

WIND-DRIVEN SEDIMENT AND SOIL ORGANIC CARBON LOSSES ACROSS CONUS USING THE EPIC MODEL: A CROPLAND AND RANGELAND COMPARISON

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Wind Erosion

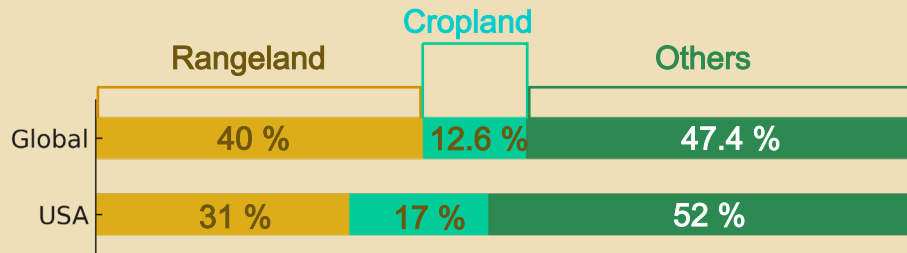
- Wind can redistribute and erode soils, removing fine soil particles and resources (carbon, nitrogen)



65 t/ha soil was eroded and 50 mm of soil blown from cropland in Kansas 1995
(photo by USDA, 1996)

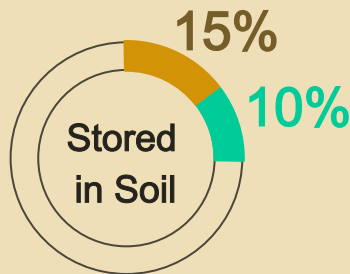
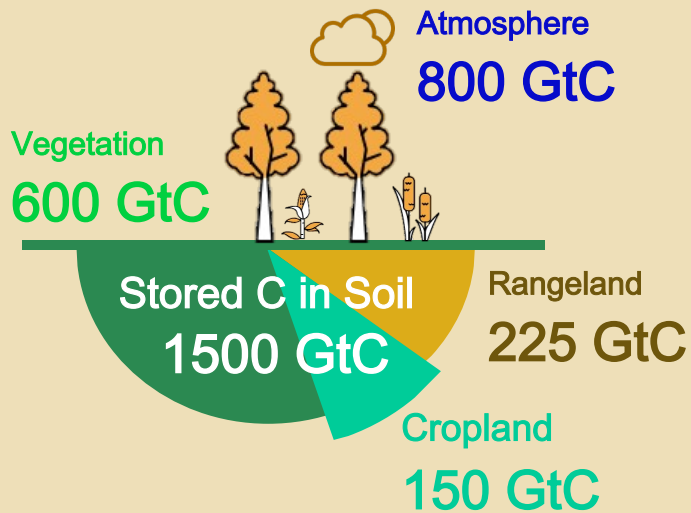


A haboob dust storm into Phoenix, Arizona in 2006
(Photo by Sedona red rock news)



Land Surface (%)

Global Soil Organic Carbon Storage



1 GtC yr^{-1}

The global SOC erosion by wind

2 mm

1% SOC raise:
2 mm water capacity increase

Knowledge Gaps in Wind Erosion



Current situation

Wind erosion is episodic, so long-term, national-scale records are scarce; field monitoring is limited. Most studies focus on croplands.

1

Insufficient Studies

Limited National scale wind erosion validation against monitoring data



2

Land type Bias

Studies focus more on croplands than rangelands, with limited integration across land types.



3

Wind-driven SOC gap

Limited wind-driven SOC loss in carbon budget



Problems

Objectives

National- scale comparison by land type

Hypothesis: Wind erosion; rangeland > cropland

Observation based evaluation

Integrated SOC assessment

Hypothesis: Wind-driven SOC share $\uparrow$ in rangeland.

Seasonal contrasts by land type

Hypothesis: Rangeland seasonality low; cropland peak after harvest.

