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PERSPECTIVE

Grassland Research

Diverse perennial circular forage systems are needed to foster resilience, ecosystem services, and socioeconomic benefits in agricultural landscapes

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Abstract

Prevailing agricultural systems dominated by annual crop monocultures, and the landscapes that contain them, lack resilience and multifunctionality. They are vulnerable to extreme weather events, contribute to degradation of soil, water, and air quality, reduce biodiversity, and negatively impact human health, social engagement, and equity. To achieve greater resilience, stability, and multiple ecosystem services therein, and to improve socioeconomic outcomes, we propose a practical framework to gain multifunctionality at multiple scales. This framework includes forages within agroecosystems that have the essential structural features of diversity, perenniality, and circularity. These three structural features are associated with increased resilience, stability, and provision of several ecosystem services, which in turn improve human health and socioeconomic outcomes. This framework improves understanding of, and access to, tools and materials for promoting the adoption of diverse circular agroecosystems with perennial forages. Application of this framework can result in land transformations that solve sustainability challenges in agriculture if policy, economic, and social barriers can be overcome by a transdisciplinary process of equitable knowledge production.

KEYWORDS

climate change, forages, multifunctionality, resilience, soil health, sustainability, transdisciplinary

INTRODUCTION

Agricultural production is faced with the challenges of adapting to climate change and socioeconomic disruptions, providing ecosystem services, and reducing pollution while simultaneously fostering human health and supporting social and economic well-being and inclusion. Increasing climate variability calls for more resilient and stable agricultural systems. Intensification of agriculture during the past 70 years has increased yield per unit of land by promoting low-diversity, high-disturbance cropping systems that depend on high amounts of external inputs such as fertilizers, irrigation, and germplasm with greater harvest index and shorter life cycle (Cassman, 1999). Federal policies such as farm subsidies, credit, and insurance programs have encouraged intensification. In spite of yield benefits, there are also many undesirable outcomes, including degradation of soil, water, and air quality; loss of biodiversity; negative impacts on human health; and exclusion of marginalized populations (Ramankutty et al., 2018). Thus, critics of intensification call for a redesign of agricultural systems and the landscapes in which they occur (Bommarco et al., 2013) supported by policies that do not disincentivize such innovation.

Mitigating the impact of agricultural intensification requires new frameworks for research, production, commercialization, and policy. Examples of proposed frameworks include "organic," "sustainable," "natural," "regenerative," "carbon smart," and "ecological" agriculture. Often these frameworks are defined by expected outcomes rather than structural features of the system, and result in confusion among farmers, researchers, policymakers, and consumers. Moreover, prevailing conventional approaches to research and outreach can themselves become barriers to adoption of innovation. Therefore, the goal of this perspective paper is to describe a straightforward and practical framework for fostering greater benefits and fewer undesired impacts of agriculture. This framework is based on agroecosystems containing forages that have the structural features of diversity, perenniality, and circularity, and use of transdisciplinary approaches to foster transitions to these systems.

Diverse perennial circular forage systems (DPCFSs), an agroecosystem type described below, offer a more sustainable alternative to input intensification approaches. Broad-scale adoption of DPCFS will result in these benefits accruing at the community, society, and global scales. However, government policies such as farm subsidies, financial credits, and insurance programs frequently disincentivize change. Current "linear" economies (as opposed to "circular," see below) result in negative externalities, market failures, and missed markets. Additionally, many social barriers exist, including farm labor structures, scales of production, producer concerns about market reliability, and access to information. Farmer and consumer values and attitudes can also present barriers to change.

In this paper, we present a nonsystematic integrative literature review (Snyder, 2019) to synthesize the literature on the linkages between structural features of agroecosystems (diversity, perenniality, and circularity) and the system outcomes (resilience, ecosystem services, and socioeconomic benefits). We also review the related socioeconomic and political barriers to adoption and alternative enabling conditions for a landscape transition from currently prevailing agroecosystem to DPCFS that emerge from a transdisciplinary process (Figure 1).

