namely improved crop yields (Pywell et al., 2015; Schulte et al., 2017; Smith et al., 2008; Virginia et al., 2018), decreased yield volatility over time (Gaudin et al., 2015; Li et al., 2019), improved pest management (Bommarco et al., 2013; Chaplin-Kramer et al., 2011), improved soil health (Albizua et al., 2015; Berendsen et al., 2012; Ghimire et al., 2018; McDaniel et al., 2014; Postma et al., 2008), and increased pollinator diversity (Guzman et al., 2019; Schulte et al., 2017).

Furthermore, diversification at the field scale is embedded within multiscale landscape dynamics that serve a critical role in managing for, and maintaining, greater crop diversity at other scales (Birkhofer et al., 2018; iPES-FOOD, 2016; Renting et al., 2009). An individual farm's ecosystem is both influenced by and influences the regional pool of crop and non-crop species and associated habitats. These interactions are referred to as the "landscape effect" (Benton, 2012, p. 9). In turn, greater crop diversity at the landscape scale can boost overall yields (Burchfield et al., 2019), improve yield stability to weather and climate volatility (Abson et al., 2013; Manns and Martin, 2018), support pest and disease control (Chaplin-Kramer et al., 2011; Gardiner et al., 2009; Ratnadass et al., 2012), and promote overall pollinator diversity (Hass et al., 2018; Tscharntke et al., 2005).

Despite the mounting evidence of the benefits of crop diversity, path dependencies in U.S. agriculture present significant barriers to diversification. Path dependency can be defined as “resistance to changing the way things have always been done, even if business as usual seems to be increasingly maladaptive” (Barnett et al., 2015, p. 2). Increasing commodification of agricultural land use reinforces a high-yielding, productivist agricultural paradigm perpetuated by infrastructure, machinery, and institutional norms (Magrini et al., 2018, 2019; G. E. Roesch-McNally et al., 2018). This self-reinforcing cycle may “lock” farmers into certain technological and political regimes (e.g., pest management strategies, crop breeding, reliance on crop insurance, etc.) that do not adequately respond to the implications of a changing climate (Annan and Schlenker, 2015; Chhetri et al., 2010) and other environmental shocks and stressors (Barnett et al., 2015).

Therefore, it is urgent to assess the structural barriers and bridges to crop diversification, particularly factors beyond the field scale, that drive current path dependencies. Biophysical realities of agricultural landscapes – climatic variability, water availability, and soil characteristics – shape and are shaped by processes of diversification or simplification, creating a baseline of environmental suitability for certain crops to grow and thrive (Burchfield and Nelson, 2021; Burchfield and Schumacher, 2020; Goslee, 2020). Yet, on-farm factors such as fertilizer use, labor, and irrigation play a crucial role in the success and stability of farm outputs (Burchfield and Schumacher, 2020), and government subsidies and assistance strongly influence farmer decision-making and priorities (Bowman and Zilberman, 2013; Graddy-Lovelace and Diamond, 2017; Zulauf, 2019). Thus, there is a pressing need to understand how biophysical realities, farmer decision-making, and government policy interact and influence the path dependencies that drive landscape simplification or diversification.

This study aims to elucidate path dependencies in U.S. agricultural landscapes that (dis)incentivize crop diversification. In so doing, we address two main research questions: 1) what are the biophysical and socioecological factors most predictive of agricultural diversity across the U.S.; and 2) how do these factors vary regionally? By focusing on the regional scale, we fill a research gap calling for a deeper understanding of human-environmental interactions at multiple scales across agricultural landscapes (Coomes et al., 2019; Duarte et al., 2018; Swift et al., 2004). In assessing how these factors are associated with agriculturally diverse or non-diverse landscapes, we aim to provide structural context for how and why farmers and farmworkers make decisions toward or away from diversification within these regions and landscapes.

2. Methods

We use random forest (RF) permutation variable importance measures to determine which biophysical and socioecological factors are most predictive of county-level crop diversity measures at the regional scale. These importance measures naturally account for interactive and/or non-linear effects among the predictor variables not possible in a standard correlation analysis. What differentiates our analysis from previous studies using random forests is the focus on the predictive power of each explanatory variable, rather than simply focusing on accurate predictions.

2.1. Predictor variables

We utilized a novel panel dataset constructed from several open-source databases containing information about U.S. agricultural land use, climate and soil characteristics, on-farm use of inputs and assistance, and farmer demographics. These data include observations for all counties in the coterminous U.S. for the U.S. Department of Agriculture (USDA) Census of Agriculture (COA) years 2012 and 2017, which are the most recent years available (USDA NASS, 2019a). The USDA COA is administered every five years to all farms and ranches selling at least $1,000 of their products. It also includes soil data from the Harmonized World Soil Database disseminated by the Food and Agriculture Organization (FAO) (Fischer et al., 2008), bioclimatic variables from the WorldClim project (Hijmans, 2017), and irrigated extent from the Moderate Resolution Imaging Spectroradiometer (MODIS) Irrigated Agriculture Dataset (MIrAD) provided by the U.S. Geological Survey (USGS) (Brown et al., 2019). Our research questions aim to determine the influence of external factors on agricultural diversity at a moment in time. As such, we did not include any lagged effects of prior agricultural diversity (see Appendix B, SI Figures 1A-1C for county-level regression of each response variable on change through time). For additional information and detail on methodological procedures, all code can be found on GitHub (github.com/kspangler1/regional-diversity).

2.1.1. Variable selection

It is well documented that RF permutation variable importance measures are negatively impacted by an excess number of highly related explanatory variables (Biau and Scornet, 2016). Thus, we performed a manual variable selection to minimize variable overlap based on both data availability and collinearity as foundational rules of elimination. First, we row-wise deleted any variables that were more than eight percent missing for both 2012 and 2017 and removed any variables that were a direct linear combination of any other variables.

We observed several pairs of highly collinear variables among the candidate explanatory variables (see Appendix B, SI Figures 2A-2C for correlation matrices). For soil variables, we consulted with a soil health expert to rank all soil variables in order of priority (between one and three, one being top priority) as they relate to agricultural production (Cowan, 2020). Based on this expertise, we removed: 1) eight qualitative variables due to their redundancy and lack of interpretability and 2) five quantitative variables based on high collinearity (correlation > 0.8) with variables of greater importance to agriculture that are more stable over time. For instance, topsoil pH was removed because it is actively managed for by farmers from season to season and therefore varies in many places across time and space, but we retained subsoil pH due to its known importance to agriculture and its relative stability over time (Ebabu et al., 2020; Metwally et al., 2019). For correlated climate variables, we assessed pairwise correlations by the following set of rules: 1) drop any climate variable that measures a range in favor of the minimum and maximum values; 2) drop monthly climate measurements and retain quarterly measurements; 3) retain any climate variable that is an annual summary. Finally, all else being equal for highly correlated COA variables (rho > 0.8) we retained the variable with the higher availability. Thus, we dropped % female operators (retaining % male operators), land tenure as full owner (retaining part owner), labor expenses (retaining the number of all laborers), acres of fertilizer use (retaining percent cropland), and commodity sales (retaining chemical and fertilizer expenses).

2.1.2. Imputation

Following these variable selection processes, we would have removed 475 counties for 2012 (15.2% of all 3,108 counties) and 422 counties for 2017 (13.6%) due to missing COA data via row-wise deletion. To avoid this costly data removal, we performed imputation for missing data. First, we verified that the COA variables were not appreciably different between 2012 and 2017 by checking the distribution from 1997 to 2017 (see GitHub link to RF-imputation-COA.html). Given that all COA variables varied minimally from 2012 to 2017, we imputed missing data for counties in 2012 by infilling with its value in 2017, and vice versa. After systematically imputing these values, we deleted 134 counties in each year that had no data reported, and therefore no data to impute, in either year for retained COA variables.

2.1.3. Final predictor variables

Final predictor variables include measures of six main characteristic types: 1) farm(er) characteristics, 2) farm inputs, 3) land use, 4) assistance and income, 5) soil characteristics, and 6) climate (Table 3-1; see Appendix B, SI Table 1 for full descriptions). All variables are summarized to the county level, the highest resolution at which all data are available. Variables were standardized (where applicable) using “total operated acres” (USDA NASS, 2019b).

Table 3-1: Predictor variable categories and units

Variable	Units
Farm(er) Characteristics	
Primary producer's age	Avg. age
% acres operated by male farmers	% ag acres
Land tenure	% ag acres
On-farm experience	Avg. years
Farm size	Med. #
Farm inputs	
Fertilizer expense	$/ag acre
Manure acres	% ag acres
Chemical expense	$/ag acre
Irrigation	% ag acres
Labor	*n*/ag acre
Machinery	$/ag acre
Land use	
% cropland	% cty
% pastureland (excluding cropland)	% cty
Assistance & income	
Commodity sales	$/operation
Government programs	$/operation
Soil characteristics	
Topsoil gravel content	%vol.
Topsoil sand fraction	% wt.
Topsoil silt fraction	% wt.
Topsoil reference bulk density	Kg/dm3
Topsoil organic carbon	% weight
Subpsoil pH (H2O)	$-\log(H^+)$
Topsoil CEC (clay)	Cmol/kg

Topsoil CEC (soil)	Cmol/kg
Topsoil calcium carbonate	% weight
Topsoil gypsum	% weight
Topsoil sodicity (ESP)	%
Topsoil salinity (Elco)	dS/m
Climate	
Mean annual temperature	°C
Mean diurnal range	°C
Temperature seasonality	sd*100
Mean temperature of wettest quarter	°C
Mean temperature of driest quarter	°C
Mean temperature of warmest quarter	°C
Total (annual) precipitation	mm
Precipitation seasonality	coefficient
Precipitation of warmest quarter	mm

While this dataset contains a wide range of variables that are openly and reliably accessible, they are far from a comprehensive list of the variables we know are key to U.S. agricultural production. They omit key demographic factors (e.g., race and ethnicity of both farmers and farmworkers), financial factors (e.g., corporate revenue and influence), and other important ecological factors (e.g., topography). These omissions limit our ability to build models that *explicitly* include sociopolitical processes such as Indigenous land dispossession and knowledge appropriation (Caradonna and Apffel-Marglin, 2018; Dunbar-Ortiz, 2014), racial discrimination (Ayazi and Elsheikh, 2015; Minkoff-Zern and Sloat, 2017), dismissal of queer rural identities (Dentzman et al., 2020), and corporate power over seeds, land, and trade markets (Baines, 2015; Clapp and

Purugganan, 2020). However, such data have not been systematically or reliably collected for national or sub-national representativeness.

Nonetheless, the predictors in our dataset do gauge several important factors that both drive current sociopolitical contexts and represent past sociopolitical forces. These include: 1) reliance on external chemical and mechanical inputs (farm inputs); 2) binary gender-based differences in farm management (% acres operated by female/male farmers) in light of historical inequities in U.S. agricultural land access for women (Carter, 2017); 3) the importance of land ownership (land tenure) and related experience (on-farm experience) in the context of the systematic exclusion of marginalized farmers and farmworkers in achieving such tenure and experience (Calo and De Master, 2016); 4) migrant and non-migrant farmworkers (number of laborers), particularly considering their inequitable legal representation and treatment (Soper, 2020), and 5) the significance of commodity production (commodity sales) and government assistance (government programs) as representations of the commodification and expansion of U.S. production.

2.2. Response variables

The response variables measure agricultural land use diversity through three metrics, computed using only agricultural land pixels from the USDA NASS Cropland Data Layer (CDL) (USDA NASS, 2020) and aggregated for every county in the coterminous U.S.: Shannon's diversity index (SDI), Simpson's diversity index (SIDI), and Richness (RICH). SDI is one of the most common measures of landscape diversity, measured as the proportional abundance of each land use category in a county (Aguilar et al., 2015; Burchfield et al., 2019; Goslee, 2020; Gustafson, 1998). SIDI measures the probability that two random pixels (in the case of CDL data, 30-meter pixels) comprise different land uses and is less affected by rare land use categories than the SDI. Finally, RICH measures the number of agricultural land use categories (see Appendix B, SI Table 2 for full descriptions). These metrics operationalize crop diversity as both configurational (i.e., how much space each land use comprises) and compositional (i.e., what each land use is), accounting for spatial but not temporal variation within a given year.

2.2.1. Reclassification of Cropland Data Layer

While the overall cropland classification accuracy for the CDL dataset is notably high (89.4% in 2012 and 82.9% in 2017) (USDA NASS, 2021), crop- and region-specific classification accuracy rates are notably low (Reitsma et al., 2016). To address these error rates, we grouped functional crops together into broader categories – an approach recommended by Lark et al. (2017) – to improve data reliability. Broader categories were defined by the U.S. National Vegetation Classification (USNVC) database within the Agricultural and Developed Vegetation world formation type (Faber-Langendoen et al., 2016) (Appendix B, SI Table 3). With this reclassification, we recalculated SDI, SIDI, and RICH for final analyses.

2.2.2. Bootstrap sensitivity analysis

Current approaches for estimating landscape diversity do not account for differences in the percentage of land devoted to agricultural land use. For example, prior to reclassification, San Francisco County, CA has only 39 pixels (30m resolution) devoted to agricultural use, whereas Tioga County, PA has more than a half-million agricultural pixels. Both counties have an SDI score of 0.52, but the estimate for Tioga County is more reliable given its larger agricultural land area. Thus, we conducted a bootstrap sensitivity analysis (Efron, 1979) of the estimated diversity scores for each county. This analysis samples, with replacement, the parcels of agricultural land within each county. Each bootstrap sample is the same size as the original sample with some observations appearing more than once, and others not at all. In practice, roughly two-thirds of the original observations are represented in each bootstrap sample, and diversity scores are estimated for 500 bootstrap samples in each county. Figure 3-1 plots the standard deviation of the bootstrapped diversity scores against the number of pixels devoted to agricultural land.

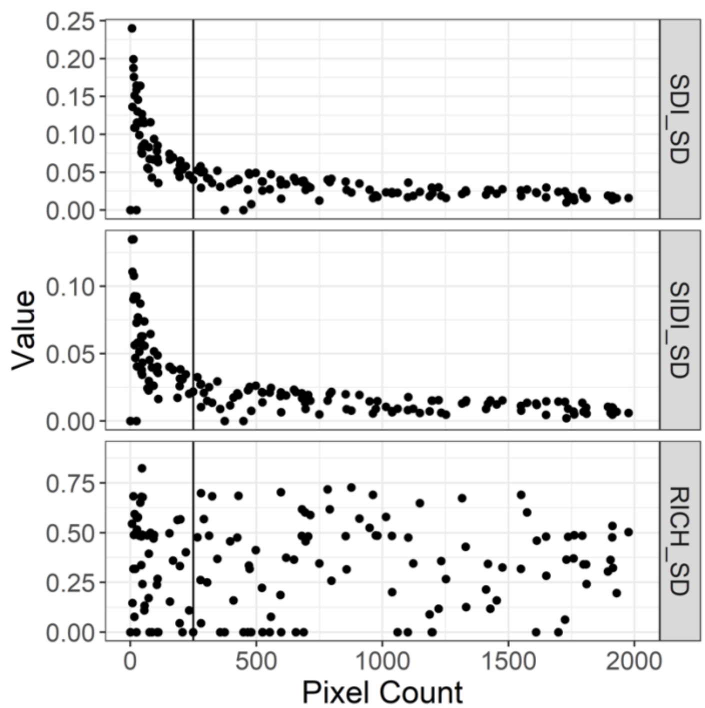


Figure 3-1: Standard deviation of bootstrapped SDI, SIDI, and RICH plotted against number of agricultural land pixels (vertical line indicates 250-pixel cutoff).

As expected, the sensitivity of SDI and SIDI are highly related to the number of agricultural pixels in each county. The standard deviation of the bootstrap diversity metrics levels out at roughly 250 pixels, so we removed any county with less than 250 pixels of agricultural land from our analyses. A good portion of these counties, unsurprisingly, already had missing values for the Census data. In total, a 250-pixel cutoff removed 39 counties for 2012 and 10 counties for 2017 after variable selection, imputation, and row-wise deletion. Of the 3,108 total initial U.S. counties, our final dataset included 2,874 counties for 2012 and 2,903 for 2017.

2.3. Analysis

First, we examined the distribution each response variable. SIDI was heavily skewed to the left, while SDI and RICH were normally distributed. To preserve interpretability of model results, and since RF does not make any assumptions about the distribution of the data, we made no transformation of the three response variables.

We then divided counties into Farm Resource Regions (FRR) as defined by the USDA Economic Research Service (ERS) (Figure 3-2). These regions reflect geographic specialization of agricultural production at the county-scale as determined by a cluster analysis of four other agricultural land use classifications: 1) NASS Crop Reporting Districts, 2) Land Resource Regions, 3) County Clusters of U.S. farm characteristics, and 4) outdated USDA Farm Production Regions (ERS, 2000).

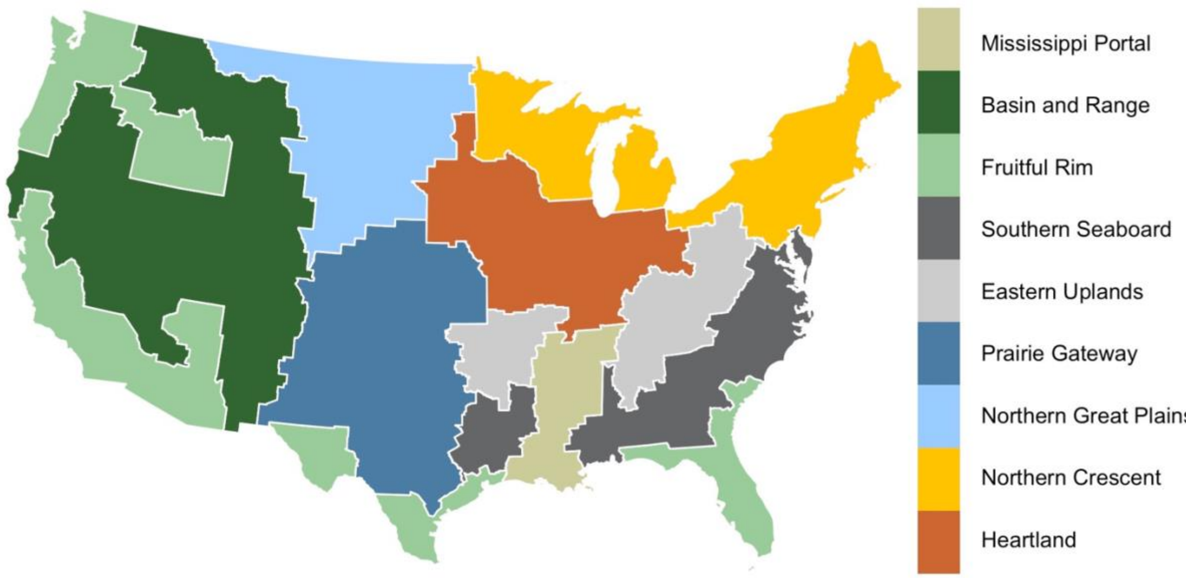


*Figure 3-2***:** Farm Resource Region (FRR) Designations, reprinted from Spangler et al. (2020)

Using the randomForest package (Liaw and Wiener, 2002) in R (R Core Team, 2020), we built an RF regression model for all three response variables in 2012 and 2017 using all counties for each FRR (i.e., 3 models for each of the 9 FRRs in 2 different years, totaling 54 RF models). RF regression is a particularly adept method at handling complex, non-linear interactions among predictors with large datasets, and it does not require any distributional assumptions about the data. It has been used to accurately predict regional and global crop yields (Jeong et al., 2016), as well as regional crop diversity (Goslee, 2020).

Another attractive feature of RF modeling is that it provides accurate models without excessive tuning of hyperparameters. However, Grömping (2009) states that the number of trees required for stable variable importance measures are typically more than those required for accurate predictions. Further, Probst et al. (2019) indicates that the stability of variable importance measures only increases as the number of trees in the forest increases. As such, we used 2,000 trees per forest – four times the default value – to achieve stability without compromising accuracy. Variable importance measures were also shown to be insensitive to a doubling of the default value of mtry – the number of variables considered for splitting at each node of the tree. Given this insensitivity, all regional random forest models use default hyper-parameters with a fourfold increase in the number of trees fit in each model.

From each model, we assessed out-of-bag (OOB) percent variance explained from the full model, as opposed to cross-validated error, because we are more interested in variable importance than predictive accuracy. We use permutation-based random forest variable importance (Breiman, 2001) to compare the relative importance of the explanatory variables in each agricultural region. These relative measures are calculated by dividing the importance measures of each region by the maximum importance measure in each region. We selected this measure given its widespread acceptance and use, though there are many variations of this variable importance approach (Wei et al., 2015). Some of these variations are intended to address introduced bias when simultaneously considering categorical and quantitative predictor variables, though these concerns are mitigated when, as in our case, all explanatory variables are quantitative (Strobl et al., 2007).

We also assessed partial dependence of several of the most consistently important variables across regions from different predictor categories. Partial dependence plots are one way to visualize the marginal influence of a variable with a precedence for use in ecology (Cutler et al., 2007). These plots visualize the effect of a single variable on the prediction of diversity after accounting for the average effects of all other variables

(Friedman et al., 2001). While such plots are powerful ways to visualize potentially non-linear influences of a variable across its range, they are limited in their ability to visualize variable interactions. We focused on six variables that were, consistently the most strongly predictive of diversity across regions: 1) temperature seasonality, 2) precipitation seasonality, 3) percent cropland, 4) percent pastureland, 5) chemical input, and 6) fertilizer input.

3. Results

We focus our results on SDI – the most widely used metric of agricultural diversity – and on 2017 – the most recently available year for Census of Agriculture data. Results from our other two response variables, and from 2012, are included in Supplemental Information (SI); the results of these analyses are consistent with our findings for SDI in 2017. First, we present summary statistics delineated by Farm FRR. We then provide the results of the regional RF regression models, specifically 1) how variables most strongly associated with agricultural diversity (variable importance) vary across regions, and 2) how these variables differentially influence regional diversity (functional relationships of key variables). We conclude by discussing the implications of these models and by contextualizing them within broader conversations about agricultural diversification.

3.1. Descriptive statistics

Mean regional SDI for 2017 ranges between 0.81 and 1.19 for 2017, with the lowest mean value in the Eastern Uplands (0.81) and the highest in the Northern Great

Plains (1.19) (Table 3-2; see Appendix B, SI Table 4 for 2012 data). Unsurprisingly, the Heartland region, which has the greatest number of counties (540), has a low average SDI (0.91) as well as a low standard deviation (0.16), indicating that this region is both agriculturally less diverse than most other regions and counties therewithin are more homogenous. The Mississippi Portal is the smallest region (152 counties) and has both a low SDI and standard deviation value. Like the Heartland, it is comparatively less diverse and more homogenous than other regions, particularly due to its small geographic area and a regional commodity focus on cotton, rice, and soybeans. The Fruitful Rim and Northern Crescent have comparatively high mean SDI values (1.08 and 1.11, respectively) and high standard deviations across counties (0.42 and 0.35, respectively). These divergences illustrate how landscapes within diverse regions have a wider range of heterogeneous farming systems (e.g., high-end vegetable, fruit, and nut production in California) across counties than less diverse regions.

Table 3-2: Summary statistics by FRR in 2017

FRR	# of counties	Mean SDI value	Standard deviation of SDI
Heartland	540	0.91	0.16
Northern Crescent	388	1.11	0.35
Northern Great Plains	175	1.19	0.12
Prairie Gateway	373	0.97	0.29
Eastern Uplands	394	0.81	0.45
Southern Seaboard	461	0.94	0.36
Fruitful Rim	251	1.08	0.42

Basin and Range	169	0.87	0.38
Mississippi Portal	152	0.86	0.22

3.2. Variable importance across regions

The relative importance of variable categories is consistent across regions (Figure 3-3), with climate characteristics, farm inputs, and land use being the strongest predictors of SDI. This is also true for SIDI and RICH in 2017 (see Appendix B, SI Figures 3A and 3B) and for all three response variables in 2012 (Appendix B, SI Figures 4A-4C). In the context of these models, soil characteristics, assistance and income, and farm(er) characteristics are less important predictors of regional agricultural diversity.

Although the variable categories predictive of diversity are consistent across regions, clear differences exist across regions regarding the distribution of variable importance. For regions such as the Northern Great Plains, specific climate variables (e.g., temperature seasonality) are substantially more important than most other variables in predicting SDI. This is also true for regions like the Northern Crescent, where farm input variables (e.g., chemical inputs) explain the majority of SDI variance. However, for the Heartland and Southern Seaboard, predictive importance is distributed more evenly across predictors. For these regions with more evenly distributed variable importance, soil and farm(er) characteristics are similarly important to climate, inputs, and land use, placing less predictive power on any one variable category.

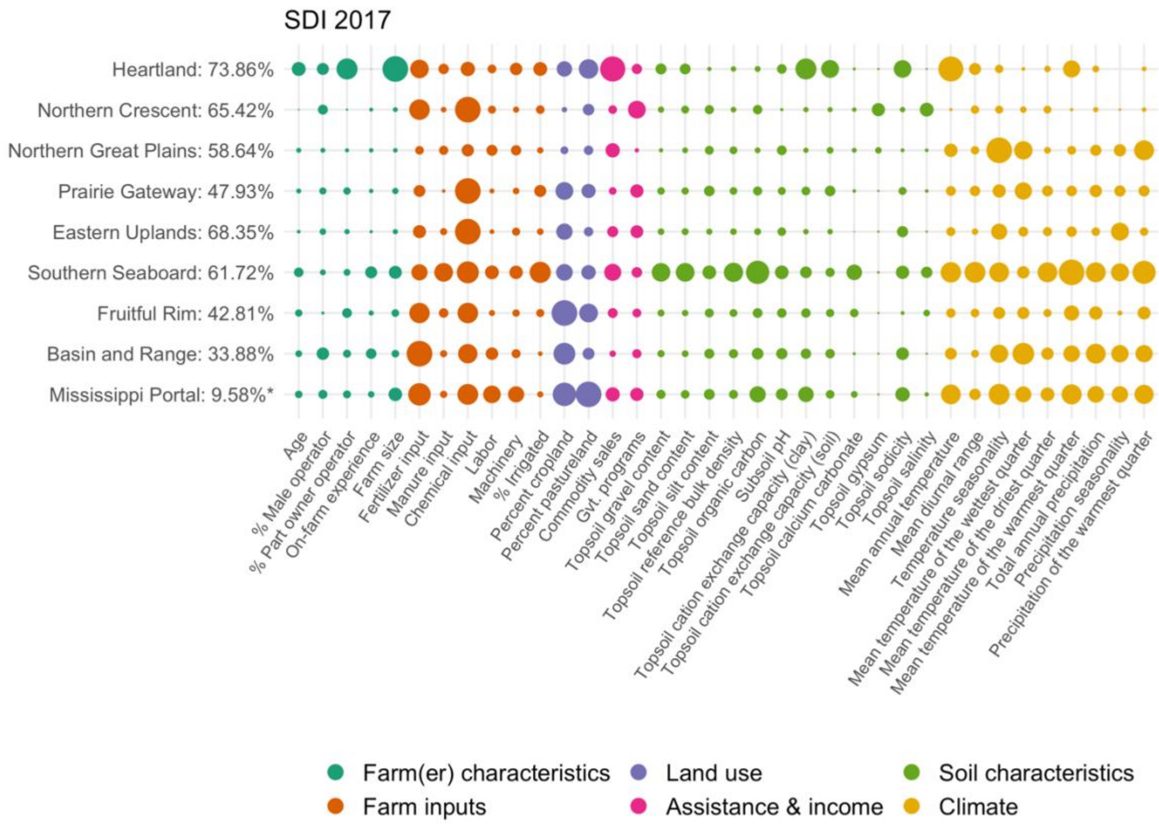


Figure 3-3: Variable importance by FRR for SDI in 2017. The size of the bubble indicates variable importance: the most important variables are the largest bubbles, and the size of the bubbles in each region are standardized by the maximum importance measure in each region **The model for the Mississippi Portal only explains 9.58% of variance. We still included these results for consistency across models, but these results are not reliable.*

In addition, model performance varies regionally. The two regions with the lowest mean SDI – the Heartland and Eastern Uplands – exhibit the highest percentage of variance explained (roughly 74% and 68%, respectively). This points to the ways that less diverse landscapes are easier to model and predict, particularly at a broader regional level. Nonetheless, the Northern Great Plains and Northern Crescent exhibit high average SDI values and comparatively high model performance (roughly 59% and 65% variance explained respectively). Importantly, the Mississippi Portal, one of the least diverse regions, exhibited an unreliably low model performance of less than 10% variance explained. This highlights the importance of intra-regional dynamics that are difficult to consistently capture at larger spatial scales and the data-hungry nature of RF modeling.