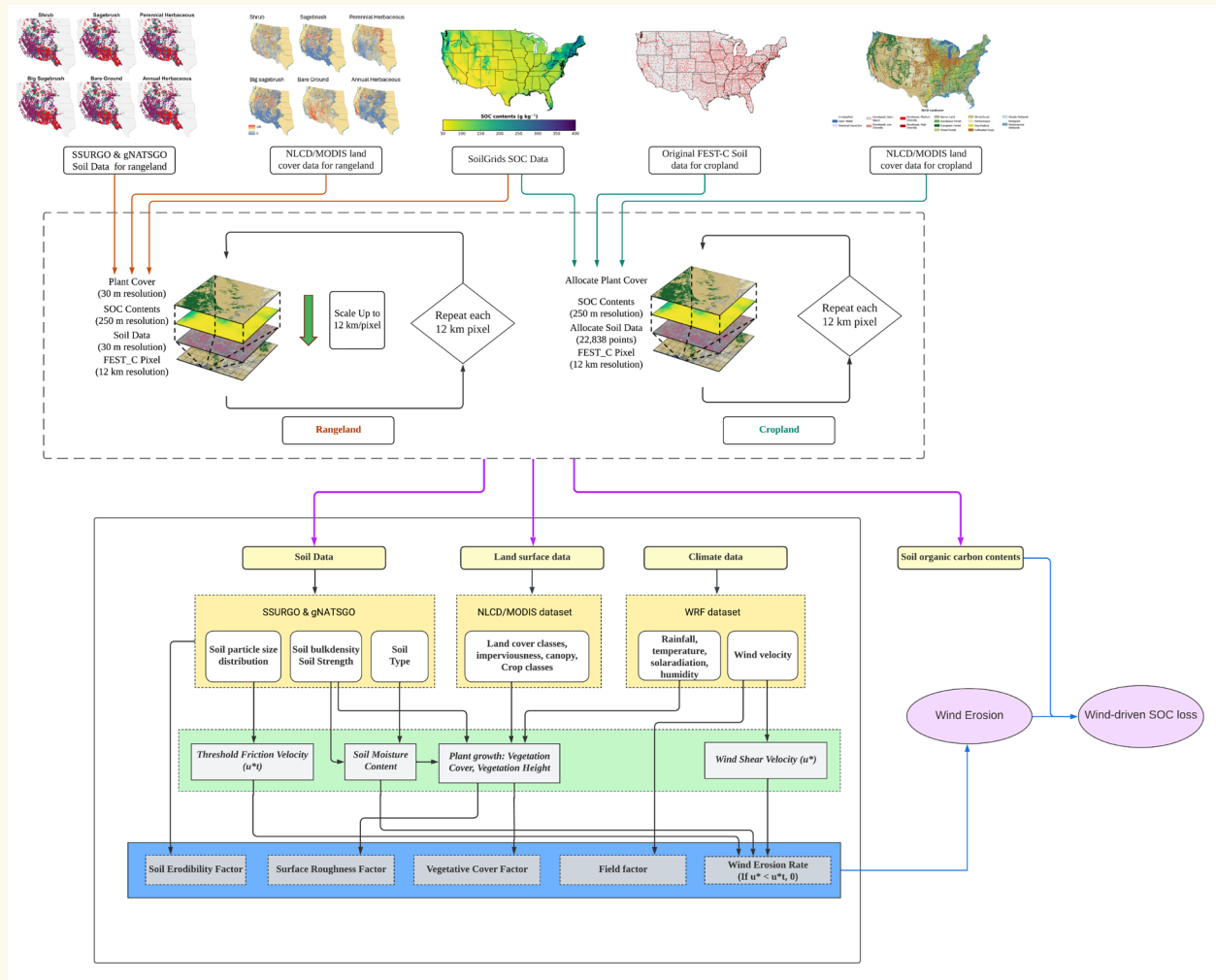


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Material and methods



National scale Wind Erosion Modeling process



Wind Erosion Equation in EPIC

$$YW = SEF * SRF * VCF * FD * \int_0^t \frac{YWR}{WL} dt$$

Where, YW is wind erosion (kg m^{-2}), SEF is soil erodibility factor, SRF is surface roughness factor, VCF is vegetative cover factor, FD is field distance factor, ER is potential erosion rate ($\text{kg m}^{-1}\text{s}^{-1}$), YWR is the erosion rate ($\text{kg m}^{-1} \text{s}^{-1}$), WL is the mean unsheltered (m), t is the duration when the friction velocity (u_*) exceeds the threshold friction velocity (u_{*t}) of the surface.

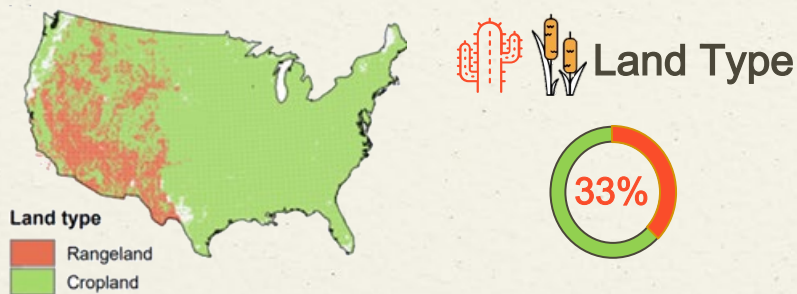
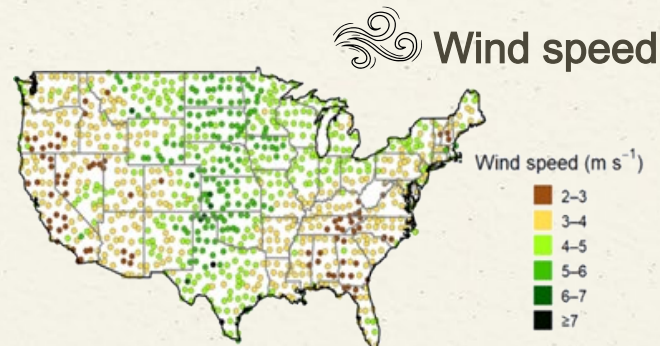
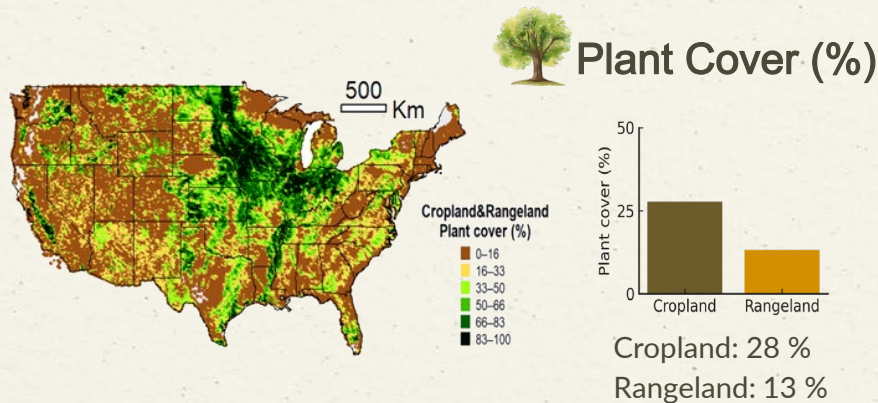
$$YWR = \begin{cases} c \frac{\rho_a}{g} \left[u_*^2 - u_{*t}^2 - 0.5 \left(\frac{sw}{wp} \right)^2 \right]^{1.5} & u_* > u_{*t} \\ 0 & u_* < u_{*t} \end{cases}$$

c is an empirical parameter ≈ 2.5 , ρ_a is the air density (kg m^{-3}), g is the acceleration of gravity (m s^{-2}). sw and wp are the actual and 1500 kPa water content of the surface soil layer.

