Mitigating Groundwater Decline with Bioenergy Crops: Strategic Transitions in the U.S. High Plains

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Research Objective

- The Ogallala Aquifer underlies much of the U.S. High Plains region. The agricultural economy in this region relies heavily on the Ogallala Aquifer and vital resource for the nation's food security.
- In this study we estimate the maximum long-term benefits of producing alternative bioenergy feedstocks in the currently irrigated areas in the region considering groundwater limitations and market conditions and evaluate change in land and water use.

Methods

Our economic analysis has two major steps:

I. Developing crop budgets for each agricultural system for 180 counties for five crop system alternatives (resulting in 900 budgets).

II. Constructing an individual 30-year mixed integer linear programming (MILP) model for study area counties to determine the optimal cropland system choices, groundwater use based on cropping activities, and net present value (NPV) for a representative field. The aim is to find the best management practices that maximize both current profits and the life of the aquifer.

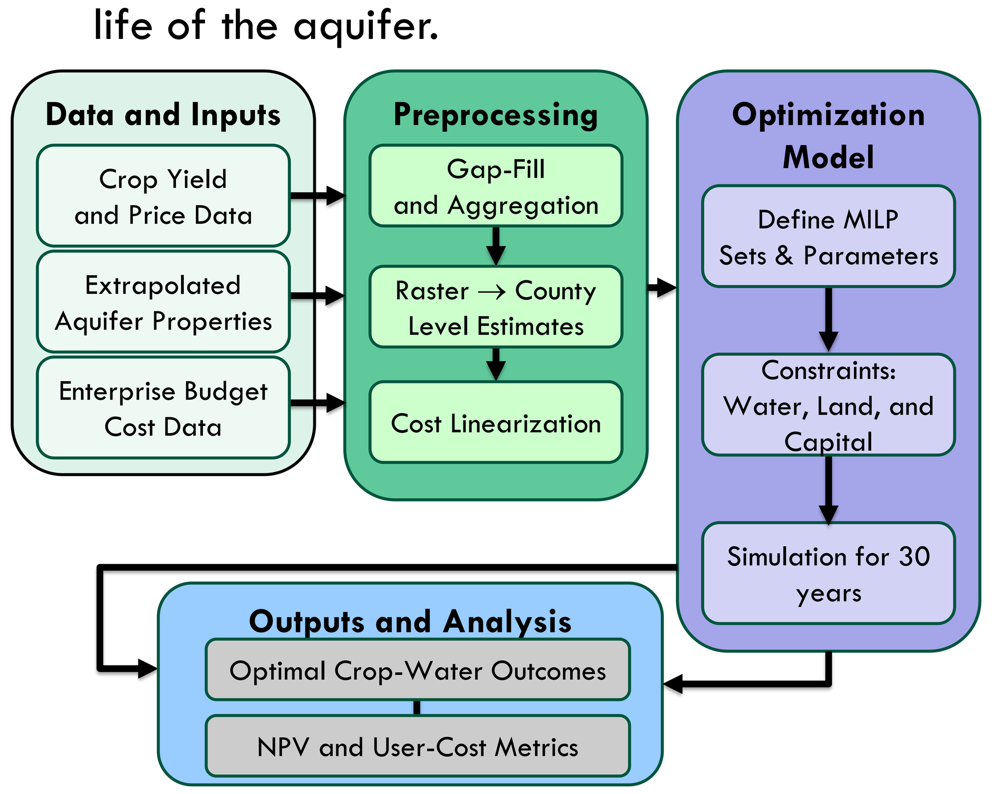

Figure 1. Integrated Workflow for Bioeconomic Optimization of Crop and Water Use

References

Deines, J. M., M. E. Schipanski, B. Golden, S. C. Zipper, S. Nozari, C. Rottler, B. Guerrero, V. Sharda. 2020. Transitions from irrigated to dryland agriculture in the Ogallala Aquifer: land use suitability and regional economic impacts. Agric. Water Manag., 233, Article 106061

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Findings

We find significant spatial variation in groundwater availability and crop transitions from irrigated corn to bioenergy crops across the High Plains, with important implications for long-term agricultural sustainability. Modeled transitions to dryland systems and bioenergy adoption reveal differences across states driven by heterogeneity in aquifer volume, storage, extraction rates, and recharge dynamics. Figure 2 summarizes this variation: **Map A** shows current aquifer volumes, with deeper reserves in Nebraska and northern Kansas. **Map B** highlights early dryland transition zones in the south, where depletion occurs sooner. **Map C** presents future opportunity zones for bioenergy adoption, based on economic feasibility measured as opportunity cost per acre. These patterns underscore the need for region-specific strategies.