3.3. Functional relationships of key variables

The partial dependence plots of several variables that were consistently important (Figures 3-4 – 3-7) show the diverse ways that farm inputs, climate, and land use influence regional diversity, emphasizing the presence of regionally specific drivers of agricultural production. First, consider the overall importance of climate in predicting crop diversity; Figures 3-4A and 3-4B illustrate the functional relationships between temperature seasonality (A) and precipitation seasonality (B) with SDI. As temperature seasonality (TS) increases (or as temperatures become more variable) in the Eastern Uplands and Fruitful Rim, SDI sharply increases and then plateaus, indicating wide temperature ranges across counties in each region that influence the diversity of crops grown. Yet, all other regions exhibit a slightly negative or neutral trend between TS and SDI: as TS increases, SDI decreases or stays the same, indicating that places with more seasonal temperatures do not inherently support greater crop diversity. A similar trend is observable with precipitation seasonality (PS) (or the variability of precipitation by season). For the Eastern Uplands, as PS increases, so does diversity; this is particularly true for counties well above the regional mean PS value. This means that counties in this region with the highest PS are much more likely to support a greater diversity of crops than those with less PS. For the Northern Crescent and Southern Seaboard, there is a slightly positive effect on SDI as PS increases; this positive relationship occurs for the counties with an average PS value. For all other regions, there is no observable positive or negative effect from PS, emphasizing how precipitation, as one of many climatic factors, creates baseline conditions for agricultural production and possibilities for diversification, as opposed to being a driver of diversification.

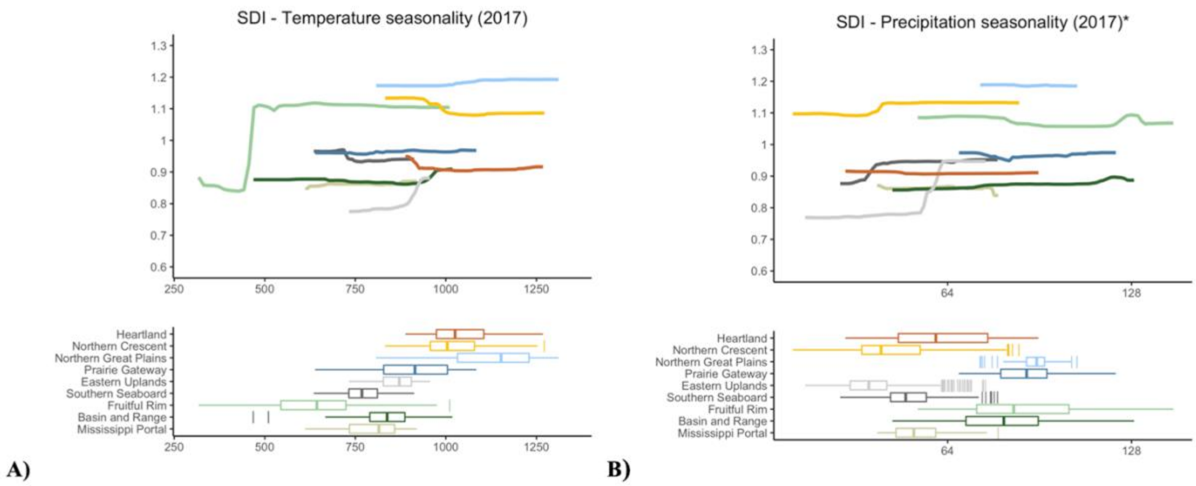


Figure 3-4: Partial dependence plots of temperature seasonality (TS) (4A) and precipitation seasonality (PS) (4B) as a function of SDI in 2017

Percent cropland is a highly predictive factor of SDI that exhibits different functional relationships across regions (Figure 3-5A). For the Northern Crescent, Eastern Uplands, and Southern Seaboard regions, there are discernable positive relationships between percent cropland and SDI, where counties with more croplands show higher levels of agricultural diversity. These positive relationships occur for the counties with percent cropland close to the regional mean. In the Heartland and the Prairie Gateway, the opposite is true: for counties with percent cropland close to the regional mean, SDI begins to decrease. Moreover, counties in the Heartland have the highest average percent cropland of any region (~80%), reflecting its high concentration of simplified crop production. For the Fruitful Rim, Basin and Range, and Prairie Gateway, there is no effect between increasing percent cropland and SDI. This neutral relationship indicates that percent cropland is a highly predictive yet intrinsic factor in determining the diversity of crops grown in each region, and, thus, the directionality of its influence is indeterminable.

Percent pastureland exhibits a neutral relationship in predicting SDI, with a few exceptions. For most regions, such as the Northern Crescent, Prairie Gateway, and Fruitful Rim, the effect of pastureland on predicting agricultural diversity is neither positive nor negative. Like cropland presence, the presence of pastureland within these counties is intrinsically important to the diversity of crops grown but does not increase or decrease such diversity. However, in regions such as the Heartland, Northern Great Plains, and Basin and Range, counties close to the regional mean of percent pastureland begin to increase in crop diversity until they eventually plateau again. This is particularly interesting for the Basin and Range, a region with the lowest average percent cropland and highest percent pastureland, indicating that pasture production is a strong driver of regional crop diversity. The only region where percent pastureland has a negative effect on SDI is the Southern Seaboard.

Crop diversity in all regions is highly responsive to expenditures on fertilizers and chemicals but quickly experiences diminishing returns. Moreover, the threshold of these diminishing returns is different for every region (Figure 3-6). Most notably, the Heartland is the region with both the highest average chemical and fertilizer expenses per acre; increasing chemical and fertilizer expenses both have an observably negative relationship with SDI. For counties at the regional average of input use, SDI begins to decrease and quickly plateaus; in other words, higher input use is associated with *decreasing* crop diversity.

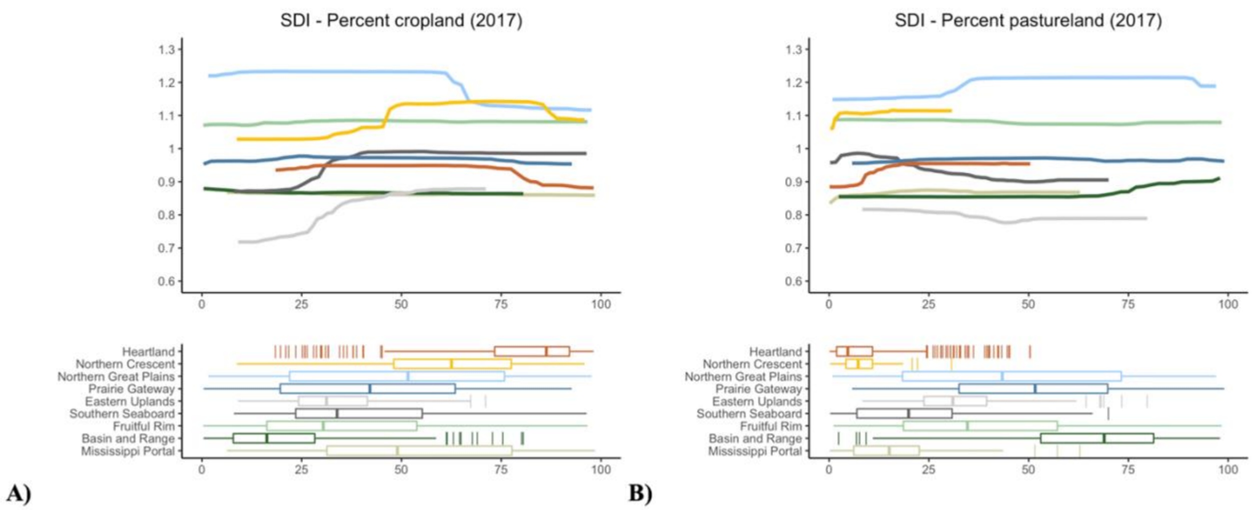


Figure 3-5: Partial dependence plots of percent cropland (5A) and percent pastureland (5B) as a function of SDI in 2017

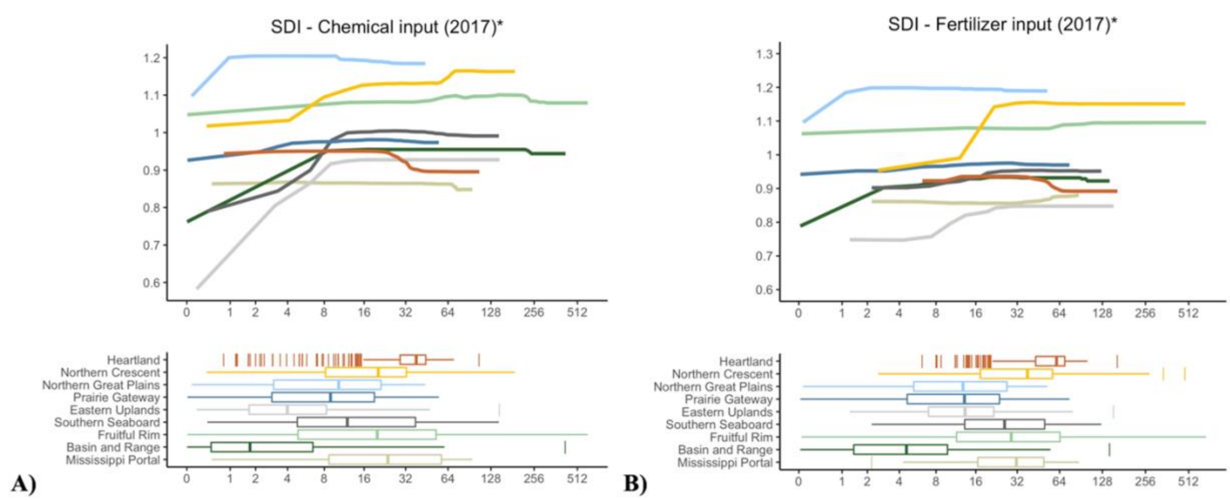


Figure 3-6: Partial dependence plots of chemical input (6A) and fertilizer (6B) as a function of SDI in 2017 **Data are visualized on the log scale to better visualize the lower end of the highly skewed data. Notice that each tick mark on the x axis represents a doubling of the previous value, rather than a fixed increment between values.*

Contrastingly, the Eastern Uplands, Basin and Range, and Northern Crescent regions exhibit the sharpest increase in crop diversity as chemical and fertilizer input use increases. These increases occur for counties close to the regional mean of input use and then plateaus, meaning that counties with the highest input use do not support greater crop diversity than those with average input use. Other regions, namely the Fruitful Rim and Northern Great Plains, consistently include counties with the highest SDI values and exhibit a neutral response to increasing input use, suggesting that their diversity is not dependent on their use of agricultural inputs.

4. Discussion

Our results show that factors most strongly predictive of agricultural diversity across U.S. landscapes operate distinctly at a regional level. These distinct regional relationships contribute to path dependencies that present resistance to enhancing agrobiodiversity in U.S. agriculture. First, major U.S. regions exhibit significantly different levels of crop diversity, where the most diverse regions support a wider array of farming systems that deviate from the average, and the least diverse support more homogenous systems. Second, climate, land use norms, and farm inputs are consistently the most important categories for predicting agricultural diversity across regions; variability exists in the relative regional importance of variables within these categories, however. Our models also perform differently, pointing to the existence of distinct intra-regional dynamics that we cannot explain at the regional level with the data we have included in these analyses. These intra-regional dynamics are evident in the various functional relationships that exist between key climate, land use, and input variables for predicting diversity.

Regional differences in agricultural diversity, paired with the importance of climate, land use, and farm input variables in predicting such diversity, highlight the need to consider the regional scale and its influence on path dependencies in U.S. agriculture. Our models illustrate clear and consistent trends that operate within and across nine U.S. regions that may not be evident at the micro (field or farm) or macro (national or international) scales. For example, soil metrics did not prove to be as important a biophysical predictor as climate in our regional models, despite soil health and management being strong factors in understanding crop suitability (Zabel et al., 2014) and farmer decision-making (G. Roesch-McNally et al., 2018) at the field scale. Furthermore, federal subsidy assistance and policies strongly dictate domestic and international markets, commodity supply chains, as well as farmer livelihoods and adaptation (Annan and Schlenker, 2015; Graddy-Lovelace, 2017; Graddy-Lovelace and Diamond, 2017), yet were not comparatively important in predicting regional crop diversity. Thus, considering multiple scales of interaction is crucial to a deeper understanding of what constrains and enables processes of diversification.

Climate characteristics play a pivotal role in defining the biophysical possibilities of regional crop and commodity production. Metrics of seasonal precipitation and temperature are consistently important factors in predicting agricultural diversity within and across regional landscapes. The strong importance of climate in predicting agricultural diversity underscores the importance of understanding how climate affects what farmers can reasonably do within a given landscape. This is particularly salient considering how climate change may shift the suitability of landscapes for major crops northward (Lant et al., 2016), increase the sensitivity of the agricultural economy (Liang et al., 2017), and contribute to greater yield variability globally (Ray et al., 2015). Thus, any volatility in current and future regional climates will likely have a strong effect on the potential for, and success of, agricultural diversification.

The importance of land use patterns, namely the presence and concentration of cropland and pastureland, in predicting agricultural diversity across regions emphasizes how past land use reinforces current and future land uses. The importance of these factors captures the path dependencies that have determined where and why agricultural land is located and managed. Our results show the regional specialization and intensification of commodity production, where agricultural landscapes are either dominated by crop production or rangelands, never equally covered by both (Spangler et al., 2020). The negative effect of increasing percent cropland on diversity in regions already largely dominated by cropland (e.g., Heartland) accentuates the self-reinforcing cycle of intensified commodity production; in this region, cropland expansion has driven and continues to drive the simplification of these landscapes (Hart, 1986, 2001; G. E. Roesch-McNally et al., 2018). This history exacerbates the sociopolitical and ecological challenges of transitioning these landscapes toward alternative production systems (Lawler et al., 2014). Yet, for other regions less dominated by cropland (e.g., Eastern Uplands, Southern Seaboard, and Northern Crescent), the relationship between percent cropland and diversity is slightly positive. This finding presents broad evidence that allocating more land to crop production in *certain* regions may support greater crop diversity, provided such expansion is intentionally integrated with other socioecological benefits to the landscape (Kremen, 2015; Kremen and Merenlender, 2018). This is also true for increasing pastureland in regions such as the Basin and Range and Northern Great Plains, considering recent research that supports the potential for integrated crop-livestock systems as a viable pathway toward enhancing agrobiodiversity (Bonaudo et al., 2014; Franzluebbers et al., 2014; Olmstead and Brummer, 2008; Poffenbarger et al., 2017).

Finally, chemical and fertilizer use operate as technological lock-ins, extending the viability of simplified systems. We know that increasing input use is an unviable and unsustainable pathway toward agricultural diversification. Mounting evidence illustrates the harmful environmental and social externalities of our increased reliance on external inputs to agriculture, including Gulf of Mexico hypoxia, nutrient runoff, decreased air quality (Prokopy et al., 2020), declines in pollinator abundance and diversity (Sponsler et al., 2019), and even decreased yields (Burchfield and Nelson, 2021). Our results show diminishing diversity returns from increased input expenditure, where crop diversity in many regions responded positively to increasing chemical and fertilizer expenditures initially, but quickly plateaued. This trend suggests that initial increases in crop diversity rely, in part, on increasing fertilizer and chemical inputs, which is consistent with the well-documented reliance on inputs throughout commercial annual cropping systems in the U.S. (Culman et al., 2010; De Notaris et al., 2018; Gardner and Drinkwater, 2009). However, the diversity plateau in the fertilizer and chemical partial dependence plots provides compelling evidence that diversification beyond the regional status quo will not be driven by greater reliance on chemical and fertilizer use. Furthermore, for the Heartland, where intensified annual commodity production is most heavily concentrated

(Hart, 1986; Hudson, 1994), the results suggest that excessive use of chemical and fertilizer use promote simplification and inhibit diversification of agricultural landscapes.

5. Future research

This study presents multiple future research directions. First, the definition of a region could be explored through various other regional boundaries to assess how this change in scale influences our results. Methodologically, regarding the bootstrap sensitivity analysis, we used a simple cutoff method to eliminate any counties below a threshold of reliability. One issue with a simple cutoff is that small changes to the boundary could potentially lead to large changes in the final outcomes. Therefore, future research could consider a weighting scheme that handles differences in the landscape metric sensitivities in a *continuous* way. Furthermore, it would be worthwhile to explore alternative methods and measures of variable importance to further corroborate the results discussed in this paper. Finally, there is strong potential for qualitative research to meaningfully build from these modeling efforts to more deeply contextualize how these regional path dependencies operate within and across rural communities and agricultural landscapes.

6. Conclusions

Developing pathways to alternative agricultural systems requires a fundamental reckoning with current path dependencies in U.S. agriculture. We show that these path dependencies, and the associated lock-ins of current agricultural land use, operate distinctly within and across U.S. regions. The consistent importance of biophysical and nonactionable factors, like climate, and actionable factors, such as land use and farm inputs, as highly predictive regional factors exemplify how these factors are deeply intertwined with the diversity (or lack thereof) of agricultural landscapes. These important factors, and their functional relationships with crop diversity, also highlight how *resistant* the systems within each region may be to alternative pathways and adaptation.

Imagining alternative, diversified agricultural systems – an increasingly urgent necessity in the face of a changing climate and widening sociopolitical inequity – requires a fundamental shift away from regional pathways that lock farmers and farmworkers into maladaptive systems. These pathways reinforce the current U.S. productivist paradigm and the structural barriers to farmer adoption of alternative management strategies. We can begin this shift, in part, by developing regionally specific agricultural policies that: 1) respond to contextualized biophysical constraints, 2) consider prior and current land use dynamics and the ways they shape future land use, and 3) support more resilient agricultural systems that are less reliant on agrichemical inputs to maintain productivity. We call for more research that explicitly considers the multiple scales of interaction that constrain and enable the efficacy and implementation of these regional policies, from micro- to macroscales. This research will facilitate the critical and intentional contextualization of how farmers and farmworkers across the U.S. operate within, and respond to, heterogenous biophysical and sociopolitical contexts. Agrobiodiversity increases system resilience and has positive boundary effects for neighboring farm(er)s and ecological systems; by more appropriately addressing regional drivers of agricultural land use, with an eye towards future cropscapes, we can be sensitive to farm(er) concerns and needs while breaking current path dependencies and creating more resilient and responsive U.S. agricultural landscapes.

References

Abson, D.J., Fraser, E.D., Benton, T.G., 2013. Landscape diversity and the resilience of agricultural returns: a portfolio analysis of land-use patterns and economic returns from lowland agriculture. Agriculture & Food Security 2, 2. https://doi.org/10.1186/2048-7010-2-2

Aguilar, J., Gramig, G.G., Hendrickson, J.R., Archer, D.W., Forcella, F., Liebig, M.A., 2015. Crop species diversity changes in the United States: 1978–2012. PLOS ONE 10, e0136580. https://doi.org/10.1371/journal.pone.0136580

Aizen, M.A., Aguiar, S., Biesmeijer, J.C., Garibaldi, L.A., Inouye, D.W., Jung, C., Martins, D.J., Medel, R., Morales, C.L., Ngo, H., Pauw, A., Paxton, R.J., Sáez, A., Seymour, C.L., 2019. Global agricultural productivity is threatened by increasing pollinator dependence without a parallel increase in crop diversification. Glob Change Biol 25, 3516–3527. https://doi.org/10.1111/gcb.14736

Albizua, A., Williams, A., Hedlund, K., Pascual, U., 2015. Crop rotations including ley and manure can promote ecosystem services in conventional farming systems. Applied Soil Ecology 95, 54–61. https://doi.org/10.1016/j.apsoil.2015.06.003

Altieri, M.A., Nicholls, C.I., 2009. Agroecology, small farms, and food sovereignty. Monthly Review 61, 102. https://doi.org/10.14452/MR-061-03-2009-07_8

Anderson, C.R., Bruil, J., Chappell, M.J., Kiss, C., Pimbert, M.P., 2019. From Transition to Domains of Transformation: Getting to Sustainable and Just Food Systems through Agroecology. Sustainability 11, 5272. https://doi.org/10.3390/su11195272

Annan, F., Schlenker, W., 2015. Federal crop insurance and the disincentive to adapt to extreme heat. American Economic Review 105, 262–266. https://doi.org/10.1257/aer.p20151031

Auch, R.F., Xian, G., Laingen, C.R., Sayler, K.L., Reker, R.R., 2018. Human drivers, biophysical changes, and climatic variation affecting contemporary cropping proportions in the northern prairie of the U.S. Journal of Land Use Science 13, 32–58. https://doi.org/10.1080/1747423X.2017.1413433

Ayazi, H., Elsheikh, E., 2015. The Farm Bill: Corporate Power and Structural Racialization in the United States Food System. Haas Institute for a Fair and Inclusive Society at the University of California Berkeley, Berkeley, CA.

Baines, J., 2015. Fuel, feed and the corporate restructuring of the food regime. The Journal of Peasant Studies 42, 295–321. https://doi.org/10.1080/03066150.2014.970534

Barnett, J., Evans, L.S., Gross, C., Kiem, A.S., Kingsford, R.T., Palutikof, J.P., Pickering, C.M., Smithers, S.G., 2015. From barriers to limits to climate change adaptation: path dependency and the speed of change. E&S 20, art5. https://doi.org/10.5751/ES-07698-200305

Benton, T.G., 2012. Managing agricultural landscapes for production of multiple services: the policy challenge. PAGRI 1, 12.

Berendsen, R.L., Pieterse, C.M.J., Bakker, P.A.H.M., 2012. The rhizosphere microbiome and plant health. Trends in Plant Science 17, 478–486. https://doi.org/10.1016/j.tplants.2012.04.001

Biau, G., Scornet, E., 2016. A random forest guided tour. TEST 25, 197–227. https://doi.org/10.1007/s11749-016-0481-7

Birkhofer, K., Andersson, G.K.S., Bengtsson, J., Bommarco, R., Dänhardt, J., Ekbom, B., Ekroos, J., Hahn, T., Hedlund, K., Jönsson, A.M., Lindborg, R., Olsson, O., Rader, R., Rusch, A., Stjernman, M., Williams, A., Smith, H.G., 2018. Relationships between multiple biodiversity components and ecosystem services along a landscape complexity gradient. Biological Conservation 218, 247–253. https://doi.org/10.1016/j.biocon.2017.12.027

Bommarco, R., Kleijn, D., Potts, S.G., 2013. Ecological intensification: harnessing ecosystem services for food security. Trends in Ecology & Evolution 28, 230–238. https://doi.org/10.1016/j.tree.2012.10.012

Bonaudo, T., Bendahan, A.B., Sabatier, R., Ryschawy, J., Bellon, S., Leger, F., Magda, D., Tichit, M., 2014. Agroecological principles for the redesign of integrated crop–livestock systems. European Journal of Agronomy 57, 43–51. https://doi.org/10.1016/j.eja.2013.09.010

Bowman, M.S., Zilberman, D., 2013. Economic Factors Affecting Diversified Farming Systems. E&S 18, art33. https://doi.org/10.5751/ES-05574-180133

Breiman, L., 2001. Statistical Modeling: The Two Cultures. Statistical Science 16, 199–231.

Brown, J.F., Howard, D.M., Shrestha, D., Benedict, T.D., 2019. Moderate Resolution Imaging Spectroradiometer (MODIS) Irrigated Agriculture Datasets for the Conterminous United States (MIrAD-US): U.S. Geological Survey data release [WWW Document]. USGS. URL https://doi.org/10.5066/P9NA3EO8.

Burchfield, E.K., Nelson, K.S., 2021. Agricultural yield geographies in the United States. Environ. Res. Lett. https://doi.org/10.1088/1748-9326/abe88d

Burchfield, E.K., Nelson, K.S., Spangler, K., 2019. The impact of agricultural landscape diversification on U.S. crop production. Agriculture, Ecosystems & Environment 285, 106615. https://doi.org/10.1016/j.agee.2019.106615

Burchfield, E.K., Schumacher, B.L., 2020. Bright spots in U.S. corn production. Environ. Res. Lett. 15, 104019. https://doi.org/10.1088/1748-9326/aba5b4

Calo, A., De Master, K., 2016. After the Incubator: Factors Impeding Land Access Along the Path from Farmworker to Proprietor. JAFSCD 1–17. https://doi.org/10.5304/jafscd.2016.062.018

Caradonna, J.L., Apffel-Marglin, F., 2018. The regenerated chacra of the Kichwa-Lamistas: an alternative to permaculture? AlterNative: An International Journal of Indigenous Peoples 14, 13–24. https://doi.org/10.1177/1177180117740708

Carter, A., 2017. Placeholders and changemakers: Women farmland owners navigating gendered expectations. Rural Sociology 82, 499–523. https://doi.org/10.1111/ruso.12131

Chaplin-Kramer, R., O'Rourke, M.E., Blitzer, E.J., Kremen, C., 2011. A meta-analysis of crop pest and natural enemy response to landscape complexity: Pest and natural enemy response to landscape complexity. Ecology Letters 14, 922–932. https://doi.org/10.1111/j.1461-0248.2011.01642.x

Chhetri, N.B., Easterling, W.E., Terando, A., Mearns, L., 2010. Modeling Path Dependence in Agricultural Adaptation to Climate Variability and Change. Annals of the Association of American Geographers 100, 894–907. https://doi.org/10.1080/00045608.2010.500547

Clapp, J., 2018. Mega-Mergers on the Menu: Corporate Concentration and the Politics of Sustainability in the Global Food System. Global Environmental Politics 18, 12–33. https://doi.org/10.1162/glep_a_00454

Clapp, J., Purugganan, J., 2020. Contextualizing corporate control in the agrifood and extractive sectors. Globalizations 17, 1265–1275. https://doi.org/10.1080/14747731.2020.1783814

Coomes, O.T., Barham, B.L., MacDonald, G.K., Ramankutty, N., Chavas, J.-P., 2019. Leveraging total factor productivity growth for sustainable and resilient farming. Nat Sustain 2, 22–28. https://doi.org/10.1038/s41893-018-0200-3

Cowan, J., 2020. Personal communication.

Culman, S.W., DuPont, S.T., Glover, J.D., Buckley, D.H., Fick, G.W., Ferris, H., Crews, T.E., 2010. Long-term impacts of high-input annual cropping and unfertilized perennial grass production on soil properties and belowground food webs in Kansas, USA. Agriculture, Ecosystems & Environment 137, 13–24. https://doi.org/10.1016/j.agee.2009.11.008

Cutler, D.R., Edwards, T.C., Beard, K.H., Cutler, A., Hess, K.T., Gibson, J., Lawler, J.J., 2007. Random Forests for Classification in Ecology. Ecology 88, 2783–2792. https://doi.org/10.1890/07-0539.1

De Notaris, C., Rasmussen, J., Sørensen, P., Olesen, J.E., 2018. Nitrogen leaching: A crop rotation perspective on the effect of N surplus, field management and use of catch crops. Agriculture, Ecosystems & Environment 255, 1–11. https://doi.org/10.1016/j.agee.2017.12.009

Dentzman, K., Pilgeram, R., Lewin, P., Conley, K., 2020. Queer Farmers in the 2017 US

Census of Agriculture. Society & Natural Resources 1–21. https://doi.org/10.1080/08941920.2020.1806421

Duarte, G.T., Santos, P.M., Cornelissen, T.G., Ribeiro, M.C., Paglia, A.P., 2018. The effects of landscape patterns on ecosystem services: meta-analyses of landscape services. Landscape Ecology 33, 1247–1257. https://doi.org/10.1007/s10980-018-0673-5

Dunbar-Ortiz, R., 2014. An Indigenous Peoples' History of the United States. Beacon Press, Boston.

Ebabu, K., Tsunekawa, A., Haregeweyn, N., Adgo, E., Meshesha, D.T., Aklog, D., Masunaga, T., Tsubo, M., Sultan, D., Fenta, A.A., Yibeltal, M., 2020. Exploring the variability of soil properties as influenced by land use and management practices: A case study in the Upper Blue Nile basin, Ethiopia. Soil and Tillage Research 200, 104614. https://doi.org/10.1016/j.still.2020.104614

Efron, B., 1979. Bootstrap Methods: Another Look at the Jackknife. Ann. Statist. 7. https://doi.org/10.1214/aos/1176344552

ERS, 2019. Agricultural Productivity in the U.S. [WWW Document]. USDA Economic Research Service. URL https://www.ers.usda.gov/data-products/agricultural-productivity-in-the-us/ (accessed 3.30.19).

ERS, 2000. Farm Resource regions (Agricultural Information Bulletin No. 760). USDA Economic Research Service, Washington, DC.