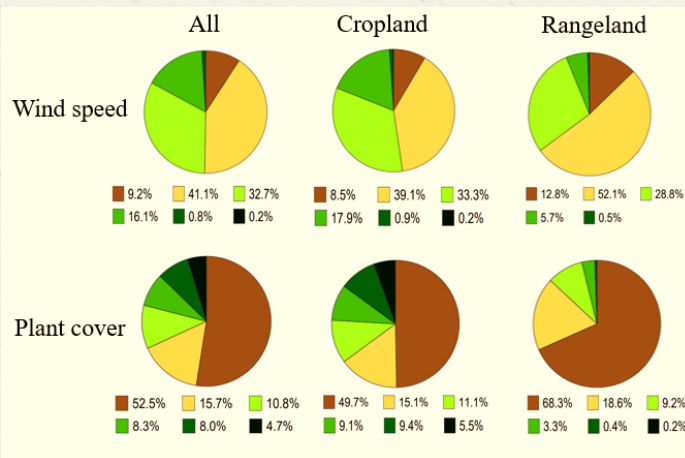
$$u_* = 0.0408 * u \quad u_{*t} = 0.0161 * \sqrt{DIAM}$$

u is the wind speed at time t in m s^{-1} , and DIAM is the soil particle diameter in m.

CONUS info in rangeland and cropland



Cropland: 159 Mha (67 %),
Rangeland: 78 Mha (33 %)





