Eroding the Future

How Soil Loss Threatens Farming and Our Food Supply

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Marcia DeLonge

Karen Perry Stillerman

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Overview

Soil forms the foundation of our farm and food systems and is just as important to our well-being as breathable air and clean water. Many farming methods common in the United States today degrade soils by rupturing and turning them with a plow or other method (repeated tillage) or leaving soils bare and unprotected for much of the year. When farm fields are made vulnerable in these ways, wind and water carry the most productive soil—topsoil—away faster than new soil can form, and this essential resource disappears. This constitutes the process of erosion.

Although erosion rates have slowed since the US Department of Agriculture (USDA) began estimating them in the 1980s, soil loss from the nation's farms is still unsustainable. Every year, US croplands lose at least twice as much soil to erosion as the Great Plains are estimated to have lost annually during the peak of the Dust Bowl. The Union of Concerned Scientists explored the potential for soil erosion nationally through the end of this century if today's trends prevail. Using current USDA estimates, we found that US croplands will lose an additional half-inch (28 billion tons) of soil by 2035 and nearly three inches (148 billion tons) by 2100. Given that the natural formation of an inch of soil takes a century or longer, the loss of soil by 2100 equals at least 300 years' worth. Even more soil would be lost if rates reverted to the higher levels of previous decades. To avoid such losses and create more resilient farm and food systems, government policies must support farmers in adopting proven methods of conserving and rebuilding soil.

Introduction

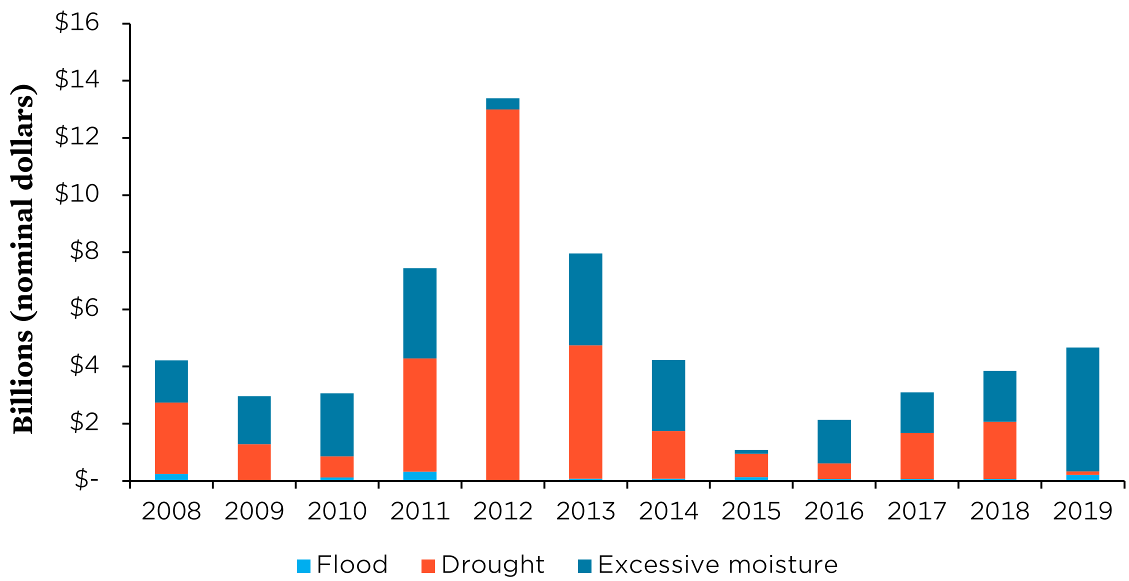
Soil forms the foundation of every nation's food and farm system and is a key life support system for the planet, yet this essential resource has long been neglected. Soil erosion is a natural process, but it has been vastly and needlessly accelerated by unsustainable agricultural practices in many regions across the United States and globally. The demise of many early civilizations has been attributed to neglect of soil, yet untenable rates of erosion persist around the world (Montgomery 2007a).