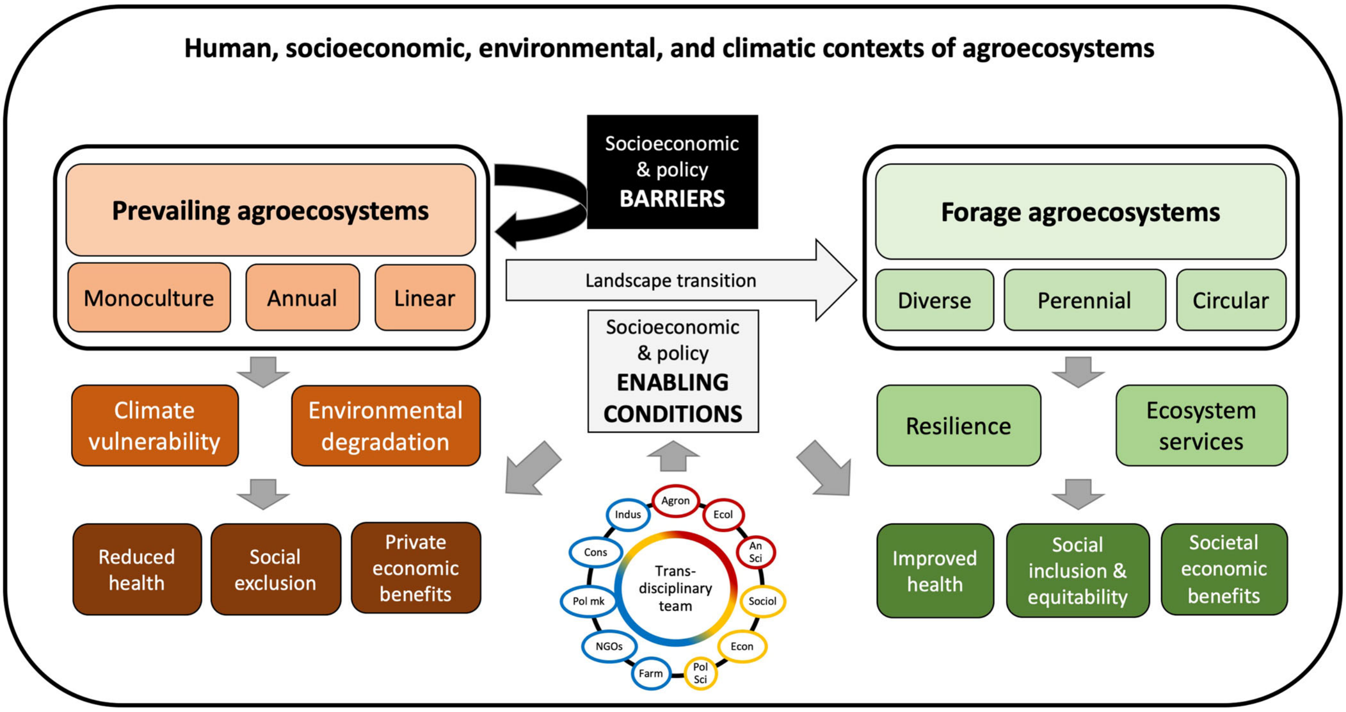

FIGURE 1 Conceptual framework: Structural features of agroecosystems (diversity, perenniality, circularity) are linked to environmental (resilience and ecosystem services) and socioeconomic (health, inclusion, and societal benefits) outcomes. A landscape transition from prevailing agroecosystems to diverse, perennial, circular, forage systems requires overcoming socioeconomic and political barriers and creating enabling conditions through a transdisciplinary process that includes disciplinary scientists in agronomy (Agron), ecology (Ecol), animal science (An Sci), sociology (Sociol), economics (Econ), political science (Pol Sci), farmers (Farm), specialists from non-government organizations (NGOs), policy makers (Pol mk), consumers (Cons), and industry personnel (Indus).