0 3

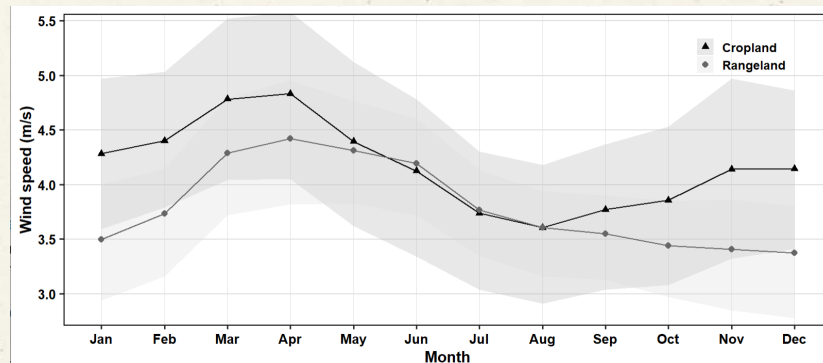
Results and Discussion



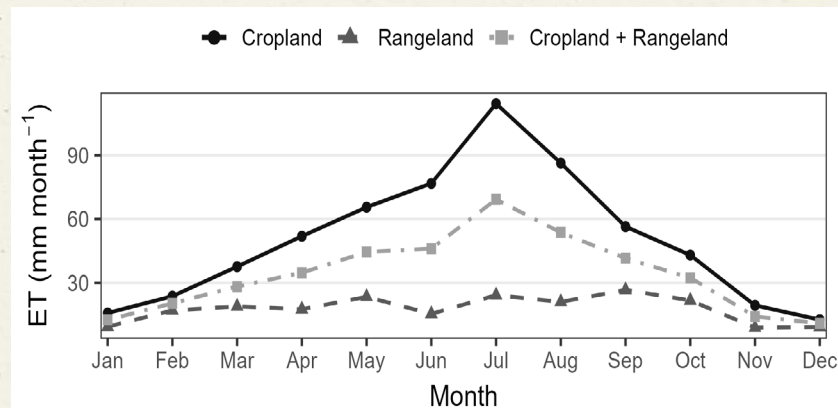
Monthly Wind Erosion



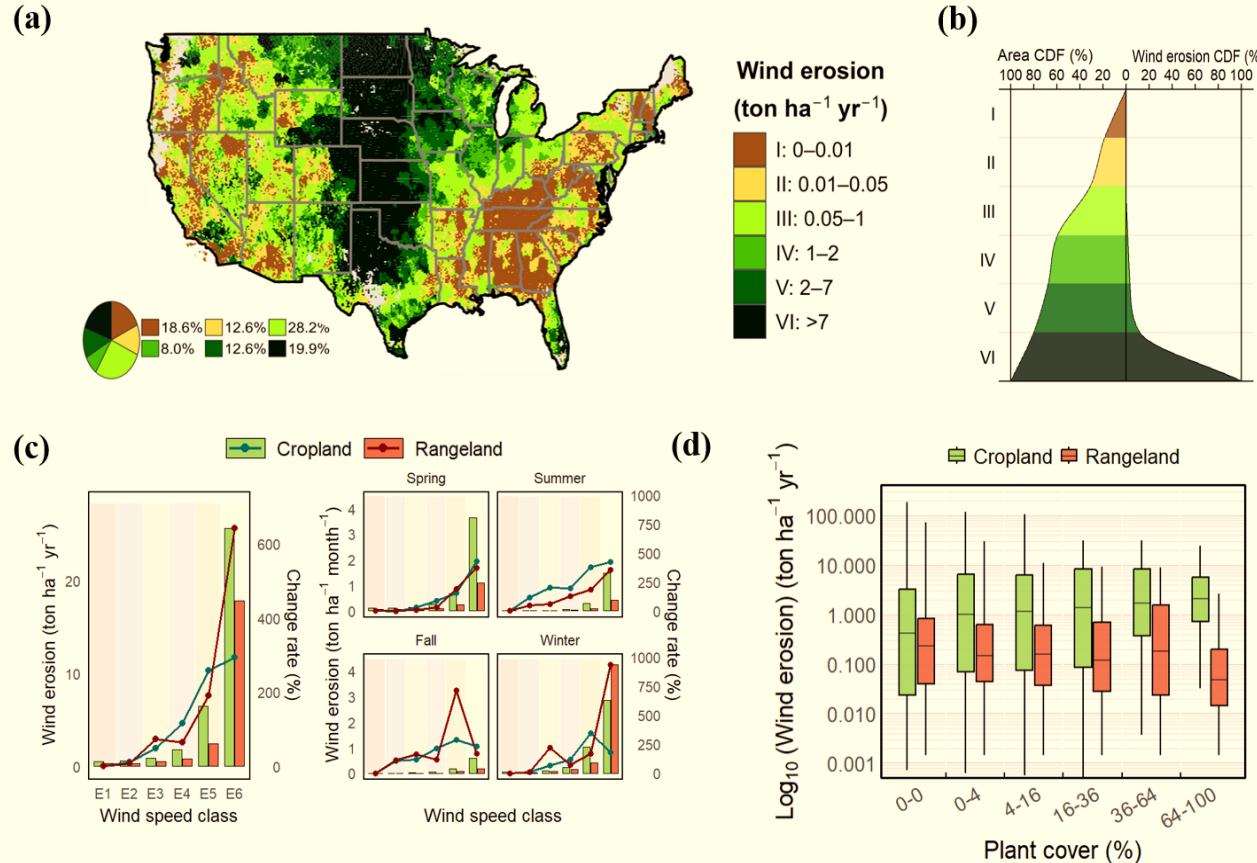
Wind Speed



ET

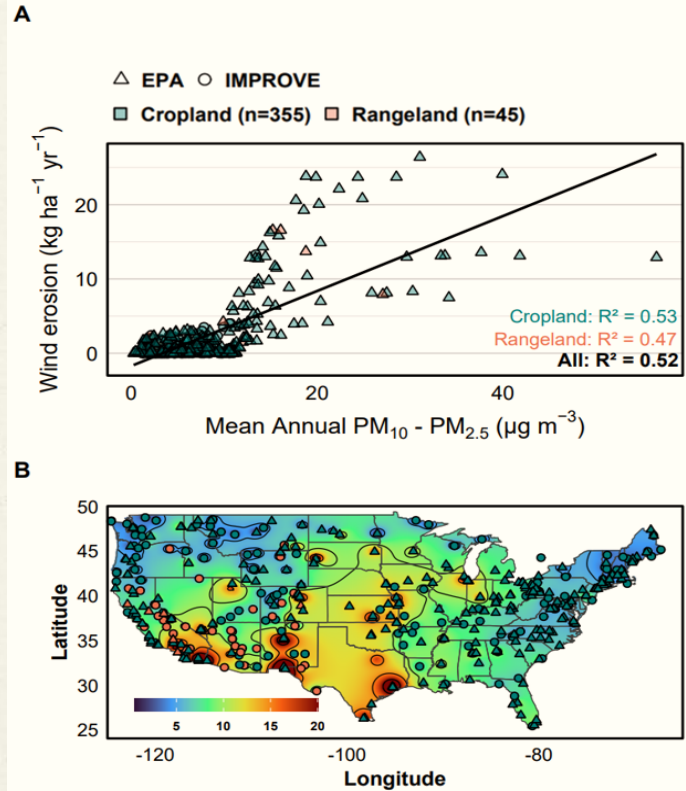


Annual Wind Erosion



- Strongest over the Great Plains (a)
- 90% of wind erosion occurs in VI wind erosion class. (b)
- Wind speed show main factor to wind erosion
- Plant cover has a smaller influence

Wind Erosion Simulation Assessment



Cropland

$R^2=0.53$ (355 points)

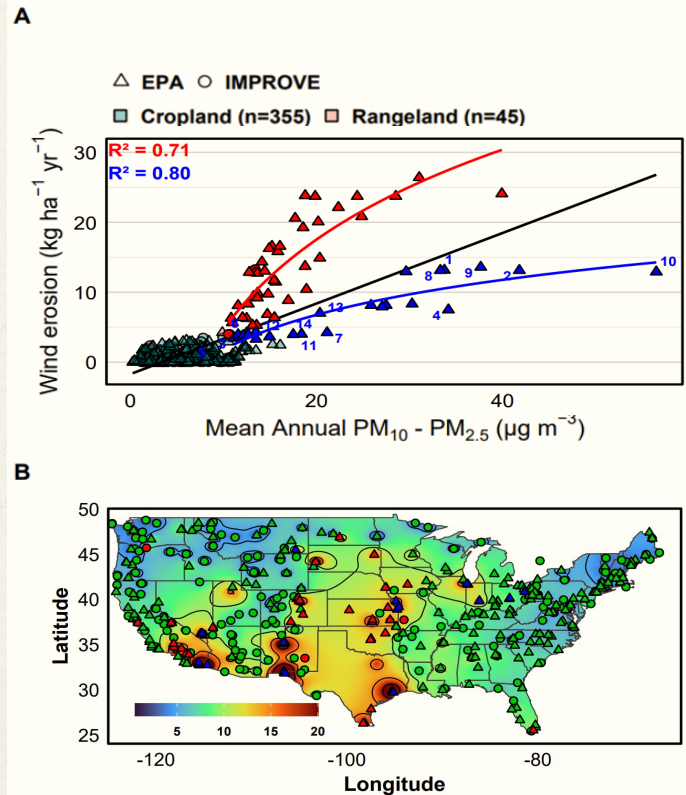
Rangeland

$R^2=0.47$ (52 points)

Wind erosion is compared against coarse mass ($\text{PM}_{10}-\text{PM}_{2.5}$)

- A clear relationship emerges when wind erosion > 4 and Coarse mass $> 10 \mu\text{g m}^{-3}$

Wind Erosion Simulation Assessment



Cropland

$R^2=0.53$ (355 points)

Rangeland

$R^2=0.47$ (52 points)

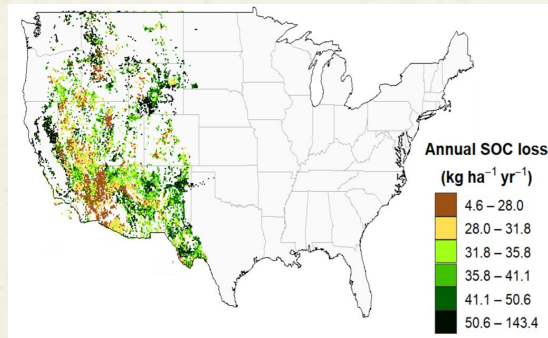
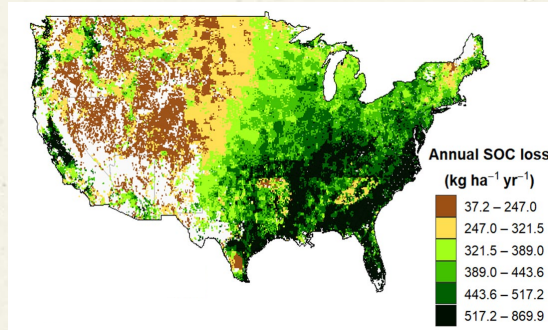
Wind erosion is compared against coarse mass ($\text{PM}_{10} - \text{PM}_{2.5}$)

- A clear relationship emerges when wind erosion > 4 and Coarse mass $> 10 \mu\text{g m}^{-3}$

The data split into two regimes relative to the trendline.