Globally, far too many farms still lose soil faster than natural rates of erosion and faster than natural processes can form new soil (Montgomery 2007b). The Food and Agricultural Organization of the United Nations has warned that erosion rates are so high that they threaten the future of farming as we know it (Pennock 2019). In the United States, policies and programs established after the devastating 1930s Dust Bowl, the nation's best-known erosion event, have led to significant reductions in wind and water erosion (NRCS n.d.). However, erosion rates are still too high in some US farming areas. In parts of Iowa, for example, researchers estimated the cumulative cost of soil erosion from yield losses in corn and soybean production over 10 years to be $315 million (Cruse 2016).

In addition, climate change will likely increase the chances for extreme, Dust Bowl–type weather, which could have devastating consequences for today's US farming systems (Glotter and Elliott 2017). Further, increased frequency of both dry periods and more intense rainfall is expected to exacerbate erosion, with consequences including reduced agricultural productivity, increased water pollution, and damage to downstream communities. Both US and global scientific reports have stressed that climate-driven accelerations to erosion amplify threats to agriculture and food production (IPCC 2019; Reidmiller et al. 2018).

Erosion not only threatens future farms and farmers but also imposes costs in the short term. For farmers, erosion brings a direct loss of nutrients and carbon, which can, in turn, reduce crop yields, farm profits, and land values (Duffy 2012; Fenton, Kazemi, and Lauterbach-Barrett 2005; NRCS 2009).[1] Erosion washes excessive soil into dams, drainage ditches, and waterways, which can degrade the aesthetic, recreational value and flood control capacity of ecosystems, and require expensive dredging and cleanup (ILF 2013).[2] Wind erosion can also contribute to fine particulate air pollution problems, with health effects for downwind communities, particularly for those without the resources to invest in mitigation and protection (Kundu and Stone 2014).

Figure 1. The Steep Costs of Droughts, Floods, and Heavy Rainfall in the United States



Data show national crop insurance indemnities from 2008 through 2019 for droughts, floods, and excess moisture from heavy rainfall.
Note: Decreased erosion rates and resulting improvements to soil health could increase resilience to such extreme events, which are expected to worsen due to climate change.
SOURCES: Basche 2017; IPCC 2019; Martin et al. 2020; Reidmiller et al. 2018; RMA 2019.

Scaled up, the costs of soil erosion are pronounced. In the United States, the costs associated with the Dust Bowl were estimated in 1939 to have been approximately $400 million per year ($7.4 billion per year in today's dollars).[3] The costs included lost productivity and hundreds of thousands of additional dollars for various damages reported by affected towns (Hansen and Libecap 2004). In another study, damage from wind and water erosion in the United States was estimated to cost $44 billion, including $27 billion in lost productivity and $17 billion in broader environmental costs (Pimentel et al. 1995). A more recent modeling study suggested that water erosion reduces global gross domestic product by approximately $8 billion annually and increases world food prices. However, that analysis accounted for only agricultural production losses and not public costs such as biodiversity loss, flooding, soil carbon decline, water pollution, and related damages (Sartori et al. 2019).

While today's high rates of soil erosion are costly and alarming, there is also good news. Decades of scientific research and practice have revealed ways to improve soil health and reverse the trend of soil loss. Methods include adoption of more diverse crop rotations, cover crops, and reduced- and no-till farming (minimal soil disturbance; Montgomery 2017). Moreover, rebuilding soil health is increasingly seen as a key step toward addressing both climate change adaptation and mitigation (IPCC 2019; Reidmiller et al. 2018). For one thing, better soil health may increase farmers' and nearby communities' resilience to droughts and floods, potentially reducing the tremendous costs of the damage from these events to farms and surrounding communities (Basche 2017). From 2009 to 2018, federal crop insurance indemnities for damages related to droughts and floods reached $52 billion (Stillerman and DeLonge 2019; Figure 1).

How Soil Forms and How It Is Lost

Soil erosion and soil formation are natural processes that depend on a wide range of factors, including starting "parent materials,"[4] topography, vegetative cover, weather and climate, and other biological factors. Both processes can be accelerated or slowed by different land management practices.[5] The soils that result from these processes and factors are characterized by the composition of a few characteristic layers, or soil horizons. The uppermost horizons, commonly referred to as the topsoil, constitute a relatively shallow layer that is most favorable to plant growth, richest in organic matter, and responsible for most of the soil's native fertility (NRCS 2015). Below the topsoil lies additional soil, often referred to as the subsoil, which is more depleted of nutrients.

