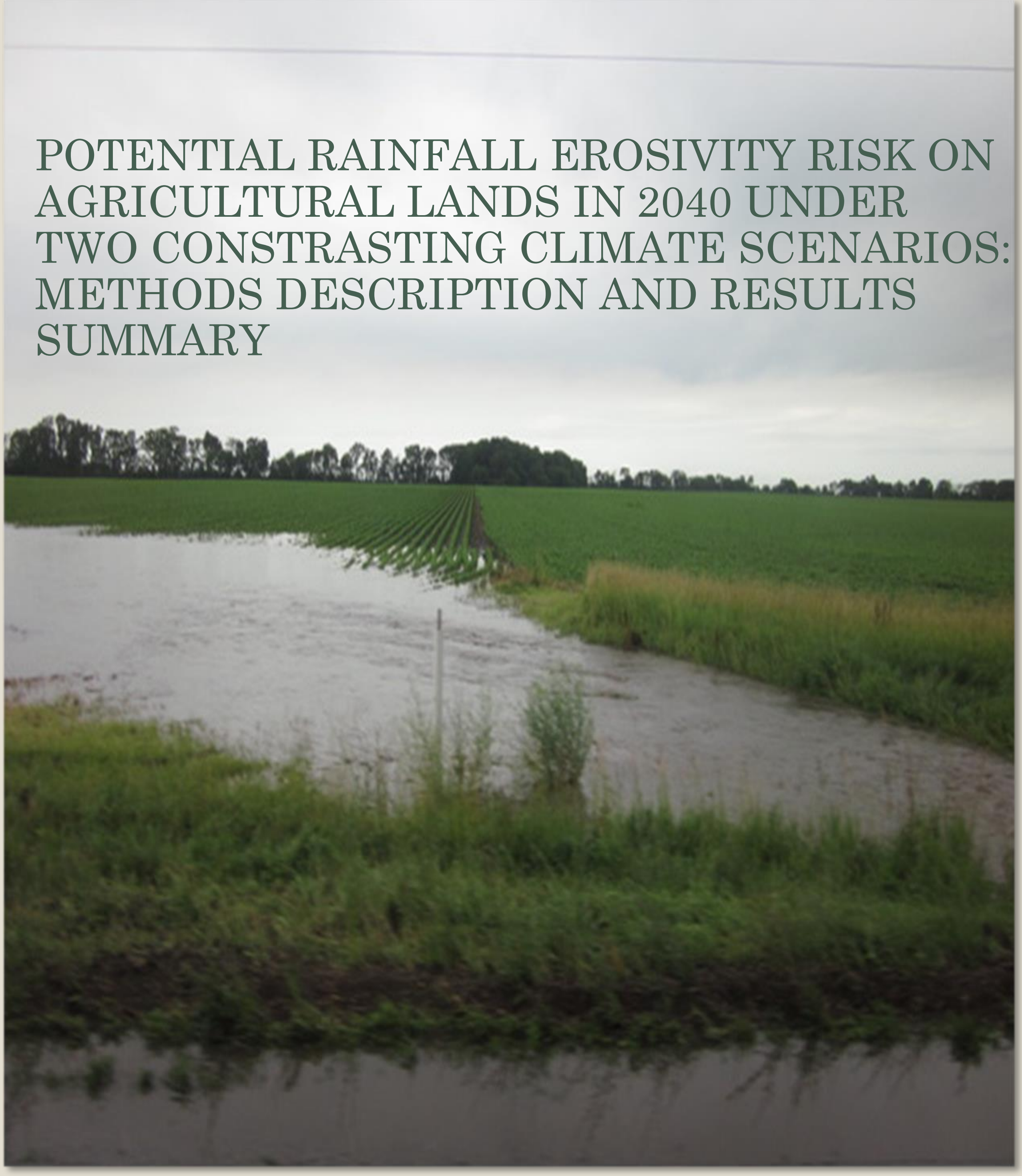
POTENTIAL RAINFALL EROSIVITY RISK ON AGRICULTURAL LANDS IN 2040 UNDER TWO CONSTRASTING CLIMATE SCENARIOS: METHODS DESCRIPTION AND RESULTS SUMMARY