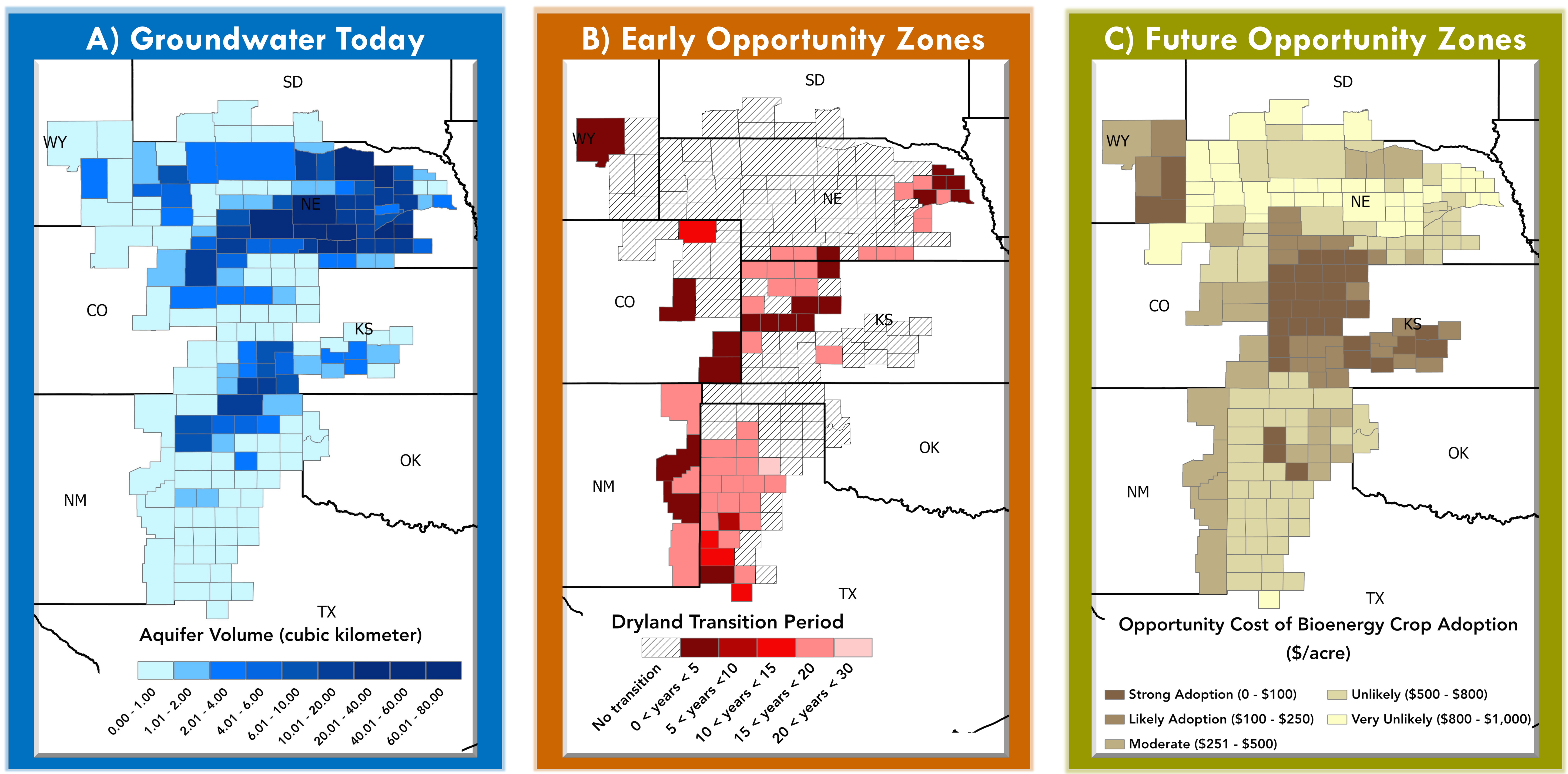

Figure 2. Visualizing the Future of Crops and Aquifers in the High Plains: Spatiotemporal Patterns of Groundwater Conditions and Bioenergy Crop Transition Opportunities

