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ORIGINAL ARTICLE

Crop diversification as landscape change: using land systems science to understand agricultural trajectories in North Carolina

Andrea Rissing[1] · **Emily Burchfield**[2]

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Abstract
Diversifying crop systems represents a promising pathway to improved climate resilience in agriculture. After a century of radical crop system simplification, understanding processes of crop system diversification requires accounting for multiple interlinked factors and their contexts. This article suggests that the theoretical tools of land systems science offer a particularly useful approach for understanding processes of crop diversification at the meso-level. Results are presented from a mixed-methods project that used national datasets to identify agriculturally important counties in the United States whose cropping systems trended strongly towards either simplification or diversification between 2008 and 2020, then used in-depth interviews in two neighboring counties with opposite diversification trajectories to identify explanatory factors. Actors in both counties employed similar logic and values vis-à-vis markets, equipment, labor, and relationships, but were embedded within distinct ecological and political contexts that strongly influenced their diversification trajectories. We argue that crop diversification can be more productively understood as a meso-level process of land use change than a function of individual decision-making. Land systems approaches' attention to social and biophysical dimensions, historical perspectives, and emphasis on embedding actors within socio-environmental contexts offer benefits for future work on processes of crop diversification.

Keywords Human–environment systems · Agriculture · Diversity · Land use change · Mixed methods

Introduction

Under a warming climate, severe stresses in global food systems include increased food insecurity, pollinator die-off, waterway contamination, rural livelihood precarity, and herbicide resistant weeds (Matzrafi et al. 2019). Still largely governed by policy and production priorities born of the twentieth century's more temperate climate, contemporary agricultural systems must rapidly adapt along multiple dimensions. Within production spheres, diversifying crop systems offers a promising adaptation. A fundamental tenet of ecology is that more diverse ecosystems are more resilient (Cardinale et al. 2012; Hooper & Vitousek 1997; Loreau et al. 2001; Pimentel et al. 1997; Tilman et al. 2014). Empirical work across the environmental, social, and agricultural sciences shows that this pattern holds for cultivated ecologies; more diverse cropping systems also exhibit better responses to the challenges enumerated above (Dainese et al. 2019; Swift et al. 2004).

As one indicator of agricultural diversity (which can also include, for example, diversity of enterprises, insect species, or operation scales), crop diversity—the diversity of cultivated plants—is notable both for being tightly connected to management decisions and for its ongoing, steep decline in the United States (U.S.). One of the primary agricultural trends of the past century has been the ascendance of industrialized grain monocultures. In the U.S., this simplification is evident at both farm (Dimitri et al. 2005) and county (Aguilar et al. 2015) scales. A complex of policies, technologies, and market forces worked in tandem over the twentieth century to winnow the national crop portfolio. These include federal supports for a narrow range of agro-commodities

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✉ Andrea Rissing
arissing@asu.edu

Emily Burchfield
emily.burchfield@emory.edu

[1] School of Sustainability, Arizona State University, 777 E University Dr, Tempe, AZ 85281, USA

[2] Department of Environmental Sciences, Emory University, 400 Dowman Drive, Atlanta, GA 30322, USA

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(O'Donoghue et al. 2009), improved availability of chemical fertilizers (Russel and Williams 1977), research and development efforts to optimize grain genetics (Vanloqueren & Baret 2009), and the expansion of grain markets through, for example, export to developing countries (Cullather 2010; Friedmann 1982; McMichael 2000), ethanol processing (Mumm et al. 2014; Oliveira et al. 2017), and a growing livestock sector (Weis 2013). Pathways towards (re)diversification are murky, yet complex systems are never homogenous. Within a dominant system of monocultures, threads of diversity can appear. Understanding how diverse crop systems have newly emerged can yield powerful lessons for understanding future adaptive processes.

Although typically approached as a function of individual operator decision-making, we argue that crop diversification can also productively be understood as a process of land use change. The meso-scale of landscapes, by which we mean both a mosaic of land use outcomes and "the historical and political and cultural elements of that landscape" (Perfecto et al. 2019, p. xviii) which is inherent to land systems approaches, deftly captures many of the explanatory factors underlying crop diversification. Within environmental change scholarship, the areas of crop diversification and land change science have been unnecessarily siloed, hindering the ability of sustainable agricultural research to generate robust recommendations for increasing crop diversity. After briefly reviewing the benefits of diversified cropping systems and introducing the land systems approach, we present results from a mixed-methods case study of county-level crop diversification trajectories in the southeastern U.S. Using a land systems approach to guide our analysis helps reveal multidimensional, contextual, and historical factors that together explain why two bordering counties displayed opposite crop diversification trajectories. Conceptualizing crop diversification as a process of landscape change, as opposed to the aggregated result of individual producers' decisions, opens novel avenues for understanding its catalysts and supports.

Background

Crop diversification

Agriculture accounts for over 50% of U.S. land area, and over 60% of this agricultural land is cultivated with corn, soy, or wheat (Bigelow and Borchers 2017; Spangler et al. 2020). While there have been regional variations in crop diversity, the overall national trend has been one of continued simplification since the early twentieth century (Aguilar et al. 2015; Dimitri et al. 2005). Monocultural production of annual crops facilitates agricultural industrialization, a process strongly associated with negative impacts on the social fabric of rural communities, indicated by, for example, civic participation rates, presence and quality of community services, and population declines (Goldschmidt 1947; Lobao & Stofferahn 2008). This simplification of agricultural landscapes also has well-established negative impacts on ecosystem health including soil degradation, loss of habitat, reductions in water quality, and loss of pollinator diversity (Landis 2017; Tiemann, et al. 2015). In contrast, recent meta-analyses of international research comparing production systems finds that crop diversification, either spatially or temporally, contributes to multidimensional agricultural resiliency by enhancing the biodiversity of wild species, water quality, soil fertility, and pest control (Beillouin et al. 2021; Tamburini et al. 2020). Field (Davis et al. 2012; Liebman et al. 2013) and modeling studies further find that diversified cropping systems produce yields equal to or exceeding simplified systems (Nelson & Burchfield 2021; Renard and Tilman 2019).