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SAVING THE LAND THAT SUSTAINS US

Potential Rainfall Erosivity Risk on Agricultural Lands in 2040 Under Two Contrasting Climate Scenarios: Methods description and results summary[1]

FUT 2040 Modeling Brief

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[1] **A companion brief for the *FUT 2040* report on climate modeling:** Sorensen, A., R. Murphy, and T. Nogeire-McRae. 2023. *Farms Under Threat 2040: Projected Climate Impacts on the Growing Conditions for Rainfed Agriculture in the Contiguous United States.* Washington D.C.: American Farmland Trust.

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Summary

As part of its Farms Under Threat 2040 climate modeling, American Farmland Trust projected the erosive impact of rainfall on farmlands and ranchlands across the continental United States to 2040 under two climate scenarios. The results highlight the agricultural lands that could experience the greatest increases in soil erosion due to future changes in precipitation patterns. Keeping the land covered and minimizing tillage in these areas may help to protect topsoil and reduce erosion.

Overview

Researchers have consistently observed close linkages between climate change and soil erosion (Li and Fang 2016), and studies across the world project an increase in global soil erosion under climate change (Eekhout and de Vente 2022). This increase in erosion has significant implications for global food security. The degradation of soil quality by erosion reduces crop yields, disrupts ecosystem services, and alters the global carbon cycle (Thaler et al. 2021). Additionally, changing temperature and precipitation patterns can affect soil erosion by impacting plant biomass production, water infiltration rates, soil moisture, land use, and crop management (Li and Fang 2016). Rainfall and runoff are the most common drivers of soil erosion in agricultural landscapes, causing about 58% of the erosion observed on U.S. cropland in 2017 with the remainder (42%) due to wind erosion (USDA 2020).

In this study, we project rainfall erosivity, the erosive impact of rainfall, to 2040 under two climate scenarios using monthly precipitation projections. We then compare these projections to historic average erosivity for the years 1950-2005. The results highlight agricultural lands that may experience the greatest future increase in erosivity due to future changes in precipitation patterns. Agricultural lands in areas where the largest increases in erosivity are projected to occur could see the most benefit from employing land management practices that maximize soil cover and minimize disturbance to protect topsoil and reduce erosion.

The method we employ here is easily applicable to current and future monthly precipitation data and can be updated with new and more refined precipitation projections as they become available, or combined with estimates of current erosion risk. All national data from this work are publicly available.

Methodology

Rainfall erosivity (R) can be calculated as a function of maximum 30-minute rainfall intensity and total storm kinetic energy (Nearing 2001). Unfortunately, sub-hourly precipitation data are not available in sufficient spatial or temporal resolution for many locations or for future climate projections. Common alternative methods for estimating R utilize relationships between monthly or annual precipitation and observed R calculated from sub-hourly measurements (Nearing 2001, Segura et al. 2014). Generally, there is good agreement between observed R and R estimated from monthly precipitation under current climate conditions (Panagos et al. 2017). This work follows the examples of other country, continental, or global-scale research (Borelli et al. 2020, Nearing 2001, Panagos et al. 2017), applying generalized relationships between projected precipitation and observed R to estimate changes in future rainfall erosivity on agricultural lands in the continental U.S.

Future climate input data and scenarios

We used projections of monthly precipitation from NASA's Earth Exchange Downscaled Climate Projections (NEX-DCP30) as inputs for our erosivity projections. The projections represent ensemble means of 33 general circulation climate models used in the Coupled Model Intercomparison Project Phase 5 (CMIP 5) and are available in 30 arc second (approximately 1 km^2) resolution for the continental US. These projections are available for several Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP) scenarios that represent a range of future greenhouse gas emissions (GHG) trajectories, depending on actions society may take to mitigate future GHG emissions.

To align with AFT's *Farms Under Threat 2040* projections of climate impacts on growing conditions for rainfed agriculture in the continental U.S (Sorensen et al. 2023), we focused this analysis on two RCPs scenarios: one representing a future with high GHG emissions (RCP 8.5) and the other (RCP 2.6) representing a future where society takes immediate action to reduce GHG emissions. We also apply the same approach to historic precipitation data (1950-2005) from NEX-DCP30 to serve as a baseline scenario for comparison to future changes in erosivity.