Faber-Langendoen, D., Keeler-Wolf, T., Meidinger, D., Josse, C., Weakley, A., Tart, D., Navarro, G., Hoagland, B., Ponomarenko, S., Fults, G., Helmer, E., 2016. Classification and Description of World Formation Types (Gen. Tech. Rep. No. RMRS-GTR-346). Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Fagundes, C., Picciano, L., Tillman, W., Mleczko, J., Schwier, S., Graddy-Lovelace, G., Hall, F., Watson, T., 2019. Ecological costs of discrimination: racism, red cedar and resilience in farm bill conservation policy in Oklahoma. Renew. Agric. Food Syst. 1–15. https://doi.org/10.1017/S1742170519000322

Fischer, G., Nachtergaele, F., Prieler, S., van Velthuizen, H.T., Verelst, L., Wiberg, D., 2008. Global Agro-ecological Zones Assessment for Agriculture (No. GAEZ 2008). IIASA; FAO, Laxenburg, Austria; Rome, Italy.

Franzluebbers, A.J., Lemaire, G., de Faccio Carvalho, P.C., Sulc, R.M., Dedieu, B., 2014. Toward agricultural sustainability through integrated crop-livestock systems: Environmental outcomes. Agriculture, Ecosystems & Environment 190, 1–3. https://doi.org/10.1016/j.agee.2014.04.028

Friedman, J., Hastie, T., Tibshirani, R., 2001. The elements of statistical learning, 10th ed, Springer Series in Statistics. Springer, New York.

Gardiner, M.M., Landis, D.A., Gratton, C., DiFonzo, C.D., O’Neal, M., Chacon, J.M., Wayo, M.T., Schmidt, N.P., Mueller, E.E., Heimpel, G.E., 2009. Landscape diversity enhances biological control of an introduced crop pest in the north-central USA. Ecological Applications 19, 143–154. https://doi.org/10.1890/07-1265.1

Gardner, J.B., Drinkwater, L.E., 2009. The fate of nitrogen in grain cropping systems: a meta-analysis of 15N field experiments. Ecological Applications 19, 2167–2184. https://doi.org/10.1890/08-1122.1

Gaudin, A.C.M., Tolhurst, T.N., Ker, A.P., Janovicek, K., Tortora, C., Martin, R.C., Deen, W., 2015. Increasing crop diversity mitigates weather variations and improves yield stability. PLOS ONE 10, e0113261. https://doi.org/10.1371/journal.pone.0113261

Ghimire, R., Machado, S., Bista, P., 2018. Decline in soil organic carbon and nitrogen limits yield in wheat-fallow systems. Plant Soil 422, 423–435. https://doi.org/10.1007/s11104-017-3470-z

Gleissman, S., 2015. Agroecology: The ecology of sustainable food systems, 3rd ed. CRC Press, Boca Raton, FL.

Goslee, S.C., 2020. Drivers of Agricultural Diversity in the Contiguous United States. Front. Sustain. Food Syst. 4, 75. https://doi.org/10.3389/fsufs.2020.00075

Grab, H., Danforth, B., Poveda, K., Loeb, G., 2018. Landscape simplification reduces classical biological control and crop yield. Ecol Appl 28, 348–355. https://doi.org/10.1002/eap.1651

Graddy-Lovelace, G., 2017. The coloniality of US agricultural policy: articulating agrarian (in)justice. The Journal of Peasant Studies 44, 78–99. https://doi.org/10.1080/03066150.2016.1192133

Graddy-Lovelace, G., Diamond, A., 2017. From supply management to agricultural subsidies—and back again? The U.S. Farm Bill & agrarian (in)viability. Journal of Rural Studies 50, 70–83. https://doi.org/10.1016/j.jrurstud.2016.12.007

Grömping, U., 2009. Variable Importance Assessment in Regression: Linear Regression versus Random Forest. The American Statistician 63, 308–319. https://doi.org/10.1198/tast.2009.08199

Gustafson, E.J., 1998. Quantifying landscape spatial pattern: What is the state of the art? Ecosystems 1, 15.

Guzman, A., Chase, M., Kremen, C., 2019. On-Farm Diversification in an Agriculturally-Dominated Landscape Positively Influences Specialist Pollinators. Front. Sustain. Food Syst. 3, 87. https://doi.org/10.3389/fsufs.2019.00087

Hart, J.F., 2001. Half a Century of Cropland Change. Geographical Review 91, 525. https://doi.org/10.2307/3594739

Hart, J.F., 1986. Change in the Corn Belt. Geographical Review 76, 51.

https://doi.org/10.2307/214784

Hass, A.L., Kormann, U.G., Tscharntke, T., Clough, Y., Baillod, A.B., Sirami, C., Fahrig, L., Martin, J.-L., Baudry, J., Bertrand, C., Bosch, J., Brotons, L., Burel, F., Georges, R., Giralt, D., Marcos-García, M.Á., Ricarte, A., Siriwardena, G., Batáry, P., 2018. Landscape configurational heterogeneity by small-scale agriculture, not crop diversity, maintains pollinators and plant reproduction in western Europe. Proc. R. Soc. B 285, 20172242. https://doi.org/10.1098/rspb.2017.2242

Hauter, W., 2012. Foodopoly: The Battle Over the Future of Food and Farming in America. The New Press, New York.

Hendrickson, M.K., Howard, P.H., Miller, E.M., Constance, D.H., 2020. The food system: Concentration and its impacts. Family Farm Action Alliance.

Hijmans, R.J., 2017. Dismo package version 1.1-4 [WWW Document]. R. URL https://rdrr.io/cran/dismo/man/biovars.html (accessed 7.1.20).

Hudson, J.C., 1994. Making the Corn Belt: A Geographical History of Middle-Western Agriculture. Indiana University Press, Bloomington, IN.

iPES-FOOD, 2016. From uniformity to diversity: A paradigm shift from industrial agriculture to diversified agroecological systems. International Panel of Experts on Sustainable Food systems, Brussels, Belgium.

Jeong, J.H., Resop, J.P., Mueller, N.D., Fleisher, D.H., Yun, K., Butler, E.E., Timlin, D.J., Shim, K.-M., Gerber, J.S., Reddy, V.R., Kim, S.-H., 2016. Random Forests for Global and Regional Crop Yield Predictions. PLoS ONE 11, e0156571. https://doi.org/10.1371/journal.pone.0156571

Key, N., 2019. Farm size and productivity growth in the United States Corn Belt. Food Policy 84, 186–195. https://doi.org/10.1016/j.foodpol.2018.03.017

Kremen, C., 2015. Reframing the land-sparing/land-sharing debate for biodiversity conservation. Ann. N.Y. Acad. Sci. 1355, 52–76. https://doi.org/10.1111/nyas.12845

Kremen, C., Iles, A., Bacon, C., 2012. Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture. Ecology and Society 17. https://doi.org/10.5751/ES-05103-170444

Kremen, C., Merenlender, A.M., 2018. Landscapes that work for biodiversity and people. Science 362, eaau6020. https://doi.org/10.1126/science.aau6020

Landis, D.A., 2017. Designing agricultural landscapes for biodiversity-based ecosystem services. Basic and Applied Ecology 18, 1–12. https://doi.org/10.1016/j.baae.2016.07.005

Lant, C., Stoebner, T.J., Schoof, J.T., Crabb, B., 2016. The effect of climate change on rural land cover patterns in the Central United States. Climatic Change 138, 585–602. https://doi.org/10.1007/s10584-016-1738-6

Lark, T.J., Mueller, R.M., Johnson, D.M., Gibbs, H.K., 2017. Measuring land-use and land-cover change using the U.S. department of agriculture's cropland data layer: Cautions and recommendations. International Journal of Applied Earth Observation and Geoinformation 62, 224–235. https://doi.org/10.1016/j.jag.2017.06.007

Lawler, J.J., Lewis, D.J., Nelson, E., Plantinga, A.J., Polasky, S., Withey, J.C., Helmers, D.P., Martinuzzi, S., Pennington, D., Radeloff, V.C., 2014. Projected land-use change impacts on ecosystem services in the United States. Proceedings of the National Academy of Sciences 111, 7492–7497. https://doi.org/10.1073/pnas.1405557111

Li, M., Peterson, C.A., Tautges, N.E., Scow, K.M., Gaudin, A.C.M., 2019. Yields and resilience outcomes of organic, cover crop, and conventional practices in a Mediterranean climate. Sci Rep 9, 12283. https://doi.org/10.1038/s41598-019-48747-4

Liang, X.-Z., Wu, Y., Chambers, R.G., Schmoldt, D.L., Gao, W., Liu, C., Liu, Y.-A., Sun, C., Kennedy, J.A., 2017. Determining climate effects on US total agricultural productivity. Proceedings of the National Academy of Sciences 114, E2285–E2292. https://doi.org/10.1073/pnas.1615922114

Liaw, A., Wiener, M., 2002. Classification and Regression by randomForest 2, 5.

MacDonald, J.M., Hoppe, R.A., 2017. Large family farms continue to dominate U.S. agricultural production (Statistic: Farm Economy), Amber Waves. Economic Research Service.

Magrini, M.-B., Anton, M., Chardigny, J.-M., Duc, G., Duru, M., Jeuffroy, M.-H., Meynard, J.-M., Micard, V., Walrand, S., 2018. Pulses for Sustainability: Breaking Agriculture and Food Sectors Out of Lock-In. Front. Sustain. Food Syst. 2, 64. https://doi.org/10.3389/fsufs.2018.00064

Magrini, M.-B., Béfort, N., Nieddu, M., 2019. Technological Lock-In and Pathways for Crop Diversification in the Bio-Economy, in: Agroecosystem Diversity. Elsevier, pp. 375–388. https://doi.org/10.1016/B978-0-12-811050-8.00024-8

Manns, H.R., Martin, R.C., 2018. Cropping system yield stability in response to plant diversity and soil organic carbon in temperate. Agroecology and Sustainable Food Systems 42, 28.

McDaniel, M.D., Tiemann, L.K., Grandy, A.S., 2014. Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. Ecological Applications 24, 560–570. https://doi.org/10.1890/13-0616.1

Meehan, T.D., Werling, B.P., Landis, D.A., Gratton, C., 2011. Agricultural landscape simplification and insecticide use in the Midwestern United States. Proceedings of the National Academy of Sciences 108, 11500–11505. https://doi.org/10.1073/pnas.1100751108

Metwally, M.S., Shaddad, S.M., Liu, M., Yao, R.-J., Abdo, A.I., Li, P., Jiao, J., Chen, X., 2019. Soil Properties Spatial Variability and Delineation of Site-Specific Management Zones Based on Soil Fertility Using Fuzzy Clustering in a Hilly

Field in Jianyang, Sichuan, China. Sustainability 11, 7084. https://doi.org/10.3390/su11247084

Minkoff-Zern, L.-A., Sloat, S., 2017. A new era of civil rights? Latino immigrant farmers and exclusion at the United States Department of Agriculture. Agriculture and Human Values 34, 631–643. https://doi.org/10.1007/s10460-016-9756-6

Nassauer, J.I., 2010. Rural landscape change as a product of US federal policy, in: Primdahl, J., Swaffield, S. (Eds.), Globalisation and Agricultural Landscapes. Cambridge University Press, Cambridge, pp. 185–200. https://doi.org/10.1017/CBO9780511844928.011

Olmstead, J., Brummer, E.C., 2008. Benefits and barriers to perennial forage crops in Iowa corn and soybean rotations. Renew. Agric. Food Syst. 23, 97–107. https://doi.org/10.1017/S1742170507001937

Paul, C.M., Nehring, R., Banker, D., Somwaru, A., 2004. Scale economies and efficiency in U.S. agriculture: Are traditional farms history? Journal of Productivity Analysis 22, 22.

Pellegrini, P., Fernández, R.J., 2018. Crop intensification, land use, and on-farm energy-use efficiency during the worldwide spread of the green revolution. Proceedings of the National Academy of Sciences 115, 2335–2340. https://doi.org/10.1073/pnas.1717072115

Petersen-Rockney, M., Baur, P., Guzman, A., Bender, S.F., Calo, A., Castillo, F., De

Master, K., Dumont, A., Esquivel, K., Kremen, C., LaChance, J., Mooshammer, M., Ory, J., Price, M.J., Socolar, Y., Stanley, P., Iles, A., Bowles, T., 2021. Narrow and Brittle or Broad and Nimble? Comparing Adaptive Capacity in Simplifying and Diversifying Farming Systems. Front. Sustain. Food Syst. 5, 564900. https://doi.org/10.3389/fsufs.2021.564900

Poffenbarger, H., Artz, G., Dahlke, G., Edwards, W., Hanna, M., Russell, J., Sellers, H., Liebman, M., 2017. An economic analysis of integrated crop-livestock systems in Iowa, U.S.A. Agricultural Systems 157, 51–69. https://doi.org/10.1016/j.agsy.2017.07.001

Postma, J., Schilder, M.T., Bloem, J., van Leeuwen-Haagsma, W.K., 2008. Soil suppressiveness and functional diversity of the soil microflora in organic farming systems. Soil Biology and Biochemistry 40, 2394–2406. https://doi.org/10.1016/j.soilbio.2008.05.023

Probst, P., Wright, M.N., Boulesteix, A., 2019. Hyperparameters and tuning strategies for random forest. WIREs Data Mining Knowl Discov 9. https://doi.org/10.1002/widm.1301

Prokopy, L.S., Gramig, B.M., Bower, A., Church, S.P., Ellison, B., Gassman, P.W., Genskow, K., Gucker, D., Hallett, S.G., Hill, J., Hunt, N., Johnson, K.A., Kaplan, I., Kelleher, J.P., Kok, H., Komp, M., Lammers, P., LaRose, S., Liebman, M., Margenot, A., Mulla, D., O'Donnell, M.J., Peimer, A.W., Reaves, E., Salazar, K., Schelly, C., Schilling, K., Secchi, S., Spaulding, A.D., Swenson, D., Thompson, A.W., Ulrich-Schad, J.D., 2020. The urgency of transforming the Midwestern U.S. landscape into more than corn and soybean. Agric Hum Values 37, 537–539. https://doi.org/10.1007/s10460-020-10077-x

Pywell, R.F., Heard, M.S., Woodcock, B.A., Hinsley, S., Ridding, L., Nowakowski, M., Bullock, J.M., 2015. Wildlife-friendly farming increases crop yield: evidence for ecological intensification. Proceedings of the Royal Society B: Biological Sciences 282, 20151740. https://doi.org/10.1098/rspb.2015.1740

R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna.

Ramankutty, N., Mehrabi, Z., Waha, K., Jarvis, L., Kremen, C., Herrero, M., Rieseberg, L.H., 2018. Trends in global agricultural land use: Implications for environmental health and food security. Annual Review of Plant Biology 69, 789–815. https://doi.org/10.1146/annurev-arplant-042817-040256

Ratnadass, A., Fernandes, P., Avelino, J., Habib, R., 2012. Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review. Agron. Sustain. Dev. 32, 273–303. https://doi.org/10.1007/s13593-011-0022-4

Ray, D.K., Gerber, J.S., MacDonald, G.K., West, P.C., 2015. Climate variation explains a third of global crop yield variability. Nat Commun 6, 5989. https://doi.org/10.1038/ncomms6989

Reganold, J.P., Jackson-Smith, D., Batie, S.S., Harwood, R.R., Kornegay, J.L., Bucks, D., Flora, C.B., Hanson, J.C., Jury, W.A., Meyer, D., Schumacher, A., Sehmsdorf, H., Shennan, C., Thrupp, L.A., Willis, P., 2011. Transforming U.S. Agriculture. Science 332, 670–671. https://doi.org/10.1126/science.1202462

Reitsma, K.D., Clay, D.E., Clay, S.A., Dunn, B.H., Reese, C., 2016. Does the U.S. Cropland Data Layer Provide an Accurate Benchmark for Land-Use Change Estimates? Agronomy Journal 108, 266–272. https://doi.org/10.2134/agronj2015.0288

Renting, H., Rossing, W.A.H., Groot, J.C.J., Van der Ploeg, J.D., Laurent, C., Perraud, D., Stobbelaar, D.J., Van Ittersum, M.K., 2009. Exploring multifunctional agriculture. A review of conceptual approaches and prospects for an integrative transitional framework. Journal of Environmental Management 90, S112–S123. https://doi.org/10.1016/j.jenvman.2008.11.014

Roesch-McNally, G., Arbuckle, J.G., Tyndall, J.C., 2018. Soil as Social-Ecological Feedback: Examining the “Ethic” of Soil Stewardship among Corn Belt Farmers. Rural Sociology 83, 145–173. https://doi.org/10.1111/ruso.12167

Roesch-McNally, G.E., Arbuckle, J.G., Tyndall, J.C., 2018. Barriers to implementing climate resilient agricultural strategies: The case of crop diversification in the U.S. Corn Belt. Global Environmental Change 48, 206–215. https://doi.org/10.1016/j.gloenvcha.2017.12.002

Schulte, L.A., Niemi, J., Helmers, M.J., Liebman, M., Arbuckle, J.G., James, D.E., Kolka, R.K., O'Neal, M.E., Tomer, M.D., Tyndall, J.C., Asbjornsen, H., Drobney, P., Neal, J., Van Ryswyk, G., Witte, C., 2017. Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn–soybean croplands. Proceedings of the National Academy of Sciences 114, 11247–11252. https://doi.org/10.1073/pnas.1620229114

Smith, R.G., Gross, K.L., Robertson, G.P., 2008. Effects of crop diversity on agroecosystem function: Crop yield response. Ecosystems 11, 355–366. https://doi.org/10.1007/s10021-008-9124-5

Soper, R., 2020. How wage structure and crop size negatively impact farmworker livelihoods in monocrop organic production: interviews with strawberry harvesters in California. Agric Hum Values 37, 325–336. https://doi.org/10.1007/s10460-019-09989-0

Spangler, K., Burchfield, E.K., Schumacher, B., 2020. Past and Current Dynamics of U.S. Agricultural Land Use and Policy. Front. Sustain. Food Syst. 4, 21. https://doi.org/10.3389/fsufs.2020.00098

Sponsler, D.B., Grozinger, C.M., Hitaj, C., Rundlöf, M., Botías, C., Code, A., Lonsdorf, E.V., Melathopoulos, A.P., Smith, D.J., Suryanarayanan, S., Thogmartin, W.E., Williams, N.M., Zhang, M., Douglas, M.R., 2019. Pesticides and pollinators: A socioecological synthesis. Science of The Total Environment 662, 1012–1027. https://doi.org/10.1016/j.scitotenv.2019.01.016

Strobl, C., Boulesteix, A.-L., Zeileis, A., Hothorn, T., 2007. Bias in random forest variable importance measures: Illustrations, sources and a solution. BMC Bioinformatics 8, 25. https://doi.org/10.1186/1471-2105-8-25

Swift, M.J., Izac, A.-M.N., van Noordwijk, M., 2004. Biodiversity and ecosystem services in agricultural landscapes—are we asking the right questions? Agriculture, Ecosystems & Environment 104, 113–134. https://doi.org/10.1016/j.agee.2004.01.013

Thaler, E.A., Larsen, I.J., Yu, Q., 2021. The extent of soil loss across the US Corn Belt. Proceedings of the National Academy of Sciences 118, 8.

Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecology Letters 8, 857–874. https://doi.org/10.1111/j.1461-0248.2005.00782.x

USDA NASS, 2021. Cropscape and Cropland Data Layers - FAQ's [WWW Document]. United States Department of Agriculture National Agricultural Statistics Service. URL https://www.nass.usda.gov/Research_and_Science/Cropland/sarsfaqs2.php#Section1_11.0 (accessed 3.15.21).

USDA NASS, 2020. Cropscape and Cropland Data Layer [WWW Document]. USDA National Agricultural Statistics Service. URL https://nassgeodata.gmu.edu/CropScape/ (accessed 7.1.20).

USDA NASS, 2019a. USDA National Agricultural Statistics Service Quick Stats [WWW Document]. URL https://quickstats.nass.usda.gov/ (accessed 10.20.18).

USDA NASS, 2019b. Appendix B: General Explanation and Census of Agriculture Report Form (Geography Area Series, Part 51 No. AC-17-A-51). United States Department of Agriculture, Washington, DC.

van der Ploeg, J.D., Laurent, C., Blondeau, F., Bonnafous, P., 2009. Farm diversity, classification schemes and multifunctionality. Journal of Environmental Management 90, S124–S131. https://doi.org/10.1016/j.jenvman.2008.11.022

Virginia, A., Zamora, M., Barbera, A., Castro-Franco, M., Domenech, M., De Gerónimo, E., Costa, J.L., 2018. Industrial agriculture and agroecological transition systems: A comparative analysis of productivity results, organic matter and glyphosate in soil. Agricultural Systems 167, 103–112. https://doi.org/10.1016/j.agsy.2018.09.005

Wei, P., Lu, Z., Song, J., 2015. Variable importance analysis: A comprehensive review. Reliability Engineering & System Safety 142, 399–432. https://doi.org/10.1016/j.ress.2015.05.018

Zabel, F., Putzenlechner, B., Mauser, W., 2014. Global Agricultural Land Resources – A High Resolution Suitability Evaluation and Its Perspectives until 2100 under Climate Change Conditions. PLoS ONE 9, e107522. https://doi.org/10.1371/journal.pone.0107522

Zimmerer, K.S., de Haan, S., Jones, A.D., Creed-Kanashiro, H., Tello, M., Carrasco, M., Meza, K., Plasencia Amaya, F., Cruz-Garcia, G.S., Tubbeh, R., Jiménez Olivencia, Y., 2019. The biodiversity of food and agriculture (Agrobiodiversity) in the anthropocene: Research advances and conceptual framework. Anthropocene 25, 100192. https://doi.org/10.1016/j.ancene.2019.100192

Zulauf, C., 2019. Whole farm safety net programs: an emerging US farm policy evolution? Renew. Agric. Food Syst. 1–9. https://doi.org/10.1017/S1742170519000279

CHAPTER IV

CROP DIVERSIFICATION IN IDAHO'S MAGIC VALLEY: THE PRESENT AND THE IMAGINARY[5,6]

Abstract

The simplification of agricultural landscapes, particularly in the United States (U.S.), has contributed to alarming rates of environmental degradation. As such, increasing agrobiodiversity throughout the U.S. agri-food system is a crucial goal toward mitigating these harmful impacts, and crop diversification is one short-term mechanism to begin this process. However, despite mounting evidence of its benefits, crop diversification strategies have yet to be widely adopted in the U.S. Thus, we explore these barriers and bridges to crop diversification for current farmers in the Magic Valley of southern Idaho – a region with quantitatively high agricultural diversity. We address two main research questions: 1) how and why do farmers enact temporal and/or spatial strategies to manage crop diversity, and 2) what are the barriers and bridges to alternative diversification strategies? Through a political agroecology and spatial imaginaries lens, we conducted and analyzed 15 farmer and 14 key informant in-depth interviews between 2019 and 2021 to gauge what farmers are currently doing to manage crop diversity (the

---

[5] The target journal for this paper is *Agronomy for Sustainable Development.* Co-authors include Emily Burchfield, Claudia Radel, Douglas Jackson-Smith, and River Johnson.

[6] This research was supported, in part, by USU's Climate Adaptation Science Program through the National Science Foundation under Grant No.1633756 and USU's Presidential Doctoral Research Fellowship. This work was also supported, in part, by U.S. Department of Agriculture (USDA) National Institute of Food and Agriculture grant number 2020-67019-31157. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the USDA.

present) and how they imagine alternative landscapes (the imaginary). We found that farmers in the Magic Valley have established a regionally diversified landscape relying primarily on temporal diversification strategies – crop rotations and cover cropping – but do not necessarily pair these with other field-scale diversification strategies. In some cases, current strategies competed with other conservation practices, like conservation tillage. Further, experimenting with alternative practices and imagining new landscapes is possible (and we found evidence of such among the farmers in this study), but daily challenges and structural constraints make these processes not only difficult but unlikely and even “dangerous” to dream of. To support agroecological transformation, the realities and humanities of *who* is farming must be centered as much as *how* they farm, and we must reckon with past and present land use paradigms to re-imagine what is possible.

1. Introduction

Globally, agrobiodiversity is declining (Dainese et al. 2019; Kleijn et al. 2011). Agricultural production – particularly in the United States (U.S.) – is becoming increasingly homogenized in its number of crops (Aguilar et al. 2015; Auch et al. 2018; Baines 2015) and associated genetic diversity (Harlan 1975; Heal et al. 2004). Specialization of commodity production has resulted in simplified agricultural landscapes that are intrinsically reliant on external chemical inputs (Aguilar et al. 2015; Brown and Schulte 2011; Landis 2017; Meehan et al. 2011; Nassauer 2010; Spangler et al. 2020). This simplification and intensification of agricultural landscapes has contributed widely to environmental degradation, including pollinator diversity loss, nutrient pollution in waterways, greenhouse gas emissions, among others (Kremen and Merenlender 2018;

Prokopy et al. 2020; Ramankutty et al. 2018; Sponsler et al. 2019). To counteract these processes of simplification, increasing agrobiodiversity throughout the agri-food system is a crucial goal toward mitigating such harmful impacts and working toward a more sustainable future (Aizen et al. 2019; Petersen-Rockney et al. 2021; Spangler et al. 2020; Waha et al. 2020).

Crop diversification is one short-term mechanism that can be implemented by current farmers to increase agrobiodiversity across agricultural landscapes. It encompasses a suite of on-farm practices to diversify the crop and non-crop species and land uses of an operation temporally and spatially. Temporal diversity can be achieved through practices such as diverse crop rotations (Davis et al. 2012) or cover cropping (Bell et al. 2014; Schipanski et al. 2014). Spatial diversity is measurable at a given place in time and enacted through wide-ranging practices: intercropping or polycropping (Daryanto et al. 2020; Mead and Wiley 1980), precision conservation (Delgado and Berry 2008), buffer strips, riparian corridors, and hedgerows (Kremen et al. 2012), creating wildlife habitat patches within and across plots (Pywell et al. 2015), or integrating crops and livestock (Franzleubbers and Stuedemann 2014; Sulc and Franzleubbers 2014). Accumulating evidence exhibits broad benefits to implementing these practices, such as improved crop yields (Burchfield et al. 2019; Gaudin et al. 2015; Pywell et al. 2015; Schulte et al. 2017; Smith et al. 2008), decreased yield volatility over time (Abson et al. 2013; Di Falco and Perrings 2005; Li et al. 2019), improved pest management (Bommarco et al. 2013; Chaplin-Kramer et al. 2011), improved soil health (Albizua et al. 2015; Berendsen et al. 2012; Ghimire et al. 2018; McDaniel et al. 2014; Postma et al. 2008), increased pollinator diversity (Guzman et al. 2019; Hass et al. 2018; Raderschall et al. 2021; Schulte et al. 2017), and overall greater productivity, or output per acre, than industrial operations (Kremen and Miles 2012; Virginia et al. 2018). Moreover, conserving the diversity of on-farm crops can improve agroecosystem resilience and food security in the face of climatic change and disturbance (Isbell et al. 2021; Massawe et al. 2016; Matsushita et al. 2016).

However, such diversification strategies are yet to be widely adopted and accepted across the U.S. First, the concept of diversified farming lacks a clearly defined and accepted conceptual framework, and, thus, what differentiates it from non-diversified farming is often unclear (Hufnagel et al. 2020). Second, temporal and spatial diversity have not been adequately defined and operationalized in recent research, which obfuscates discussions of diversification strategies (Aramburu Merlos and Hijmans 2020). Third, perceptions of agricultural biodiversity differ between researchers and farmers: researchers may hold idealistic views of the value of diversification, whereby farmers may not view those same processes positively (Maas et al. 2021). Finally, highly input-intensive production systems, specifically those relying on inputs such as genetically modified crop breeds and glyphosate-based herbicides, are socially, technologically, and economically locked into modern agricultural systems; these lock-ins impede crop diversification at all levels of the value chain and promote short-term profit over long-term resilience (Clapp 2021; Cradock-Henry 2021; Meynard et al. 2018; Roesch-McNally et al. 2018a). These factors amount to significant micro- and macroscale barriers to diversification that remain to be more deeply explored.

This paper assesses the barriers and bridges to agricultural crop diversification. Using a qualitative approach through semi-structured interviews and participant observation, we sought to better understand farmers' and agricultural stakeholders' lived experiences of and perspectives on managing agricultural diversity in the Magic Valley of southern Idaho. We addressed two main research questions: 1) how and why do farmers enact temporal and/or spatial strategies to manage crop diversity, and 2) what are the barriers and bridges to alternative diversification strategies? We focused on the Magic Valley as a region with notable high agricultural diversity, hoping that it would be a place to learn from as a model of diversification and transformation. Understanding current strategies of managing crop diversity can provide clarity to the fuzziness of what differentiates diversified and non-diversified farming by identifying what farmers are already doing (or not doing) and what enables or constrains them. Considering and imagining alternative diversification strategies helps elucidate what farmers would (or would not) do to change their operation's level of diversity. In this process of imagining new landscapes, we aim to gauge how farmers envision their land and its transformative potential within current and new realities (Sippel and Visser 2021; Watkins 2015). Assessing these two dynamics in tandem – the present and the imaginary – points to the values and barriers of the current U.S. agricultural system, contextualized within the Magic Valley, as well as potential pathways for change and transformation.