Pathways towards crop diversification

In response, researchers have sought to understand pathways capable of re-diversifying U.S crop systems. Many studies pursue this question by investigating farmer or operation characteristics that correlate with increased crop diversification. For example, studies have found that farmers cultivating marginal or sloping land are more likely to implement diversification (Cutforth et al. 2001; Wang et al. 2021). Factors associated with pursuing diversification further include farm soil types, market access (including the ability to sell locally), equipment limitations, knowledge of alternative crops, organic production practices, and production costs (Lancaster & Torres 2019; Rosenberg et al. 2022; Torres et al. 2021). Paralleling adaptation of broader conservation practices, researchers have also found that farmers diversify in response to climate threats (Ishtiaque 2023; Knutson et al. 2011). In addition, a growing body of research applies agent-based models and bioeconomic models to simulate and predict the on-farm practices and contexts that support crop diversification (Baggio et al. 2015; Bert et al. 2011; Burchfield & Gilligan 2016).

At the same time, socio-political structures such as, for example, the presence and proximity of markets, infrastructure, or community norms, can sharply circumscribe farmers' choices. By creating path dependencies (i.e., where past actions constrain currently available actions), such structural contexts can effectively render simplified crop systems the most reasonable option (Roesch-McNally et al. 2018; Weisberger et al. 2021) or, in contrast, create opportunities for certain types of crop diversification, such as temporal diversification (Spangler et al. 2022a, b). Weituschat et al. (2022) found that institutional settings, such as existing regulations, standards, and policy networks, can create "cognitive lock-ins," where alternative cropping strategies like diversification appear consistently unattractive to farmers. Three recent systematic reviews have unanimously concluded that such structural factors exert tremendous power in shaping farmers' management decisions (Carlisle 2016; Prokopy et al. 2019; Tacconi et al. 2022). Updating their review of quantitative research on farmers' conservation behaviors, Prokopy et al. (2019, p. 531) conclude a "critical shortcoming" in the research is an overemphasis of social-psychological factors at the expense of these structural issues.

Most studies exploring real-world bridges and barriers to crop diversification to date explicitly or implicitly focus upon the farm operation and/or individual operator. At heart, they ask: what kind of farmer and what kind of farm is more likely to diversify? Here, we see a fundamental mismatch in scales of inquiry. Although some benefits of crop diversification, such as market resiliency, improved yields, or pathogen control, accrue directly to operators, many others—including pollinator support, wildlife habitat, richer local food systems, and water regulation—benefit the region as a whole. Similarly, the structures that largely determine the feasibility of simple or diverse crop mixes exist at meso- and/or macro-levels. As noted above, there have been many *farm-scale* studies examining the adoption of ecologically beneficial agricultural practices (Lamarque et al. 2014; Feenstra 2002; Carolan 2005), yet relatively few studies examine how farms in the same area interact or the complex ways in which meso- and macro-scale factors intersect to shape crop systems (van Dijk et al. 2015). As a complement to studies asking, *what are the drivers of farmers' decision-making?*, we suggest that asking, *what contexts are conducive to diversification?*, is a useful approach for establishing how transformative change can occur. Here, context comprises not just the ways in which individual farmers interact, but the complex and integrated socio-environmental system in which cropping systems are embedded. Shifting perspective from the operation to the landscape thus offers a scalar lens better aligned with the full set of both drivers and benefits of crop diversification. We follow recent agricultural social science that has approached diversification through regional lenses, such as examining farmers' explanations for Idaho's "quantitatively agriculturally diverse" Magic Valley (Spangler et al. 2022a, b, p. 11), categorizing and comparing successful crop diversification pathways in three European regions (Revoyron et al. 2022), or analyzing environmental impacts of cocoa agroforestry beyond the farm-level in Ghana (Parra-Paitan and Verburg 2022). This shift in the level of inquiry requires a concomitant analytical shift. We suggest that approaching crop diversification as a process unfolding (or not) at the landscape level offers several novel benefits. Below, we briefly describe the land systems approach and the advantages it confers to crop diversification research.

Land use change

Land change science (LCS) is a relatively new area within interdisciplinary social-ecological scholarship. The approach's intellectual lineage traces through twentieth century cultural ecology to nineteenth century German *Landschaft* tradition; today, its broad foci cross global environmental change and sustainability, and its specific questions center on understanding the key pathways of change affecting the coupled human–environment systems that constitute "land" (Turner & Robbins 2008). LCS is further distinguished through its attention to identifying institutional mechanisms that support sustainable decision-making and governance, Earth system interactions, and empirical measures (ibid, pp. 300–301). As capacious as LCS is, the approach has also been criticized for its adherence to neoclassical economic models. Munroe et al. (2014) identify pervading assumptions of an autonomous rational actor, the primacy of market levers as forces for positive change, absolute resource scarcity, and the inherently siloed view of economic and social spheres as specific ways that neoclassical economic assumptions effectively limited LCS' utility for complex socio-environmental issues.

Turner et al. (2020) have recently responded to and integrated such critiques into a novel framework of land use change. Building on prior work (Lambin & Meyfroidt 2010; Meyfroidt et al. 2018), the 2020 framework synthesizes decades of socio-ecological theories in land system sciences. Aggregating "virtually all of the variables found in land system explanations," Turner et al. (2020, p. 492) distill eight explanatory variables connecting social and biophysical subsystems that, they assert, together account for how land is used and how this may change. These are environmental conditions and dynamics; environmental services; techno-managerial strategies and infrastructures; previous land use; institutions; demographic conditions; economic structure; and actors' attributes. Responding to Munroe et al. (2014), a particular strength of the new framework is its deemphasis of the primacy of "land users (e.g., individuals, households, managers, corporations, states) as independent actors" (Turner et al. 2020, p. 492). "Decision-making" as a discrete force is backgrounded in favor of charting less atomistic causal pathways. The framework conceptualizes the roles of actors' attributes alongside the intertwined economic structures, institutions, and demographic conditions that constitute the more social components of a socio-ecological system. As these elements shape and are shaped by previous land use and the system's more biophysical dimensions, land use practices continue or change. In this way, we see the LCS framework as answering Prokopy et al.'s (2019) call above to reorient agricultural research priorities to encompass broader structural issues and longitudinal time frames; along with biophysical conditions, such dimensions largely constitute the context in which farm management practices take place and to which they respond.