Approach to projecting erosivity

Direct estimation of rainfall erosivity requires long term observational data of rainfall amount and intensity (Segura et al. 2014) that is not available in sufficient temporal or spatial resolution across the continental U.S. Therefore, for studies of national scale, alternative approaches that make use of available precipitation data are needed. One approach used by other national scale studies (Nearing 2001, Segura et al. 2014) developed by Renard and Freimund (1994) derives estimates of erosivity from monthly and annual precipitation data, which are available globally. Briefly, this approach calculates a modified Fournier coefficient to relate monthly and annual precipitation (F), as shown in Equation 1, where F is the modified Fournier index value, p_i is average monthly precipitation, and P represents average annual precipitation:

$$F = \frac{\sum_{i=1}^{12} p_i^2}{P} \qquad (1)$$

To account for large differences in regional precipitation patterns, we applied one of the two following regression equations to the resulting F value. Equation 2 is better suited for areas with average annual precipitation greater than 800mm/31in, and Equation 3 is more accurate in areas with average annual precipitation less than 800mm (Renard and Freimund 1994):

$$\text{R-factor} = .07397F^{1.847} \qquad (2)$$

and

$$\text{R-factor} = 95.77 - 6.081F + 0.4770F^2 \qquad (3)$$

These equations were developed by first calculating R-factor values using observed rainfall from rain gauge stations, then finding a relationship between these values and more readily available monthly and annual precipitation, and finally extending estimated R-factor values based on monthly and annual precipitation data to areas where no rain gauge data was available (Renard and Friemund 1994).

While the equations above for estimating the relationship between monthly precipitation and erosivity provide a better fit with observed R for most of the U.S (Nearing 2001), they do not perform nearly as well in mountainous areas in the western U.S or in areas in Washington, Oregon, northwestern California, and Idaho with high annual precipitation that falls primarily in the winter months (Segura et al. 2014). For this reason, we excluded these areas from our analysis.

To create a baseline erosivity layer representing historic average erosivity conditions, we used the historic scenario data from the NEX-DCP30 dataset and applied the above relationships to average monthly and annual precipitation for 1950-2005. For future projections to 2040, we used average monthly and annual precipitation from 2031-2050 (a 20-year period with 2040 as the midpoint) to reduce the influence of interannual variability in the projections.

For each RCP we considered, we then compared the future assessment of R to the historic average and developed percent change maps to summarize the largest increases in potential R.

Additional factors influencing erosion

For this study, we also created national layers of soil erodibility, which is a measure of the susceptibility of soil particles to detachment and by runoff and raindrop impact (USDA, 2021), the influence of slope length on runoff, and the impact of agricultural land cover, all of which form part of the RUSLE2 approach to estimating potential soil loss from erosion. However, due to a lack of high-resolution data that would inform the future landcover component of the erosion assessment, and no feasible method for estimating the impact of land management practices across the entire U.S agricultural land base, we elected not to combine the above components into a single erosion layer. Rather, we focused this research on changes in the primary driving force of erosion (erosivity due to rainfall) to highlight areas of increased susceptibility. The additional data layers estimating erodibility and slope length can be shared upon request.

Limitations

The approach we used in this study is not able to capture increases in storm frequency or intensity as we were limited to using monthly and annual precipitation averages. Management practices that could reduce soil erosion by rainfall were also not included due to data limitations. In addition, the work presented here does not consider the future erosive impacts of wind or snowmelt. Finally, this work is subject to the same inherent uncertainties of all modeled projections of future climate.

Results

The results of this work are available as raster datasets covering the continental U.S. at approximately 1 km (.62 mile) resolution. Figure 1 shows the percent change in erosivity as compared to historic baseline for the continental U.S.

