FARMING SYSTEM DESIGN FOR SUSTAINABLE AGRIFOOD SYSTEMS: THEORIES AND PRACTICES

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Trade-offs among ecosystem services in diversified agricultural landscape designs for the North China Plain

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Introduction

Ecosystem services (ESs) supply is central to multifunctional agricultural landscapes. Since the Green Revolution, crop production has intensified, leading to landscapes dominated by a few cereal species and reliant on high chemical inputs to meet growing demands for provisioning services (Tilman et al., 2002). While these landscapes emphasize provisioning services, they often undermine non-provisioning ESs and aggravate disservices, such as greenhouse gas emissions and biodiversity loss (Foley, 2005). Addressing diverse ESs at the landscape scale is vital to satisfy stakeholder needs (de Groot et al., 2010). Landscapes with smaller fields and denser edges can enhance multifunctionality and boost regulating services like pest control (Landis, 2017). However, trade-offs between ESs and divergent stakeholder interests make planning complex (Wilhelm et al., 2020). Redesigning landscapes to be multifunctional and sustainable is thus challenging. The North China Plain, a major maize, wheat, and cotton production area, faces sustainability issues from intensive practices like wheat-maize double cropping (Cheng et al., 2023). Recent policies call for more balanced ESs via "Agriculture Green Development" (Shen et al., 2020). This region serves as a case study for redesigning landscapes to balance ESs and stakeholder priorities. This study presents a model-based framework to redesign multifunctional landscapes that address ESs supply issues. Applied to two Quzhou landscapes, it aims to: 1) Redesign landscapes with improved crop management and diversification across multiple ESs; 2) Explore ES trade-offs and synergies. The case studies illustrate the method's relevance for broader use in specialized cropping areas.

Methods

We followed five steps to explore alternative agricultural landscapes and their performance using the Landscape IMAGES model, which highlights ES trade-offs and synergies while integrating stakeholder preferences. Step 1: Two case study landscapes in Quzhou were selected. One is intensively cropped with wheat-maize double cropping; the other is more extensive with cotton monoculture. Step 2: Optimization objectives were defined based on stakeholder priorities, focusing on ESs with low supply or high importance (Cheng et al., 2023; 2025). A literature review and local survey identified key ESs. These indicators served as redesign objectives and were modeled in Landscape IMAGES. Step 3: Candidate land uses (cropping systems and management) were selected based on farmer surveys, including semi-natural habitats. Land-use rules followed local policies and ecological principles. ES performance was evaluated using survey data. Step 4: A multi-objective optimization examined ES trade-offs and synergies. Improved designs were generated with the Differential Evolution algorithm, and optimal designs were selected based on Pareto efficiency. These Pareto-optimal landscapes were analyzed for trade-offs and synergies.

Results

We observed trade-offs between gross margin and non-provisioning ESs. Nonetheless, gross margin, biocontrol potential, and crop diversity could be substantially improved in both landscapes (Figures 1 and 2).

