A transdisciplinary approach to landscape transformation towards perennial, diverse, circular systems: why and how.

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Keywords: Diverse Perennial Circular Systems; Resilience; Forage; Transdisciplinary

Abstract.
Prevailing agricultural systems in the U.S. are dominated by intensification through annual crop monocultures and high amounts of external inputs. Increased yields per unit of land have resulted but many undesirable environmental, ecological, and socioeconomic outcomes have co-occurred. Lack of resilience within intensified agricultural systems is a factor in these outcomes. Redesign of agricultural systems and changes in federal policy are needed to better support resilience in agriculture. Redesign for greater resilience must encourage adoption of agricultural systems that are diverse, perennial, circular, and include forages. We developed a transdisciplinary framework within a project orientation with a focus on crops and forages as agents of landscape transformation, and a diverse team of researchers, stakeholders and agency personnel. Our framework features a national network of farmers engaged in prevailing agriculture and practices of diverse, perennial, circular forage systems. Network farmers are collaborating with project scientists to gather on-farm data for better understanding of the opportunities and challenges to greater agricultural resilience. Over the next five years we aim to analyze the economic conditions, social structures, and public policies that prevent wider adoption of diverse perennial circular forage systems, and develop strategies to overcome these constraints.

Introduction
Prevailing agricultural systems in the U.S. are dominated by intensification through annual crop monocultures and high amounts of fertilizers, irrigation, and germplasm (Cassman, 1999). Increased yields per unit of land have resulted but undesirable outcomes have co-occurred, including: degradation of soil, water, and air quality; loss of biodiversity; negative impacts on human health; and exclusion of marginalized populations. Undesirable outcomes are attributed to lack of resilience in these systems - an inability to withstand and recover from disruption or crisis in extreme weather, climate change, and market shocks (Bowles *et al.*, 2020; Picasso *et al.*, 2019). Thus, there is a call for redesign of agricultural systems to better support resilience for greater sustainability in agriculture (Bommarco *et al.*, 2013).

We argue the most effective approach to redesign for greater resilience is adoption of agricultural systems that share three common features: diversity, perenniality, and circularity. Diverse systems include multiple species of crops and forages over time (i.e., crop rotations), spatial diversity (e.g. intercropping multiple crop species), or both. Perennial systems include perennial crops or cover in the crop rotation. Circular systems recycle nutrients rather than move them off-field and off-farm where they can become sources of pollution (Jurgilevich *et al.*, 2016). Because they are highly adaptable to a wide range of environmental, grazing and/or harvest conditions, forages are essential component for resilience.

Critical innovation is needed to transform agricultural systems towards greater resilience through the incorporation of the three features described above. Knowledge production and communications must support yield goals as well as delivery of ecosystem services across all landscape types, and achievement of greater equity and inclusion among farmers. Specifically, an innovative framework is needed to encourage landscape transformation toward diverse perennial circular forage systems (DPCFS) that are well-matched to the landscapes that contain them. Such a framework must also manage social barriers, access to information, farmer and consumer values, and negative attitudes towards to change.

Transdisciplinarity is often described as the involvement of disciplinary experts and stakeholders in collaborative processes for solving complex real-world problems (Groß and Stauffacher 2014, Halvorsen *et al.* 2015). Transdisciplinary principles emphasize integration of multiple perspectives and understandings into new, shared understandings, and empowerment of those who have historically been excluded from knowledge production and decision-making (Hirsch Hadorn *et al*. 2008). Transdisciplinarity is needed for addressing complex sustainability problems, integrating input from all relevant actors, increasing legitimacy and accountability of research outcomes, building credibility from the start, and assuring relevance for end users (Lang *et al*., 2012). Thus, transdisciplinarity in a project orientation provides a transformative approach for overcoming deeply entrenched political, cultural, technical, and economic barriers to the adoption of DPCFS.

Methods and Study Site

For landscape transformation toward DPCFS, we developed a transdisciplinary framework with a focus on crops and forages as agents of landscape transformation. We assembled a large, diverse team of more than 50 researchers and stakeholders from 23 universities, two USDA-ARS centers, 12 farmer organizations, several NGOs, and multiple industry organizations. Building a diverse team to frame the problem jointly and define objectives and methods together is the first step in a successful transdisciplinary project (Lang *et al*., 2012). We are applying our framework to agro-ecoregions within 23 states encompassing all major climate types and all major ecoregions of the US.

Our framework features multiple transdisciplinary touchpoints: designed collaboration (Hall *et al.* 2019), support by project management grounded in transdisciplinary and team science best practices (Bennett *et al.* 2021, Sahneh *et al.* 2021), strategic communications (McGreavy *et al.* 2022), joint planning and governance by a multi-disciplinary steering committee (Hollaender *et al.* 2011), application of integrative methods is key for transdisciplinary progress (Lang *et al*., 2012), and counsel by a diverse advisory board. Special attention was put on balancing the mix of gender, age, career stage, disciplinary background, ethnicity, and geographic location. Our steering committee is composed of the project director, leaders of six sub-teams organized around the project's major objectives (described below), and the project manager.