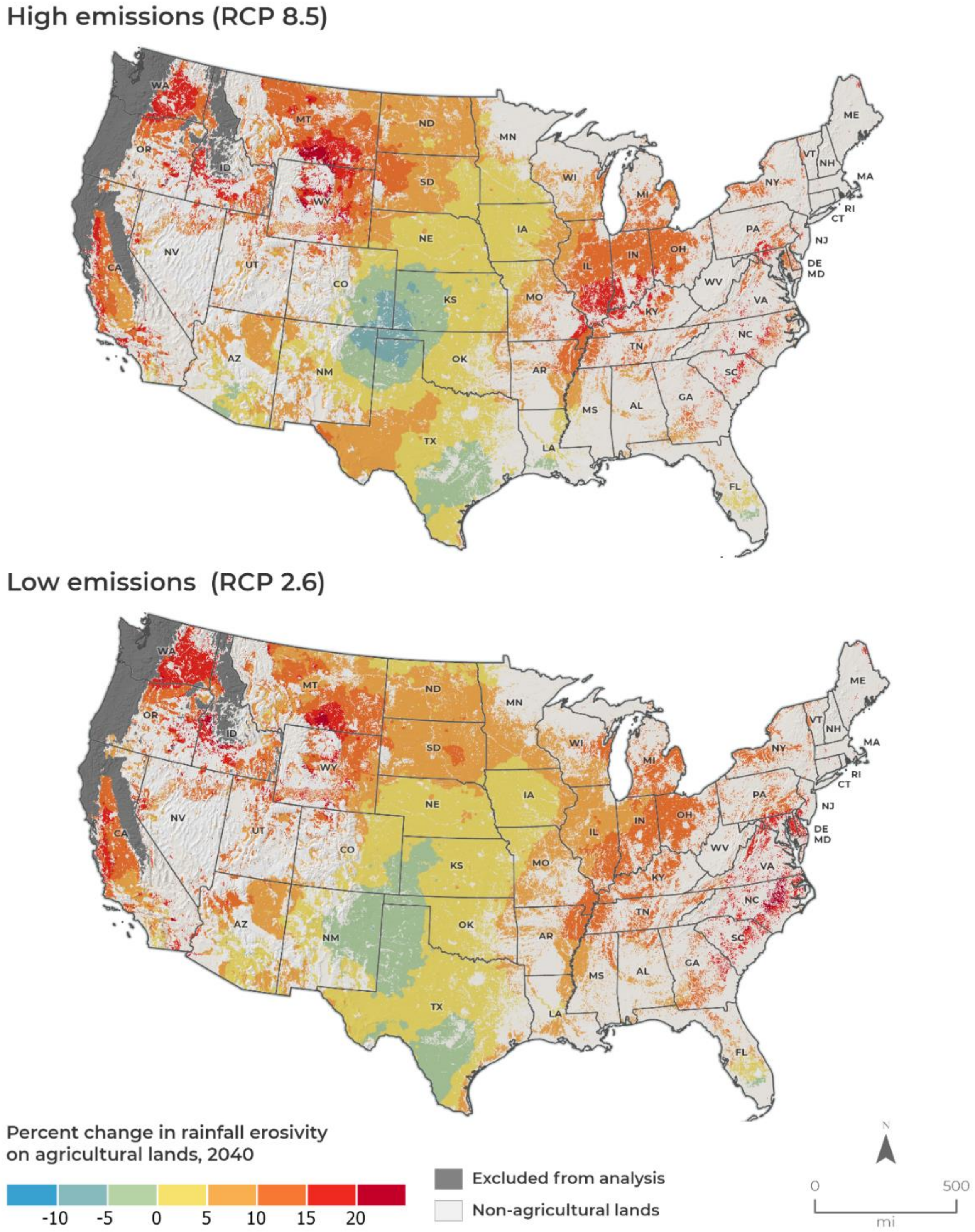

Figure 1. Percent change in rainfall erosivity on agricultural lands between historic average (1950-2005) conditions and 2040 for a high (RCP 8.5) and a low emissions scenario (RCP 2.6).

For both scenarios, the highest areas of increased erosivity occur in parts of the Southeast, California, Washington, and the Midwest. However, the high emissions scenario has notable increases in erosivity change in the Midwest (Illinois, Indiana and Ohio), while the low emissions scenario projects higher rates of erosivity change in the Southeast.