In balanced ecosystems, where plants above ground and roots belowground protect soil year-round, soil erodes at roughly the same rate as it is formed. Estimates suggest that soil formation occurs at average rates of 0.04-0.08 millimeters (mm) per year. This equals about 0.16-0.32 inches over 100 years—that is, it takes *between three and six centuries* just to make an inch of soil (Montgomery 2007b). And when soil is managed in ways that leave it bare, damaged, and depleted of organic matter, wind and water can more easily displace it. Agricultural practices such as excessive tillage, conversion of diverse and perennial landscapes to annual monoculture systems, and overgrazing can all accelerate erosion. And when erosion rates exceed generation rates, the nutrient-rich topsoil on which a farm's profitability, resilience, and sustainability depend gradually disappears (Table 1). The results of significant erosion events can be catastrophic, but even imperceptible annual changes can cause big problems over time.

Table 1. Global and National Erosion Rates Vary by Agricultural Practices and Locations

Erosion Example	Tons/Acre/Y	Pounds/Acre/Y	Mm/Y	Inch/Y
Global Farms Using Conventional Plowing	21.1	42,172	3.94	0.155
US Croplands (1982, erosion by water)	3.8	7,640	0.71	0.028
US Croplands (1982, erosion by wind)	3.2	6,420	0.60	0.024
US Croplands (2015, erosion by water)	2.7	5,420	0.51	0.020
US Croplands (2015, erosion by wind)	1.9	3,820	0.36	0.014
Global Farms Using Conservation Agriculture*	0.7	1,328	0.12	0.005

Farmland erosion rates vary widely by location and by prevailing agricultural methods. As this table shows, US cropland erosion rates declined appreciably between 1982 and 2015, but they are still unsustainably high. For comparison, average rates of soil formation are approximately 0.04 millimeters (mm) per year.
Notes: Soil loss can be measured by weight (tons per acre per year or pounds per acre per year) and by depth (mm per year or inches per year). To estimate the depth of soil lost, we assumed a soil bulk density of 1,200 kilograms per cubic meter, as in Montgomery (2007b).
** In the cited study, "conservation agriculture" is defined by the use of practices such as conservation tillage, no-till methods, perennial cover (including grasses), and terraces.*
SOURCES: Montgomery 2007b; NRCS and CSSM 2018.

Several agricultural practices can help reduce erosion rates. A global synthesis found that fields managed using conventional agriculture, defined by the use of conventional plowing methods, have an average erosion rate of 3.94 mm soil per year (median = 1.54 mm/y). In contrast, fields managed using conservation agriculture practices (such as conservation tillage, no-till farming, and terracing) lose only a mean of 0.12 mm soil per year (median = 0.08 mm/y; Montgomery 2007b).

Additional research has pointed to many effective approaches to reduce erosion. For example, a study from Iowa State University showed that the practice of planting strips of native prairie plants on just 10 percent of corn and soybean fields had outsized consequences.[6] These fields saw just 5 percent of the soil loss of conventional fields, greatly reduced loss of nutrients, and increased biodiversity (Schulte et al. 2017). Another study from Iowa State University found that moving from standard corn-soybean rotations to improved crop rotations could reduce soil erosion by up to 60 percent and nitrogen runoff by up to 39 percent, while maintaining or increasing crop yields and farmers' per-acre profits (Hunt, Hill, and Liebman 2019).

Estimates from the National Resources Conservation Service (NRCS) suggest that conservation practices can reduce sheet and rill erosion (which occurs when runoff water forms small channels as it concentrates down a slope) by an average of 0.86 tons per acre per year on highly erodible lands, and 0.33 tons per acre per year on non-highly erodible lands (representing 45 and 40 percent reductions, respectively; NRCS 2017). Similarly, conservation practices were found to reduce edge-of-field sediment loss from water erosion by an average of 1.79 tons per acre per year on highly erodible lands, and 0.61 tons per acre per year on other lands (representing 56 and 53 percent reductions, respectively; NRCS 2017). Another recent study showed erosion reductions of 30 percent following organic farming compared with conventional farming, and of 61 percent with reduced tillage farming versus intensively tilled organic farming, when evaluating erosion driven by heavy rainfall (Seitz et al. 2019). The same study demonstrated that increasing organic matter and maintaining at least 30 percent soil cover were factors reducing erosion, supporting previous findings (Seitz et al. 2019).