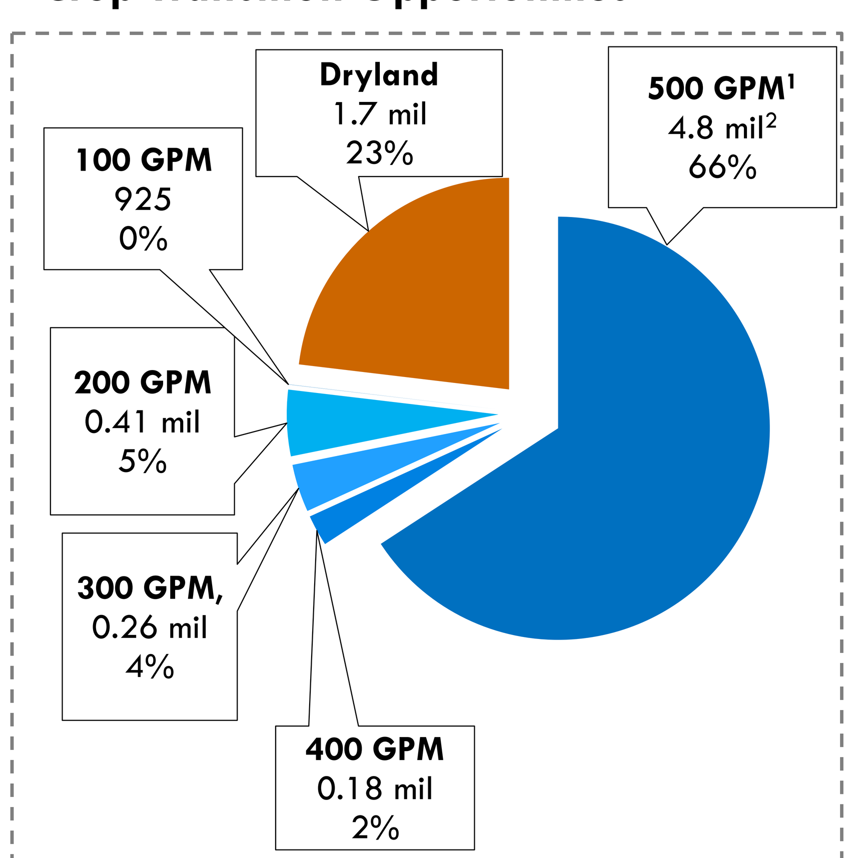

Figure 3. Land Use (Irrigation and Dryland) Area Breakdown by Pumping Rate, [1]*gallons per minute (GPM),* [2]*acres*

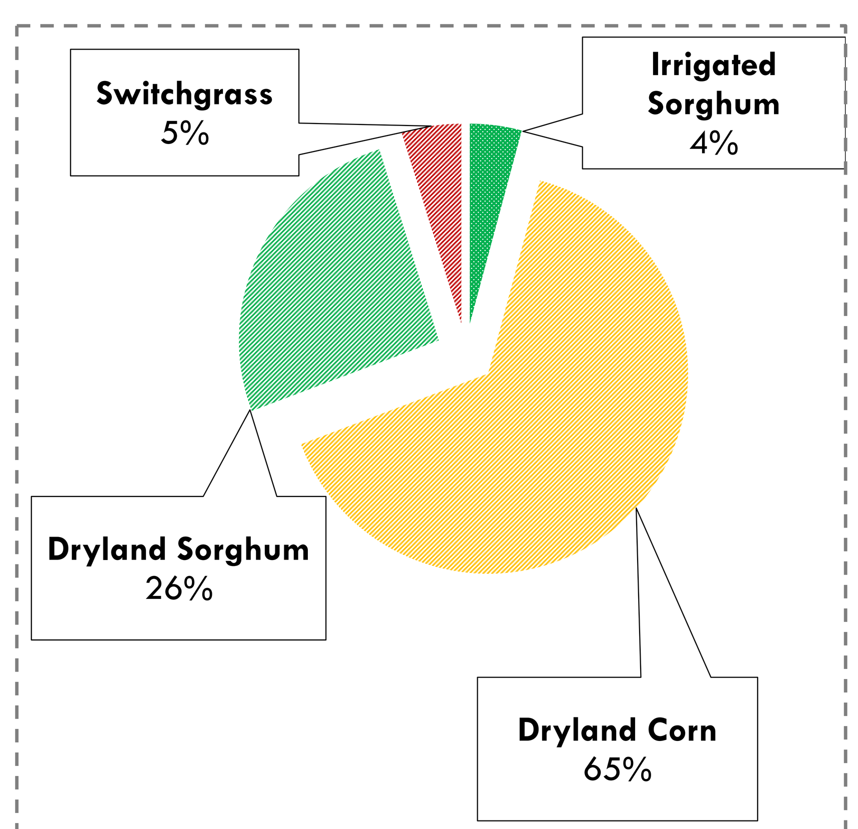

Figure 4. Land Use Transition: Cropland Area Shares After Irrigated Corn Phase-Out