Other frameworks have been effectively applied to understanding crop diversification. For example, Tacconi et al. (2022) organize their review of the drivers and constraints of on-farm diversity around the Sustainable Rural Livelihoods Framework and Edwards-Jones (2006) uses the theory of planned behavior to review quantitative studies of farmer decision-making. Meynard et al. (2018) bridge agronomy and economics to explain how socio-technical lock-ins impede the adoption of minor crops in France. Charting causal explanations for farm management is clearly a dynamic research area benefiting from the contributions of diverse theoretical perspectives. Such work to date, however, tends to maintain the individual farm operation as the primary unit of analysis, obscuring the ways that cultivated landscapes supersede their constituent fields through shared regional histories, ecologies, and policies. As Spangler et al. (2022b, p. 1) argue, the "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."

We enumerate three reasons land systems approaches may be able to unlock new insights into crop diversification. First, deeply rooted in and reflective of socio-ecological research traditions, the Turner et al. (2020) LCS framework captures the inescapably mutual influence of land's social and biophysical dimensions. Agriculture exclusively occurs at the human–environment interface. Frameworks for understanding agricultural change must robustly attend to the influence of, for example, both soil organic matter content and diverse federal commodity programs; leaving either area uninterrogated misses important forces that shape agricultural management and outcomes. Second, the LCS framework offers an inherently multilevel explanation of land use. Farmers are important actors on agricultural landscapes, but as multiple recent reviews have documented, crop diversification and broader conservation research to date have tended to over-emphasize their agentive roles. By grounding actors' attributes alongside and influenced by diverse, multilevel variables, an LCS approach may better capture the complexity of crop system change. Third, an LCS approach guides research towards longitudinal explanations. By accounting for the entropy exerted by, for example, physical infrastructures and previous land use, the framework improves upon ahistorical approaches by explaining the forces alternately reproducing or evolving agricultural land use.

Taking the above as our starting point, we model a two-step process for understanding how crop system heterogeneity can emerge from homogeneity. First, we present comparative results not between farmers who cultivate diverse or simple crop mixes, but between one high-yielding county whose crop portfolio has been trending towards diversification, and a bordering high-yielding county that has been simplifying. This analytical scale allows us to identify influential meso-level factors while also facilitating micro-level interactions to ensure our data reflects the lived experiences of the counties. Second, we adapt Turner et al.'s (2020) framework to guide our analysis of interviews with agricultural stakeholders in these two counties to demonstrate how land systems approaches can bring fresh explanations to crop diversification research.

Methods

Approach

Our methodological approach combines "big data" and "deep data." "Big data" surveys the entire U.S. to identify counties where exceptionally high agricultural productivity co-occurs with strong trajectories towards either diversified or simplified crop mixes. "Deep data" concentrates on these outlier counties and their histories to identify explanatory factors.

Big data

We used county borders to operationalize the landscape concept because this is the scale at which most publicly available agricultural data is reported in the U.S. As described in Burchfield and Nelson (2021), we define exceptionally productive counties by modeling the extent to which yields of the five major crops that make up nearly 80% of cultivated land in the U.S. (USDA NASS CDL 2021)—corn, alfalfa, hay, soy, and (winter) wheat—deviate from what is expected given county-level norms, regional expectations (regions here defined using the USDA's Farm Resource Regions), and annual exposure to sun (growing degree days), soil (topsoil organic carbon, pH, cation exchange capacity, and sodicity), and water (total annual precipitation and the percent of a county's agricultural land that is irrigated). Areas with yields more than two standard deviations above what one would expect given regional biophysical realities were selected as "surprisingly productive counties."

Of this subset of counties, we identified counties with strong crop diversification or simplification trajectories since 2008. To measure trajectories for the entire country, we computed annual county-level metrics of crop diversity using the USDA's Cropland Data Layers, a 30-m resolution raster dataset classifying agricultural land use for the coterminous U.S. annually since 2008 (USDA NASS CDL 2021). We computed crop diversity using the Shannon Diversity Index (SDI), a widely used index of diversity that measures the proportional abundance of each land use category in a given region (Turner 1990). We then quantified the direction

Table 1 Summary of participant occupations by county

		Bertie	Washington	Both	Total
Occupation (n)	Producer	5	9	0	14
	Agricultural Expert	7	3	8	18

Table 2 Summary of participant demographics. Both counties presented together

		All participants ($n = 32$)	
		n	Proportion
Gender	Male	25	78%
	Female	7	22%
Race	White	29	91%
	Black	3	9%
Education	High school	4	13%
	Associate degree or some college	12	38%
	Bachelor's degree	6	19%
	Graduate degree	10	31%
Age	18 to 34	5	16%
	35 to 54	10	31%
	55 to 64	9	28%
	65 or older	8	25%

of land use change through time by fitting a linear trend to the county-level SDI observations and extracting the slope of this line, with positive slopes indicating counties with strong diversification trajectories and negative slopes indicating counties with strong simplification trajectories (Figs. 1 and 2, Appendix 1).

In each Farm Resource Region (FRR),[1] we identified counties that were surprisingly productive, as defined above, with the strongest (defined as more than one standard deviation above average land change slopes) simplification and diversification slopes.