- **Red points:** Mainly near Great Plains and high wind speed areas
- **Blue points:** Urban areas with low surrounding cropland

Gross SOC loss



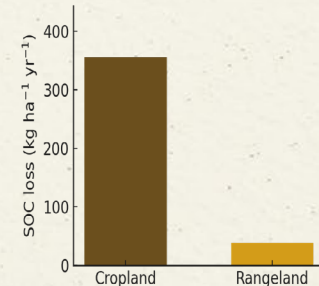
SOC loss via microbial respiration rises with temperature and actual ET because microbial and enzymatic activity is sensitive to temperature and moisture.

- In rangelands, wind erosion increases toward the interior, while SOC loss decreases.

- Average SOC loss

Cropland: 355 kg ha⁻¹ yr⁻¹

Rangeland: 52.6 kg ha⁻¹ yr⁻¹



Analysis & development



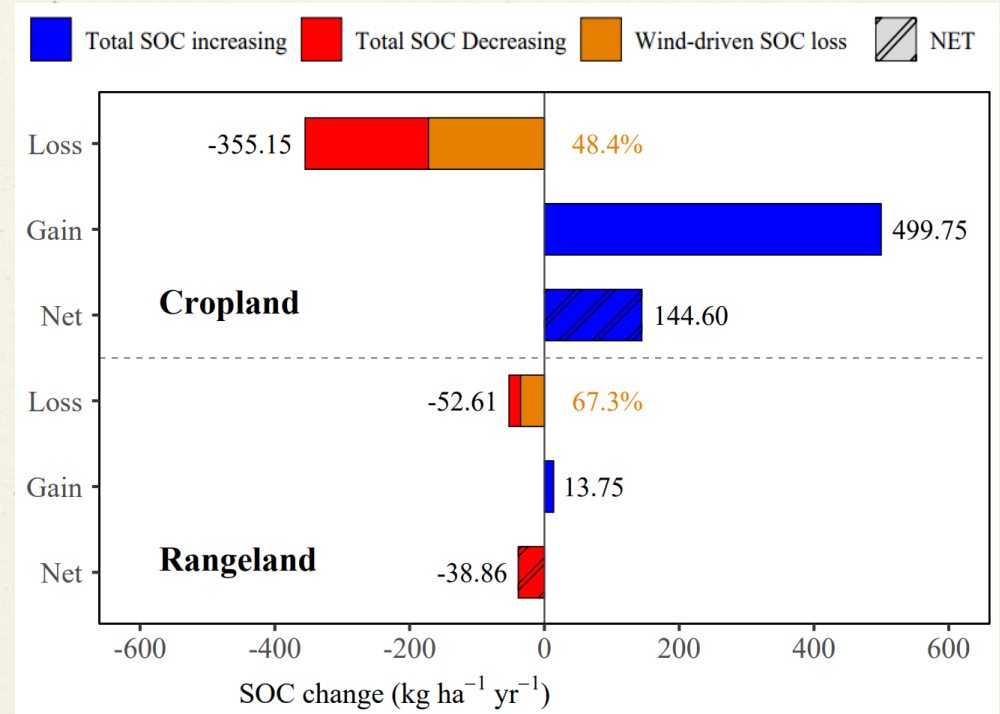
Cropland

- High losses, high gains—croplands remain relatively balanced.



Rangeland

- Rangelands have smaller SOC losses but even smaller gains, resulting in net SOC declines.
- The wind-driven share of gross SOC loss is larger in rangelands than in croplands.



Comparisons with previous results

Land type	Annual SOC loss (t C ha ⁻¹ yr ⁻¹)	Annual SOC gain (t C ha ⁻¹ yr ⁻¹)	Annual net SOC change (t C ha ⁻¹ yr ⁻¹)	Wind-driven SOC loss (t C ha ⁻¹ yr ⁻¹)	Region Scale	Description/Indicators Assessed	Source
Cropland	0.24-0.47	0.25-0.63	0.06-0.22 (+)	0.08-0.22	CONUS (National scale)	159 Mha	This study
	-	-	0.085–0.132 (+)	-	CONUS (National scale)	10.6-16.6 Mt C yr ⁻¹ (125.4 Mha)	Ogle et al., (2023)
	-	-	0.274 (+)	-	CONUS (National scale)	134 Mt CO ₂ yr ⁻¹ (133.5 Mha)	Moore et al., 2023
	-	-	0.12-0.14 (+)	-	CONUS (National scale)	14.6-17.5 Tg C yr ⁻¹ (124Mha)	Ogle et al. (2010)
	-	-	0.02–0.06 (+)	-	USA (National scale)	2.4–8.7 Mt C/yr (150-151 Mha)	U.S. Environmental Protection Agency (2024)
	-	0.2–0.6	-	-	Global 0.28–0.43 Gt C yr ⁻¹	(1,510–1,611 Mha)	Lessmann et al. (2022)
	-	0.12	-	-	CONUS (National scale)	5.3 Mt C yr ⁻¹ (44 Mha)	Aragon et al., (2024)
	-	-	-	0.5	Western Australia	0.5 Mha	Harper et al. (2010)
	0.58	-	-	-	Watershed	Northwestern Illinois (10.54 ha)	Olson et al. (2016)
	-	-	-	0.4-1.9	6 Sites	Southwestern Australia	Chappell & Baldock (2016)
	-	-	-	0.01–0.1	CONUS (Global scale)	-	Chappell et al. (2019)
Rangeland	0.027-0.061	0.008-0.017	0.015-0.047 (-)	0.01-0.041	CONUS (National scale)	Western USA (79 Mha)	This study
	-	-	-	0.122	Site	Inner Mongolia, China	Song et al. (2024)
	-	-	0.0007-0.044 (-)	0.132	Site	USA rangeland	Cho et al. (2025)
	-	-	-	0.037	National Scale	Forest/Shrub/Crop/ Grass/Desert northwest China	Lei et al. (2019)

Results vs. Hypothesis

Hypothesis: Wind erosion; rangeland > cropland

Hypothesis not supported: Wind erosion was higher in cropland than rangeland, driven mainly by higher wind speeds rather than vegetation cover.