We have developed multiple spheres of research, outreach, and coordination activity with designed interconnectedness to fulfill our objectives (described below). Interconnectedness is fostered through strategic communication among members of the steering committee and between the steering committee and all personnel of the project, and through tracking of critical milestones and hand-offs of intermediate deliverables between team members. One sphere is central to all other spheres and thus forms the "backbone" of our transdisciplinary framework; the *National Farm Pairs Network* comprised of farmers from across the U.S. The *Network* includes pairs of farmers where one farmer in each pair is practicing a system of prevailing agriculture while the other farmer in the pair is practicing a DPCFS. Farm pairs are the source of agronomic, edaphic, and socioeconomic data for robust statistical analyses, including Life Cycle Assessment, to illuminate the benefits and challenges of prevailing and DPCFS, as well as barriers to adoption of DPCFS.

Within the next five years we aim to: 1) identify and characterize prevailing systems and DPCFS; 2) quantify and compare the resilience and ecosystem services offered by these systems; 3) quantify and analyze direct and indirect economic, health, and social implications of increased adoption of DPCFS; 4) analyze the economic conditions, social structures, and public policies that prevent wider adoption of DPCFS and develop strategies to overcome these constraints; 5) develop extension media, activities, and actionable decision tools to communicate concepts about the benefits of DPCFS; and 6) develop and incorporate educational materials on the importance of resilience, ecosystem services, and economic value of integrating DPCFS for K-12 and university curricula. In the long-term we aim to increase

support for adoption of DPCFS, recommend federal and state policies to incentivize adoption of DPCFS, and increase land area in DPCFS across the US.

Results and Discussion

For a transdisciplinary team to remain engaged and committed, targeted products must be generated early in the process (Lang *et al.*, 2012). In our first year, we have reached multiple target audiences including the general public, children, farmers, non-profit organizations, forage industry personnel and crop consultants, undergraduate and graduate students, extension educators, national and international forage agronomists and livestock researchers, data scientists, and federal policymakers. Our reach was achieved through media broadcasts, educational activities involving K-12 students in hands-on activities, focus group events, engagement with professional and industry networks, and providing undergraduate and graduate student research opportunities. We also reached target audiences through peer-review publications.

We organized farm pair coordinators and recruiters in 26 states, and developed a *Handbook* for coordinators and recruiters. We have also established protocols for on-farm data collection by farmers in the *Farm Pairs Network*. Details of the development of the National Farm Pairs Network is described by Cassida and Lamp., in these Proceedings. We completed a set of forage suitability maps for the conterminous US and for Alaska, Hawaii, and Oregon. A series of 50 forage species "selection cards" is in progress for extension audiences, intended as quick-reference guides to a wide range of forages and their potential suitability for various agroecoregions across the U.S. The entire series will be published upon the completion of all cards. More details are provided by Hannaway in these Proceedings. We created the *National Forage Data Hub*, a database for collecting all existing forage data in the U.S., including variety trials and field experiments. The *Hub* serves as a central repository for existing forage data within the US. The purpose is to make existing data available to the public, to minimize research redundancy, and to optimize regional systems. A user interface is under construction and will be tested and made available to the public in 2023. More details are provided by Marshall *et al*., in these Proceedings. We conducted policy focus groups in Spring 2022, to better understand barriers and challenges farmers are facing, specifically those who are trying to access federal programs to support diverse circular perennial production systems. We found that farmers who are college educated, have financial resources, have existing relationships with USDA and lenders, and know how to navigate agencies, are better able to get the help they need from USDA. Producers without these advantages were less able to get needed help. More details are provided by Krome *et al*., in these Proceedings.

Throughout this process intentional effort was put into facilitating continuous evaluation (through a dedicated professional evaluation team), mitigating conflicts (between disciplines and among project participants), and enhancing participation as recommended by Lang *et al*. (2012). In the first year of the project balancing the short-term urge for progress and results with the long-term slow process of building community and transdisciplinary understanding was one of the main roles of the leadership team.

Conclusion

Diverse perennial circular forage systems such as those with crop rotations that include perennial forages, living mulches, intercropping, or grass-legume pastures have the potential to foster resilience to climate change and economic disruptions as well as provide ecosystems services and greater socioeconomic inclusivity across many types of agricultural landscapes. Greater knowledge and awareness of these systems, and policy and economic measures can help promote these systems and overcoming social, economic and policy barriers with the goal of social inclusion, economic wellbeing, and human health. A transdisciplinary approach involving researchers from a broad range of disciplines and diverse stakeholders is being convened for redesign of agricultural systems to include diverse perennial circular forage systems and to engage in social change to make needed landscape transformation happen.

Principles and practices from previous transdisciplinary projects and the research community have proven essential to the short and long term success of this project.

Acknowledgements

This work was funded by USDA NIFA Sustainable Agricultural Systems Coordinated Agricultural Project grant # 2021-68012-35917.

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