Deep data

The Southern Seaboard FRR stood out from the initial analysis as one of the only instances where counties with strongly simplifying and strongly diversifying crop systems directly bordered each other (Fig. 3, Appendix 1). Furthermore, both authors were physically based in Atlanta, Georgia at the time, making repeated visits to this site feasible. For both of these reasons, we selected these counties—North Carolina's Bertie County (diversifying) and Washington County (simplifying)—for the second, qualitative phase (Fig. 4, Appendix 1). Between October 2021 and January 2022, the first author conducted four fieldwork trips to Bertie and Washington Counties. Each trip lasted between 3 and 6 days. Twenty-eight semi-structured interviews were conducted with thirty-two producers and non-producer agricultural experts[2] (Table 1). Because of the small size of our sample, we report basic participant demographics for the total sample rather than broken out by counties (Table 2).

Potential participants were initially identified through recommendations from Cooperative Extension staff and the authors' personal networks. From these initial contacts, a snowball sample (Biernacki & Waldorf 1981) was constructed. Because we were focused on understanding county-level differences, we did not identify producers who were themselves "diversifying" or "simplifying," but rather asked producers in each county about times they had changed what crops they grew. For producers, questions focused on their farm's history, changes in their crop portfolio, factors influencing cropping decisions, and future plans. Basic farm information including length of time farming, acreage, gross sales, and farming practices was also collected. Farmer participants were largely representative of their regions' agriculture; farm size ranged from 250 to 3200 acres, and the most commonly grown crops across both counties were corn, soybeans, and wheat, and, in Bertie, cotton and peanuts as well. For non-producer agricultural experts, questions addressed how the county and region had changed, perceived drivers of those changes, and the logic and priorities they observed producers employing. Most interviews lasted between 60 and 75 min. As would be expected for this sample size (Francis et al. 2010; Guest et al. 2006; Marshall et al. 2013), saturation was reached roughly two-thirds of the way through fieldwork when no new explanations for cropping patterns were expressed by interviewees.

Before fieldwork, the first author conducted two open-ended, unrecorded key informant interviews (KII); four additional KII were conducted during fieldwork. Key informants were experts in North Carolina agriculture, including current and former staff members of statewide farm organizations. The goals of KII were to establish deeper familiarity with North Carolina's Coastal Plain and conduct member checks (Koelsch 2013).

[1] The USDA Economic Research Service divides the country into nine Farm Resource Regions (FRRs). FRRs are determined by geographies of agricultural commodity specialization and do not necessarily follow state boundaries, making them useful categorizations for production-focused research (see USDA ERS Agricultural Information Bulletin Number 760 (September 2000)).

[2] For four interviews, two people were interviewed simultaneously; the remainder were one-on-one. Twenty-two interviews were conducted in-person at a place of the participant's choosing, typically farm office, place of work, or home. Six interviews were conducted over Zoom.

Data analysis

With permission, all semi-structured interviews were recorded. Interviews were transcribed and cleaned by a student assistant. Interviews were coded using NVivo software. The initial codebook was designed deductively. Driven by the project's research questions, codes focused on understanding ecological and historical differences between the counties, explanations for crop diversification or simplification, and perceptions of relevant drivers. The codebook was refined through inductive codes reflecting emergent themes of interest. These included experiences with peanut and tobacco quota systems, farm labor, and the region's histories. Analysis focused on understanding the extent of and reasons for similarities and differences between the counties' agricultural experiences.

Results

Multiple stories emerged to illuminate and complicate the counties' crop diversification trajectories. We discuss our comparative results structured around seven of the eight explanatory elements comprising Turner et al.'s (2020) framework for theorizing land use change. First, we compare the biophysical and edaphic profiles of the two counties; these characteristics correspond to the framework element *environmental conditions and dynamics.* Then, we present the primary factors interviewees indicated in their explanations for the addition, continuation, or elimination of crops. These generally grouped along four themes: *markets, equipment and timing, labor,* and *relationships.* We see these themes as corresponding with Turner et al.'s (2020) framework elements of *economic structures, techno-managerial strategies and infrastructures, demographic conditions,* and *actors' attributes*; we organize subsections "Economic structures: market opportunities" through "Actors' attributes: relationships" along these pairings. Finally, in the final two subsections (Previous land use: tobacco legacies and Previous land use: the story of clary sage), we situate the above influences within the region's ecological and political histories, which converged to shape distinct county-level agricultural contexts. These two subsections both correspond to the *previous land use* element within the Turner et al. (2020) framework in different ways. These subsections describe Bertie County's history as a tobacco-dependent county and the immense changes following the end of the tobacco and peanut quota systems in 1998 and the diversification impacts of the region's enduring tobacco-era infrastructure. In this way, the "Previous land use: tobacco legacies" subsection also touches on the *institutions* element as it addresses changes in policy, and the "Previous land use: the story of clary sage" subsection also touches on *infrastructures*; we have opted to group both under *previous land use* as we believe this is the most transparent way of representing the lasting impacts of the counties' twentieth century agricultural profiles. The elements intertwine; our organization is meant to guide the reader through the overlapping forces that together shaped distinct county-level cropping trajectories, not to imply forces acted in isolation.