Hypothesis: Wind-driven SOC share ↑ in rangeland.

Hypothesis supported: Wind-driven SOC comprised a larger share in rangeland (67%) than cropland (48%), yet per-area wind-driven loss was higher in cropland due to higher SOC content.

Hypothesis: Rangeland seasonality low; cropland peak after harvest.

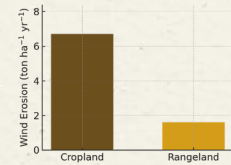
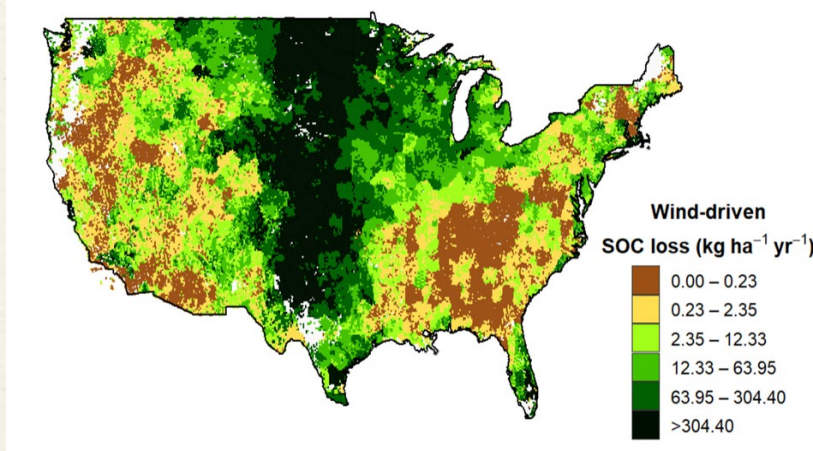
Partially supported: Rangeland showed low seasonality, but cropland did not peak after harvest; autumn winds were weak, so wind erosion stayed low despite reduced cover.

Conclusions

- Croplands show greater wind erosion than rangelands despite higher vegetation cover, mainly due to strong spring winds over the Great Plains.
- In croplands gross SOC losses are high but larger SOC gain yield a net annual SOC increase, whereas in rangelands SOC loss was small but SOC gain was much smaller, resulting SOC declines.
- The share of gross SOC loss attributable to wind is larger in rangelands than in croplands.
- Effective mitigation should target periods of strong wind and low vegetation in winter and spring with residue retention, cover maintenance, and windbreaks.

Thank you

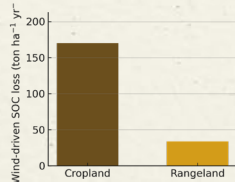
Wind - driven SOC loss



Wind erosion

Cropland: $6.7 \text{ ton ha}^{-1} \text{yr}^{-1}$

Rangeland: $1.6 \text{ ton ha}^{-1} \text{yr}^{-1}$



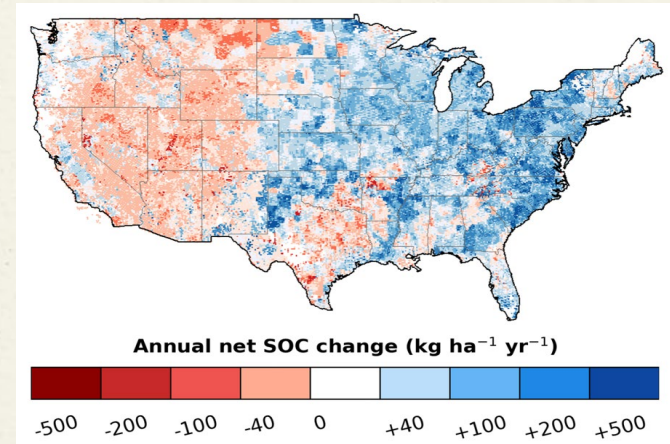
Wind driven SOC loss

Cropland: $170 \text{ kg ha}^{-1} \text{yr}^{-1}$

Rangeland: $45 \text{ kg ha}^{-1} \text{yr}^{-1}$

SOC Variation

- The vegetation-driven increase in SOC gain outweighs the increase in SOC loss.
- Actual ET generally rises with NPP, soil-carbon inputs increase with ET; SOC gains are largest where ET is sufficient to sustain inputs while temperatures remain low enough to limit decomposition.



×4.18

Cropland has 4.18× the wind erosion of rangeland.

38.8 kg

38.8 kg ha⁻¹ yr⁻¹ net SOC loss in rangeland

Winter - Spring

The period of strongest wind erosion

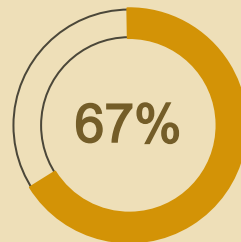
 27.03 Mt yr⁻¹ (159Mha)
 13.53 Mt yr⁻¹ (301 Mha)