Table 1 presents acres and percentage of agricultural land in the continental U.S. that are projected to face a 10% or greater increase in erosivity. We found that 258 million acres in the low emissions scenario (RCP 2.6) may experience a 10% or greater increase in erosivity by 2040, compared to 293 million acres of agricultural land in the high emissions scenario (RCP 8.5). These values represent a 13% increase of agricultural land facing greater than 10% increase in erosivity in the high emissions scenario.

Table 1. Agricultural lands with a 10% or greater increase in erosivity by 2040

Agricultural land with 10% or greater increase in erosivity (2040)		
Climate Scenario	**Acres of Agricultural Land (millions)**	**Percent of Agricultural Land**
Immediate climate action (RCP 2.6)	258.4	27
High emissions (RCP 8.5)	293.3	31

Discussion

Our results show that changes in future precipitation will likely bring greater challenges to agricultural lands in the near future due to increased erosivity. Although this work focuses on a future that is less than 20 years away, differences in projected erosivity patterns between the low emission and high emissions scenarios were already detectible. The climate scenario in which no action is taken to reduce greenhouse gas emissions (RCP 8.5) resulted in more acres facing a 10% or greater increase in erosivity (Table 1).

Land management practices can help reduce erosion and maintain topsoil.

Targeting erosion prone areas for soil conservation practices like strip-cropping and no-till that slow surface runoff and promote infiltration may be necessary to prevent excessive erosion and downstream sedimentation due to intensified precipitation (Garbrecht et al. 2014).

Strategies to mitigate erosion can vary depending on the type of erosion as well as terrain conditions. For example, sheet erosion occurs when rainwater does not infiltrate into the ground and instead uniformly removes soil in thin layers across a wide area. The most effective strategy to prevent sheet erosion over agricultural fields is to keep soils covered with mulch or living vegetation (Duiker 2018). Implementing cover crops and no-till practices can significantly reduce erosion risks and provide many other benefits to farmers (Claassen et al. 2018; Thaler et al. 2019; AFT 2023). Rill erosion occurs during heavy rains when small rills or rivulets form over an entire hillside. For areas with rill erosion, farmers can use strip cropping (alternating strips of high and low residue crops along the contour). Contour planting can also help by avoiding runoff flowing along rows. For areas at risk for gully formation, the best course of action is to maintain permanent vegetation with dense root systems to slow down runoff and hold soil together (Duiker and Weld 2022). Other options include grassed waterways, strip cropping, terraces, or flow diversions (Duiker and Weld 2022). In addition, farmers can also add properly timed applications of solid manure to increase soil organic matter and boost biological activity. This will improve the soil's structure and infiltration capacity and help reduce all forms of erosion.

However, although these types of conservation tools can help prevent erosion by water, they have not yet been widely adopted and implemented (Garbrecht et al. 2015). A recent worldwide analysis of conservation management practices (including agroforestry, cover cropping, no-till, reduced tillage, and residue return) found that these practices reduced surface runoff by an average of 67% and erosion by an average of 80% compared with controls (Du et al. 2022). The use of cover cropping provided the largest decreases in surface runoff and soil erosion, highlighting how effective the continuous cover of vegetation can be in combatting runoff and erosion.

Next steps

To improve accuracy of erosivity or erosion projections and quantify uncertainty in resulting predictions, access to a dataset of observed erosivity or erosion with sufficient coverage at the national level would be necessary. The National Resources Inventory (NRI), maintained by the U.S. Department of Agriculture Natural Resources Conservation Service), includes this information. Incorporating the inventory's observed erosivity and erosion could greatly improve predictions, allowing future modeling work to better account for regional differences in precipitation, as well the impacts of management practices on mitigating erosion. Additionally, an improved assessment of land cover using the U.S. Geological Survey's Normalized Difference Vegetation Index (NDVI) as well as documented land cover impacts on reducing erosion from the literature would be needed to arrive at a nationwide projection of future soil loss due to erosion from rainfall.

Acknowledgements

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For access to the projected erosivity data, please contact *maps@farmland.org*

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