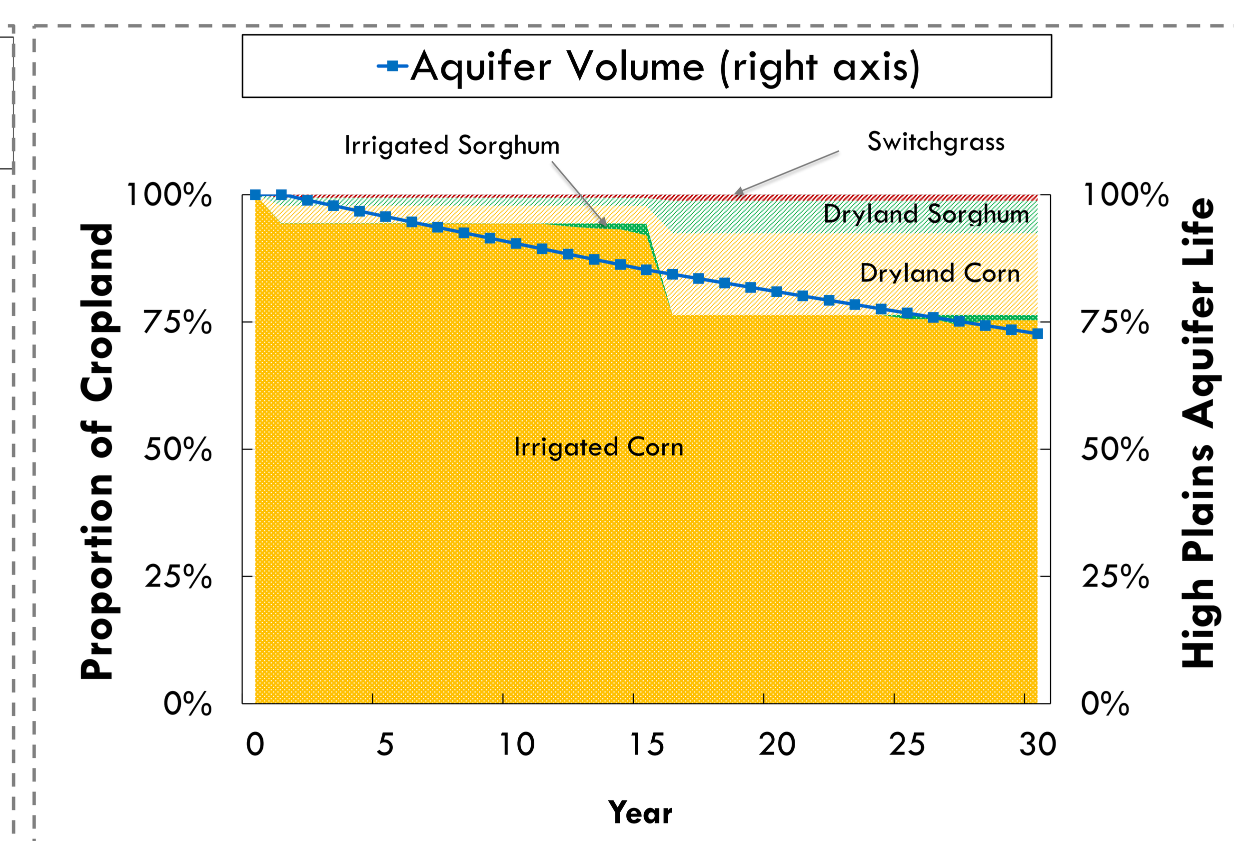

Figure 5. Land Use Shift from Irrigated Corn and Aquifer Depletion Over a 30-Year Horizon

Key Insights

- Our modeling indicates a clear and progressive decline in irrigation capacity over 30 years as high-capacity wells are displaced by lower-capacity systems and dryland agriculture.
- At the start, irrigated cropland is predominantly supported by high-capacity wells (500 GPM), accounting for 69% (TX) to 88% (NE) of irrigated systems. As groundwater availability declines, the reinvestment decision brings about the transition (15-year mark), with 3% increase in acreage relying on lower capacity wells (200 to 300 GPM), particularly in Kansas and Texas. Concurrently, dryland agriculture also expands to 5.5% as reinvestment in irrigation is no longer economically viable.
- By the end of the simulation period, dryland cropping systems displace an average of 23.1% of previously irrigated areas (ranging from 43.5% in Texas to 20.6% in Nebraska).
- Overall, dryland corn accounts for 67.9% of the transitioned area, followed by dryland sorghum (27.1%) and switchgrass (5%). Together, these dryland crops replace 1.73 million acres of irrigated land without reducing profitability.

Next steps / future work

- **Field-Level Analysis (~60,000 farms):** Future research will refine crop-water dynamics by modeling at the field scale to capture regional heterogeneity and groundwater responses.
- **Spatial Data & Pivot Investment Timing:** Incorporating detailed data on soils, precipitation, and aquifer conditions, alongside phased pivot investments, will improve temporal precision.
- **Field Size Variability Within Farms:** Accounting for varying field sizes will enhance the accuracy of land and water management decisions, especially in short- and medium-term planning.

Acknowledgments

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