0.04 GtC yr⁻¹

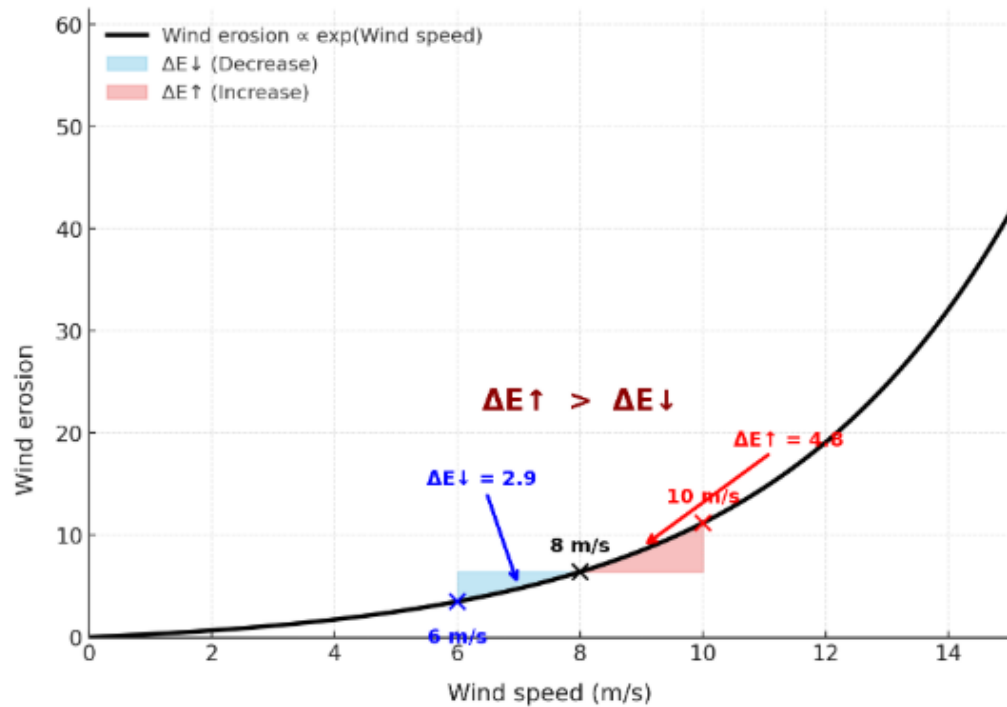
SOC loss by wind in CONUS

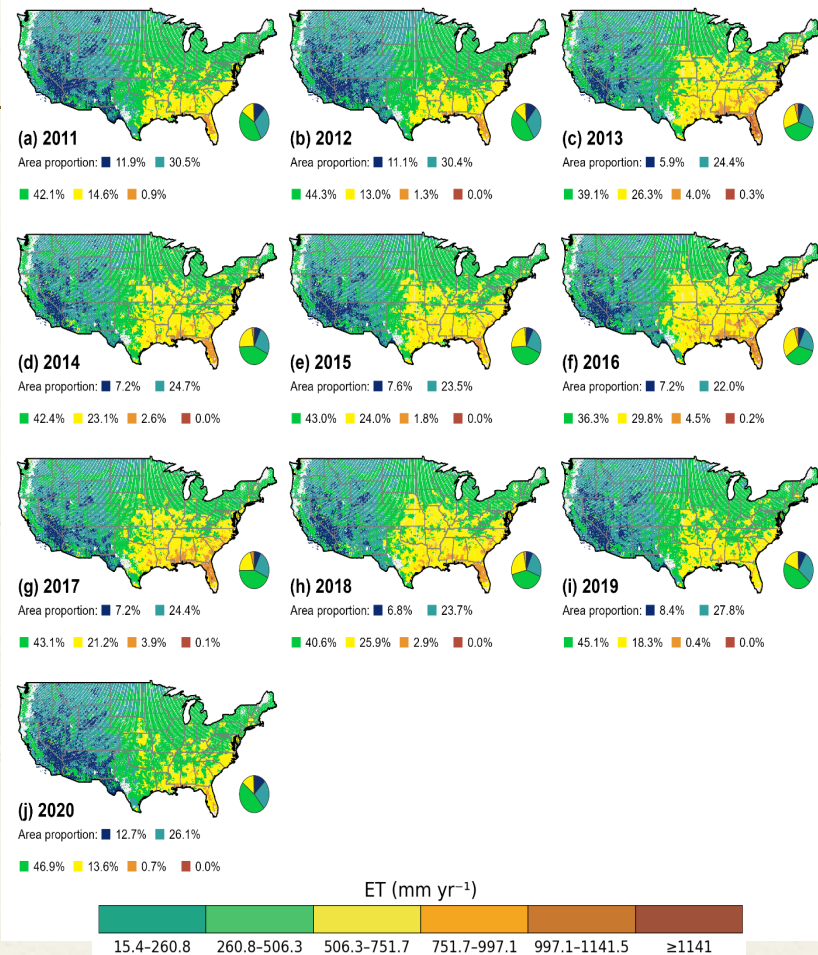
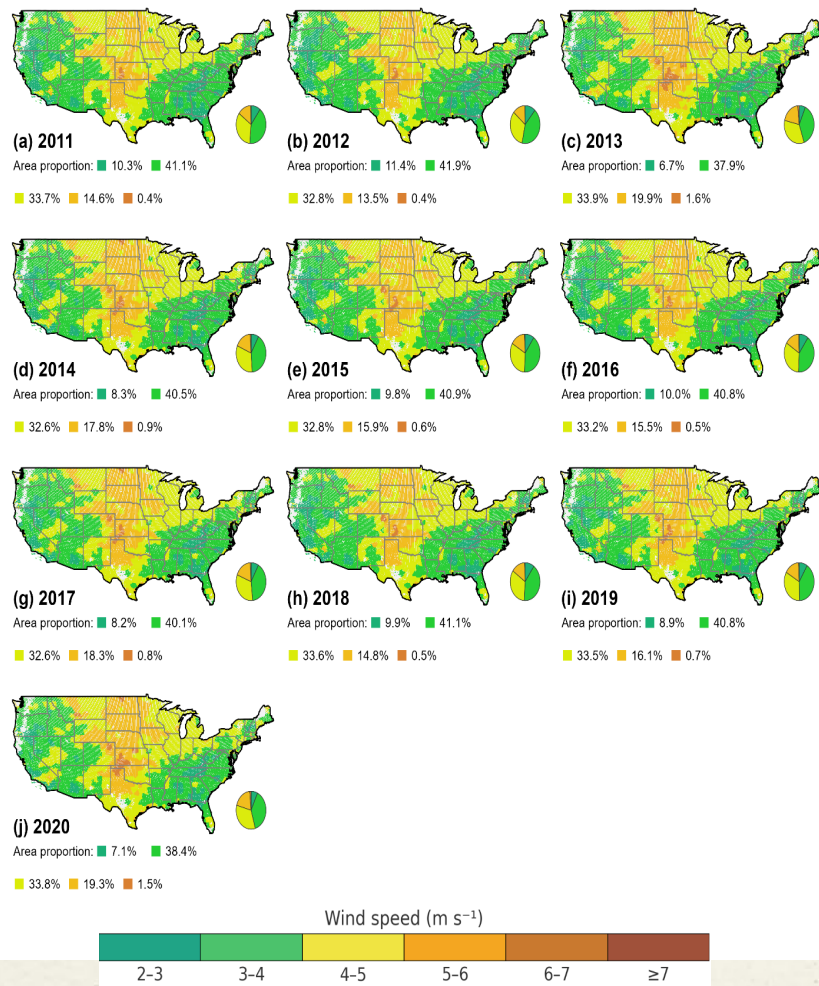
Wind - driven
SOC
loss percent in
total soc loss in
rangeland