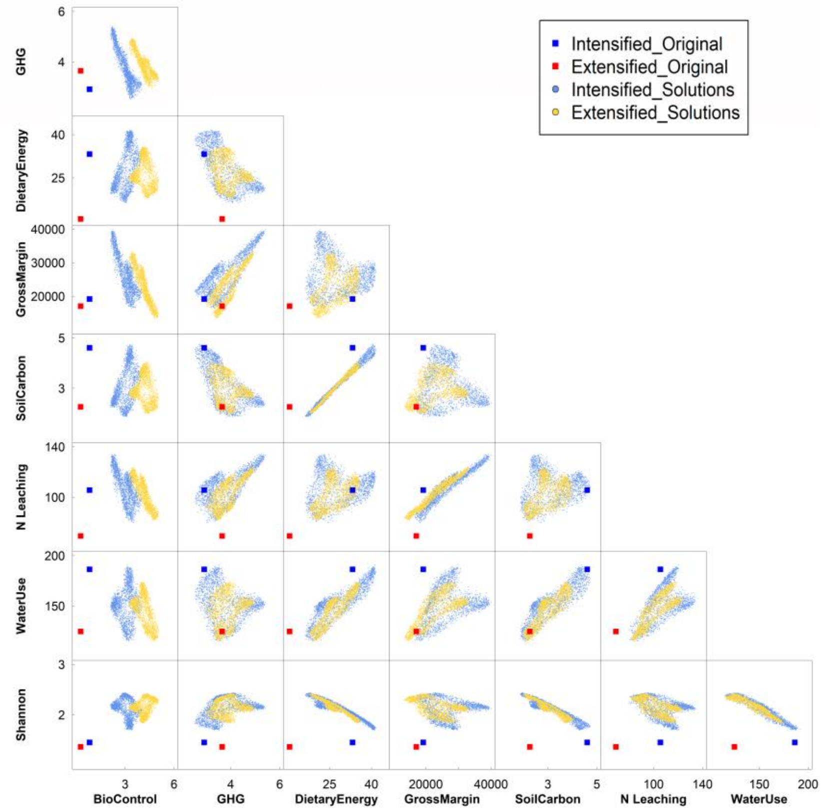

Figure 1. Relationships among ES indicators in Pareto-optimal landscape alternatives for an intensified (blue) and a relatively extensive (yellow) landscape. Red and blue squares indicate original landscape ES performance. The units of indicators: BioControl (% of maximum); GHG (Mg CO_2 eq. ha^{-1} year^{-1}); DietaryEnergy (persons ha^{-1} year^{-1}); GrossMargin (CNY ha^{-1} year^{-1}); SoilCarbon (Mg CO_2 eq. ha^{-1} year^{-1}); N Leaching (kg ha^{-1} year^{-1}); WaterUse (mm year^{-1}); ShannonIndex (unitless).

Discussion

The multi-objective optimization modeling approach in this study addresses trade-offs between provisioning and non-provisioning ecosystem services (ESs). Diversification of the landscapes shows the potential to improve multiple ESs like biological control and reduce the dis-services. This framework optimizes landscapes by incorporating diverse cropping systems and semi-natural habitats, alongside agronomic management improvements, to improve ES delivery. This model uses survey data on ESs delivery in relation to cropping systems and have the potential to include stakeholder-informed weights on the preference of different ESs. Despite strengths, limitations exist, such as reliance on one year of crop data and empirical equations that may not fully capture dynamic interactions. For example, while the model assumes that flower strips support natural enemies, it does not account for pest and natural enemy speciesspecific dynamics or pest-natural enemy interactions over time. In the current study it was not possible to engage stakeholders in indicator selection and assessment of the generated solution. Future efforts may include interactive tools, like virtual reality, to allow stakeholders to visualize and provide feedback on landscape changes.

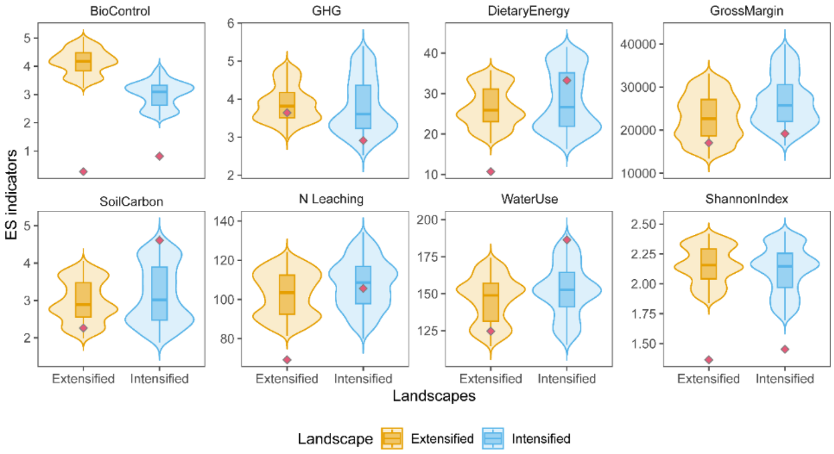

Figure 2. Distribution of ES indicator values in Pareto-optimal alternatives for both landscapes. Red dots indicate baseline ES values (Units as in Figure 1).

Perspectives

This flexible modeling framework can be applied at multiple spatial scales. It helps explore landscape alternatives, manage trade-offs among ESs, and support participatory planning to enhance multifunctionality.

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