Table 3 Comparison of study counties' key characteristics, populations, and agriculture

	Bertie	Washington
Crop trajectory	Diversifying	Simplifying
Tobacco dependent	Yes	No
Tobacco acres harvested, 1997*	4004	455
Soil drainage	Better	Poorer
Predominant soil types	Sandier loam	Muck
Counties		
Total population	17,934	11,003
White (%)	36	47.5
Black (%)	60.9	48.5
Hispanic (%)	2.4	6.2
Median household income ($)	35,042	30,941
High school degree or higher (%)	78.8	84
Agriculture		
Farm operations (#)	323	141
Mean (median) acres/operation	459 (111)	565 (132)
Acres harvested	100,830	67,996
Median net farm income ($/operation)	96,011	66,734
Full owner operators (% harvested acres)	7.5	3.0

*As reported in QuickStats for 1997 Census of Agriculture (CoA). All other ag. data from 2017 CoA (via QuickStats). Demographic data from 2020 US Census

Environmental conditions and dynamics: study locations

Bertie and Washington Counties (Table 3) are located in northeastern North Carolina on the state's Coastal Plain. The Suffolk Scarp paleoshoreline aligns nearly precisely with the counties' border, with Washington County lying to the southeast of Bertie County. The surficial units of Washington County date primarily to the Late Pleistocene, whereas Bertie County has a higher proportion of Middle Pleistocene land (Abbott et al. 2011). Less than 100 mi north of Washington County lies the Great Dismal Swamp of North Carolina and Virginia, where the country's largest maroon community centered during the eighteenth and nineteenth centuries (Sayers et al. 2007, p. 72). A combination of free and enslaved labor dug the first canals around Lake Phelps in Washington County in the late eighteenth century, but land clearing remained incomplete until heavy machinery became available in the 1960s. Today, Washington County agriculture depends on the regular ditches delineating and draining its fields into a series of canals. Interviewees frequently emphasized the edaphic differences between the two counties. Except for its far western side, much of Washington County is a rich, peaty, muck soil type (USDA Soil Conservation Service 1981), often referred to as "blacklands" soil (McMullan et al. 2016). In contrast, Bertie County's soil is generally sandier and better draining loam (USDA Soil Conservation Service 1990).

Economic structures: market opportunities

Markets render a region's economic structures consequential to actors. Unsurprisingly, nearly all participants named the presence and strength of market opportunities as an important factor affecting crop choice. Expressing a belief repeated frequently by agricultural experts and farm service providers, an Extension staff member emphasized their[3] efforts to communicate the primary importance of markets to growers. Explaining their thought process, they said, "Your first thing is, do you have a market?…You don't spend any money, you don't put anything in the ground until you have found the market." A longstanding Extension staff member said simply, "I think it all boils down to economics, why they add a crop or drop a crop." When asked about what drives the addition of new crops, another research specialist offered, "I would say the market number one." Agricultural experts largely expressed a shared belief that market signals—including the presence of an accessible buyer and, especially, commodity forecast prices—significantly explained what crops growers decided to plant.

Growers in both counties agreed with and elaborated upon this assessment. During interviews, growers were asked to "walk through" their process of adding a new crop. A representative answer was, "Just mainly looking at prices and seeing if it's going to work…mainly just looking at the input cost and what outputs will be on a crop and commodity prices is kind of what we go by when making those decisions." Indeed, many growers related stories of planting a crop in response to a new market opportunity. Interviewees in Bertie County often invoked hemp as a recent "flash in the pan," planted in response to the crop's federal legalization in 2018. One agricultural expert explained that, "[hemp] was really pushed hard, in my opinion. And a lot of growers were eager to jump on board because they thought that was going to be the future." The promise of new markets in CBD extraction and industrial fiber uses were sufficient to convince two Bertie growers interviewed for this project to experiment with planting it for 2 or 3 years in its heyday, but other Bertie growers explained the hemp market never seemed sufficiently secure. Interviewees described similar planting decisions around fresh vegetables in the past, when they experimented with growing something new when approached with a contract by a private broker seeking local sources for regional vegetable processing companies.

Techno-managerial strategies and infrastructure: equipment and timing

The influence of techno-managerial strategies and infrastructure appeared most clearly through the role that farm equipment and farm layout played in affecting farmer decisions. Across both expert and grower interviews, equipment consistently emerged as an important factor influencing crop feasibility. Notoriously expensive, equipment shapes farmers' cropping decisions in two ways. First, specialized equipment can act as a diversification disincentive. Discussing their possible interest in cotton production, one young farmer in Bertie County stated that the cost of investing in a picker and boll buggy—which they estimated cost two or three hundred thousand dollars—gave significant pause. Echoing this aversion, a young farmer in Washington County described their thought process regarding adding peanuts on fields they managed that were agronomically well-suited to peanut production: "I'm starting without no peanut equipment, period. And when you look at the price of new equipment and the price that they're getting for peanuts and the way everything looks, it was a lot of upfront cost for me." This farmer later noted that a new peanut combine would cost $140,000. The farmer who was considering adding cotton acknowledged that harvesting equipment and labor can be custom hired, but that felt risky, as well: "I like to be able to have my own harvesting equipment, so if the weather gets nasty, I know I can get it out and get it picked. Waiting on somebody else, they're going to get theirs first and you'll be last." Both cotton and peanuts require specialized harvest machinery; the associated costs create barriers to diversifying into these crops, perhaps especially for younger farmers.

Second, farmers are more likely to grow crops suited to their existing machinery. Many interviewees described farmers they knew—either neighbors or, for Extension interviewees, farmers they work with—who would keep "fixing and fixing" old equipment that was already owned outright. As one Bertie grower explained, "One machine, just need to change the heads, but that one machine will do it all. The corn, the beans, the wheat." In Washington County, another farmer echoed this logic while reflecting on the possibility of adding cotton back to the farm, a crop that their father had previously grown but which they had not: "I've got a planter that'll plant cotton. I've got a sprayer that'll spray the cotton." Equipment investments by previous generations shaped the diversification pathways today's growers perceived as viable.

[3] Given the small number of female participants, we use singular "they" throughout to mask participant gender.

Connecting to markets, these decisions were sometimes related to the region's economic infrastructure. A younger farmer in Washington County explained that their father had grown green beans for fresh markets when a processing facility opened in a nearby county and offered him a contract. After 4 years, he was up to 200 acres of green beans that were doing well, but, as his child described it, after the fourth year the brokers became dishonest. The interviewee's father sold the specialized equipment he had purchased to recoup his costs and removed beans from his rotation.