DIVERSE PERENNIAL CIRCULAR FORAGE SYSTEMS

Agroecosystems are units of agricultural productivity composed of physical, biological, socioeconomic, and cultural subsystems interacting as a community within a larger framework of human-led agricultural processes (Cordoba et al., 2020). Agroecology, as a set of agricultural practices that mimic natural ecological processes to improve agricultural sustainability, has gained global consensus as a viable approach to sustainability gains. Multiple pathways toward greater sustainability in agriculture are possible through agroecology because the concept applies across diverse subsystems types and the varied ways in which they function as communities. Transitions to the agroecosystem approach to increased agricultural sustainability include political, social, economic, environmental, and technological shifts in policies, practices, and institutions (Wenzel et al., 2020). Crop-livestock agroecosystems provide food, income, and risk reduction to farmers and contribute to agricultural value chains. Although the global environmental footprint of livestock production and consumption is a concern, a diversity of forages grown in well-managed agroecosystems have been shown to provide multiple benefits not achievable through conventional intensification of agriculture (Notenbaert et al., 2021; Rao et al., 2015). Forage crops and pastures play an important role in sustainable agriculture because of their value as a feed for livestock and for their roles in biodiversity, wildlife habitat, climate change mitigation, and soil quality. Because they are highly adaptable to a wide range of environmental and grazing/harvest conditions, forages are an essential component in agroecosystem-based approaches to agricultural suitability across landscapes.

Agricultural landscapes vary in climate, soils, infrastructure, demographics, and other characteristics. Therefore, innovative agricultural systems must be applicable across a wide range of agricultural landscapes to address the current challenges at broader scales and to achieve desired outcomes across socioeconomic strata. We argue that agroecosystem approaches are the most effective approach across variable landscapes, and that forage agroecosystems share three common structural features: diversity, perenniality, and circularity. These three structural features are linked to desirable system outcomes like resilience, ecosystem services, and socioeconomic benefits, as described in the next section. Therefore, a landscape transformation toward DPCFS can achieve sustainability and multifunctionality. Examples of DPCFS systems adaptable across a wide range of landscape types are those that include crop rotations with perennial forages (leys), living mulches, intercropping, and grass–legume pastures. Although DPCFSs have been proposed for marginal, highly erodible lands (Awasthia et al., 2017), we believe that there is realistic opportunity to expand them to highly productive lands as well. Through our proposed framework, we recommend focus on forages and crops (rather than specific livestock species) to better foster adoption of DPCFS. The result will be the transformation of agricultural landscapes toward greater sustainability. Moreover, we seek to expand the analysis of farm productivity beyond specific products such as "grains, dairy, or meat" toward broader holistic metrics of production like the private and public benefits—economic, environmental, and social—of increased resilience and biodiversity.

SYSTEM OUTCOMES AND THEIR LINK WITH STRUCTURAL FEATURES

A review of definitions of the desirable relevant system outcomes is summarized below:

- *Stability and resilience*: A key challenge in agriculture is designing agricultural systems that are productive, stable, and resilient in the face of climate change and other disruptions, while simultaneously promoting farmer profitability, soil health, clean air and water, and biodiversity (Howden et al., 2007). Stability is the minimal variability of production despite normal climate fluctuations, while resilience is the ability of a system to withstand and recover from a perturbation or crisis (Bowles et al., 2020; Picasso et al., 2019; Urruty et al., 2016). Resilient agricultural systems remain productive under extreme events (e.g., drought or flood). Stability, resilience, and productivity do not necessarily covary, so understanding each variable is relevant for adaptation to climate change (Picasso et al., 2019; Sanford et al., 2021).
- *Ecosystem services* are the benefits that society receives from ecosystems or agroecosystems, regardless of their market value (Millennium Ecosystem Assessment, 2003). These benefits include provisioning (e.g., food, drinking water), regulating (e.g., pollination, erosion control), cultural (e.g., recreation, esthetics), and/or supporting (e.g., nutrient cycling, soil formation). Concerns about the loss of ecosystem services from farms due to intensification (Wagner et al., 2021) have given rise to calls for an alternative approach. Ecological or sustainable intensification increases productivity and ecosystem services by relying on diversification and greater resource use efficiency within agroecosystems (Franzluebbers et al., 2020; Samways et al., 2020; Tittonell, 2014). For example, soil health and resilience of agricultural systems depend on building or maintaining soil organic carbon (SOC), and improved agricultural management can increase sequestration of atmospheric CO_2 and contribute to climate change mitigation. Markets are responding to consumers' interest in low-carbon solutions, and an increasing number of food corporations are setting targets to reduce their carbon emissions. On a per-area basis, in spite of benefits for yield, high-input agricultural systems result in higher global warming potential, higher risk for acidification, more eutrophication, and more toxicity to humans compared to low-input systems (Darre et al., 2020; Nemecek et al., 2011, 2015; Picasso et al., 2014).
- *Human health*: Negative health outcomes and negative societal impacts attributed to agricultural pollution in the United States support the development of more