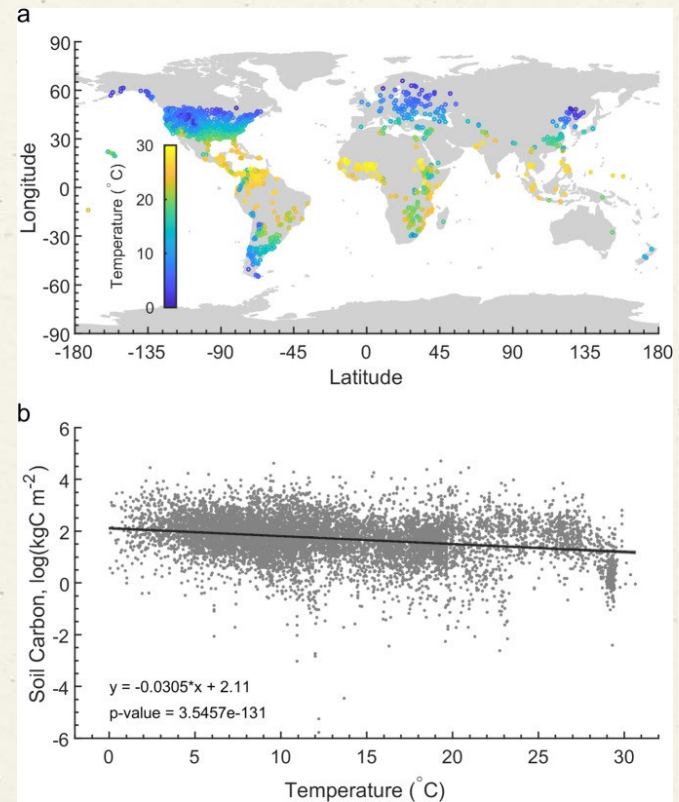
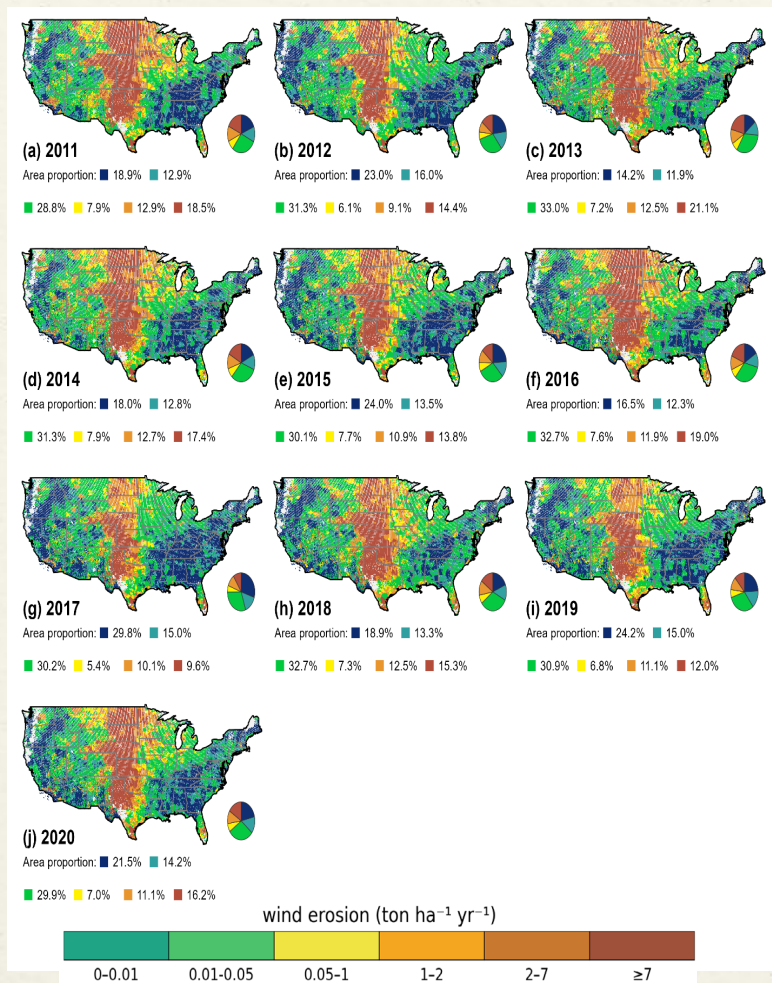


Urban points location number of the
Interagency Monitoring of Protected
Visual Environments (IMPROVE) and EPA

No	City name
1	San Diego
2	San Diego
3	Detroit
4	San Diego
5	Detroit
6	Chicago
7	Chicago
8	Albuquerque
9	Albuquerque
10	Albuquerque
11	St. Louis
12	St. Louis
13	St. Louis
14	Denver







The location of the soil profiles (a) and observed overall relationships between C storage in the top 50 cm of mineral soil and mean annual temperature (b). (Hartley et al., 2012)