On-farm layout and the timing of different tasks also emerged as key factors. A large-scale farmer in Bertie county who, over the course of four decades had added and subtracted many crops, explained concisely that, "When you have two crops you harvest at the same time, that'll get you in a bind." Their preference was for crops with consecutive, rather than simultaneous, planting or harvesting schedules. Elucidating how farm layout also impacts timing, another interviewee explained why they stopped growing strawberries in Washington County. These berries were profitable and locally popular; one enthusiastic customer regularly bought 20 pounds to bake charity pies. Several years into farming, however, an opportunity arose to rent a significant acreage, well-suited for corn production, located a considerable distance from the main farm. Strawberry harvest co-occurs with corn planting, and while these overlapping time frames had been feasible when all fields were nearby, adding a distant farm made the timing too challenging because of the required transit time. Despite enjoying strawberry production and growing them profitably, the farmer ceased cultivating them to focus on grain.

Demographic conditions: labor

Bertie and Washington Counties have both been steadily losing population. These demographic trends affect crop mixes because fewer people are available to help with full-time or seasonal labor needs. Echoing findings in California (Guthman 2019, pp.129–151), interviewees frequently pointed to the difficulty and expense of finding labor as constraining forces. For example, two growers interviewed for this project had previously planted hemp; most did not. When asked why, some expressed general distrust or uncertainty about crops that seem faddish; others pointed to hemp's particularly high labor needs. The role of H-2A labor[4] in the region also was mentioned frequently. An agricultural guestworker visa program, H-2A labor had previously been primarily associated with the area's tobacco production. During this project, agricultural experts in both counties reported H-2A labor was increasing regionally due to domestic labor shortages. For example, after switching to H-2A labor, one farmer explained they had dropped several hundred acres of a specialty crop in favor of sweet corn and melons to make the best use of the labor they were now legally obligated to pay. "You get H-2A here, you got to work them regardless," they explained, "corn and watermelons, we have a full day work, seven days a week if we want to do it." Another grower explained that labor demands disincentivized diversifying into certain crops, such as tobacco: "I can't just decide to grow tobacco next year because I'd have to have barns, pullers, grain houses, H-2A labor housing, but I could grow milo [grain sorghum] this year easily, because all it takes is a planter like I have." Aside from H-2A, the need to consider different crops' harvest and planting schedules was also mentioned by one knowledgeable agricultural expert as a force shaping cropping systems; crops such as broccoli and cabbage, they explained, can be harvested roughly consecutively, facilitating easier coordination of labor crews and making them more appealing than other possible pairings.

Actors' attributes: relationships

Finally, growers discussed the importance of personal relationships—particularly family members and other growers—in their own farm management decisions. The most individually focused element within Turner et al.'s (2020, p. 494) framework is "actor's attributes," which includes not only people's specific characteristics, but also "shared values, beliefs, and norms." In both counties, personal relationships could drive either simplification or diversification as they reinforced existing crops or signaled novel crops. On the simplification side, one young farmer in Washington Country grew the same mix of corn and soybeans that their father and grandfather had. While they experimented with management strategies, they were deeply opposed to changing their crop mix. They explained that—in addition to having land well-suited to successful grain production—they had taken to heart the "If it ain't broke, don't fix it" message from previous generations. On the diversification side, many farmers who had experimented with adding new crops credited a neighbor with the initial idea: one had secured a contract at a nearby peanut buying station through a neighbor's connection, and the opportunity to raise seed crops as an enterprise occurred to a different farmer after talking with a neighbor who did so. In one case, non-farming neighbors had provided the catalyst for a young Bertie grower to add edible greens to meet expressed demand for kale, salad, and collards. For the most part,

[4] Under an H-2A visa, seasonal agricultural workers from other countries are permitted to work temporarily on U.S. farms. The employer must demonstrate that employing H-2A workers will not adversely affect wages or conditions for U.S. workers and must provide housing for workers. Most H-2A workers come from Mexico. The program has been expanding rapidly in recent years (Castillo et al. 2021).

however, farmer interviewees indicated the importance of their social networks of other growers. Here, the role of informal social institutions, another element within Turner et al.'s (2020) framework, also becomes apparent in reproducing or shifting land use. In both counties, farmers described early morning meetings over coffee or biscuits at local shops as crucial places to exchange information, often daily. Mentoring relationships were also important, as one younger Washington County farmer explained, "We've all got a couple of growers we lean on…I've got some older guys I call when I have a question." Growers in both counties also regularly indicated that they turned to Extension staff, research specialists, and private consultants to talk over management decisions.

Previous land use: tobacco legacies

As described in the "Environmental conditions and dynamics: study locations" section, Washington and Bertie Counties' soils differ drastically. Washington County growers cultivating high organic matter soils prioritize grain; Bertie County growers have historically planted more tobacco, cotton, and peanuts in sandier soils. These differences set the stage for divergent outcomes following the peanut and tobacco marketing quota system buyouts in 2002 and 2004, respectively. Many grower and expert interviewees advised that "tobacco doesn't like wet feet," explaining its relative absence from Washington County's poorly drained fields. Furthermore, early KIIs emphasized the importance of the quota systems for this region, leading us to add interview questions about interviewees' experiences and perceptions thereof. Whereas the themes identified above appeared similarly between the two counties, one of the clearest county-level distinctions to emerge was post-buyout experiences. No Washington county grower expressed that the policy change had impacted them or their county significantly. Bertie County growers differed in the degree to which they had personally been impacted by the end of price supports, but agreed, along with the agricultural experts, that their county had undergone significant changes following the policy change.

Tobacco has no close substitute; it is highly labor-intensive; its end products are uniquely taxed; and end product price is only loosely related to raw product cost (Paarlberg 1964, p. 226). As New Deal-era supply management policies were slowly dismantled following World War II, the tobacco industry and political allies invoked these characteristics to justify the continuation of tobacco's quota systems. Tobacco and peanut quotas entitled the quota holders to "the exclusive right to sell a set amount of their commodity at or above the support price within a geographic area" (Dohlman et al. 2009, p. 7). After 1962, quota allotments were untethered from land, allowing quota rights to function as assets. Throughout the 1980s, various legislative efforts to shift program costs away from the Treasury arose (for detailed legislative histories see Benson 2011, p. 97–112 and Bennett 2014, p. 100–111). Strikingly, these programs persisted essentially unchanged during a period of neoliberal reorientation towards market-based policies.