Table 2. Management Practices on US Agricultural Lands

	Thousands of Farm/Ranch Operations			Millions of Acres	
	2007	2011–2012	2016–2017	2011–2012	2016–2017
Organic	20.4	9.0	14.2	3.6	5.0
Cropland	1,685.3	1,551.7	1,475.6	389.7	396.4
Conventional Tillage	-	405.7	264.9	105.7	80.0
Conservation Tillage	-	195.7	217.1	76.6	97.8
No-Till	-	278.3	279.4	96.5	104.5
Cover Crop Planting	-	133.1	153.4	10.3	15.4
Agroforestry	-	-	30.9	-	-
Rotational or Management-Intensive Grazing	388.9	288.7	265.2	-	-
Conservation Methods	503.9	-	-	-	-

Although research has documented the effectiveness of various agricultural practices reducing soil erosion, US farmers have adopted such practices on just a fraction of the nation's farm acres. To speed adoption, farmers need increased public policy support in the form of research, technical assistance, and incentives.

Notes: Data shown here are from the US Census of Agriculture, which has limited information on adoption rates of conservation agriculture practices. Data on organic operations and croplands are from 2011 and 2016, rather than 2012 and 2017, respectively. Organic data represent farms meeting National Organic Program standards in 2007, and US Department of Agriculture organic certified farms thereafter. In 2007, the census question on conservation methods asked, "At any time during 2007, did this operation . . . use conservation methods such as no-till or limited tilling, filtering runoff to remove chemicals, fencing animals from streams, etc.?"

SOURCES: NASS 2007; NASS 2020.

Despite the benefits of improved practices, they remain relatively rare on US agricultural land (Table 2). For example, while practices such as no-till and conservation tillage are becoming more common, cover crop planting was practiced on just 15.4 million acres (less than 4 percent of US cropland) as of 2017. Other valuable practices, such as rotational or management-intensive grazing and agroforestry (which includes alley cropping and silvopasture), are even less commonly used. Furthermore, data on these and other practices are limited. The Census of Agriculture from the US Department of Agriculture (USDA) only began requesting information on the use of select practices in 2012.

A Brief History of Soil Erosion in the United States

[I]f this is to be a permanent nation we must save this most indispensable of all our God-given assets—the soil, from which comes our food and raiment. If we fail in this, remember that much sooner than we have expected this will be a nation of subsoil farmers. For lack of foresight and willingness to look to the future, our children will condemn us, as already I have heard the children condemn the practices of their forebears in a number of American communities where erosion has turned back the hands of progress by laying waste the very productive substance of the country. (Bennett 1933)

Soil erosion is not a new concern for either the US public or the federal government. Perhaps the best-known case of erosion in the United States is the 1930s Dust Bowl. During the early 20th century, US farmers dramatically expanded unsustainable grazing and farming practices across the Great Plains. In particular, farmers encouraged by rising wheat prices in the 1910s and 1920s plowed up millions of acres of deep-rooted native grasses. Later, when the Great Depression struck and wheat prices fell, farmers plowed even more grassland.

In 1930, a sustained period of severe drought began. The combination of degraded soils, drought, high winds, and resulting dust storms brought widespread ecological, economic, and social devastation. Extensive crop failures and livestock deaths led to farm bankruptcies and mass migration, which contributed to the Great Depression's bank closures, business losses, and high unemployment.

By 1933, Hugh Hammond Bennett, a surveyor for the USDA Bureau of Soils, was warning that some of the nation's important farmland had no more than seven inches of topsoil and was eroding at rates that could leave farms with no topsoil at all within 50 years. Then, during two of the worst years of the Dust Bowl (1934 and 1935), an estimated 1.2 billion tons of soil were lost from approximately 100 million acres in the Great Plains (Cook, Miller, and Seager 2008).[7] Researchers consider the massive drought, which began in 1932, and the plowing of more than 100 million acres of native vegetation to be major contributors to the Dust Bowl, though there were other driving factors (Coppess 2019).