sustainable practices (Giannadaki et al., 2018), including diverse perennial systems. There are clear and critical relationships between land use/land cover and environmental and human health (Peters et al., 2016; Temme et al., 2013). We can improve environmental sustainability and global carrying capacity by understanding and managing these relationships (Willett et al., 2019), and by designing agricultural systems for better human health outcomes.

- *Social inclusion*: Structural inequalities take many forms. In the United States, for instance, they pose barriers to farmers of color and women farmers, while privileging White male farmers. Although people of color account for over a quarter of the US population, they account for less than 3% of US landowners and only 4% of all owner-operators (Horst & Marion, 2019). Farmers of color are disproportionately tenant farmers and disproportionately low-resource farmers. Women account for fewer than 25% of primary farm operators, although they are more than 51% of the US population, and farms operated by women earn 40% less than farms operated by men (Fremstad & Paul, 2020). However, both farmers of color and women farmers are disproportionately represented in sustainable farming systems. While it is important not to reify the relationship between marginalized groups and more sustainable practices, this existing investment in sustainable systems does present interesting opportunities. In other countries, farmers from ethnic minority groups, farmers who are lower caste, and those from subsistence farming communities may face similar barriers as those described above. Research around the world, and across many decades, indicates that producers who are women and those who have less access to economic capital are nearly universally at a disadvantage in accessing the resources central to conventional agricultural success. It is possible that greater social investment in sustainable systems, such as DPCFS, could benefit groups that historically have had less access to agricultural innovations.
- *Economic well-being*: Environmentally sustainable agricultural systems will be adopted only if they are economically viable (Baumgart-Getz et al., 2012). Consequently, it is necessary to assess the economic value of these systems narrowly (short-run, private, and on-farm benefits) and broadly (long-run, public, or off-farm benefits). However, there is lack of actionable estimates for how environmental conditions evolve over time in response to varying production practices (Stevens, 2018). In spite of the knowledge gap, there is evidence that transitioning to more environmentally sustainable systems can enhance social and economic well-being for farmers, rural communities, and society at large (see, e.g., Jaenicke, 2016; Lyson & Guptill, 2004; Marasteanu & Jaenicke, 2019; Poulsen, 2017; Volkov et al., 2022).

Three main structural features of agroecosystems are defined below, with their linkages to the system outcomes:

- *Diversity*: Diverse systems include multiple species of crops and forages over time (crop rotations), spatial diversity (e.g., intercropping multiple crop species), or both. The ecosystem services' benefits of diversity are well documented in both the ecology and agriculture literature (Picasso, 2018). Diversity is a driver of productivity and resilience (Oliver et al., 2015; Picasso et al., 2011). Crop diversity also reduces disease, pest, and weed pressure (Davis et al., 2012; Liebman et al., 2008). Resilience is enhanced in diverse crop rotations as a result of mechanisms such as the portfolio effect, complementarity, functional redundancy, connectivity, and so on (Biggs et al., 2012; Picasso et al., 2011). Diversity increases the stability and/or resilience of long-term crop yields or cropping systems' performance in the long term (Bowles et al., 2020; Degani et al., 2019; Li et al., 2019; Sanford et al., 2021). Intercropping and perennial mulches can increase productivity and profitability (Berti et al., 2021; Osterholz et al., 2020), and reduce the agricultural carbon footprint (Yu et al., 2015). In addition, diverse systems increase biodiversity while reducing risks due to weather and market change.
- *Perenniality*: Perennial forages or cropping systems include perennial crops or cover in the crop rotation, and can provide many benefits to the environment, such as year-round soil cover, carbon sequestration, and nutrient retention for many years. Cropping systems dominated by perennials have been positively associated with pollinator habitat quality, soil and nutrient conservation, and accrual of SOC (Sanford, 2014; Schulte et al., 2017). Carbon input and soil organic carbon increase is greater in rotations including perennials compared with annual-only rotations (King & Blesh, 2018). Cropping systems that include perennials increase soil root biomass, activity of soil flora and fauna, and consequently increase SOC and total nitrogen. Reducing tillage and increasing the amount of living soil cover enhance soil structure, which improves water and nutrient supply to crops, reduces runoff, and improves surface water quality (Lal, 2020; Nunes et al., 2018). Perenniality also reduces the interannual variability of yields and increases yield stability. Perennial forages such as alfalfa (*Medicago sativa* L.) can provide several regulating services, such as reduced soil erosion and nutrient losses to water (Osterholz et al., 2019).
- *Circularity*: Circular systems recycle nutrients rather than moving them off-field and off-farm to the atmosphere, surface waters, and groundwater, where they can become sources of pollution (Jurgilevich et al., 2016). Cropping systems integrating legumes and livestock in diverse perennial circular systems, for example, add to the system through atmospheric N_2 fixation by legumes and by plant root uptake of nutrients deposited in manure and urine. Similarly, nutrients in the forage not consumed by livestock are reutilized by the crops themselves. Crop–livestock systems with perennial crops also enhance soil aggregate stability while reducing erosion potential (Fultz et al., 2013).

SOCIOECONOMIC-POLITICAL CONTEXT

Disruptions to natural nutrient cycling currently challenging agriculture and human society are driven by economic, political, and other social processes. Understanding and changing those processes will allow society to adapt to resultant environmental impacts (Foster et al., 2010). We argue that increased adoption of DPCFS can support both mitigation of, and adaptation to, those disruptions by providing new economic opportunities for farmers while contributing to a more inclusive and equitable agricultural system. Within environmental social sciences, there exist several perspectives about how social, political, and economic institutions react and respond to ongoing ecological degradation and social inequity. For example, a treadmill of production analysis predicts the internalization of unintended ecological and social costs currently unaccounted for in our economic production systems (e.g., Gould et al., 2008). Critical political ecology perspectives examine the internal contradictions of modern economic processes and seek to redesign more circular material economies (e.g., Foster et al., 2010). Ecological modernization argues that the growing ubiquity of environmental feedback results in the evolution of social institutions of modernity to accommodate and adapt to that feedback (Mol et al., 2009). In spite of the tensions between interpretations of macro social change and conflict, our pragmatic approach to landscape transformation focuses on mobilizing social, political, and human capital (Flora et al., 2015) to identify and leverage opportunities for transformation of agricultural systems.

Farmer value orientation influences decision-making regarding production system choices. In many cases, an environmental and communitarian orientation predicts greater openness to adopting sustainable agriculture practices, while more individualistic and instrumental values' orientation is associated with a preference for conventional practices (Jackson-Smith & Buttel, 2003). Frameworks incorporating farmer knowledge networks and adaptive decision-making exist and provide crucial insight into farmers' concerns regarding adoption of these practices (Rosch-McNally et al., 2017). Farmers use various types of rationales in decision-making processes (Finan, 2011), and notions of personal identity and what it means to be a "good farmer" can lend further insight into social factors related to farmer motivations for adopting sustainable practices (Mcguire et al., 2013).