1.1 Political agroecology & spatial imaginaries: A framework of transformation

This research draws on the established fields of political ecology and agroecology and how they converge into an emerging framework of political agroecology. Political agroecology is an ideological framework grounded in the need for a new agri-food system (or *regime*), whereby the sociopolitical factors of our current regime have resulted in asymmetrical and unjust distributions of material goods, information, and other resources (González de Molina 2013; González de Molina et al. 2019). Rather than a suite of practices to implement, agroecology is an approach, framework, and movement that, at its core, aims to minimize external, chemical inputs and maximize ecological health and social equity (Altieri et al. 2015; Dumont et al. 2021) Diversification is a central tenant of agroecology, whereby intentionally diversifying the crop and non-crop species within a farm or landscape can counteract the ecological and socioeconomic conditions of industrialized monocultures (Kremen et al. 2012; Stratton et al. 2021). The diversification process serves as a mechanism to begin and support the 'agroecological metamorphoses' of the agri-food regime – a systems-level transition that gradually builds from contextualized changes and radically breaks systemic order at the same time (González de Molina et al. 2019). Within political agroecology, the need for scaling agroecology to "ever-greater numbers over ever-larger territories" (Mier y Terán Giménez Cacho et al. 2018, p. 639) is urgent and essential for this scope of change.

Fundamental to political agroecology is that technological innovation alone is insufficient for such metamorphosis; social and economic change must be right alongside it, wherein agroecosystem sustainability reflects structural power relations as much as biophysical properties (González de Molina 2013). Without the politics of this institutional change at the heart of agroecology, "experiences will be condemned to be 'islands of success' amid a sea of privation, poverty and environmental degradation" (González de Molina 2013, p. 46). For agroecology to be most transformative, it must be centered on the synergies between and agency of people and nature and de-centered away from a sole focus on profit and "the market" (Anderson et al. 2019).

Within the need for systems-level transformation, the role of spatial imaginaries is crucial to imagine and “dream of abundant and diverse futures” (Collard et al. 2015) and, ultimately, a new agri-food regime. Spatial imaginaries are stories and ideas about spaces and places that are both individually constructed and shared collectively (Driver 2005; Watkins 2015). Recent research has expanded this concept rooted in human geography to focus on agrarian realities (Wolford 2004), land transformation (Sippel and Visser 2021), and how the socio-political context within which our imagination befalls can limit and constrain the possibilities of climate change adaptation (Nightingale et al. 2020). We conceptualize spatial imaginaries in this study to encompass the current values, views, and visions of agricultural landscapes (“the imaginary”) and how they relate to (or differ from) political agroecological metamorphosis. In understanding what farmers are currently doing to diversify the landscapes of the Magic Valley, as well as how they imagine alternatives, we contribute to this growing body of literature that seeks to identify sustainable and diverse pathways of agricultural systems transformation.

2. Materials and methods

2.1 Study site

Idaho’s Magic Valley is an agriculturally diverse region. It officially comprises eight counties: Blaine, Camas, Cassia, Gooding, Jerome, Lincoln, Minidoka, and Twin Falls (Figure 4-1). Prior research has identified southcentral Idaho as a place with high temporal diversity (Aramburu Merlos and Hijmans 2020) and high spatial diversity with exceptionally high yields for major commodities (Burchfield et al. 2019; Burchfield and

Nelson 2021; Nelson and Burchfield 2021). Idaho's top state-wide commodities, by acres harvested, include hay, wheat, sugar beets, barley, potatoes, dry edible beans, and corn grain, among other specialty commodities like lentils (Mertz and Welk 2018), and the Magic Valley is located at the heart of this booming agribusiness (Hines et al. 2018). Furthermore, it is a central locale of large-scale dairy producers across the arid western U.S. (Leytem et al. 2021). As a result of the widespread agglomeration of dairy farms across the west (Spiegal et al. 2020), Idaho has the 4th highest number of dairy cows nationwide, and the Magic Valley is home to 71% of those cows (Hines et al. 2018). Therefore, we selected this region as our study site due to its strong commercial agribusiness *and* diverse crop production. We hoped that this combination of commercialization and diversification would help advance our understanding of how agricultural landscapes become diverse within and across farm operations, as well as provide a framework for transition toward greater diversification.

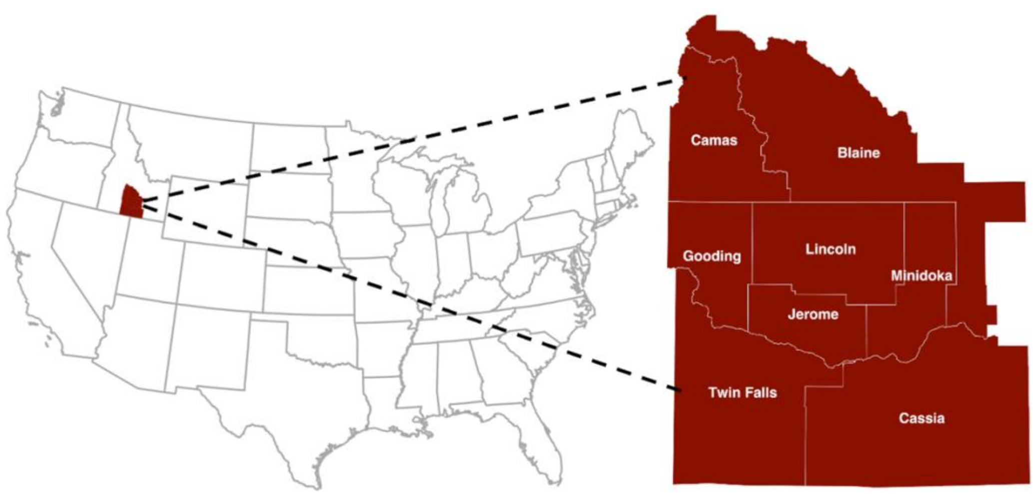


Figure 4-1: Counties of Idaho's Magic Valley

2.2 Participant sampling

This study relied on mixed qualitative methodologies, including a total of 13 key informant interviews, 15 farmer interviews, engagement with two farmer group meetings, and participant observation across the Magic Valley. This number of interviews was based on data saturation and prior research suggesting that six to ten in-depth interviews is an adequate sample size to reach data saturation and converge on common metathemes (Guest et al. 2006, 2020). We conducted a first phase of fieldwork in 2019 with the key informants and four farmers, selected through purposive snowball sampling (Tongco 2007). Key informants included stakeholders from the National Resource Conservation Service (NRCS), Farm Services Agency (FSA), County Extension agents and researchers, Soil and Conservation District Board members, employees of Valley Agronomics LLC, a local input supplier, and a manager of a local canal company. Farmers were sampled by recommendation of key informants. In 2021, we interviewed the final 11 farmers over phone and video calls (due to the COVID-19 pandemic). In this second phase, farmers were invited to participate through two main channels: 1) a recruitment flyer circulated through virtual networks of participants from 2019, and 2) direct recruitment calls and emails using the FarmMarketiD software and the USDA Organic Integrity Database. Any farmer with available contact information who operated roughly 100 acres or more within the Magic Valley was contacted. Over 100 initial phone calls and emails were made, although not all contact information was reliable; follow-up contact was made after two weeks of no response. Farmers who agreed to participate during this phase were compensated $50. In total, from 2019 to 2021, we conducted 29 interviews with 14 different farmers (one farmer was interviewed twice): two women and

12 men, between the ages of 27 and 91. All were white, which is representative of the overwhelming whiteness and maleness of U.S. farm operators (Horst and Marion 2019). Of these 14 participants, four were certified organic, and operation sizes ranged from 300 to 4,000 acres. Farmers were from Twin Falls (2), Cassia (3), Minidoka (1), Lincoln (4), Gooding (2), and Blaine (1) counties.

2.3 Data collection

We used two different interview approaches between 2019 and 2021. In 2019, all 13 key informants and four farmers were interviewed through an informal approach. Fieldwork was conducted in-person by two researchers, with dynamic and open-ended interviews occurring in farmers' homes or on their operation and in key informants' offices. Questions included gauging 1) factors that are important in managing their land, 2) how they relate to their broader landscapes, 3) improvements they want to make in the next decade, and 4) perspectives on federal subsidy and conservation programs. The format was exploratory and, thus, unstructured. Participant observation occurred at farmer group meetings, where both researchers observed and took notes, asking questions when appropriate. In 2021, virtual interviews were conducted using standardized, yet semi-structured interview protocol. Reflections and notes from prior interviews informed this farmer interview guide; conversations flowed naturally and often went beyond the structured questions, although every interview addressed each question. The questions guided discussions about 1) farmer livelihoods and backgrounds, 2) current diversification strategies, 3) labor challenges, 4) imagined alternatives with unlimited resources, 5) relationships with neighbors, 6) current engagement with federal policies and programs, and 7) sources of trusted information (see SI Table 1 for interview question guide). Interviews lasted between 30 minutes and two hours and, with consent, were audio recorded.

2.4 Data analysis

Farmer interviews were transcribed, first using the Otter.ai software and then manually checked for accuracy. Using ATLAS.ti – the qualitative coding software – the 15 farmer interview transcripts were coded using a closed and open coding scheme (Saldana 2016). This coding scheme was first drafted prior to the coding process using notes and reflections taken during the data collection phase and informed by relevant literature. These draft codes were then edited based on the “test coding” of three transcripts to capture any unexpected and unincluded themes, and the test codes were discussed among two group members (Nowell et al. 2017). Once finalized, one person applied the codebook to all interview transcripts, and no new codes were added; the final codebook included five code groups and 40 codes (see SI Table 2 for full codebook). We summarized each code across interviews, noting thematic patterns and diverging opinions and identifying illustrative quotes. Key informant interviews were used as a tool to provide broader perspectives on the history of the region and current agricultural production. Thus, they were audio recorded but not directly transcribed; detailed notes were collected during the interview process and were merged and summarized but not formally coded. Rather, these notes were used to update the 2021 questionnaire and triangulate farmer perspectives and experiences.

3. Results and discussion

This section presents the results of the thematic analysis and their implications in the context of relevant literature. We first explore the theme of the "diversification present" – a contextualized look at how farmers are currently managing crop diversity in the Magic Valley. This theme characterizes the regional farming practices to establish a baseline of what has become normalized for agricultural production. This baseline provides needed clarity to then discuss and distinguish what alternative diversification strategies might look like – the "imaginary" (Hufnagel et al. 2020). This dynamic between the diversification present and imaginary illustrates where, in this region, farmers are starting from and where they envision going (and not going).

3.1 Managing diverse crops: the present

The Magic Valley is home to a diverse suite of crops raised year to year. Main crops in the area are hay, alfalfa, pasture (grasses), corn (silage and grain), barley, wheat, beans (edible and for seed), potatoes (edible and for seed), sugar beets, beef cattle, dairy cows, peas, and oats. Sugar beets, potatoes, and bean seeds are the primary cash crops – those that farmers raise for the largest profit and that often define the rest of their operation. Sugar beets can only be grown by purchasing "shares" from the associated cooperative that dictate how many acres any one farmer can dedicate to raising them. Farmers describe sugar beets as "the ideal cash crop" because, given the tightly regulated market supply, their market price is consistently stable and highly profitable. Potatoes – often considered Idaho's trademark – are also an important cash crop (Figure 4-2); several competitive markets for company contracts exist that demand different varieties. These contracts are most often offered through larger corporations that guarantee a certain price per acre for a specified variety of potato, established often before the farmer even plants them. Beans (edible and seed) are prevalent as well, but some farmers say that business has "for some reason, left the area;" some speculated that this was due to being outcompeted by the influx of large dairy operations over recent decades. With this influx, dairy cows and beef cattle, as well as their associated crops for feed, remain a stronghold in the local economy.

Figure 4-2: Potato field in Blaine County, Idaho

The established suite of crops grown in this region has been structurally reinforced by the competition for contracts and market shares, necessitating farmers to be flexible with respect to their primary enterprise or focus from one year to the next. Particularly since the availability of sugar beet shares is low, and potato and bean contracts are not a given each year, this flexibility relies on several crops being raised in any one given year, as well as the willingness to adjust how much of each crop is grown. Being flexible and, therein, diversified, helps minimize risk and uncertainty. As one farmer described,

> "You never know what's gonna make you money one year to the next, so I don't think there's any one thing… A combination of them all tend to be a better thing. Usually when you think, 'Oh, one thing is gonna make me money,' and it turns out, it's one of the other things, so you just never know."

Further, despite year-to-year volatility in market prices, most farmers report a net positive income over recent years and decades. Although in some individual years they report a negative income, farmers feel that these crops work in their operations, primarily because they are well-suited for the environmental and ecological conditions of their area.

To manage these crops, farmers rely primarily on temporal diversification strategies: crop rotations and cover cropping. These diversification strategies – those that diversify the agricultural landscape over time rather than in space – have broadly been found to contribute positively to the ecological health and productivity of farm operations (Tamburini et al. 2020) and the stabilization of crop yield from year to year (Manns and Martin 2018; Renard and Tilman 2019). In this region, these strategies are used along a gradient of implementation by organic and non-organic farmers alike and have been normalized throughout the region as "the way we do things here" by farmers.

3.1.1 Crop rotations

While farmers in the midwestern Corn Belt may be less likely to adopt diversified crop rotations (Wang et al. 2021), a multi-year crop rotation with *at least* three different crops (but often more) is foundational to managing crop diversity in the Magic Valley. The ability to rely on these rotations is described as "an advantage over Midwest farmers" and, more specifically stating that, in reference to the main crops of the Midwest, a "corn-soy rotation is not a good rotation." These rotations rely on prioritizing cash crops, rotating in alfalfa between "real" crops every two to six years, and avoiding growing commodities like corn, wheat, or barley two years in a row on the same plot. Alfalfa is seen as essential to mix into the crop rotation, particularly if it stays in the ground for three to five years. One farmer described, "That's been the standard for us for 40 years. We've always had a good rotation of alfalfa; that always helps your fertility of the soil since it's nitrogen-fixing." Alfalfa is also great for weed control – "good rest for the crops" – due to the frequent required cutting that makes "the weeds eventually give up and the hay takes over." Further, in this area, it is a great crop to grow given the density of dairies who use it for fodder or silage; farmers may even engage in trading alfalfa for manure (and vice versa) with willing neighbors – an example of how the proximity of livestock and crop production can be mutually beneficial for farmers involved and the broader landscape (Bonaudo et al. 2014; Costa et al. 2014).

Primary cash crops dictate the flow of crop rotations, and this rotation schedule is edited and decided upon each year, even multiple times a year. To manage diseases and pests (Myers et al. 2008), farmers can rely on, for any one plot, one potato harvest every five years and two to three sugar beet harvests every five years. This leads potato producers to seek out landowners to rent land from (and ideally establish a long-term relationship with), rather than own all their cultivated land. The prioritization of potatoes creates a “puzzle” for farmers to work around, figuring out what crops go where and how to maximize their potato yields each year. An organic farmer, when describing how they plan their crop rotation schedules, discussed how “every six months [the rotation schedule] changes based on how crops are performing or market pressure, but, principally, how crops perform” (namely, their yield). Furthermore, they described a spreadsheet they use to plan their crop rotations several years in advance for each plot they farm. Of this plan, they said, “I built this spreadsheet the way I did particularly to demonstrate where we needed to move potatoes around, because they are really key cash crops for us. They're sort of… everything else has to work around them in many ways.” Other farmers, typically those who are older and have been growing the same crops in rotation for decades, say that to plan their fields for the coming year, they “sit down in the winter and figure it out with the team.”

Irrigation infrastructure is also a large part of this decision-making process. The type of irrigation used on each plot is crucial in determining when and how to rotate crops. For example, some crops (e.g., corn) require pivot irrigation, and other crops (e.g., beans) require gravity irrigation; bean seeds must be gravity-irrigated to be certified Idaho seed and be eligible for sale within the state. Furthermore, nearly every farmer described a decades-long process of updating all their infrastructure to pivot systems – an expensive but highly desirable outcome that saves them time, energy, and money due to its impressive efficiency. In this process, the boundaries of their fields have been restructured by the placement and reach of each center pivot. One farmer stated specifically that, after 50 years of slowly updating all their infrastructure to center pivots, they went from 14 fields down to six, requiring a total redesign of what crop goes where and how to rotate them. In this way, technological improvements and how they intersect with political factors (e.g., market demand) can serve as a driver of landscape transformation and strongly influence diversification decisions.

3.1.2 Cover cropping

Cover crops have become an important part of soil health management and, ultimately, diversifying the suite of crops grown. Common cover crops in this area include triticale, rye, barley, mixes like vetch, triticale, peas and radishes, as well as phacelia. They are described as something to use anytime a farmer is worried about soil erosion on all or part of their land, particularly the “deeper, rougher ground” or the “sandy ground” to prevent erosion from wind or water. In fact, farmers characterized a good cover crop as one that can be killed easily in the spring and one that holds the ground down so that “the good soil doesn’t just blow away.” Farmers stated that benefits of cover cropping include improving the soil health (e.g., increasing earthworm populations), holding down the soil to prevent erosion, suppressing weeds in-between planting cash crops, and producing more forage and feed for the cattle. A non-organic farmer described their changing perspective on cover crops as of recent years: “We’re learning that it's so important and normal for bacteria in the soil being fed all winter. By leaving those roots in, particularly the growing plants, it fixes a lot of nitrogen and increases the organic matter in the soil. That’s what we’re trying to do with the cover crops.”

Although beneficial, cover cropping was consistently described as a labor-intensive endeavor and one that must be constantly balanced with profitability. The timing of planting cover crops presents a challenge, occurring immediately following a fall harvest – ideally at the same time of the harvest and even on the same day. Figuring out the "right" cover crop is also a challenge, depending on what follows the cover crop and how well it complements that goal. For example, one farmer, for whom beans are their main cash crop, described their devastating realization that a winter wheat cover crop was suppressing their bean yields. Another farmer who tries to plant cover crops each winter season detailed how difficult this process can be:

> "We just didn't get cover crops in behind our potatoes and same thing with most of our bean fields. You've gotta have your planting cover crops in a limited season environment. You've gotta have your seed on site before you harvest your cash crop. You've gotta have the seed in the drill and the tractor running when the combine of the potato digger, or whatever, pulls out of the field. Otherwise, you're just putting yourself in a bind, and you may just spend money on seed, and you don't get anything back. That's true if you're planting cover crops in July or August or September or November. And the other thing, of course, is to choose the right species."

Infrastructural updates, such as installing pivot irrigation systems, can make managing and watering cover crops less burdensome, especially compared to gravity-fed irrigation systems. However, it does not eliminate the fact that cover crops are "an extra step, more work, and another expense" – a reality that continues to deter farmers from expanding their cover cropping efforts in Magic Valley and beyond, like the Midwest (Roesch-McNally et al. 2018b). For example, in response to an NRCS-proposed cover cropping project, a board member from a conservation district meeting expressed opposition to the project by describing cover crops as weeds, saying, “The definition of a weed is the wrong plant at the wrong time.”

These extra labor demands can further compete with the incentive to employ other conservation practices, such as reduced or no tilling. While some farmers use cattle to graze cover crop grasses or forage, tilling in the spring to chop and kill the cover crop lessens the labor required to then immediately plant their cash crop. For those that are trying to implement reduced or no till, cover cropping with alfalfa or hay presents a barrier. One solution is to plant potatoes immediately following hay: harvesting potatoes inevitably requires tillage, so they try to consolidate all tillage for when potatoes fall in their rotation to then hit the “reset button” on their fields and “start trying to go back to a reduced till regime.” In trying to elongate the time in between growing potatoes and reduce tillage, one said, “The challenge with that is coming up with crops that are high enough value per acre for us to grow to survive and to pay the bills. That is the kicker.”

3.2 Experimenting with and envisioning alternatives: the imaginary

3.2.1 Experimenting

Experimentation of cropping practices and landscape design within agroecosystems has long been identified as a crucial piece of enhancing resilience and ecosystem service provisioning (Biggs et al. 2012). In the Magic Valley, experimentation with new crops, rotations, and on-farm practices is occurring, although not widespread. Most farmers follow their standardized crop rotation patterns, largely because that pattern has proven to be both successful and profitable for several decades for long-term farmers. This crop rotation pattern is adjusted season to season based on different market pressures, soil quality, and labor availability, but, for the most part, the crops and the objectives stay the same. Choosing the right variety from season to season is a choice based on the nexus of several factors: availability of seed, disease tolerance, past experiences and the variety's "track record," expected weather patterns for the upcoming season, "popularity on the market," and ultimately, what is expected will turn the greatest profit. One non-organic farmer described a philosophy that has guided their career for decades: "When I took Agricultural Economics in college, the professor said, 'In farming, you always choose the right job,' and he spelled out 'right' using dollar signs." Thus, given the importance of the market and its potential for profit, the ability to experiment with new varieties was described as a privilege. Another organic farmer stated, "Very few of our acres do we just get to say, 'Oh, let's grow this variety.' No, most of it is market driven; the markets call for a specific variety." Such experimentation was also described as a risk that needs to be balanced with time and energy requirements because, even with a high financial return, learning to cultivate and manage a new specialty crop may demand a "really high intensity of work that makes my [a farmer's] satisfaction disappear."

While many older, non-organic farmers felt satisfied in finding what works and sticking with it, several younger, organic famers expressed a direct desire to try new things on their operation and push the boundaries of what is possible. One organic farmer put it this way:

> "I refer to this quote a lot of times: 'If you always do what you've always done, you'll always get what you've always got.' A lot of people are just happy to get what they've always got. But we ask ourselves, 'How can I get more out of this day? How can I get more out of this field? How can we be more effective? How can we push it and find out just how far we can do?' It's the drive to get as much done as we possibly can with what we've got… It's like there's an end goal with what we want to achieve and accomplish, and if we can get there faster by being a little more creative, then golly, let's go full throttle!"

This creativity was expressed in being willing to try entirely new crop rotations without proven success by other farmers and uncommon cover crop mixes. Rationale for employing such experimentation included the philosophy that, "You don't know what you don't know," as well as the goal of trying to "disrupt the standardization and the predictive cycles you might have for pests or nutrient deficiency."

3.2.2 Imagining beyond

When asked how they would diversify their farm if they could do anything with unlimited resources (e.g., time, money, labor, etc.), most farmers did not describe a desire to implement diversified alternatives to their current operation. Ultimately, they responded saying either they 1) would not change anything about their operation or 2) would downsize to free up more of their time, with the caveat that if they had not already transitioned to pivot irrigation, they would do that because of how much time and energy it saves them. These responses were grounded in the need to grapple with their current reality, rather than hope for another one. Farmers said they are “happy where we are,” they “have all the ground we need,” and what they’re currently doing “makes us a living and pays the bills and the labor,” helping them navigate the volatility of agricultural markets and land “right in the middle.” Their current practices were attributed to decades of optimizing crop choices, seed varieties, machinery, and rotation schedules, of which they were proud. One older, non-organic farmer explained how instead of diversifying their crop production, they would raise *fewer* crops to free up more of their time and take more vacations:

> “I think reality being what it is, I don't think that we would want to raise any other crop. The beans are a lot of trouble, and sometimes I wish we only raised hay. If I continue to farm here, say in five years, and we decided that we can make it financially just raising the hay and the wheat, that's what we'll do… We are stuck on the farm all summer long from sometime in April until sometime in October. So, we've never taken a summer vacation! If we weren't raising beans, then we could probably take a few more days off.”

In contrast, some farmers (only four of the 14 interviewed) did describe – or imagine – alternative landscapes and farming systems that expanded from their current ones. The farmers who described alternative landscapes include building a demonstration farm in partnership with the Nature Conservancy to showcase soil-building practices (e.g., intercropping), as well as raising more warm-weather cover crops to “bank more nutrients,” trying out new cover crops, and adding new cash crops to their rotations. With the ability to update irrigation equipment and tractors, some wanted to expand more on current markets and add a whole new product to their operation (e.g., adding cheese-making on to an organic dairy operation). In addition to wanting more time in the day to “go back to squeezing in a run once a day,” a younger, organic farmer imagined a farm that expanded its influence to have global impacts:

> “We have beliefs of more to this life than just eat, sleep, drink and die; there's more purpose to it. So, we’ve talked about that all the time – to be a part of something bigger than just what we are. Our goal is to create an operation that has outreaching impacts on accomplishing good in parts of the world where they don't have that opportunity. It’s gonna take 30 years, maybe, to get there but…”

Through this process of imagining, these farmers revealed the passion woven into their operation’s success and its future potential. In describing the resources that they would want and need to “juice up” their organic operation, one farmer even exclaimed that they did not want to talk more about this because such wishful thinking was “dangerous” and, therein, difficult. The danger and difficulty of such imagining is likely rooted in hesitancy to dream *outside of* present constraints and toward future landscapes, particularly because such imaginings are inextricably linked to one’s own land use decisions and agency; past and present experiences shape the possibilities we can imagine

(Mische 2009; Sullivan-Wiley and Teller 2020). This process is also inherently stifled by capitalist paradigms of agriculture (Rissing, 2021; Roux-Rosier et al. 2018), as well as day-to-day barriers that make agricultural livelihoods difficult and exhausting.

3.2.3 Daily challenges and structural constraints

Imagining (and, thus, enacting) alternative diversification strategies is constrained by the daily challenges and sociopolitical context within which farmers in the Magic Valley operate. Generally, farmers often must make daily decisions with great uncertainty and imperfect information, as they balance financial, familial, and self-identity factors (to name a few) with the physical toll of their job (Eitzinger et al. 2018; Emerton and Snyder 2018; Findlater et al. 2019; Isbell et al. 2021; Jarosz 2011; McGuire et al. 2013; Valliant et al. 2017). Beyond these daily challenges, sociopolitical factors, such as financial incentives, machinery development, or genetic crop breeding, can "lock" farmers into their current perspectives and practices, pushing alternative ways of farming and thinking farther out of their current reality (Magrini et al. 2018; Meynard et al. 2018). We identify these sources of daily struggle and structural constraint to show how envisioning alternative landscapes is not only difficult but disincentivized within their realities.

Performing daily on-farm labor was consistently cited as one of the most difficult challenges of both managing their current operations and enacting potential changes. In general, the workload of farming is incredibly demanding, and duties vary by season. One farmer described what a typical workday is like for them during the summer season:

> “Leave at four o'clock in the morning, check the water with a flashlight before we have to go out, brand and move cattle, come back in the dark, check the water again, go to bed at midnight, get up again at 4 or 5 AM or earlier. It’s not that way year-round; we’re just like any farmer that puts the effort in to manage.”

The workload, although seasonally variable, is a constant pressure, making it difficult to get away for a rest or holiday. A dairy farmer recollected a sentiment from their father: “The cows do not know it’s your birthday. They do not know when it’s Christmas. They do not know that it's Thanksgiving. So, I suggest you get out there and get your work done.” Such obligations can strain personal time and relationships and inherently limit the ability to take on more responsibilities or begin to imagine a new reality.

Moreover, maintaining a full-time and seasonal workforce poses its own challenges. Farmers asserted that retaining full-time employees is difficult because “they seem to come and go, and it don’t matter what you’re paying them; it’s just the fact that there’s too many other options out there.” Those who have had a consistent full-time staff for several years considered themselves “incredibly lucky.” For farmers relying on seasonal laborers, it is difficult to find laborers, pay them a living and fair wage, and ensure that each person is properly trained. Of this process, one farmer lamented, “It's a constant cycle of retraining: every year we’re training new people and making sure they understand, only to, when wintertime comes, to lay them off.” Finding help locally is difficult and has led several farmers to turn to the H-2A visa program for seasonal migrant workers for the physically demanding “grunt labor” and those who are specialty operators. Farmers who utilize the H-2A program spoke highly of the work ethic of and quality work from these migrant workers. Several said that they get the same workers each year, and those workers will bring their cousins and siblings; some have had the same group of workers for roughly 30 years. However, this program is described as somewhat restrictive and difficult to keep up with because "they [the program] keep upping the wage" – a necessary requirement to adequately value and protect migrant farmworkers' knowledge, dignity, and physical effort in a system that too often has not done so (Klocker et al. 2020; Minkoff-Zern & Sloat 2017). One farmer described it as follows:

> "We're dictated on what we have to pay them. We have to pay for their transportation, and meals, and hotels on their way up from Mexico and on their way back, and we have to provide them the housing. That was one requirement that was a little hard to overcome. Being able to find housing 1) in the housing market that we're in right now, and 2) that is affordable as well. That was definitely a challenge, for sure."