Acknowledging the severity of soil degradation across the country and taking the opportunity to mitigate the consequences through improved land management, Congress passed a law in 1935 directing the secretary of agriculture to establish a Soil Conservation Service (SCS). It also declared that the federal government had permanent responsibility for reducing water and wind erosion of the nation's soils. In 1994 the SCS's name was changed to the National Resources Conservation Service (NRCS n.d.).

Fortunately, the end of the severe drought in the Great Plains put an end to the Dust Bowl by the close of the 1930s, shortly after the establishment of the SCS. The Great Plains has not experienced a similar disaster since the Dust Bowl—even during severe drought—thanks primarily to the establishment of crop cover due to advances in irrigation and a heavy reliance on the Ogallala aquifer. The aquifer is, however, a finite resource that is rapidly being exhausted, and the annual crops that it sustains do not reduce erosion or build soil at the rates of the perennial vegetation that they replaced (Coppess 2019; Glover et al. 2010).

While programs made possible by the 1935 legislation and the SCS contributed to reduced erosion rates, unsustainable rates of soil loss continue. As a result, topsoil has decreased in many areas (Lerch et al. 2005). For example, research in Missouri suggested that one field lost about 7.7 inches of topsoil over the past 120 years (Geist 2013). Studies in Iowa have suggested that the state has lost 6.8 inches of topsoil since 1850 (Smith 2017). In North Dakota, estimates indicate that five inches of topsoil were lost from 10 million acres (Bennett 2019).

Today, NRCS operates the primary federal programs that support farmers in fighting erosion. Two major programs—the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP), introduced in 1996 and 2002, respectively—support improved practices on acres used for agricultural production. These popular programs have assisted on millions of acres of land to address a variety of natural resources concerns, including erosion.

While information on specific outcomes from these programs is limited, an early NRCS study estimated that EQIP has reduced erosion rates on highly erodible lands by as much as 8.6 tons per acre (NRCS 2009). Using more conservative estimates of erosion reduction rates that reflect the potential for conservation practices to reduce soil erosion across whole farms, the Union of Concerned Scientists estimated that CSP-supported practices reduced erosion on participating farms by 2.6 tons per acre per year (Stanley 2018). Return on investment in CSP—which achieves not just erosion reduction but also improvements in biodiversity on and around farms, water quality, and wildlife habitat—delivers nearly $4 in benefits to US farmers and taxpayers for every dollar spent (Stanley 2018).

More recent soil health case studies have documented environmental and economic benefits on corn-soybean farms in Illinois and Ohio and on diversified crop farms in New York (Bodell et al. 2019). The use of soil health practices supported by CSP and EQIP in these states reduced runoff and erosion; increased water-holding capacity and organic matter content; and resulted in annual changes in per acre net income of $34 to $55, or annual changes in total net income of $25,000 to $82,000 (Bodell et al. 2019). Despite these documented environmental benefits and the excellent return on investment, limited resources have resulted in CSP supporting, on average, only half the number of farmers who apply to participate in the program (NSAC 2015).

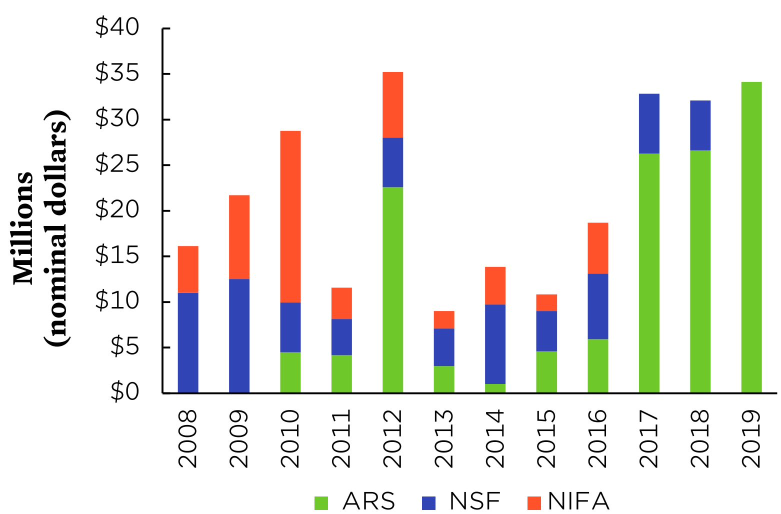
Estimating Erosion Rates: Background on Challenges and Outcomes