North Carolina was and remains the country's leading producer of tobacco. Following Republicans' senate wins in 1980, North Carolina Republican Senator Jesse Helms chaired the Senate Agriculture, Nutrition, and Forestry committee, a role which he held until 1987. Helms fiercely defended the interests of Southern constituents and tobacco companies such as RJ Reynolds (Benson 2011; Bennett 2014). Where grain commodity groups had opposed supply management policy in the second half of the twentieth century (Winders 2009), the tobacco industry and growers alike were amenable to reducing production acreage in exchange for price supports. As a labor-intensive crop, small tobacco acreages made sense for many families, and price supports made small acreages valuable, even lucrative. Quota systems also protected small farms from the consolidation-inducing market forces that shaped other regions. A Bertie County farmer interviewed for this project, whose father had owned tobacco quota, reflected that, "quotas made every small farm feasible," a view widely shared by other interviewees.

In the 1980s and 1990s, medical science reached consensus about smoking's deleterious health effects. This evidence created immense pressure on public supports for tobacco, but it was global competition from lower cost producers that ultimately ended the quota systems in both tobacco and peanuts (Dohlman et al. 2009). Under the buyouts, quota owners received payments, as did active tobacco growers. Peanut growers did not qualify for payments. Following this landmark legislation, peanut and tobacco prices and acreage fell, farm businesses consolidated, foreign demand increased in response to lower prices, and new freedom in planting geography led to regional shifts in where commodities were grown (Dohlman et al. 2009).

The analyses that led us to Bertie and Washington Counties began 4 years after the tobacco quota system ended. Interviewees for this project widely agreed that Bertie and Washington Counties experienced this landmark agricultural policy differently. Bertie was tobacco dependent, a state determination made based on tobacco production, tobacco employment, and tobacco-related manufacturing (Beacham 2002). Washington County produced a fraction of the tobacco as Bertie. Bertie's status as a tobacco-dependent county made it eligible for state-funded grants through the North Carolina Tobacco Trust Fund Commission (NCTTFC), which was established by the North Carolina General Assembly in 2000 to distribute funds from the Master Settlement Agreement.[5] These grant programs were created, in part, to assist former tobacco farmers. One agricultural expert interviewed for this project had worked in Bertie County under an early NCTTFC grant. They described how rural development organizations worked urgently in the early twenty-first century to support small-scale tobacco farmers: “There were all kinds of projects like flowers, sweet potato packing houses, just you name it, and people were trying it.” Although Russo (2012) found that North Carolina tobacco growers were more likely to switch into industrial poultry production than direct-marketing, several examples appeared during this project of growers pivoting to diverse specialty crops after leaving tobacco. For example, one Bertie County farmer observed, “Our neighbor, he grows vegetable crops. No, he would not have done that under the quota system…. There wouldn't have any reason for it. He could have made a good living with quota.” On a different farm, old tobacco seeding equipment was repurposed to seed vegetable starts after sitting unused, sparked by a new initiative by a local food bank. In contrast, Washington County growers and experts alike struggled to think of ways that their county had been impacted. As one Washington County farmer whose family had rotated corn and soybeans for generations said, “It didn’t affect me because I mean, we never grew tobacco or anything like that.”

Previous land use: the story of clary sage

In 2017, Bertie County’s fourth-most produced crop by acreage as reported by the USDA was “Herbs, dried.” This herb was clary sage, grown for the chemical compound sclareol. Sclareol’s industrial uses include consumer products such as detergents and as a cigarette additive. From roughly 2013 to 2017, clary sage exploded across Bertie County. Similar to the specialty crop diversification described above, many of the growers turning to clary sage were in search of tobacco replacements. An expert expressed the belief that, “Tobacco farmers make excellent sage farmers…sage is more of a specialty crop. It takes more attention to detail and I think you get a lot of that with the tobacco farmers.” However, Bertie County’s extant infrastructures also catalyzed and accelerated this crop’s growth.

The primary market for clary sage was the global bioprocessing and botanical extraction company Avoca, purchased from the tobacco company RJ Reynolds (RJR) by Pharmachem in 2003. Bertie County is home not only to Avoca’s headquarters, but also its physical processing plant. This plant had been built by RJR in 1962 to ensure domestic sources for inputs, but quickly closed before reopening again in the 1970s. In the early 2000s sage contracts began expanding significantly. Several factors drove Avoca’s increased demand for sclareol, including consumer demand for phosphate-free household cleaners (Markovich 2016) and Avoca’s discovery that clary sage can be stored post-harvest, greatly expanding the extraction timeframe. For several years, Avoca offered generous and reliable contracts to grow clary sage. They estimated that 40% of their contracts had been with growers producing in Bertie County. The crop’s peculiar planting schedule likely also contributed to increased crop diversification. Planted in August and harvested the following June, clary sage was often double cropped with soybeans (following the sage) and wheat (preceding the sage).

Although thousands of acres of sage were grown during this project’s quantitative analysis time frame, no farmer interviewed for this project had current sage acres. This was largely attributed to the recent development of synthetic sclareol, which undercut markets for extracted sclareol. Interviewees were divided on the crop’s future in eastern North Carolina; as one Bertie County farmer said, “It was good while it lasted.”

Sage was a key crop in Bertie County’s diversification trajectory in the 2010s. It was underlain by the county’s tobacco history, including extraction infrastructure, a physical testament to tobacco’s legacy and ongoing influence over contemporary southern landscapes.