Often, the Spanish-English language barrier between farm managers and workers adds to these difficulties, as well, for both farm managers and workers alike.

Beyond labor demands, reliance on federal subsidies and crop insurance present barriers to diversification by incentivizing only certain commodities on which farmers rely to be competitive. Most farmers participate in federal subsidy programs, even if they wish they did not have to. The most frequently used programs are the Price Loss Coverage (PLC) and Agricultural Risk Coverage (ARC) programs that pay farmers the difference when the actual revenue from a certain covered commodity falls below the effective reference price or market average price for that year; each commodity must be separately covered to receive these payments. The amount of money received from these programs was consistently described as “not a lot, but every little bit helps.” Another farmer said, “It’s usually so small that I’m like, ‘Well, that’ll buy a pair of socks.’” In contrast, the payment programs in response to the COVID-19 pandemic were described as bigger than those regular subsidies and much more helpful. Another farmer described the impact of that support: “If we had not had that COVID-related government assistance, we would not have been able to make our payrolls this year because of crop failures, not because of COVID.” Farmers in the Magic Valley expressed reluctance about taking advantage of these federal subsidy programs and acknowledged feelings of guilt and frustration regarding taking “free handouts” and “corporate welfare.” Yet, without that assistance, they state that they could not compete with other farmers, and it has been a “necessity over the eons of time – from the 1930s on up.”

Farmers describe a mixed relationship with crop insurance and its ability to mitigate risk for their operation. Disaster, fire, and hail insurance are the most common, but most have never (luckily) had to collect on them. Several farmers have never needed to enroll in or rely on crop insurance based on their farm’s microclimate and diversity of crops, whereby southern Idaho “has the advantage over the farmers in the Midwest: We raise a variety of crops… some will be down and yet others will be up, so it makes a good balance.” However, several organic farmers described the crop insurance programs negatively, stating they have yet to find a good option to insure all their different crops. One described it as follows:

> "The payment wouldn't cover all of our losses because we can't insure all of the beans because we grow stock seed to comply with Idaho bean laws that can be planted back here, but that stock seed can't be insured. The crop insurance program doesn't work for diverse operations in counties that don't have good data sets for that crop. It's really designed to keep people on a treadmill, in my opinion. Keep people on a treadmill of a few key crops in areas where they're traditionally grown."

This lack of support and flexibility from crop insurance has resounded through prior research studies, affirming the notion that it too often fails to mitigate maladaptive outcomes (Müller et al. 2017). This reality has driven the farmers in the Magic Valley for whom it does not support to work with other organizations as alternative risk mitigation strategies, like the Nature Conservancy, that provide capital and support to farmers trying to diversify their crop rotations.

Finally, market volatility and pressure to secure contracts presents ongoing challenges to alternative diversification strategies. Although "spreading out one's eggs into different baskets" on the crop market was identified as a desirable and lucrative goal, the market prices of crops and commodities largely dictate what farmers grow and, ultimately, specialize in. The volatility of these prices is consistently a concern for dairy farmers and crop producers alike. The price of wheat can change dramatically from one year to the next, directly affecting how much corn they grow in comparison to the wheat. The price of milk often changes, presenting a source of stress and instability, even month to month. In some years, the premium for organic milk can help ensure the investment to transition to organic is profitable, but, in other years, it is just the opposite. In the same way, the organic crop and commodity markets may not be reliable enough to provide a profitable return within the first few years of investment and transition, especially because "the market is smaller so it's easier to flood." If there is not a market for certain crops, farmers will likely not grow it. Thus, producing crops for which a supply and demand market is not yet well-established puts farmers at too high of a risk for investing money up front that they may not earn back, on top of an already volatile profit return.

Securing contracts (both formal and informal) for cash crops is important for ensuring a profit from year to year. These contracts are typically secured during the year prior to cultivation, ideally before anything is in the ground to help plan how much land is dedicated to each crop. Sugar beets, given that they are operated through a market-share cooperative, have maintained stable pricing and profit returns for several decades. Farmers cite this as one of the most desirable cash crops: "When I say it's been consistent, I mean, I have a brother-in-law that grows sugar beets, and he pretty much can pencil in the same profit every year, year in and year out. Because of that, [the costs] to purchase those shares have skyrocketed." Unlike sugar beets, potato prices can fluctuate dramatically from year to year. This volatility is, in part, buffered by maintaining a diversity of potato varieties that can secure contracts across different companies. The ability to secure formal contracts was described as desirable and an ongoing process of maintaining good relationships with vendors and representatives. Although, some even prefer informal agreements in place of formal contracts to gain more flexibility and access to fair deals:

> "Well, these efforts are really based on relationships, whether you have a contract or not. A contract is sometimes only as good as the people behind it, and so it doesn't really matter in many cases. There's just a lot of trust involved in a lot of these operations. If you have dairy customers and dairy partners who you've grown forward for over a long time, you know what to expect from them: you know when you can get paid or you know they're willing to work with you (or you're willing to work with them if they're behind on payment or something). Whereas if you had a contract, you might not have that flexibility."

Every farmer described the need to adapt to market pressures and the status of their contracts every year to be able to turn a profit. The necessity to keep up with market demand dictates what farmers can (and will) do on their operation. This narrative of market limitation reverberates across the U.S., specifically in the Corn Belt where "corn is king" (Roesch-McNally et al. 2018a, pp. 211–212), making alternative crops outside the corn-soy (and occasionally wheat) rotation seem largely unviable. Therein, these limitations make it intrinsically difficult for farmers to make decisions that lie outside of, or even push back against, their local and regional production norms (the diversification present). Such decision and action may counteract their profit returns as well as established expectations of what makes them a 'good farmer' to their neighbors and community (Lavoie and Wardropper 2021; McGuire et al. 2013).

Conclusions

This research contributes several important findings toward understanding barriers and bridges to crop diversification and, ultimately, agroecological transformation. Given that the Magic Valley is a region characterized by quantitatively agriculturally diverse landscapes as compared to the rest of the U.S., we expected, through a qualitative approach, to gain a deeper understanding of how farmers manage current crop diversity and find a model of how to imagine transitions toward diversification. We did find that farmers have established a regionally diversified landscape relying primarily on temporal diversification strategies – crop rotations and cover cropping. We did not find evidence that these temporal strategies are paired with other field-scale diversification strategies (e.g., intercropping or non-crop habitats), and, in some cases, they competed with other conservation practices, like conservation tillage. Further, experimenting with and imagining alternatives to these strategies is possible (and we found evidence of such among the farmers in this study), but daily challenges and structural constraints make these processes not only difficult but unlikely and even "dangerous" to dream of. Most farmers did not show interest in or desire to extrapolate their current strategies to a new, more diversified reality. Agricultural diversity and diversification were not normatively good or wholly desirable for these farmers; while diversification helped to maintain balance to their operation and be competitive on the crop market, it was not something they were necessarily aiming toward.

By using qualitative methods in this study to contextualize and interrogate quantitative findings from prior studies, we find that the implementation of certain crop diversification strategies within a landscape – and locating places and farmers that are currently doing so – does not inherently *promote* or *enact* agroecological transformation. In the ways that agroecology cannot be reduced to a set of practices, the accumulation of crop diversification practices across a landscape may not inherently lead to pathways of sustainable change. While crop diversification in and of itself is still likely to boost ecological benefits, the prevalence of these temporal strategies reflects more of the regional normalization of crops and their proven-successful rotations rather than an active and intentional process of diversification toward agroecological transition and, ultimately, 'metamorphosis' (González de Molina et al. 2019). Such normalization of specific crop rotations and practices may even limit future diversification innovations, 'locking out' (as opposed to locking in) agroecological alternatives (Boulestreau et al. 2021). The work of scaling agroecology must go beyond field boundaries toward paradigmatic shifts.

The agricultural imaginaries of the farmers in this study reflect a reality that is physically and emotionally demanding, as well as structurally constrained. Political agroecology posits that transformation can occur when profit and "the market" are decentered (Anderson et al. 2019), but farmers' present realities must inherently value such factors to maintain their livelihoods. Further, the imagination of future, "abundant" landscapes reflect dominant social values and paradigms at present (Sullivan-Wiley and Teller 2020). This means that farmers are not simply reluctant or resistant to enacting and envisioning alternative strategies but also repetitively disincentivized to do so through commodity incentives (e.g., subsidies), risk mitigation options that often fails diversified farmers (e.g., crop insurance), and the daily physical and emotional demands of farming. For agroecological transformation to take place, the realities and humanities of *who* is farming must be centered as much as *how* they farm. In this, building and supporting realistic pathways of change requires a reckoning with the often-indomitable challenges associated with farming and rural livelihoods and a reimagining of what is desirable and, ultimately, possible.

References

Abson DJ, Fraser ED, Benton TG (2013) Landscape diversity and the resilience of agricultural returns: a portfolio analysis of land-use patterns and economic returns from lowland agriculture. Agriculture & Food Security 2:2. https://doi.org/10.1186/2048-7010-2-2

Aguilar J, Gramig GG, Hendrickson JR, et al (2015) Crop species diversity changes in the United States: 1978–2012. PLOS ONE 10:e0136580. https://doi.org/10.1371/journal.pone.0136580

Aizen MA, Aguiar S, Biesmeijer JC, et al (2019) Global agricultural productivity is threatened by increasing pollinator dependence without a parallel increase in crop diversification. Glob Change Biol 25:3516–3527. https://doi.org/10.1111/gcb.14736

Albizua A, Williams A, Hedlund K, Pascual U (2015) Crop rotations including ley and manure can promote ecosystem services in conventional farming systems. Applied Soil Ecology 95:54–61. https://doi.org/10.1016/j.apsoil.2015.06.003

Altieri MA, Nicholls CI, Henao A, Lana MA (2015) Agroecology and the design of climate change-resilient farming systems. Agron Sustain Dev 35:869–890. https://doi.org/10.1007/s13593-015-0285-2

Anderson CR, Bruil J, Chappell MJ, et al (2019) From Transition to Domains of Transformation: Getting to Sustainable and Just Food Systems through Agroecology. Sustainability 11:5272. https://doi.org/10.3390/su11195272

Aramburu Merlos F, Hijmans RJ (2020) The scale dependency of spatial crop species diversity and its relation to temporal diversity. Proc Natl Acad Sci USA 117:26176–26182. https://doi.org/10.1073/pnas.2011702117

Auch RF, Xian G, Laingen CR, et al (2018) Human drivers, biophysical changes, and climatic variation affecting contemporary cropping proportions in the northern prairie of the U.S. Journal of Land Use Science 13:32–58. https://doi.org/10.1080/1747423X.2017.1413433

Baines J (2015) Fuel, feed and the corporate restructuring of the food regime. The Journal of Peasant Studies 42:295–321. https://doi.org/10.1080/03066150.2014.970534

Bell LW, Moore AD, Kirkegaard JA (2014) Evolution in crop–livestock integration systems that improve farm productivity and environmental performance in Australia. European Journal of Agronomy 57:10–20. https://doi.org/10.1016/j.eja.2013.04.007

Berendsen RL, Pieterse CMJ, Bakker PAHM (2012) The rhizosphere microbiome and plant health. Trends in Plant Science 17:478–486. https://doi.org/10.1016/j.tplants.2012.04.001

Biggs R, Schlüter M, Biggs D, et al (2012) Toward Principles for Enhancing the Resilience of Ecosystem Services. Annual Review of Environment and Resources 37:421–448. https://doi.org/10.1146/annurev-environ-051211-123836

Bommarco R, Kleijn D, Potts SG (2013) Ecological intensification: harnessing ecosystem services for food security. Trends in Ecology & Evolution 28:230–238. https://doi.org/10.1016/j.tree.2012.10.012

Bonaudo T, Bendahan AB, Sabatier R, et al (2014) Agroecological principles for the redesign of integrated crop–livestock systems. European Journal of Agronomy 57:43–51. https://doi.org/10.1016/j.eja.2013.09.010

Boulestreau Y, Casagrande M, Navarrete M (2021) Analyzing barriers and levers for practice change: a new framework applied to vegetables' soil pest management. Agron Sustain Dev 41:44. https://doi.org/10.1007/s13593-021-00700-4

Brown PW, Schulte LA (2011) Agricultural landscape change (1937–2002) in three townships in Iowa, USA. Landscape and Urban Planning 100:202–212. https://doi.org/10.1016/j.landurbplan.2010.12.007

Burchfield EK, Nelson KS (2021) Agricultural yield geographies in the United States. Environ Res Lett. https://doi.org/10.1088/1748-9326/abe88d

Burchfield EK, Nelson KS, Spangler K (2019) The impact of agricultural landscape diversification on U.S. crop production. Agriculture, Ecosystems & Environment 285:106615. https://doi.org/10.1016/j.agee.2019.106615

Chaplin-Kramer R, O'Rourke ME, Blitzer EJ, Kremen C (2011) A meta-analysis of crop pest and natural enemy response to landscape complexity: Pest and natural enemy response to landscape complexity. Ecology Letters 14:922–932. https://doi.org/10.1111/j.1461-0248.2011.01642.x

Clapp J (2021) Explaining Growing Glyphosate Use: The Political Economy of Herbicide-Dependent Agriculture. Global Environmental Change 67:102239. https://doi.org/10.1016/j.gloenvcha.2021.102239

Collard R-C, Dempsey J, Sundberg J (2015) A Manifesto for Abundant Futures. Annals of the American Association of Geographers 105:10

Costa SEVGA, Souza ED, Anghinoni I, et al (2014) Impact of an integrated no-till crop–livestock system on phosphorus distribution, availability and stock. Agriculture, Ecosystems & Environment 190:43–51. https://doi.org/10.1016/j.agee.2013.12.001

Cradock-Henry NA (2021) Linking the social, economic, and agroecological: a resilience framework for dairy farming. E&S 26:art3. https://doi.org/10.5751/ES-12122-260103

Dainese M, Martin EA, Aizen MA, et al (2019) A global synthesis reveals biodiversity-mediated benefits for crop production. Science Advances 14

Daryanto S, Fu B, Zhao W, et al (2020) Ecosystem service provision of grain legume and cereal intercropping in Africa. Agricultural Systems 178:102761. https://doi.org/10.1016/j.agsy.2019.102761

Davis AS, Hill JD, Chase CA, et al (2012) Increasing Cropping System Diversity Balances Productivity, Profitability and Environmental Health. PLoS ONE 7:e47149. https://doi.org/10.1371/journal.pone.0047149

Delgado JA, Berry JA (2008) Advances in precision conservation. Advances in Agronomy 2008:1–44. https://doi.org/10.1016/S0065-2113(08)00201-0

Di Falco S, Perrings C (2005) Crop biodiversity, risk management and the implications of agricultural assistance. Ecological Economics 55:459–466. https://doi.org/10.1016/j.ecolecon.2004.12.005

Driver F (2005) Imaginative geographies. In: Cloke P, Crang P, Goodwin M (eds)

Introducing human geographies, 2nd edn. Routledge, New York, pp 144–155

Dumont AM, Wartenberg AC, Baret PV (2021) Bridging the gap between the agroecological ideal and its implementation into practice. A review. Agron Sustain Dev 41:32. https://doi.org/10.1007/s13593-021-00666-3

Eitzinger A, Binder CR, Meyer MA (2018) Risk perception and decision-making: do farmers consider risks from climate change? Climatic Change 151:507–524. https://doi.org/10.1007/s10584-018-2320-1

Emerton L, Snyder KA (2018) Rethinking sustainable land management planning: Understanding the social and economic drivers of farmer decision-making in Africa. Land Use Policy 79:684–694. https://doi.org/10.1016/j.landusepol.2018.08.041

Findlater KM, Satterfield T, Kandlikar M (2019) Farmers’ Risk-Based Decision Making Under Pervasive Uncertainty: Cognitive Thresholds and Hazy Hedging. Risk Analysis 39:1755–1770. https://doi.org/10.1111/risa.13290

Franzluebbers AJ, Stuedemann JA (2014) Crop and cattle production responses to tillage and cover crop management in an integrated crop–livestock system in the southeastern USA. European Journal of Agronomy 57:62–70. https://doi.org/10.1016/j.eja.2013.05.009

Gaudin ACM, Tolhurst TN, Ker AP, et al (2015) Increasing crop diversity mitigates weather variations and improves yield stability. PLOS ONE 10:e0113261. https://doi.org/10.1371/journal.pone.0113261

Ghimire R, Machado S, Bista P (2018) Decline in soil organic carbon and nitrogen limits yield in wheat-fallow systems. Plant Soil 422:423–435. https://doi.org/10.1007/s11104-017-3470-z

González De Molina M (2013) Agroecology and Politics. How To Get Sustainability? About the Necessity for a Political Agroecology. Agroecology and Sustainable Food Systems 37:16

González de Molina M, Petersen PF, Peña FG, Caporal FR (2019) Political Agroecology: Advancing the Transition to Sustainable Food Systems. CRC Press, Boca Raton, FL

Guest G, Bunce A, Johnson L (2006) How Many Interviews Are Enough?: An Experiment with Data Saturation and Variability. Field Methods 18:59–82. https://doi.org/10.1177/1525822X05279903

Guest G, Namey E, Chen M (2020) A simple method to assess and report thematic saturation in qualitative research. PLoS ONE 15:e0232076. https://doi.org/10.1371/journal.pone.0232076

Guzman A, Chase M, Kremen C (2019) On-Farm Diversification in an Agriculturally-Dominated Landscape Positively Influences Specialist Pollinators. Front Sustain Food Syst 3:87. https://doi.org/10.3389/fsufs.2019.00087

Harlan JR (1975) Our Vanishing Genetic Resources. Science 188:617–621. https://doi.org/10.1126/science.188.4188.617

Hass AL, Kormann UG, Tscharntke T, et al (2018) Landscape configurational heterogeneity by small-scale agriculture, not crop diversity, maintains pollinators and plant reproduction in western Europe. Proc R Soc B 285:20172242. https://doi.org/10.1098/rspb.2017.2242

Heal G, Walker B, Levin S, et al (2004) Genetic diversity and interdependent crop choices in agriculture. Resource and Energy Economics 26:175–184. https://doi.org/10.1016/j.reseneeco.2003.11.006

Hines S, Packham J, Wilmore C, Taylor G (2018) Contribution of Agribusiness to the Magic Valley Economy, 2013. University of Idaho

Horst M, Marion A (2019) Racial, ethnic and gender inequities in farmland ownership and farming in the U.S. Agriculture and Human Values 36:1–16. https://doi.org/10.1007/s10460-018-9883-3

Hufnagel J, Reckling M, Ewert F (2020) Diverse approaches to crop diversification in agricultural research. A review. Agron Sustain Dev 40:14. https://doi.org/10.1007/s13593-020-00617-4

Isbell C, Tobin D, Reynolds T (2021) Motivations for maintaining crop diversity: Evidence from Vermont’s seed systems. Ecological Economics 189:107138. https://doi.org/10.1016/j.ecolecon.2021.107138

Jarosz L (2011) Nourishing women: toward a feminist political ecology of community supported agriculture in the United States. Gender, Place & Culture 18:307–326. https://doi.org/10.1080/0966369X.2011.565871

Kleijn D, Rundlöf M, Scheper J, et al (2011) Does conservation on farmland contribute to halting the biodiversity decline? Trends in Ecology & Evolution 26:474–481. https://doi.org/10.1016/j.tree.2011.05.009

Klocker N, Dun O, Head L, Gopal A (2020) Exploring migrants’ knowledge and skill in seasonal farm work: more than labouring bodies. Agric Hum Values 37:463–478. https://doi.org/10.1007/s10460-019-10001-y

Kremen C, Iles A, Bacon C (2012) Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture. Ecology and Society 17:. https://doi.org/10.5751/ES-05103-170444

Kremen C, Merenlender AM (2018) Landscapes that work for biodiversity and people. Science 362:eaau6020. https://doi.org/10.1126/science.aau6020

Kremen C, Miles A (2012) Ecosystem Services in Biologically Diversified versus Conventional Farming Systems: Benefits, Externalities, and Trade-Offs. Ecology and Society 17:. https://doi.org/10.5751/ES-05035-170440

Landis DA (2017) Designing agricultural landscapes for biodiversity-based ecosystem services. Basic and Applied Ecology 18:1–12. https://doi.org/10.1016/j.baae.2016.07.005

Lavoie A, Wardropper CB (2021) Engagement with conservation tillage shaped by "good farmer" identity. Agric Hum Values. https://doi.org/10.1007/s10460-021-10205-1

Leytem AB, Williams P, Zuidema S, et al (2021) Cycling Phosphorus and Nitrogen through Cropping Systems in an Intensive Dairy Production Region. Agronomy 11:1005. https://doi.org/10.3390/agronomy11051005

Li M, Peterson CA, Tautges NE, et al (2019) Yields and resilience outcomes of organic, cover crop, and conventional practices in a Mediterranean climate. Sci Rep 9:12283. https://doi.org/10.1038/s41598-019-48747-4

Maas B, Fabian Y, Kross SM, Richter A (2021) Divergent farmer and scientist perceptions of agricultural biodiversity, ecosystem services and decision-making. Biological Conservation 256:109065. https://doi.org/10.1016/j.biocon.2021.109065

Magrini M-B, Anton M, Chardigny J-M, et al (2018) Pulses for Sustainability: Breaking Agriculture and Food Sectors Out of Lock-In. Front Sustain Food Syst 2:64. https://doi.org/10.3389/fsufs.2018.00064

Manns HR, Martin RC (2018) Cropping system yield stability in response to plant diversity and soil organic carbon in temperate. Agroecology and Sustainable Food Systems 42:28

Massawe F, Mayes S, Cheng A (2016) Crop Diversity: An Unexploited Treasure Trove for Food Security. Trends in Plant Science 21:365–368. https://doi.org/10.1016/j.tplants.2016.02.006

Matsushita K, Yamane F, Asano K (2016) Linkage between crop diversity and agro-ecosystem resilience: Nonmonotonic agricultural response under alternate regimes. Ecological Economics 126:23–31. https://doi.org/10.1016/j.ecolecon.2016.03.006

McDaniel MD, Tiemann LK, Grandy AS (2014) Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. Ecological Applications 24:560–570. https://doi.org/10.1890/13-0616.1

McGuire J, Morton LW, Cast AD (2013) Reconstructing the good farmer identity: shifts in farmer identities and farm management practices to improve water quality. Agriculture and Human Values 30:57–69. https://doi.org/10.1007/s10460-012-9381-y

Mead R, Wiley R (1980) The concept of a “Land Equivalent Ratio” and advantages in yields from intercropping. Experimental Agriculture 16:217–228. https://doi.org/doi:10.1017/S0014479700010978

Meehan TD, Werling BP, Landis DA, Gratton C (2011) Agricultural landscape simplification and insecticide use in the Midwestern United States. Proceedings of the National Academy of Sciences 108:11500–11505. https://doi.org/10.1073/pnas.1100751108

Mertz C, Welk R (2018) 2018 Idaho Annual Statistics Bulletin. USDA NASS Northwest Regional Field Office

Meynard J-M, Charrier F, Fares M, et al (2018) Socio-technical lock-in hinders crop diversification in France. Agron Sustain Dev 38:54. https://doi.org/10.1007/s13593-018-0535-1

Mier y Terán Giménez Cacho M, Giraldo OF, Aldasoro M, et al (2018) Bringing agroecology to scale: key drivers and emblematic cases. Agroecology and Sustainable Food Systems 42:637–665. https://doi.org/10.1080/21683565.2018.1443313

Minkoff-Zern L-A, Sloat S (2017) A new era of civil rights? Latino immigrant farmers and exclusion at the United States Department of Agriculture. Agriculture and Human Values 34:631–643. https://doi.org/10.1007/s10460-016-9756-6

Mische A (2009) Projects and Possibilities: Researching Futures in Action. Sociological Forum 24:694–704. https://doi.org/10.1111/j.1573-7861.2009.01127.x

Müller B, Johnson L, Kreuer D (2017) Maladaptive outcomes of climate insurance in agriculture. Global Environmental Change 46:23–33. https://doi.org/10.1016/j.gloenvcha.2017.06.010

Myers P, McIntosh CS, Patterson PE, et al (2008) Optimal Crop Rotation of Idaho Potatoes. Am J Pot Res 85:183–197. https://doi.org/10.1007/s12230-008-9026-2

Nassauer JI (2010) Rural landscape change as a product of US federal policy. In: Primdahl J, Swaffield S (eds) Globalisation and Agricultural Landscapes. Cambridge University Press, Cambridge, pp 185–200

Nelson KS, Burchfield EK (2021) Landscape complexity and US crop production. Nature Food 2:330–338

Nightingale AJ, Eriksen S, Taylor M, et al (2020) Beyond Technical Fixes: climate solutions and the great derangement. Climate and Development 12:343–352. https://doi.org/10.1080/17565529.2019.1624495

Nowell LS, Norris JM, White DE, Moules NJ (2017) Thematic Analysis: Striving to Meet the Trustworthiness Criteria. International Journal of Qualitative Methods 16:160940691773384. https://doi.org/10.1177/1609406917733847

Petersen-Rockney M, Baur P, Guzman A, et al (2021) Narrow and Brittle or Broad and Nimble? Comparing Adaptive Capacity in Simplifying and Diversifying Farming Systems. Front Sustain Food Syst 5:564900. https://doi.org/10.3389/fsufs.2021.564900

Postma J, Schilder MT, Bloem J, van Leeuwen-Haagsma WK (2008) Soil suppressiveness and functional diversity of the soil microflora in organic farming systems. Soil Biology and Biochemistry 40:2394–2406. https://doi.org/10.1016/j.soilbio.2008.05.023

Prokopy LS, Gramig BM, Bower A, et al (2020) The urgency of transforming the Midwestern U.S. landscape into more than corn and soybean. Agric Hum Values 37:537–539. https://doi.org/10.1007/s10460-020-10077-x

Pywell RF, Heard MS, Woodcock BA, et al (2015) Wildlife-friendly farming increases crop yield: evidence for ecological intensification. Proceedings of the Royal Society B: Biological Sciences 282:20151740. https://doi.org/10.1098/rspb.2015.1740

Raderschall CA, Bommarco R, Lindström SAM, Lundin O (2021) Landscape crop diversity and semi-natural habitat affect crop pollinators, pollination benefit and yield. Agriculture, Ecosystems & Environment 306:107189. https://doi.org/10.1016/j.agee.2020.107189

Ramankutty N, Mehrabi Z, Waha K, et al (2018) Trends in global agricultural land use: Implications for environmental health and food security. Annual Review of Plant Biology 69:789–815. https://doi.org/10.1146/annurev-arplant-042817-040256

Renard D, Tilman D (2019) National food production stabilized by crop diversity. Nature 571:257–260. https://doi.org/10.1038/s41586-019-1316-y

Rissing AL (2021) "We feed the world": the political ecology of the Corn Belt's driving narrative. Journal of Political Ecology 28:. https://doi.org/10.2458/jpe.2959

Roesch-McNally GE, Arbuckle JG, Tyndall JC (2018a) Barriers to implementing climate resilient agricultural strategies: The case of crop diversification in the U.S. Corn Belt. Global Environmental Change 48:206–215. https://doi.org/10.1016/j.gloenvcha.2017.12.002

Roesch-McNally GE, Basche AD, Arbuckle JG, et al (2018b) The trouble with cover crops: Farmers' experiences with overcoming barriers to adoption. Renew Agric Food Syst 33:322–333. https://doi.org/10.1017/S1742170517000096

Roux-Rosier A, Azambuja R, Islam G (2018) Alternative visions: Permaculture as imaginaries of the Anthropocene. Organization 25:550–572. https://doi.org/10.1177/1350508418778647

Saldana J (2016) An introduction to codes and coding. In: The Coding Manual for Qualitative Researchers. SAGE Publications, London, UK, pp 1–40

Schipanski ME, Barbercheck M, Douglas MR, et al (2014) A framework for evaluating ecosystem services provided by cover crops in agroecosystems. Agricultural Systems 125:12–22. https://doi.org/10.1016/j.agsy.2013.11.004

Schulte LA, Niemi J, Helmers MJ, et al (2017) Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn–soybean croplands. Proceedings of the National Academy of Sciences 114:11247–11252. https://doi.org/10.1073/pnas.1620229114

Sippel SR, Visser O (2021) Introduction to symposium 'Reimagining land: materiality, affect and the uneven trajectories of land transformation.' Agric Hum Values 38:271–282. https://doi.org/10.1007/s10460-020-10152-3

Smith RG, Gross KL, Robertson GP (2008) Effects of crop diversity on agroecosystem function: Crop yield response. Ecosystems 11:355–366. https://doi.org/10.1007/s10021-008-9124-5

Spangler K, Burchfield EK, Schumacher B (2020) Past and Current Dynamics of U.S. Agricultural Land Use and Policy. Front Sustain Food Syst 4:21. https://doi.org/10.3389/fsufs.2020.00098

Spiegal S, Kleinman PJA, Endale DM, et al (2020) Manuresheds: Advancing nutrient recycling in US agriculture. Agricultural Systems 182:102813. https://doi.org/10.1016/j.agsy.2020.102813

Sponsler DB, Grozinger CM, Hitaj C, et al (2019) Pesticides and pollinators: A socioecological synthesis. Science of The Total Environment 662:1012–1027. https://doi.org/10.1016/j.scitotenv.2019.01.016

Stratton AE, Wittman H, Blesh J (2021) Diversification supports farm income and improved working conditions during agroecological transitions in southern Brazil. Agron Sustain Dev 41:35. https://doi.org/10.1007/s13593-021-00688-x

Sulc RM, Franzluebbers AJ (2014) Exploring integrated crop–livestock systems in different ecoregions of the United States. European Journal of Agronomy 57:21–30. https://doi.org/10.1016/j.eja.2013.10.007

Sullivan-Wiley K, Teller A (2020) The integrated socio-perceptual approach: Using ecological mental maps and future imaginaries to understand land use decisions. Global Environmental Change 64:102151. https://doi.org/10.1016/j.gloenvcha.2020.102151

Tamburini G, Bommarco R, Wanger TC, et al (2020) Agricultural diversification promotes multiple ecosystem services without compromising yield. Sci Adv 6:eaba1715. https://doi.org/10.1126/sciadv.aba1715

Tongco M (2007) Purposive Sampling as a Tool for Informant Selection. Ethnobot Res App 5:147. https://doi.org/10.17348/era.5.0.147-158

Valliant JCD, Farmer JR, Dickinson SL, et al (2017) Family as a catalyst in farms' diversifying agricultural products: A mixed methods analysis of diversified and non-diversified farms in Indiana, Michigan and Ohio. Journal of Rural Studies 55:303–315. https://doi.org/10.1016/j.jrurstud.2017.08.017

Virginia A, Zamora M, Barbera A, et al (2018) Industrial agriculture and agroecological transition systems: A comparative analysis of productivity results, organic matter and glyphosate in soil. Agricultural Systems 167:103–112. https://doi.org/10.1016/j.agsy.2018.09.005

Waha K, Dietrich JP, Portmann FT, et al (2020) Multiple cropping systems of the world and the potential for increasing cropping intensity. Global Environmental Change 64:102131. https://doi.org/10.1016/j.gloenvcha.2020.102131

Wang T, Jin H, Fan Y, et al (2021) Farmers' adoption and perceived benefits of diversified crop rotations in the margins of U.S. Corn Belt. Journal of Environmental Management 293:112903. https://doi.org/10.1016/j.jenvman.2021.112903

Watkins J (2015) Spatial Imaginaries Research in Geography: Synergies, Tensions, and New Directions: Spatial Imaginaries. Geography Compass 9:508–522. https://doi.org/10.1111/gec3.12228

Wolford W (2004) This Land Is Ours Now: Spatial Imaginaries and the Struggle for Land in Brazil. Annals of the American Association of Geographers 94:17

CHAPTER V

CONCLUSIONS

1. Summary of Findings

Collectively, these three chapters provide a mixed method, multiscale view of how and why U.S. agriculture landscapes simplify or diversify, as well as the barriers and bridges to agricultural diversification. Through an exploratory, data-driven narrative, Chapter II addresses how U.S. agriculture operates and how it has trended toward greater simplification at a national scale. Chapter III takes a deeper look at how and why U.S. agriculture landscapes simplify or diversify at a regional scale, using nonparametric statistical modeling to identify factors most predictive of agricultural diversity across nine U.S. regions. Finally, Chapter IV identifies systemic barriers and bridges to diversification by using qualitative, in-depth insights from southern Idaho's Magic Valley to understand how and why farmers manage current crop diversity and their constraints to experimenting with and imagining alternative landscapes.