Scientists have worked to measure and understand soil erosion for decades, yet many research questions persist. Therefore, this field of study remains active. The public sector, rather than the private sector, historically has been the dominant supporter of this type of research. In recent years the public sector's share of total food and agricultural research has fallen from around 50 percent to less than 30 percent (Clancy, Fuglie, and Heisey 2016). Reduced research spending by the federal government and a surge in private sector spending has brought on this decline. If not addressed, the long-term consequences of this funding shift will be negative—and severe.

The public sector provides basic goods and services that are not, or cannot be, provided by the private sector. This includes basic research that provides the foundation for sustainable agricultural practices—in contrast to private sector research, which focuses on commercially profitable applications. To be able to reduce erosion, farmers require access to fundamental knowledge and training on what constitutes good land management. We know that transformational change is built on knowledge, and advances are more rapid when knowledge is freely available—through publicly funded research.

The National Science Foundation (NSF) and the USDA's Agricultural Research Service and National Institute of Food and Agriculture (NIFA) primarily support research in this field (Figure 2). From 2008 to 2016, NSF contributed the most on average (43 percent) to projects on soil erosion, followed by NIFA (32 percent).[8]

Figure 2. Public Research Investments in Soil Erosion in the United States



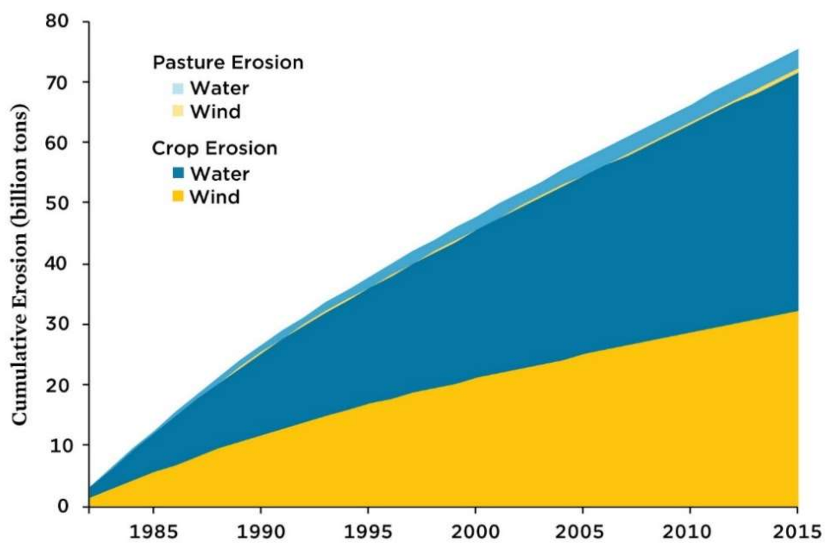
The majority of public investment in agricultural research pertaining to soil erosion comes from the National Science Foundation (NSF) and the USDA's Agricultural Research Service (ARS) and National Institute of Food and Agriculture (NIFA).
Notes: Here, we show funding from all projects supported by these agencies. The data were collected using the terms "soil AND erosion" in Federal RePORTER in September 2020 (Version 3.41.0). NSF data are reported through FY2018. NIFA data are reported through FY2016.
SOURCE: USHHS 2020.