Limitations

The USDA’s Cropland Data Layer (CDL) distills more than 110 categories of crops with impressive categorical and spatial resolution; however, it does not capture intra-crop varietal differences (i.e., Bt corn vs. non-Bt corn). It also fails to capture fields cultivated with a diversity of crops or operations with significant use of growing structures. The data are also collected at an annual timestep, and though they include several categories indicative of double cropping, intra-seasonal temporal diversity is likely obscured. Additionally, the qualitative findings are derived from a non-representative sample and may be influenced by interpersonal dynamics, such as participants’ trust or pre-existing impressions of the research topic. We worked to mitigate such effects through transparency regarding research objectives and guaranteeing anonymity. Finally, although the Turner et al. (2020) framework for theorizing land use change captures a diverse collection of influential elements, it is better used as a guide to understanding complex human-environmental change than a precise equation for predictions thereof.

[5] The 1998 Master Settlement was a multibillion dollar agreement between major tobacco companies Philip Morris, RJ Reynolds, Brown & Williamson, and Lorillard and 46 states, the District of Columbia, and five U.S. territories to settle Medicaid lawsuits stemming from the health and economic costs of tobacco.

Discussion and conclusion

After a century of radical simplification, diversifying crop systems offers a promising climate adaptation capable of supporting improved yields (Burchfield et al. 2019). Although previous studies have examined individual farmers' reasons for choosing to diversify their crop portfolio, we argue that a more holistic answer to the question of what forces support or hinder crop system diversification can be achieved through focusing on the meso-scale of landscapes. In addition to better accounting for the shared social worlds of people who farm near each other, regional histories and contexts, and the scale at which many benefits of diversification accrue, this move can also introduce fresh theoretical tools from land change science. Through its diachronic focus on integrating relevant social and biophysical factors, a land systems approach revealed critical influences in our case study that would have been easily missed by more unidimensional frameworks.

In this project, interviewees described nuanced reasons to start, stop, or continue growing specific crops. Their reasons aligned with one or more of four themes: markets, equipment, labor, and relationships. These explanations are largely established (Roesch-McNally et al. 2018; Tacconi et al. 2022; Weisberger et al. 2021), although fewer studies discuss labor availability. These explanations capture and explicate cropping rationales, but, critically, they do *not* explain the differences between Washington and Bertie counties. Although our sample size and sampling strategy is unsuitable for formal statistical analyses, the underlying logic for each explanation was shared across the counties and, indeed, appears as common sense within contemporary economic contexts. For example, no interviewee indicated that they believed finding a market should only happen after harvest or that they prefer to idle many expensive machines. Although the counties' cropping systems trended in opposite directions between 2008 and 2020, these differential trajectories were propelled by farmers using the same logics to pursue the same fundamental goals. Understanding what accounts for the differences thus requires moving from decision-making at a farm scale to the interactions between on-farm realities with biophysical, historical, cultural, and political context influencing cultivation possibilities at a landscape scale.

In recent reviews, Prokopy et al. (2019) and Hufnagel et al. (2020) both conclude that a lack of unifying theory is impeding scholarship on the adoption of conservation practices and diversification. To organize the analytical shift away from individual agency towards structural contexts, we drew upon Turner et al.'s (2020) framework for theorizing land use change as a process constituted through social and biophysical dynamics alike. We considered the framework not a finite calculus of crop indices, but a guide to the contours of crop systems in flux. The framework maintains the importance of farmers' preferences, values, and abilities, and situates these attributes alongside factors such as extant rural infrastructures, previous land use, and regional biophysical conditions. In our case study, these multiple, constitutive forces helped explain crop diversification and simplification. Pleistocene-era geologic differences across North Carolina's Coastal Plain underpin contemporary soil differences, with rich Blackland soil running through Washington County. Blackland soils' high organic matter creates a context strongly weighted towards corn production. In turn, intensive grain production set large-scale Washington farmers on a similar trajectory as the country's Corn Belt. In the Midwest as in Washington County, corn's market and biophysical characteristics incentivize economies of scale. Slightly north of the Suffolk Scarp, Bertie County's sandier, well-draining loam soils historically supported hundreds of small-scale tobacco farms. In turn, Bertie County was more affected by the dismantling of the tobacco and peanut quota systems. This shift in structural contexts removed price supports for these crops but left tobacco infrastructure intact, creating new catalysts for crop diversification.

Land change science provides a useful explanatory framework for holding in tension these overlapping forces. Reframing crop diversification as a process of land use change offers several benefits for researchers. Contemporary agricultural research largely adheres to a highly individualizing paradigm; reflecting the longstanding norms of public agricultural data collection and dissemination (Rissing et al. 2023) farms and operations are most often studied as atomized entities with insufficient attention to connecting relationships or spatio-temporal contexts. This sharply hinders researchers' abilities to account for agriculture's full complexity. A systems approach offers a complementary theoretical angle to study complex agricultural processes, such as crop diversification. Reframing crop diversification as a process of land use change further reflects that on-farm decisions are embedded in local communities as well as larger political-economic structures and regional environmental contexts. This rescaling from the farm to the landscape also encourages prioritization of emergent collectivist and collaborative modes of managing agricultural land, from environmental cooperatives (Van Dijk et al. 2015) to land trusts (Beckett & Galt 2013) and land tenure reform (Calo et al. 2021). Finally, repositioning agricultural change as a function of specific communities' historically rooted infrastructures, path dependencies, networks, and place-based knowledge is crucial to understanding possible and desirable trajectories of agricultural transition in response to climate change.

As research on sustainable agricultural transformations continues to move towards conceptualizing necessary change at scales beyond the level of the individual farmer, flexible theory attuned to such multilevel nuances will be critical. Conceptualizing crop diversification as a form of landscape change allows us not only to explain the barriers to diversification—or why it so often fails to progress—but also the bridges thereto—or what confluence of factors coalesce when cropping systems do diversify.

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Data availability De-identified transcript data may be available on a case by case basis for research purposes; please contact corresponding author with inquiries.

Declarations

Conflict of interest The authors declare no competing interests.

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