Chapter II (Paper 1): Within the National Research Council's (NRC) sustainable agricultural systems framework, I utilized national open-source datasets spanning several decades to broadly assess past and current agricultural landscapes across the U.S. This data synthesis and exploration shows that the overarching U.S. agricultural system has gradually transitioned toward a regulated and specialized system, manifested as consolidation of U.S. farms and the homogenization of crop production. Regions that are most productive for dominant crops (i.e., corn and soybeans) maintain the least crop species diversity. Fewer and fewer farms own more and more land, and these farms continue to produce a select few crops within highly mechanized processes that are concentrated in certain areas of the U.S. These changes emphasize productivity and efficiency, despite increasing concern for biodiversity loss. Further, the Farm Bill has increased in scope since 1933, but the underlying structures incentivizing and reinforcing agricultural specialization have not changed. Even though the number of crops indicated in each commodity-focused FB Title has increased over time, the national crop portfolio has become increasingly less diverse, highlighting how associated policies have failed and continue to fail to incentivize diverse production.

Chapter III (Paper 2): By using random forest permutation modeling, this study shows that the factors most strongly predictive of agricultural diversity across U.S. landscapes operate at a regionally distinct level. These regional predictors contribute to path dependencies that create resistance to enhancing agrobiodiversity in U.S. agriculture. First, major U.S. regions exhibit significantly different levels of crop diversity, where the most diverse regions support a wider array of farming systems that deviate from the average. Second, climate, land use norms, and farm inputs are consistently the most important categories for predicting agricultural diversity across regions; however, variability exists in the relative regional importance of variables within these categories. These intra-regional dynamics are evident in the various functional relationships that exist between key climate, land use, and input variables for predicting diversity. Most interestingly, increased expenditure on chemical and fertilizer inputs is associated with marginally diminishing returns, where crop diversity in many regions responded positively to increasing chemical and fertilizer expenditures initially but quickly plateaued. This highlights how reliance on these inputs will not support diversification beyond the regional status quo. The consistent importance of nonactionable biophysical factors (climate) and actionable factors (land use and farm inputs) as highly predictive regional factors exemplify how these factors are deeply intertwined with the diversity (or lack thereof) of agricultural landscapes. This pattern also highlights how *resistant* the systems within each region may be to alternative pathways and adaptation.

Chapter IV (Paper 3): This study presents in-depth qualitative interviews with farmers and key informants from southern Idaho's Magic Valley. Given that the Magic Valley is a region characterized by quantitatively agriculturally diverse landscapes as compared to the rest of the U.S., we expected, through a qualitative approach, to gain a deeper understanding of how farmers manage current crop diversity and tease out the realities of regional path dependencies. In this, we also hoped to find a model of how to imagine transitions toward diversification. We did find that farmers have established a regionally diversified landscape by relying primarily on temporal diversification strategies – specifically, crop rotations and cover cropping. We did not find evidence that these temporal strategies are paired with other field-scale diversification strategies (e.g., intercropping or non-crop habitats), and, in some cases, they compete with other conservation practices, like conservation tillage. Further, experimenting with and imagining alternatives to these strategies is possible (and we found evidence of such among the farmers in this study), but daily challenges and structural constraints make these processes not only difficult but unlikely and even "dangerous" to dream of. Most farmers did not show interest in extrapolating their current strategies to a new, more diversified reality. By using qualitative methods in this study to contextualize and interrogate quantitative findings from prior studies, we find that the implementation of certain crop diversification strategies within a landscape – and locating places and farmers that are currently doing so – does not inherently *promote* or *enact* agroecological imagination and transformation.

2. Feedback Loops Across Studies

2.1 Process

These three papers are connected conceptually and methodologically through a series of feedback loops, establishing a circular and dynamic research process. The first two papers used a data-driven approach, where I explored data that are openly and widely available, to begin to visualize and assess trends in understanding crop diversity. I used Chapter II and prior modeling efforts that assessed crop diversity across the U.S. (Burchfield et al., 2019) to identify the Magic Valley as an agriculturally diverse region. Based on this data-driven identification, I then interviewed key informants and farmers in the Magic Valley in 2019 using an exploratory and open-ended guide. This exploratory approach served as a starting point to understand how crop diversity is managed and operationalized at the field to landscape scale. These interviews illustrated that there were broader regional dynamics across the Magic Valley and Idaho that played, at least in part, a role in determining the diversity of crops grown there and how successful they are. Thus, I was motivated in Chapter III to model regional predictors of crop diversity to gauge how factors that promote or inhibit crop diversity vary across major regions of the U.S. and understand how important the regional scale is in this multiscale analysis. I then used the results of these regional analyses and reflections from the 2019 interviews to update and edit the interview questionnaire to be used in 2021 to complete Chapter IV. This involved narrowing down the question foci and identifying a clearer pathway of analysis based on such questions.

2.2 Reflections

Using national-level data to visualize and assess trends in crop diversity across the U.S. was a useful tool in providing context for what regions (or clusters of counties) are characterized by high (or low) crop diversity. This context allowed for an informed sampling strategy in choosing the Magic Valley of Idaho as a place to dig deeper into factors that support and promote high crop diversity across landscapes. This approach inherently grapples with the epistemological challenge of placing quantitative and qualitative datasets in conversation with each other. I did, in fact, find that the Magic Valley is an agriculturally diverse region with a multitude of crops grown across landscapes. In this way, this pairing of aggregated landscape metrics with qualitative inquiry was effective by leading me to a place that embodied the metric I was interested in (crop diversity).

However, quantitative metrics of crop diversity, especially those aggregated to the county scale, conflated the messiness of spatial and temporal diversification strategies often enacted across a landscape. For example, the Shannon's Diversity Index (SDI) captures the number of and amount of agricultural land-use categories in a county *annually*; therefore, it omits practices that enhance crop diversity *within* a year, such as cover cropping or intercropping. It also does not track how one field changes across several years, thus failing to account for or appropriately weight temporal crop rotation patterns.

The limitations of these metrics became apparent during qualitative fieldwork in the Magic Valley. As I came to understand in Chapter IV, this region is characterized primarily by temporal diversification strategies – those that are not easy to parse out through the quantitative metrics I relied on in Chapters II and III. Furthermore, while this region maintains high crop diversity, it is not a place readily characterized by agroecological farming practices that push beyond or outside of the productivist paradigms of U.S. agriculture. Rather, due to systemic challenges and an overwhelming daily workload, farmers only diversify their operations to the extent that the market allows them to and still earns them a profit. They also often rely heavily on external inputs to manage their soil and streamline their large operations, practices which may conflict with enacting certain conservation practices, like reduced tillage.

Exploring the nuance of farmers' livelihoods in the Magic Valley problematized using crop diversity as a quantifiable and normative metric of agroecological "success." The interdisciplinary approach used across these three studies exposed the importance of *rethinking* models and metrics often defined at the outset of a research project as important or desirable. While increasing crop diversity is an important piece of increasing agrobiodiversity, it is not the only goal of agroecological transformation. Thus, reducing agroecology down to a quantitative metric that captures just one of its elements obscured the complexities and realities of its pathways that only in-depth qualitative inquiry could illuminate. This dynamic between qualitative and quantitative methods provides motivation to continue to establish critical feedback loops between big and deep data to both build more meaningful models and ask more meaningful questions.

3. Research Contributions

This dissertation theoretically, methodologically, and practically advances our understanding of how to enhance agrobiodiversity across the U.S. agri-food system. Theoretically, I rely on the emerging framework of political agroecology as a lens to assess and situate crop diversification – a strategy that farmers can *currently* enact from the field to landscape scale. Political agroecology represents a synthesis of political ecology and agroecology to understand how to move agricultural systems toward transformation that is sustainable, just, and fundamentally different from our current agri-food regime. This project applies this framework by focusing on three scales of influence (the macro-, meso-, and microscale) to identify the multiscalar dynamics that constrain and enable agroecological transformation. In doing so, this research strengthens the political agroecology framework by elucidating structural *and* individual barriers and bridges to diversification, emphasizing how change at any one scale would be insufficient in achieving systems-level transformation. Ultimately, the documentation and analysis of these barriers and bridges through these three studies provides data-driven and grounded evidence to the importance and relevance of political agroecology as a framework of change.

Methodologically, I use multiple types of data in novel, integrative analyses. This project integrated exploratory analyses national land use data, machine learning techniques to model regional drivers of diversity, and qualitative inquiry into farmer perceptions and experiences. The combination of these approaches crosses epistemological and disciplinary boundaries to more *holistically* assess how agricultural landscapes come to be and how they can be changed. These methods working cooperatively framed a more nuanced (and practically relevant) reality than any would have in isolation, and they provide, as discussed above, a foundation for meaningful reflections on critically integrating qualitative and quantitative data. The contextualization of qualitative inquiry within broader, data-driven assessments of systemic trends can be used as a framework for future research in other agricultural communities and landscapes across the U.S. This methodological approach can also help local and state policymakers prioritize assistance and conservation initiatives based on how and where farmers feel most constrained, and landscapes are less diverse.

Practically, this research contributes to a deeper understanding of farmers' livelihoods in the Magic Valley of Idaho as they relate to the possibilities of present and future diversification. Synthesizing farmer experiences and situating them within the regional and national narratives of sociotechnical "lock-in" and path dependencies helped elucidate the daily challenges and structural constraints farmers face to enacting transformative strategies. These findings emphasize how the burden of sustainable transformation cannot fall solely on farmers' shoulders but must also translate to policy change and societal paradigm shifts. Too often, "sustainable" agricultural solutions present technological and scientific innovations that ignores or devalues the agrarian experience in the U.S. This research provides practical examples of agrarian experiences and humanities that must be at the center of such innovation.

4. Future Research Directions

The methods and findings of these three studies provide a foundation for several future research directions to build from. First and foremost, the overarching structure and methodological approach of this project could be replicated across the U.S. in different communities and regions. Maps and data explorations at the national scale presented in Chapter II, as well as more formal statistical trends at the regional scale in Chapter III, provide critical context in selecting communities and study sites for in-depth, qualitative work. As opposed to selecting a cluster of counties that are quantitatively diverse (as in Chapter IV), future research could select a cluster of counties that 1) are quantitatively non-diverse (e.g., in the Corn Belt), or 2) represent a gradient of diversity in adjacent counties. Replicating a semi-structured interview approach in contextually different regions could provide, in the aggregate, rich and narrative-driven comparisons of what enables and constrains diversification across the U.S., as well as provide stronger feedback loops between large-scale models and qualitative methods.

Second, exploring agricultural imaginaries with farmers in the Magic Valley could meaningfully build from these prior interviews. Follow-up studies could interview the same farmers (provided their consent) but dig deeper into this concept of imagining new landscapes by asking more directed landscape design questions, and even incorporating participatory mapping techniques. These imagined landscape designs could be used in quantitative landscape modeling scenarios, presenting an innovative feedback loop of quantitative and qualitative data toward sustainable transition pathways grounded in a specific place.

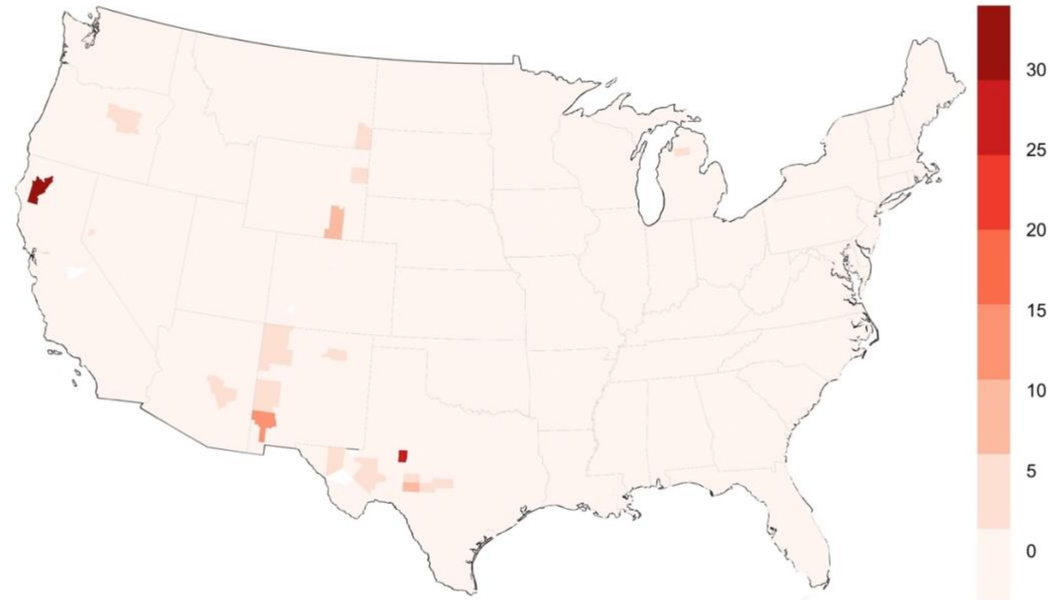
Finally, this study exposes the importance and influence of sociopolitical factors on shaping the possibilities (and lack thereof) in U.S. agriculture. However, due to data and time limitations, it falls short in interrogating the intersections of social identity, such as race, ethnicity, class, gender, physical ability, etc., with the structural elements of racism, inequity, genocide, enslavement, and discrimination upon which U.S. agriculture has been built. Such intersections are *central* to reimagining and rebuilding a more sustainable future. Future research could purposefully sample agricultural regions and participants based on the multiplicity of these social identities to listen to and document the experiences of those who, despite being historically excluded, are finding pathways to build resilient and abundant agricultural futures. Moving forward, the long-standing and diverse examples of how to transform agricultural landscapes and their associated sociopolitical structures within the U.S. can and should be uplifted.

References

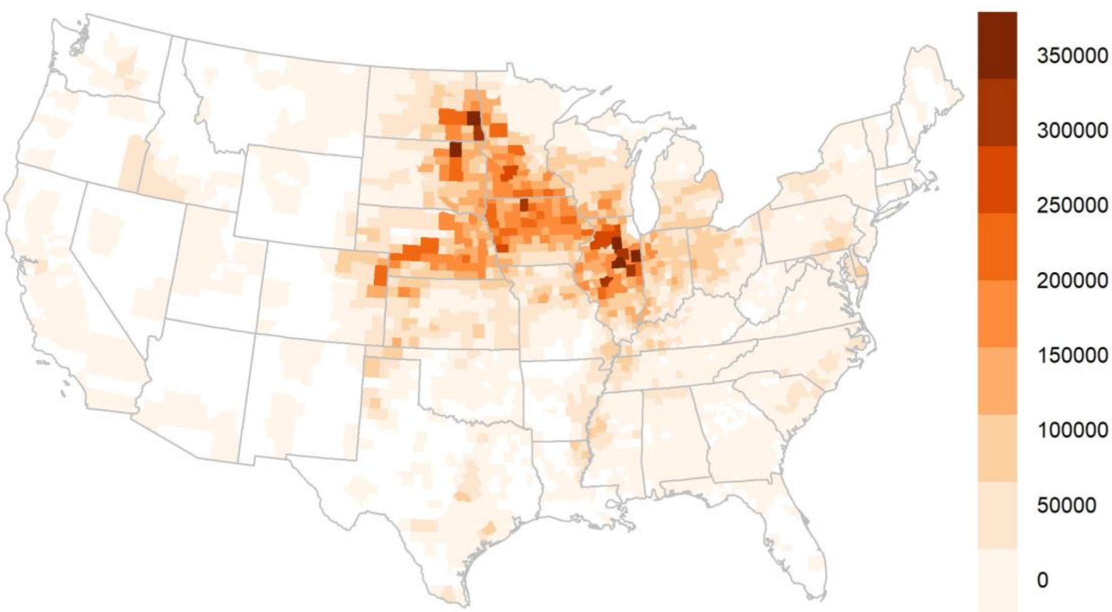
Burchfield, E., Nelson, K., and **Spangler, K**. (2019). The impact of agricultural diversification on U.S. crop production. *Agriculture, Ecosystems and Environment*, 285 (2019), 10.1016/j.agee.2019.106615.

APPENDICES

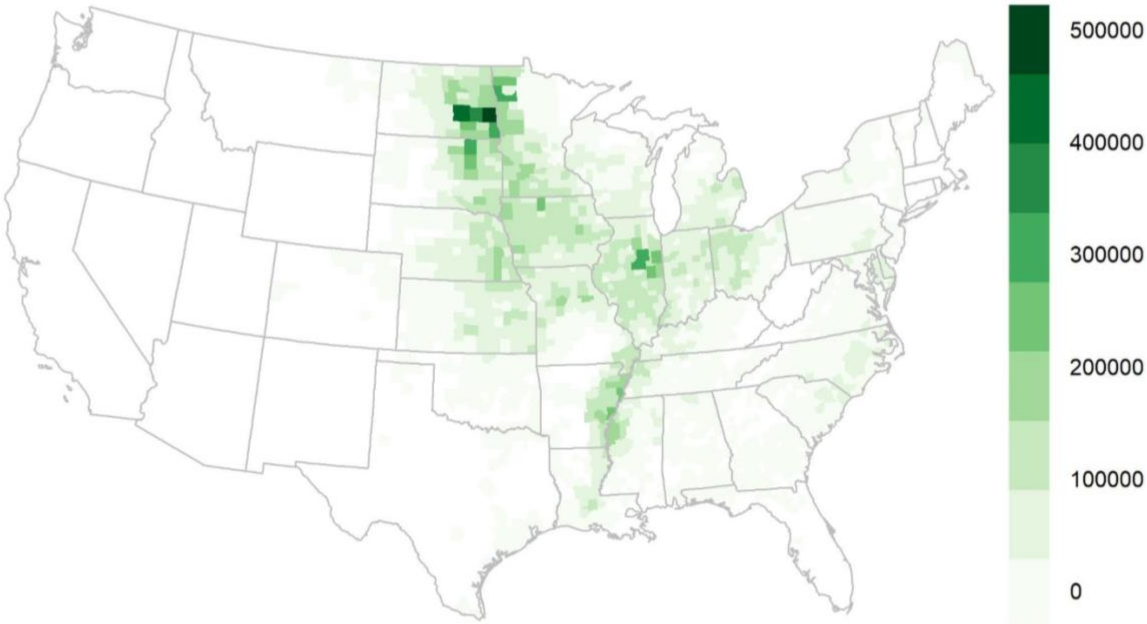
Appendix A: Supplementary Information for Chapter II



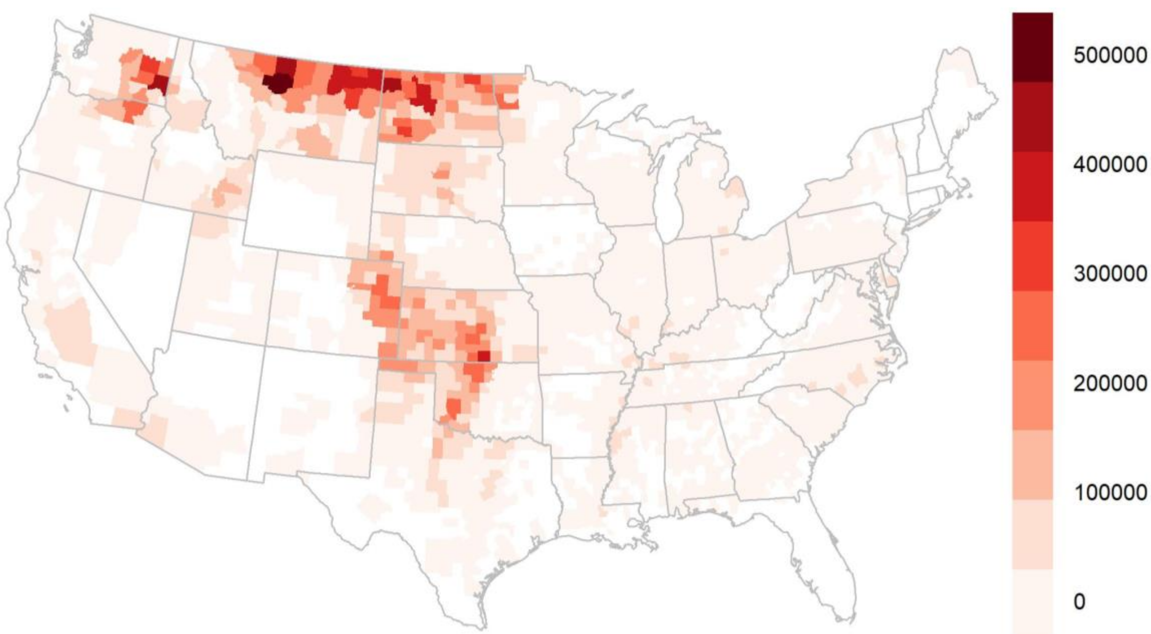
SI Figure 1: Percent change in percent cropland by county, 1974-2012 (NWALT)



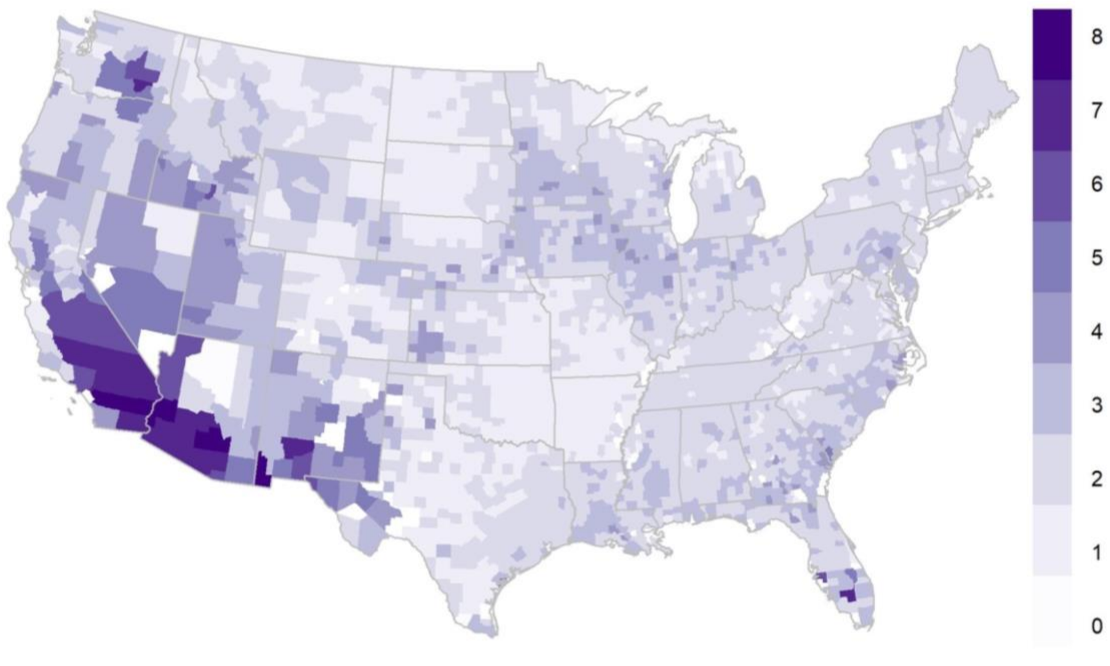
SI Figure 2: Acres harvested of corn by county (USDA 2012 Census)



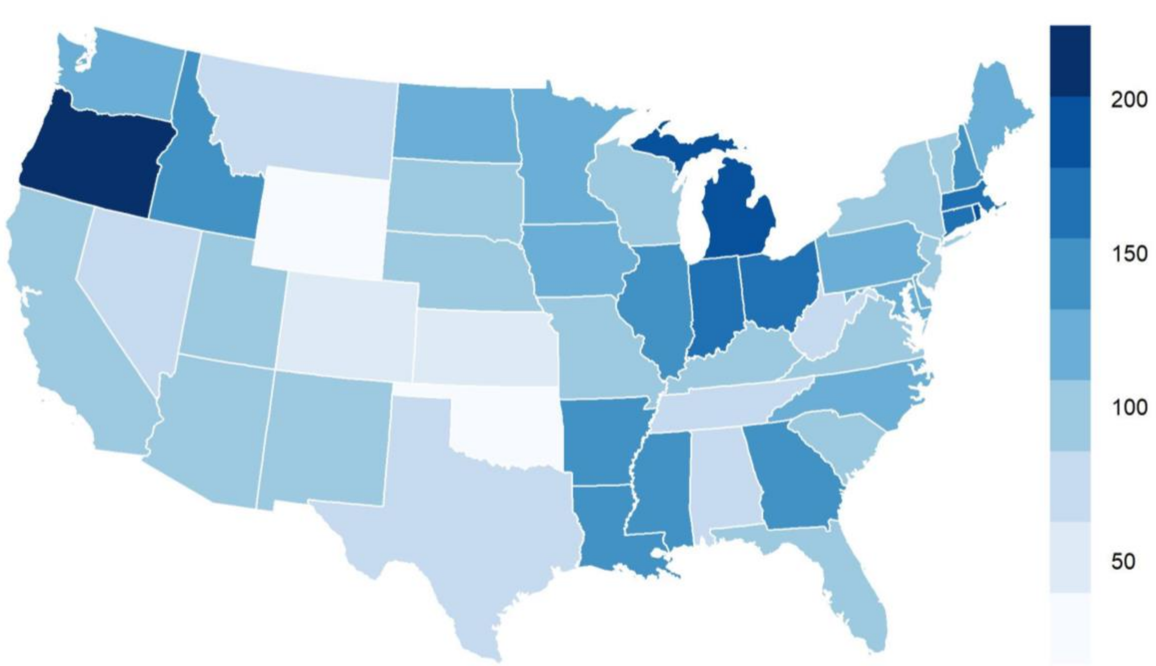
SI Figure 3: Acres harvested of soybeans by county (USDA 2012 Census)