Other publicly supported collaborative research efforts also address erosion. For example, the Long-Term Agroecosystem Research Network, launched in 2011, includes 18 sites that have conducted research over the past 19 to 100 years. Several of these sites have identified erosion as a resource concern (Spiegal et al. 2018).[9] The USDA Climate Hubs, established in 2013, consist of 10 regional hubs that deliver regionally tailored science-based tools and information pertaining to climate change effects and decisionmaking, including those related to soils and erosion (USDA 2020).[10]

Our knowledge about the rates of wind and water erosion derives from a range of measurement and modeling techniques across different landscapes. Croplands, pasturelands, and rangelands have different erosibility characteristics (Webb et al. 2020).[11] Each estimation tool and model has strengths and weaknesses, and their judicious and complementary application improves our understanding of the magnitude and threat posed by soil erosion.

The best available nationwide public estimates of erosion rates are developed as part of the National Resources Inventory (NRI; NRCS and CSSM 2018), conducted by the USDA's NRCS and Iowa State University's Center for Survey Statistics and Methodology. Congress mandated the NRI in 1972 and NRCS began publishing data in 1982. At its core, the NRI is based on detailed collection of thousands of soils located at a random sample of locations across 49 states (excluding Alaska), Puerto Rico, and the Virgin Islands. The erosion rates reported by the NRI since 1982 have been calculated through model simulations that incorporate detailed soil survey data.[12]

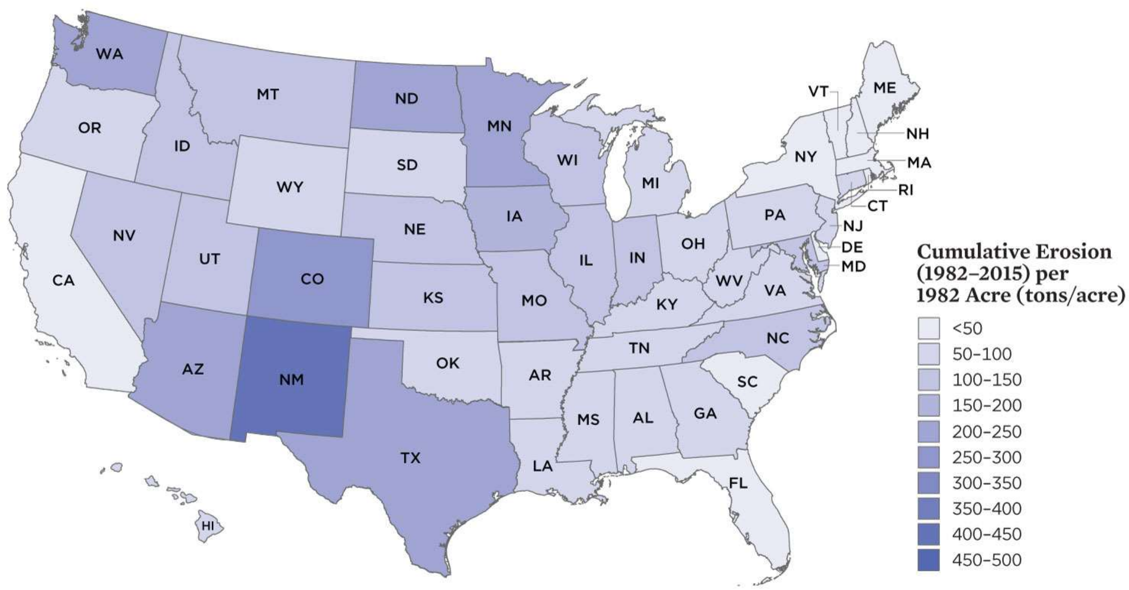
Figure 3. Eroded Soil on Croplands and Pasturelands in the United States, 1982–2015



This graph represents cumulative soil lost due to water and wind erosion on croplands and pastureland.
Notes: Data from Alaska were not available, and data from Hawaii and the Caribbean Islands were excluded for this figure. Soil erosion data are from 1982, 1987, 1992, 1997, 2002, 2007, 2012, and 2015. Losses between reported periods were linearly interpolated.
SOURCE: NRCS and CSSM 2018.