The diversity in farmer histories and values is crucial in developing effective policy and education that encourage and support the adoption of sustainable farming and land management practices (Mills et al., 2017). Social characteristics such as race, gender identity, age, and ableness are relevant in shaping those histories and values (Taylor, 2018; Wright & Annes, 2020). Transitioning to more environmentally sustainable systems can enhance social and economic well-being for farmers, rural communities, and society at large. For these synergistic benefits to be realized, however, issues of social inclusion must be intentionally addressed in the development of policy, lest we risk perpetuating existing patterns of social privilege, often invisible or ignored. The policy can be crafted in a way that serves the particular interests and needs of women and/or people of color. When diverse stakeholders are included in policy development, the resulting tools are more likely to be successfully implemented and the primary desired outcomes achieved, while also contributing to the equitable inclusion of people of color and women.

TRANSDISCIPLINARITY FOR TRANSITION TO DIVERSE PERENNIAL CIRCULAR FORAGE SYSTEMS

We argue that the transformation of agricultural landscapes to provide more environmental, ecological, and socioeconomic benefits and fewer undesirable outcomes (compared to prevailing systems of agricultural intensification) can be achieved through the adoption of diverse perennial circular systems (among others). Further, we argue that it is only through transformative approaches to knowledge production, decision-making, and problem-solving that we can overcome the deeply entrenched political, cultural, technical, and economic barriers to the adoption of these systems. For us, a central component of that approach is transdisciplinarity. We define transdisciplinarity as an ontological system that explicitly incorporates actors from a wide variety of disciplines (e.g., agronomy, sociology, economics), collaborating with each other and nonacademic practitioners (i.e., farmers, industry) and stakeholders (e.g., nongovernment organizations) to build a new, communally constituted, knowledge system (Halvorsen et al., 2015).

Transdisciplinarity processes are used to identify and address complex real-world problems by integrating multiple perspectives and understandings into new, emergent, and shared understandings. Additionally, transdisciplinary teams seek to generate this knowledge in ways that empower those who have historically been closed out of knowledge production and decision-making (Hirsch Hadorn et al., 2006). As a "transformational scientific field," transdisciplinarity is regarded as having the power to bridge knowledge and action by producing deeper understanding of issues (systems knowledge), determining more inclusive ways to make decisions, and knowledge of ways and means of realizing those decisions (Marshall et al., 2018).

CONCLUSIONS

Diverse perennial circular forage systems such as those with crop rotations that include perennial forages, living mulches, intercropping, or grass–legume pastures can foster resilience to climate change and provide multiple ecosystem services and socioeconomic benefits in agricultural landscapes. Policy and economic measures can help promote these systems by overcoming social, economic, and policy barriers with the goal of social inclusion, economic well-being, and human health. A transdisciplinary approach involving researchers from a broad range of disciplines and diverse stakeholders is needed to engage in social change to make this needed landscape transformation happen.

AUTHOR CONTRIBUTIONS

Valentin D. Picasso: Conceptualization, funding acquisition, investigation, methodology, project administration, supervision, writing–original draft, writing–review and editing. **Marisol Berti**: Conceptualization, funding acquisition, writing—original draft, writing—review and editing. **Kim Cassida**: Conceptualization, funding acquisition, writing—review and editing. **Sarah Collier**: Writing—review and editing. **Di Fang**: Writing—review and editing. **Ann Finan**: Conceptualization, funding acquisition, writing—original draft, writing—review and editing. **Margaret Krome**: Writing—review and editing. **David Hannaway**: Conceptualization, funding acquisition, writing—review and editing. **William Lamp**: Conceptualization, funding acquisition, writing—original draft, writing—review and editing. **Andrew W. Stevens**: Conceptualization, funding acquisition, writing—original draft, writing—review and editing. **Carol Williams**: Conceptualization, visualization, writing—original draft, writing—review and editing.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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