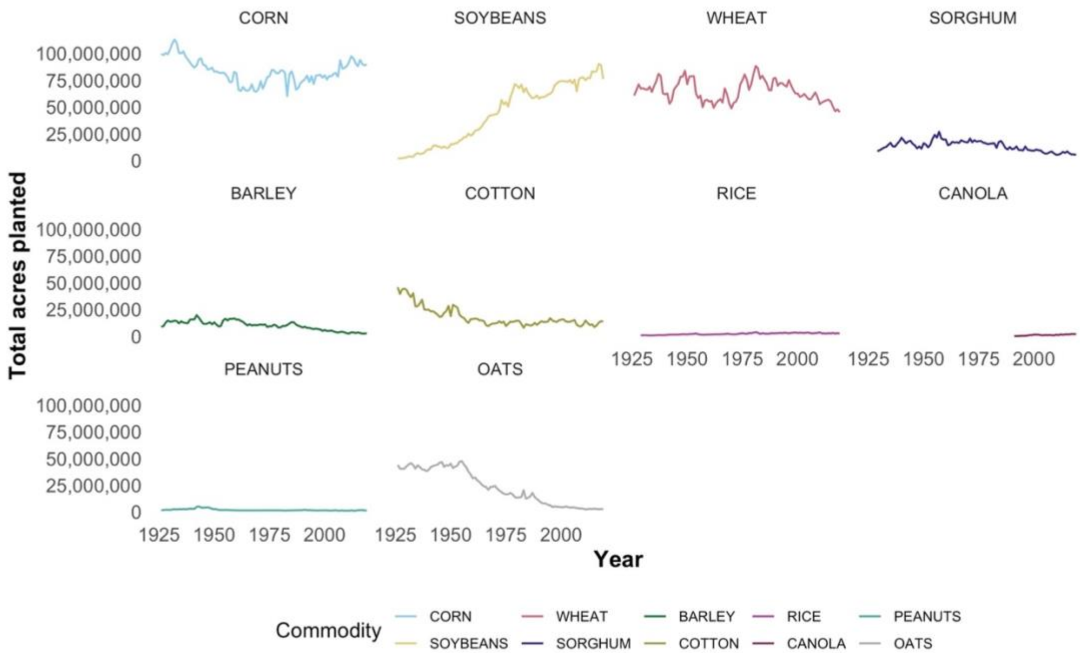
SI Figure 4: Acres harvested of wheat by county (USDA 2012 Census)



*SI Figure 5***.** Tons per acres harvested of hay per county (USDA 2012 Census)

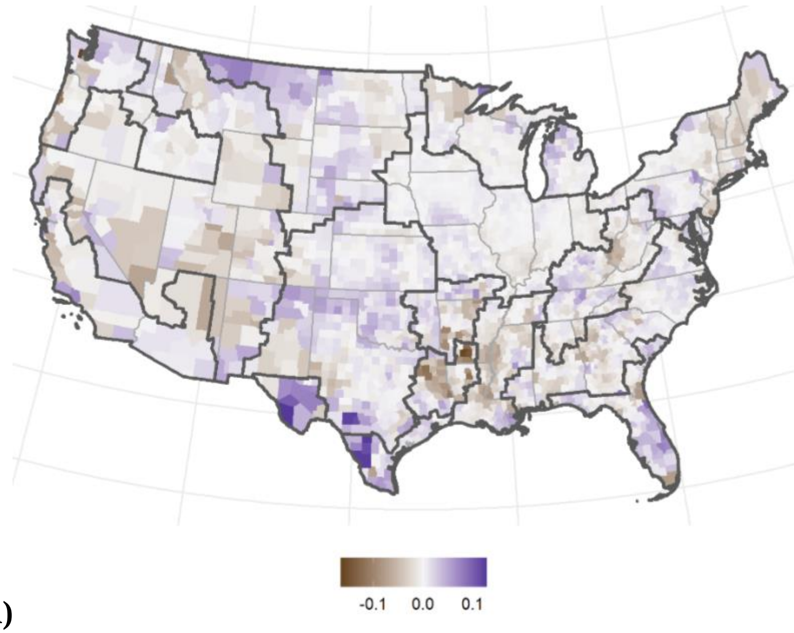


*SI Figure 6***:** Percent change in Total Factor Productivity (TFP) by state from 1960 to 2004

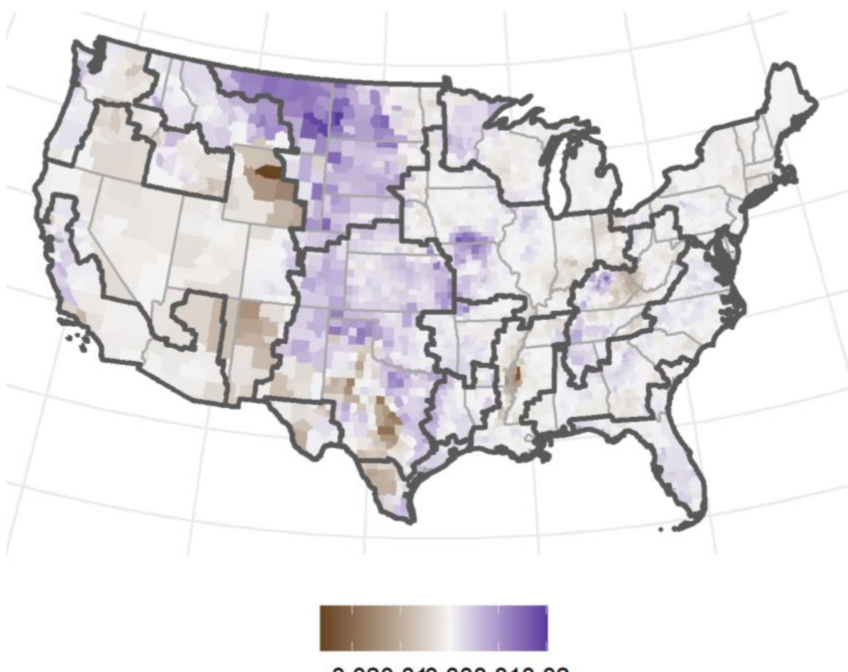


SI Figure 7: Acres planted by crop from 1926-2019 (USDA NASS Survey)

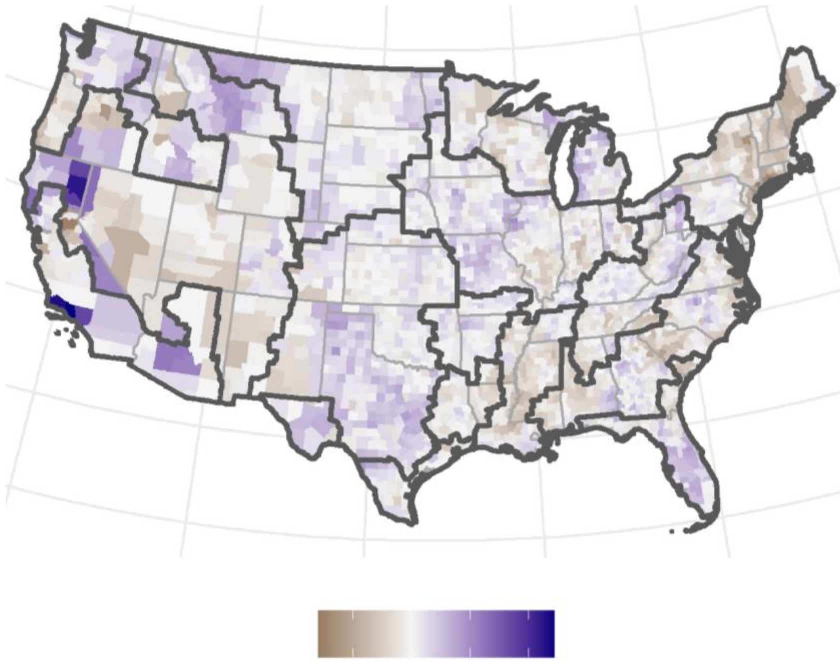
Appendix B: Supplementary Information for Chapter III



A)

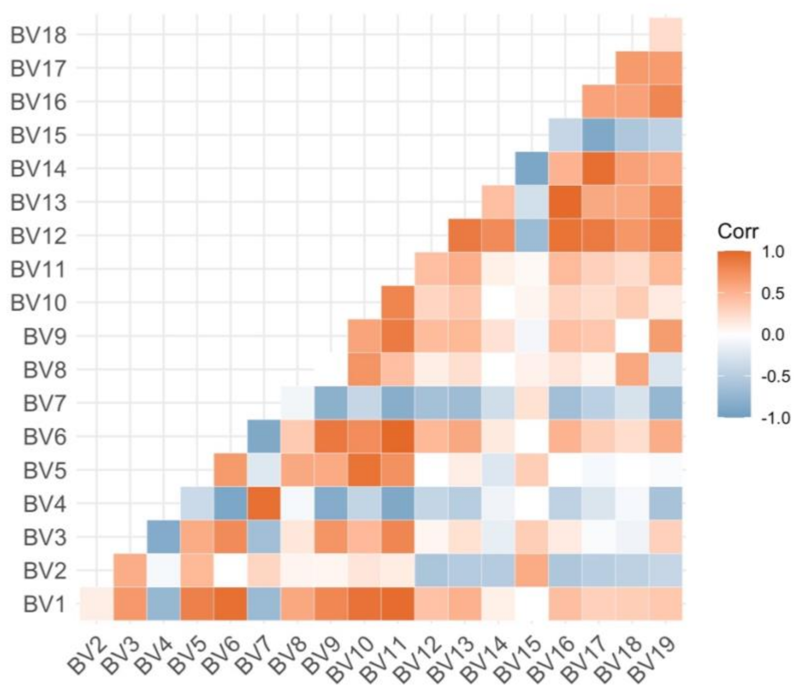


B)

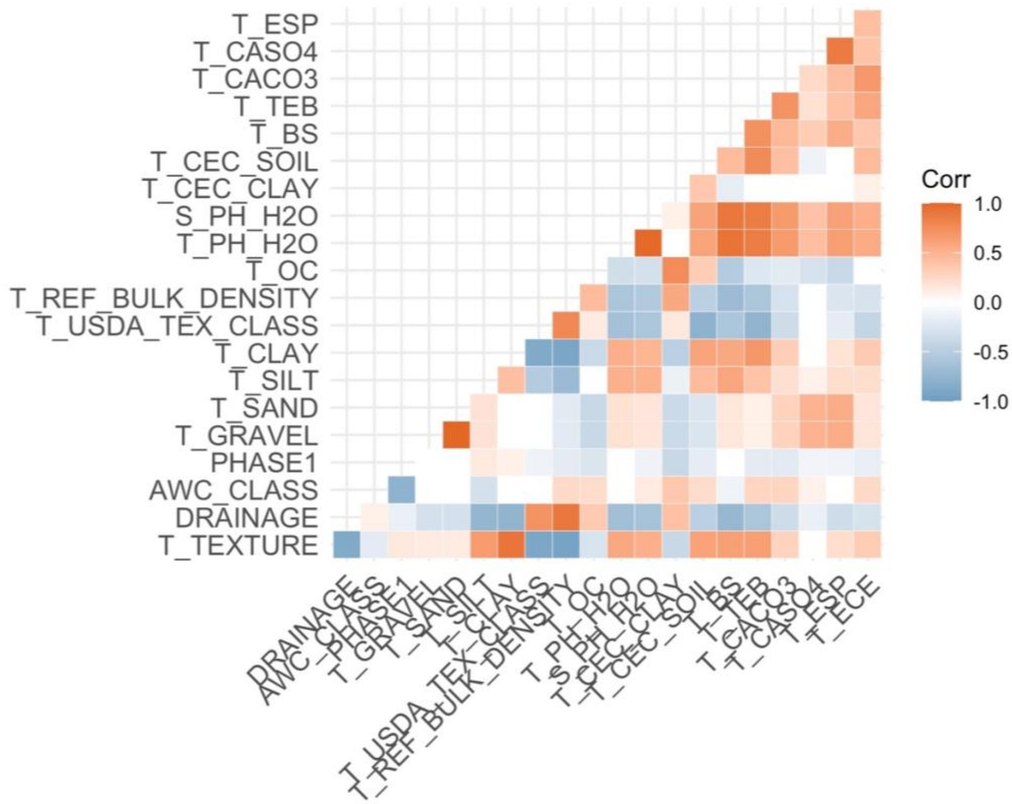


C)

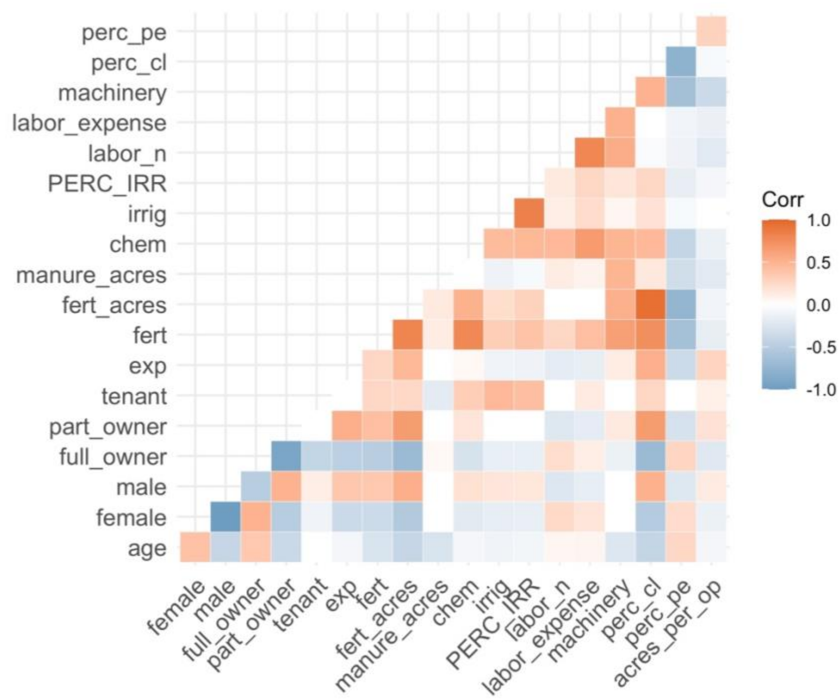
*SI Figure 1A-1C***:** County-level regression of SDI (A), SIDI (B), and RICH (C) on change through time (2008-2019). Purple indicates a positive slope of the line that best fits each county metric through time, and brown indicates a negative slope.



A)



B)



C)

*SI Figures 2A-2C***:** Correlation matrices prior to variable selection of climate (A), soil (B), and Census of Agriculture (COA) predictor variables

SI Table 1: Full description of predictor variables

Variable	Units	Description and measurement	Variable name
Farm(er) Characteristics			
Primary producer's age	Avg. age	Average age of the operations' primary producer.	age
% Acres operated by female/male Farmers	% ag acres	Percentage of the total acres operated by female (or male) farmers; measured as acres operated by female (or male) farmers and standardized by the total acres operated in a county.	female / male
Land tenure	% ag acres	Percentage of acres operated by full owners, part owners, and tenants.	part_owner
On-farm experience	Avg. years	Average years' experience of primary producer on current operation.	exp
Farm size	Med. #	Median number of agricultural acres operated per operation; measured as median acres per operation.	acres_per_op
Farm inputs			
Fertilizer expense	$/ag acre	Total expense of fertilizers, including lime and soil conditioners, rock phosphate and gypsum, and the cost of custom application, per agricultural acre; measured as total expense in USD $ and standardized by the total number of agricultural acres operated, per county.	fert
Manure	% ag acres	Total acreage on which manures were applied; measured as total acreage applied and standardized by the total number of agricultural acres operated, per county.	manure_acres
Chemical expense	$/ag acre	Total expense of chemicals applied, per agricultural acre; measured as the total expense in USD $ applied and standardized by the total number of agricultural acres operated, per county.	chem
MIrAD irrigation	% ag acres	Data from MIrAD in 2012 and 2017. Percent agricultural acres irrigated per county, based on the NLCD landcover dataset built using a mix of USDA COA data, NDVI, and NLCD	PERC_IRR
Labor	*n*/ag acre	Total number of all laborers, per agricultural acre; measured as the total number of laborers (hired, contract, and migrant) and standardized by the total number of agricultural acres operated, per county.	labor_n
Machinery expense	$/ag acre	Total asset value of agricultural machinery, per agricultural acre; measured as total machinery assets in USD $ and standardized by the total number of agricultural acres operated, per county.	machinery
Land use			
% cropland	% cty	Percentage of land in a county dedicated to cropland; measured as total acres cropland (includes crop failure, cultivated summer fallow, idle land, harvested cropland, and cropland used only for pasture) and standardized by the total number of acres in a county.	perc_cl
% pastureland (excl. pastured cropland)	% cty	Percentage of land in a county dedicated to pastureland, excluding pastured cropland; measured as total acres pasture (excl. pastured cropland_ and standardized by the total number of acres in a county.	perc_pe
Assistance & income			
Commodity sales	$/operation	Total commodity sales; measured in USD $ per operation.	comm_sales

Government programs	$/operation	Total cash receipts of government programs, per agricultural acre; measured in USD $ per operation.[7]	gvt_prog
Soil characteristics			
Topsoil gravel content	%vol.	Volume percentage gravel (materials larger than 2 mm).	T_GRAVEL
Topsoil sand fraction	% wt.	Percentage sand (particles ranging in diameter from 0.0625 to 2 mm).	T_SAND
Topsoil silt fraction	% wt.	Percentage silt (produced by mechanical weathering of rock as opposed to chemical weathering which produces clay; ranges in size from 0.002 to 0.050/0.0625 mm).	T_SILT
Topsoil reference bulk density	Kg/dm3	Property of particulate materials; the mass of many particles of the material / volume (space between particles and the space inside of pores of individual particles) they occupy.	T_REF_BULK_DENSITY
Topsoil organic carbon	% weight	Percentage of organic carbon; OC with pH is the best simple indicator of the health status of soils (moderate to high amounts of organic carbon are associated with fertile soils with good structure (codes 1-5, where 1 = very poor in organic carbon).	T_OC
Subpsoil pH (H2O)	-log(H^+)	Soil reaction; a measure of the acidity alkalinity of the soil (5 classes with specific agronomic significance).	S_PH_H2O
Topsoil CEC (clay)	Cmol/kg	Cation exchange capacity of the clay fraction (classes 1-4).	T_CEC_CLAY
Topsoil CEC (soil)	Cmol/kg	Cation exchange capacity (total nutrient fixing capacity of a soil; soil with low CEC have little resilience and cannot build up stores of nutrients); the clay content, OM content, and clay type determine the total nutrient storage capacity; values > 10 cmol/kg are considered satisfactory for most crops (class 1-5).	T_CEC_SOIL
Topsoil calcium carbonate	% weight	Total lime content; calcium carbonate is the active ingredient in agricultural lime. Low levels enhance soil structure and are generally beneficial for crop production while higher concentrations may induce iron deficiency and limit the water storage capacity of soils.	T_CACO3
Topsoil gypsum	% weight	Total calcium sulphate content; up to 2% favors plant growth, between 2 and 25% has little or no adverse effects and >25% can cause significant reduction in yields.	T_CASO4
Topsoil sodicity (ESP)	%	Exchangeable sodium percentage; indicates levels of sodium hazards in crops.	T_ESP
Topsoil salinity (Elco)	dS/m	Electrical conductivity; crops vary significantly in their resistance and response to salt in soils (levels indicate agronomic relevant limits).	T_ECE
Climate			
Mean annual temperature	°C		BV1
Mean diurnal range		Mean of max temperature – minimum temperature	BV2
Temperature seasonality		Standard deviation*100	BV4
Mean temperature of the wettest quarter	°C		BV8

[7] This category consists of direct payments from the government and includes 1) payments from Conservation Reserve Program, Wetlands Reserve Program, Farmable Wetlands Program, and Conservation Reserve Enhancement Program; 2) loan deficiency payments; 3) disaster payments; 4) other conservation programs; and 5) all other federal farm programs under which payments were made directly to farm operators. Commodity Credit Corporation (CCC) proceeds, local and state government agricultural program payments, and federal crop insurance payments are not tabulated in this category (USDA NASS, 2019, p. 759).

Mean temperature of the driest quarter	°C		BV9
Mean temperature of the warmest quarter	°C		BV10
Total (annual) precipitation	mm		BV12
Precipitation seasonality		Coefficient of variation	BV15
Precipitation of warmest quarter	mm		BV18

SI Table 2: Full description of response variables

Variable	Units	Description and measurement	Variable name
Shannon's Diversity Index	0 to ∞	A measure of landscape *diversity*; measured as the proportional abundance of each land use category in a county and used as a relative index to compare across landscapes or the same landscape at different times. SDI increases as richness and evenness increase.	SDI
Simpson's Diversity Index	0 to 1 scale	A measure of landscape *diversity*; the index value is the probability that any two cells selected at random would be from different patch types. As species richness and evenness increase, SIDI increases. SIDI ranges from 0 to 1.	SIDI
Richness	1 to ∞	A measure of landscape *diversity*; measured as the number of unique land use categories in a county. Richness approaches 1 when only one patch is present in a large landscape and increases, without limit, as the number of unique land uses increases, and the landscape area decreases.	RICH

SI Table 3: CDL crop pixel reclassification table using the U.S. National Vegetation Classification (USNVC) database

croplandcover	Description	Changeto	Description2
0	Background	0	Background
1	Corn	1	Graminoid row crop
2	Cotton	2	Forb row crop
3	Rice	3	Herbaceour wetland crop
4	Sorghum	1	Graminoid row crop
5	Soybeans	2	Forb row crop
6	Sunflower	2	Forb row crop
10	Peanuts	2	Forb row crop
11	Tobacco	2	Forb row crop
12	Sweet Corn	1	Graminoid row crop
13	Popcorn	1	Graminoid row crop
14	Mint	2	Forb row crop
21	Barley	4	Close grain crop
22	Durum Wheat	4	Close grain crop
23	Spring Wheat	4	Close grain crop
24	Winter Wheat	4	Close grain crop
25	Other Small Grains	4	Close grain crop

26	Dbl Crop WinWht/ Soybeans	7	Forb and Close grain crop
27	Rye	4	Close grain crop
28	Oats	4	Close grain crop
29	Millet	4	Close grain crop
30	Speltz	4	Close grain crop
31	Canola	2	Forb row crop
32	Flaxseed	4	Close grain crop
33	Safflower	2	Forb row crop
34	Rape Seed	2	Forb row crop
35	Mustard	2	Forb row crop
36	Alfalfa	5	Permanent pasture
37	Other Hay/Non-Alfalfa	6	Cultivated pasture
38	Camelina	2	Forb row crop
39	Buckwheat	2	Forb row crop
41	Sugarbeets	2	Forb row crop
42	Dry Beans	2	Forb row crop
43	Potatoes	2	Forb row crop
44	Other Crops	15	Free vegetation
45	Sugarcane	1	Graminoid row crop
46	Sweet Potatoes	2	Forb row crop
47	Misc Vegs & Fruits	15	Free vegetation
48	Watermelons	2	Forb row crop
49	Onions	2	Forb row crop
50	Cucumbers	2	Forb row crop
51	Chickpeas	2	Forb row crop
52	Lentils	2	Forb row crop
53	Peas	2	Forb row crop
54	Tomatoes	12	Bush fruit & berry
55	Caneberries	12	Bush fruit & berry
56	Hops	2	Forb row crop
57	Herbs	2	Forb row crop
58	Clover/Wildflowers	2	Forb row crop
59	Sod/Grass Seed	6	Cultivated pasture
60	Switchgrass	6	Cultivated pasture
61	Fallow/Idle Cropland	16	Fallow crop
63	Forest	63	No-agricultural area
64	Shrubland	64	No-agricultural area
65	Barren	65	No-agricultural area
66	Cherries	10	Tree orchard
67	Peaches	10	Tree orchard
68	Apples	10	Tree orchard
69	Grapes	13	Vineyard
70	Christmas Trees	14	Forest plantation
71	Other Tree Crops	14	Forest plantation
72	Citrus	10	Tree orchard
74	Pecans	10	Tree orchard
75	Almonds	10	Tree orchard
76	Walnuts	10	Tree orchard
77	Pears	10	Tree orchard
81	Clouds/No Data	0	Background
82	Developed	17	No-agricultural area
83	Water	17	No-agricultural area
87	Wetlands	87	No-agricultural area
88	Nonag/Undefined	88	No-agricultural area
92	Aquaculture	92	No-agricultural area
111	Open Water	111	No-agricultural area
112	Perennial Ice/Snow	112	No-agricultural area
121	Developed/Open Space	121	No-agricultural area
122	Developed/Low Intensity	122	No-agricultural area
123	Developed/Med Intensity	123	No-agricultural area
124	Developed/High Intensity	124	No-agricultural area
131	Barren	131	No-agricultural area
141	Deciduous Forest	141	No-agricultural area
142	Evergreen Forest	142	No-agricultural area
143	Mixed Forest	143	No-agricultural area
152	Shrubland	152	No-agricultural area
176	Grassland/Pasture	176	No-agricultural area
190	Woody Wetlands	190	No-agricultural area
195	Herbaceous Wetlands	195	No-agricultural area

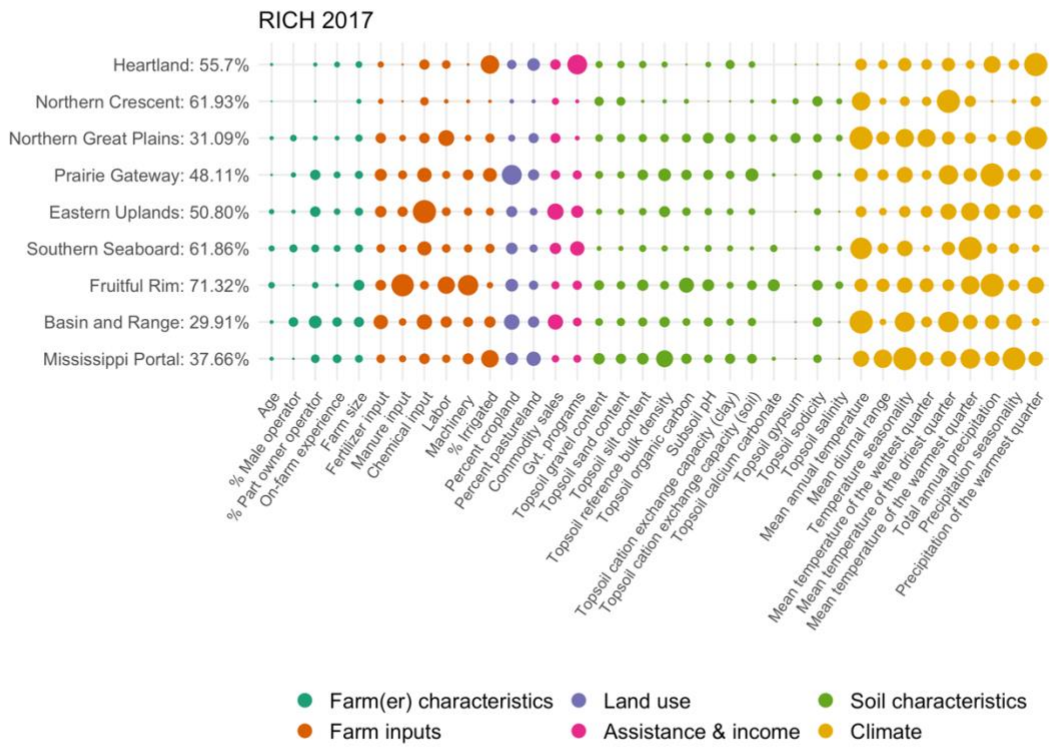
204	Pistachios	10	Tree orchard
205	Triticale	1	Graminoid row crop
206	Carrots	2	Forb row crop
207	Asparagus	2	Forb row crop
208	Garlic	2	Forb row crop
209	Cantaloupes	2	Forb row crop
210	Prunes	10	Tree orchard
211	Olives	10	Tree orchard
212	Oranges	10	Tree orchard
213	Honeydew Melons	2	Forb row crop
214	Broccoli	2	Forb row crop
215	Avocados	10	Tree orchard
216	Peppers	2	Forb row crop
217	Pomegranates	10	Tree orchard
218	Nectarines	10	Tree orchard
219	Greens	2	Forb row crop
220	Plums	10	Tree orchard
221	Strawberries	12	Bush fruit & berry
222	Squash	2	Forb row crop
223	Apricots	10	Tree orchard
224	Vetch	2	Forb row crop
225	Dbl Crop WinWht/Corn	8	Close and Graminoid row crop
226	Dbl Crop Oats/Corn	8	Close and Graminoid row crop
227	Lettuce	2	Forb row crop
228	Dbl Crop Triticale/Corn	1	Graminoid row crop
229	Pumpkins	2	Forb row crop
230	Dbl Crop Lettuce/Durum Wht	7	Forb and Close grain crop
231	Dbl Crop Lettuce/Cantaloupe	2	Forb row crop
232	Dbl Crop Lettuce/Cotton	2	Forb row crop
233	Dbl Crop Lettuce/Barley	7	Forb and Close grain crop
234	Dbl Crop Durum Wht/Sorghum	8	Close and Graminoid row crop
235	Dbl Crop Barley/Sorghum	8	Close and Graminoid row crop
236	Dbl Crop WinWht/Sorghum	8	Close and Graminoid row crop
237	Dbl Crop Barley/Corn	8	Close and Graminoid row crop
238	Dbl Crop WinWht/Cotton	7	Forb and Close grain crop
239	Dbl Crop Soybeans/Cotton	2	Forb row crop
240	Dbl Crop Soybeans/Oats	7	Forb and Close grain crop
241	Dbl Crop Corn/Soybeans	9	Graminoid and Forb row crop
242	Blueberries	12	Bush fruit & berry
243	Cabbage	2	Forb row crop
244	Cauliflower	2	Forb row crop
245	Celery	2	Forb row crop
246	Radishes	2	Forb row crop
247	Turnips	2	Forb row crop
248	Eggplants	2	Forb row crop
249	Gourds	2	Forb row crop
250	Cranberries	11	Wetland shrub horticultural
254	Dbl Crop Barley/Soybeans	7	Forb and Close grain crop

SI Table 4: Summary data by FRR (2012)

FRR	# of counties	Mean SDI value	Standard deviation of SDI
Heartland	540	0.91	0.17
Northern Crescent	389	1.07	0.35
Northern Great Plains	175	1.12	0.27
Prairie Gateway	372	0.88	0.30
Eastern Uplands	377	0.88	0.37
Southern Seaboard	450	1.03	0.32
Fruitful Rim	249	1.05	0.44
Basin and Range	170	0.85	0.40
Mississippi Portal	152	0.99	0.28

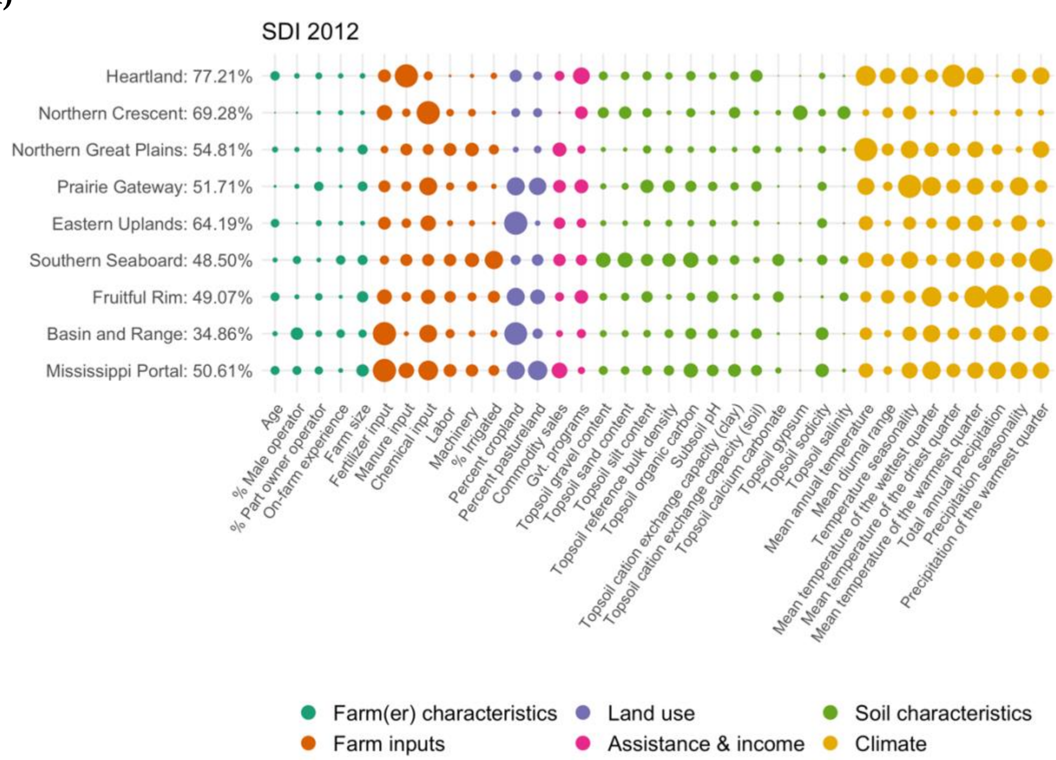
A)

B)

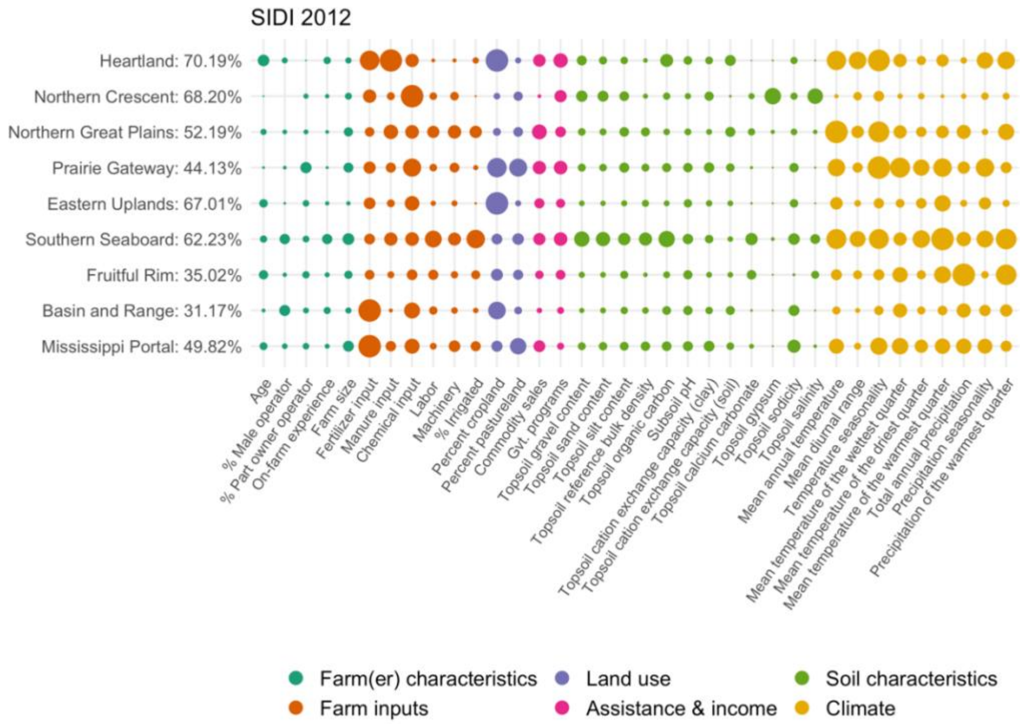


SI Figure 3A-3B: Variable importance by FRR for SIDI (A) and RICH (B) in 2017

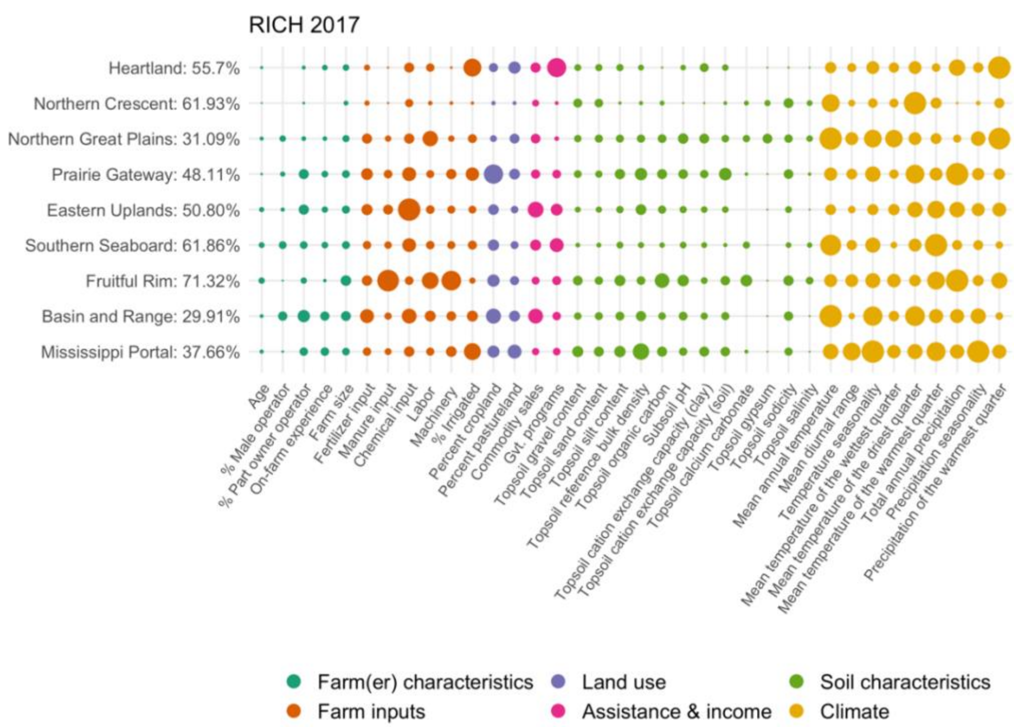
A)



B)



C)



SI Figure 4A-4C: Variable importance by FRR for SDI (A), SIDI (B) and RICH (C) in 2012

Appendix C: Supplementary Information for Chapter IV

SI Table 1: 2021 Interview question guide

1. *Tell me about yourself and your current position.

    a. How long have you been farming/working in your current occupation?
    b. How did you get involved in agriculture/your current occupation?

2. What crops do you currently grow and/or livestock do you currently raise?

    a. What, if any, is your "primary" enterprise?
        i. How did it become this way?
    b. How do you decide what varieties to grow?
        i. ****May already have been answered above*

3. [Current diversification strategies]:

    a. Walk me through your typical crop rotation patterns?
        i. How did/do you decide on these rotation patterns?
    b. Walk me through your use of cover crops, if any?
        i. How did/do you decide on these patterns?
    c. Walk me through how and why you plan your farm spatially?
        i. Do you utilize intercropping at all? Where and why?
    d. How has this farm's mix of enterprises changed over the past 3 to 5 years?

4. What are the disadvantages/challenges of these current strategies [reference what they stated above]?

5. Who does most of the fieldwork on your farm?
    a. Is it difficult to find labor?
    b. Does this vary by season?

6. If you had unlimited resources (time, labor, money, etc.), would you consider changing the level of diversification on your farm operation/in your area?
    a. If so – what would you like to do?
    b. What would you need that you currently don't have to do so?

7. How is the land that borders your farm being used?
    a. How would you describe the landscape around your farm?
        i. How diverse is that landscape?
    b. What impacts do neighboring properties have on your farm (either good or bad)?
        i. Do they influence your crop diversification strategies?

c. How is land use changing in this area? How does that impact your farm?

8. *[Current policies and programs]?

   a. Do you regularly receive any federal commodity program payments?
   b. Are you enrolled in crop insurance programs for some/all the crops you grow?
   c. Have you participated in any conservation programs or projects?
   d. Do you produce any of your crops or livestock under contract?
   e. Have you received any support or premium prices from buyers that compensate you for using more diverse crop rotations?

9. *Where do you get information about farm management/crop diversification strategies?

   a. Who are the primary people you turn to for information?
   b. What sources of information do you consider most useful to guide your crop diversification decisions?

10. Is there anything else that you want to add about what we've talked about today?

Demographic information:

- Age:
- Gender:
- Education:
- Marital status:
- Race/ethnicity:
- Farm income:
    - Gross:
    - Net:
- What is your current land ownership status (owner, tenant, owner-tenant)?
- What is the size of the land you own/manag (in acres)?
- Did you grow up on a farm?
- Do you or your family engage in off-farm work?
- Who do you share your operation with, if any?
- Are you certified organic?

*SI Table 2***:** Full codebook as used in qualitative coding in ATLAS.ti

Code	Code Group	Comment
Info_broadercommunity	**Information Sources**	Description of if and how they rely on their broader community for reliable information and who is included in their broader community
Info_internet	**Information Sources**	Description of if and how they rely on the internet for reliable information and what sources they specifically seek out
Info_magazines	**Information Sources**	Description of if and how they rely on farming magazines for reliable information
Info_neighbors	**Information Sources**	Description of if and how they rely on their neighbors for reliable information
Info_private	**Information Sources**	Description of if and how they receive reliable information from private entities, like crop advisors and field men from private companies
Neighbor_badimpacts	**Neighbor**	Description of the negative impacts their neighbors and neighbors' land have on them and their operation
Neighbor_goodimpacts	**Neighbor**	Description of the positive impacts their neighbors and neighbors' land have on them and their operation
Neighbor_land	**Neighbor**	Description of what their neighbors' land is used for
Neighbor_proximitytodairy	**Neighbor**	Description of if and how their operation is proximate to a dairy operation and the ensuing impacts
Neighbor_relationship	**Neighbor**	Description of their relationships with their neighbors and the values, benefits, or drawbacks of these relationships
CDS_challenges	**Operation**	Current Diversification Strategy: Description of challenges associated with current diversification strategies
CDS_changes	**Operation**	Current Diversification Strategy: Description of how their current diversification strategies have changed and evolved over time, as well as explanations of why. NOTE: This does not include how social and cultural norms have changed over time; this may include descriptions of how and why they started cover cropping or changed their crop rotation.
CDS_covercrop	**Operation**	Current Diversification Strategy: Description of cover cropping patterns and techniques and their rational, benefits, and difficulties
CDS_croprotation	**Operation**	Current Diversification Strategy: Description of crop rotation patterns and their rationale, benefits, and difficulties
CDS_experimentation	**Operation**	Description of the rationale, thinking, or logic behind why they experiment with new techniques, crop varieties, or even machinery related to diversification

CDS_spatialplanning	**Operation**	Current Diversification Strategy: Description of how and why they plan their farm spatially, including ecological factors, such as topography, soil, or microclimate, as well as economic, social, and other personal factors
Current_crops	**Operation**	Description of the current suite of crops grown on their operation from year to year, even if not at present
Good_quotes	**Operation**	
Imagined_alternatives	**Operation**	Description of what they would do on their operation if they had unlimited resources (time, money, land, etc.)
Irrigration_description	**Operation**	Description of their irrigation infrastructure and how it's changed over time
Labor_challenges	**Operation**	Description of challenges associated with finding, supporting, and managing labor
Labor_fulltime	**Operation**	Description of if and how they rely on full-time labor
Labor_seasonal	**Operation**	Description of if and how they use seasonal labor, including immigrant labor through the H-2A program
Land_ownership	**Operation**	Discussion of land ownerhsip and tenancy
Perceptions_organic	**Operation**	Perceptions and experiences related to organic management
Perceptions_reducedtill	**Operation**	Perceptions of reduced or no till practices and how this influences what they do on their farm
Perceptions_soilhealth	**Operation**	Perceptions of (managing for) soil health and how this affects what they do on their farm
Primary_enterprise	**Operation**	Description of their current primary enterprise on their farm
Prior_crops	**Operation**	Description of crops that used to be but are no longer grown on their operation
Resources_alternatives	**Operation**	Description of resources they do not currently have but would need to make their imagined alternatives a reality; this includes discussions of barriers to accessing these resources
Changes_lifetime	**Personal Background**	Described changes in cultural, social, and community norms that they've observed over their lifetime; NOTE: this does not include changes in crops grown or other management preferences over their lifetime (see: CDS_changes)
Childhood	**Personal Background**	Other experiences related to their childhood and agricultural exposure
Experience_agriculture	**Personal Background**	Discussion of how they were introduced to and their ensuing experience with agriculture, starting from childhood to present
Interest_agriculture	**Personal Background**	Discussion of their goals, objectives, and interests in their agricultural career
Conservation_prog	**Policies & Programs**	Description of if and how they are enrolled or engaged in conservation programs

Contract	**Policies & Programs**	Description of if and how they are under any private contracts
COVID_impacts	**Policies & Programs**	Description of policies and support related to the COVID-19 Pandemic, as well as personal, operational, and market impacts
Crop_insurance	**Policies & Programs**	Description of if and how they receive crop insurance payments
Fed_subsidies	**Policies & Programs**	Description of if and how they receive federal subsidy payments
Market	**Policies & Programs**	Description of the market that their crops, commodities, and products compete on and its volatility or stability

CURRICULUM VITAE

KAITLYN SPANGLER

5230 Old Main Hill, Logan, UT 84321 **|** kaitlyn.spangler@gmail.com

EDUCATION

Utah State University, Logan, UT

PhD | Environment and Society **2018 – 2021**

Presidential Doctoral Research Fellow

Dissertation: "Cultivating agrobiodiversity in the U.S.: Barriers and bridges at multiple scales"

Virginia Tech, Blacksburg, VA **2016 – 2018**

M.S. | Geography

Thesis: "When he comes home, *then* he can decide: Male out-migration, the feminization of agriculture, and integrated pest management in the Nepali mid-hills"

The Pennsylvania State University, Schreyer Honors College, State College, PA

B.A. | Honors in Anthropology, *magna cum laude*

B.S. | Community, Environment, and Development, *magna cum laude* **2012 – 2016**

Honors Thesis: "Assessing seasonal dietary variability and vulnerability in the Kilombero Valley"

AREAS OF SPECIALIZATION

Political agroecology; climate adaptation science; farmer livelihoods; geospatial data science; qualitative and participatory methodologies; data integration

REFEREED JOURNAL ARTICLES

McCann, R., **Spangler, K.**, Millison, A. (2021). Life paths into leading systems-level change: Higher education's potential and pitfalls. *Sustainability and Climate Change, 14*(4), https://doi.org/10.1089/scc.2021.0005.

Spangler, K., McCann, R., Ferguson, R. S. (2021). (Re-)Defining permaculture: Perspectives of permaculture teachers and practitioners across the United States. *Sustainability, 13*(10), https://doi.org/10.3390/su13105413.

Morgan, B., **Spangler, K.,** Stuivenvolt Allen, J., Morrisett, C., Brunson, M., Wang, S-Y, Huntly, N. (2021). Water availability for cannabis in northern California: Intersections of climate, policy, and public discourse. *Water, 13*(5), doi.org/10.3390/w13010005.

Spangler, K., Burchfield, E., and Schumacher, B. (2020). Past and current dynamics of U.S.

agricultural land use and policy*. Frontiers in Sustainable Food Systems, 4*(98). 10.3389/fsufs.2020.00098/full*.*

Barnett, M., **Spangler, K.,** Petrzelka, P., Filipiak, J. (2020). Power dynamics of non-operating landowner-renter relationships and conservation decision-making in the Midwestern U.S. *Journal of Rural Studies, 78* (2020)*.*

Spangler, K., Christie, M. E. (2019). Renegotiating gender roles and cultivation practices in the Nepali mid-hills: Unpacking the feminization of agriculture*. Agriculture and Human Values, 37* (2020)*.* https://doi.org/10.1007/s10460-019-09997-0

Burchfield, E., Nelson, K., and **Spangler, K**. (2019). The impact of agricultural diversification on U.S. crop production. *Agriculture, Ecosystems and Environment*, 285 (2019), 10.1016/j.agee.2019.106615.

MANUSCRIPTS UNDER REVIEW

Spangler, K., Schumacher, B., Bean, B., Burchfield, E. Path dependencies of U.S. agriculture: Regional factors of diversity. *Agriculture, Ecosystems, and Environment.*

REPORTS AND WORKING PAPERS

Spangler, K., Gayle, R., and Albrecht, Don E. 2020. "Balancing Environmental and Economic Priorities in Rural Western U.S. Communities." ASAP Research Series. Logan, UT: Western Rural Development Center. https://www.usu.edu/wrdc/publications/asap-cgs-analysis-balancing-environmental

CONFERENCE PRESENTATIONS

Spangler, **K.,** McCann, R.B., Ferguson, R.S., *Defining, decolonizing, and applying permaculture: Perspectives of permaculture teachers and practitioners nationwide.* Paper at the National Sustainability Summit, State College, PA. **2021**

Spangler, **K.,** Burchfield, E., Radel, C. *Cultivating crop diversity across agricultural landscapes in the United States.* Paper at the Landscape 2021 conference (virtual). **2021**

Spangler, **K.,** Schumacher, B., Bean, B., Burchfield, E. *Assessing structural barriers and bridges to agricultural diversification in the U.S.* Paper at the annual meeting of the American Association of Geographers (AAG) (virtual). **2021**

Spangler, K. (*Moderator*), Roesch-McNally, G. (*Panelist*), Carter, A. (*Panelist*). "Women, land, and power: How does gender intersect with agricultural decision-making and conservation in the U.S.?" Panel at the Women and Gender in Development Virtual Conference, Blacksburg, VA **2021**

Spangler, K., Morgan, B., Stuivenvolt Allen, J., Morrisett, C., Brunson, M., Wang, S-Y., Huntly, N. "Climate realities and media conversations: water availability for cannabis agriculture in California's North Coast." Poster at the Ecological Society of America Annual Meeting, Salt Lake City, UT (virtual). **2020**

Spangler, K., Burchfield, E., Schumacher, B. "*Dynamics of agricultural land use in the U.S.: Toward sustainable transitions".* Paper at the US International Association of Landscape Ecology Annual Meeting, Fort Collins, CO. **2019**

Christie, M.E., Parks, M., Puhl, M., **Spangler**, **K.,** Sumner, D., Van Houweling, E., Zseleczky, L., Montgomery, K. *Participatory mapping in gender and development research: Presenting counterhegemonic possibilities.* Poster at the annual meeting of the American Association of Geographers (AAG), Washington, D.C. **2019**

Fayad, A., Sumner, D., Christie, M.E., Shamsunnahar, M., Alam, J. M., Alemayhu, S. L., Mersie, W., **Spangler, K.,** Sah, L., Seng, K. H., and Flor, R. J. "*Through the lens of social science: How the IPM Innovation Lab is helping smallholder farmers achieve food security in the developing world."* Paper at the annual meeting of the American Phytopathological Society, Cleveland, Ohio. **2019**

Christie, M.E., **Spangler, K**., Sumner, D. "*Gendered knowledge, roles, and spaces: IPM Cultivation and social change in the Nepali mid-hills.*" Paper at the Sustainability and Development Conference at the University of Michigan, Ann Arbor, MI. **2018**

Spangler, K., Christie, M.E. *"When he comes home, then he can decide:" Feminization of agriculture and male out-migration in the Nepali mid-hills."* Paper at the annual meeting of the American Association of Geographers (AAG), New Orleans, LA. **2018**

Spangler, K., Christie, M. E. "*What's in a household? Male outmigration, community spaces, and empowerment in the Nepali mid-hills."* Paper at the Dimensions of Political Ecology (DOPE) Conference, Lexington, KY. **2018**

Christie, M. E., Sumner, D., **Spangler, K.,** Apriliani, P. D. "*Discovering and engaging gendered dimensions of international development."* Poster at the Advancing Diversity at Virginia Tech Workshop, Blacksburg, VA. **2018**

Spangler, K, Gorenflo, L., Kambi, M. "*Assessing seasonal dietary variability and vulnerability in the Kilombero Valley."* Paper at the annual meeting of the American Association of Geographers (AAG), Boston, MA. **2017**

Christie, M.E., **K. Spangler**, I. Sereno. "*Challenges using qualitative methods to integrate gender into research-for-development projects with biophysical scientists in Asia, Africa, and Latin America*." Paper at the annual meeting of the American Association of Geographers (AAG), Boston, MA. **2017**

Spangler, K. "*Gendered implications of the introduction and adaptation of Integrated Pest Management (IPM) practices in Nepal*." Paper at the Dimensions of Political Ecology (DOPE) Conference, Lexington, KY. **2017**

Christie, M. E., Sumner, D., **Spangler, K.,** Sereno, I. "*Discovering and engaging gendered dimensions of international development."* Poster at the Advancing Diversity at Virginia Tech Workshop, Blacksburg, VA. **2017**

Spangler, K., Schneider, G., Strawser, M., Montiel-Ishino, F. A. *"Water access and Quality in a village near Dodoma, Tanzania*." Paper at the annual meeting of the Society for Applied Anthropology (SfAA), Vancouver, BC. **2016**

GUEST LECTURES

Spangler, K. *"Critical Data Science: What do we do with it?"* Guest lecture for the Environmental Data Science course at Emory University, Atlanta, GA. **2020**

Spangler, K. *"Critical Data Science: What is it?"* Guest lecture for the Environmental Data Science course at Emory University, Atlanta, GA. **2020**

Spangler, K. *"Introduction to feminist political ecology."* Guest lecture for the Gender, Environment, and Development course at Virginia Tech, Blacksburg, VA. **2017**

Spangler, K. "*What's in a household? Male outmigration, community spaces, and empowerment in the Nepali mid-hills."* Monthly meeting of the Rotary Club of Montgomery County, Blacksburg, VA **2018**

Spangler, K. *"Gender and climate change."* Guest lecture for the Gender, Environment, and Development course at Virginia Tech, Blacksburg, VA. **2017**

Spangler, K. *"Gender and agrobiodiversity."* Guest lecture for the Gender, Environment, and Development course at Virginia Tech, Blacksburg, VA. **2017**

Spangler, K. "*Geography from an interdisciplinary perspective."* Class presentation for the Natural Resources Freshman Year Experience, Virginia Tech, Blacksburg, VA. **2017**

RESEARCH AND WORK EXPERIENCE

Climate Adaptation Science Program, Utah State University, Logan, UT
National Science Foundation (NSF) Trainee **2018 - 2021**

Women and Gender in Development, Center for International Research, Education, and Development (CIRED), Virginia Tech, Blacksburg, VA
Research Associate **2018**

Global Health Minor Fieldwork Program, Dar es Salaam & Dodoma, Tanzania
Student Researcher and Intern **2015**

Green Mountain Coffee Roasters Livelihoods Project, Caritas Nyeri, Nyeri, Kenya
Intern **2014**

AWARDS AND FUNDING

Presidential Doctoral Research Fellow, *Utah State University* **2018 – 2021**
Outstanding Master's Student in Geography*, Virginia Tech* **2017 – 2018**

Gary Gaile Travel Award, *Development Geographies Specialty Group, AAG* (*$200*) **2017**
Sidman Poole Endowment Fund, *Department of Geography, Virginia Tech ($1500)* **2017**
Africana Research Center Grant Recipient, *Penn State ($1500)* **2015**
Phi Kappa Phi Honors Society Member **2015 – 2017**
Paterno Fellow, *College of Liberal Arts* **2012 – 2016**
Schreyer Honors College Scholar, *Penn State* **2012 – 2016**

SERVICE

Co-chair, Justice, Equity, Diversity, and Inclusion (JEDI) Committee, S. J. Quinney College of Natural Resources **2020 – 2021**
Faculty Search Committee, Geospatial Science of Environment and Society, S. J. Quinney College of Natural Resources **2019**
Reviewer, *Agriculture and Human Values* **2019 – Present**
Reviewer, *World Development Perspectives* **2020 – Present**
Reviewer, *Environmental Research Letters* **2021 – Present**
Reviewer, *Rural Sociology* **2021 – Present**
Master Gardener, Weber County, Utah **2019 – 2021**

SPECIAL SKILLS

Languages: English, native language; KiSwahili, speak, read, and write with basic proficiency

Programming languages: R; SAS
Computer skills: ATLAS.ti; ArcGIS; Microsoft Office Suite; Adobe Photoshop and Illustrator

MEDIA COVERAGE

PDRF Student Spotlight at USU:
https://research.usu.edu/pdrf/portfolio-items/kaitlyn-spangler-spotlight/

Agrilinks article on Nepal and feminization of agriculture:
https://www.agrilinks.org/post/male-out-migration-change-households-change-public-spaces

WFMZ local news coverage on Nepal and smallholder farmer interviews:
https://www.wfmz.com/news/area/berks/berks-woman-back-after--month-study-in-nepal/article_475ea8b5-c60d-596e-9793-3aca96c47565.html