According to the NRI, the nation's croplands, representing 366.7 million acres and 1.5 million operations, account for the majority of soil loss (Figure 3). Croplands across the country currently lose an average of 2.7 tons of soil per acre (0.51 mm) each year from water erosion and 1.9 tons of soil per acre (0.36 mm) each year from wind erosion (NRCS and CSSM 2018). Erosion rates and cumulative soil losses vary by state (Figure 4). From 1982 to 2015, the states with the greatest cumulative erosion on agricultural lands, croplands, and pasturelands enrolled in the Conservation Reserve Program were, in descending order, Texas, Iowa, North Dakota, Minnesota, and Kansas.[13] However, cumulative losses per acre of land in these categories were highest in New Mexico, Colorado, Washington, Arizona, and North Dakota (Figure 4). While these numbers are high, current erosion rates are significantly lower than those from 1982, when 3.8 tons of soil were lost per acre (0.71 mm) each year from water erosion and 3.2 tons were lost per acre (0.60 mm) annually from wind erosion.

Figure 4. Cumulative Eroded Soil per 1982 Farmland Acre by State, 1982–2015



Cumulative soil eroded includes water and wind erosion on croplands, land, and pasturelands in the Conservation Reserve Program.
Notes: Erosion is shown per 1982 farmland acreage in each state, as most states lost acreage in these land use categories from 1982 to 2015 (a combined loss of more than 44 million acres). The exceptions were Kansas, Montana, Nebraska, North Dakota, and South Dakota, which together gained less than 3 million acres. As in Figure 3, soil loss during the years between measurement periods was linearly interpolated.
SOURCE: NRCS and CSSM 2018.

While reduced erosion rates since 1982 are a step in the right direction, erosion continues to threaten the farms and livelihoods of future generations. For example, erosion constitutes one of the factors driving a reduction in prime farmland in the nation's croplands.[14] This reduction amounts to 25.8 million acres—an area nearly equivalent to the entire surface area of Ohio—from 1982 to 2015.[15] Also, while the percentage of croplands exceeding so-called "tolerable" erosion rates (Hall, Logan, and Young 1985) decreased from 23 to 16 percent over the same time frame, that still left more than 59 million acres eroding above these untenable rates in 2015.

Furthermore, even at today's reduced rates, annual soil losses from croplands across the nation amount to 1.7 billion tons, or more than 1,000 tons of soil per farming operation each year. Moreover, the nation's croplands overall are losing more soil every two years than the Great Plains is estimated to have lost during eight years of the Dust Bowl (1932–39).

Average annual erosion rates reported by the NRI for the United States are substantially lower than global estimates for erosion from conventional agriculture (Table 1). However, the US estimates reported here are likely to be conservative, as the model used by the NRI does not include some sources of erosion, such as erosion from gullies, due to challenges measuring and modeling these reliably at large scales (Borrelli et al. 2017; Cox, Hug, and Bruzelius 2011). Previous research has shown that erosion rates may be higher by up to 12 times the rates published by the NRI (Cox, Hug, and Bruzelius 2011).

Scenario Analysis: Potential Future Erosion on US Croplands

Given the urgent need to halt the loss of precious soils, we explored possible future erosion scenarios in the United States, based on rates published in the NRI (NRCS and CSSM 2018). In doing so, we note the limitations of NRI estimates: NRI estimates soil loss from a segment of randomly selected hill slopes, and the hill slope segment is limited to the section on which sheet and rill loss dominates. This rate is often extended to all acres in the state or nation, and many of these acres actually accumulate soil that is eroded from upslope and, therefore, are not eroding but accumulating. This caveat and the limitation of NRI data reinforce the need for additional research to improve our knowledge of erosion science.

Our scenarios considered three possible changes to erosion rates (no change, linearly increasing rates, and linearly decreasing rates) from 2020 and 2035 (the latter year marking the 100th anniversary of the NRCS). Based on those annual rate changes, we quantified total soil losses from 2020 to 2035. Then, assuming 2035 erosion rates remain constant, we quantified potential total soil losses on croplands through the end of this century (to 2100).

Our scenarios included the following:

- **Scenario 1—Business as usual:** In this case, we assumed that erosion rates on croplands would proceed at the national average reported in the most recent NRI (4.6 tons per acre per year, including wind and water erosion). This scenario represents the case in which current practices and land use remain the same, and it assumes no changes in erosion due to climate change. For example, practices in this scenario include intensive plowing, as well as cropping practices that leave soils exposed during much of the year.

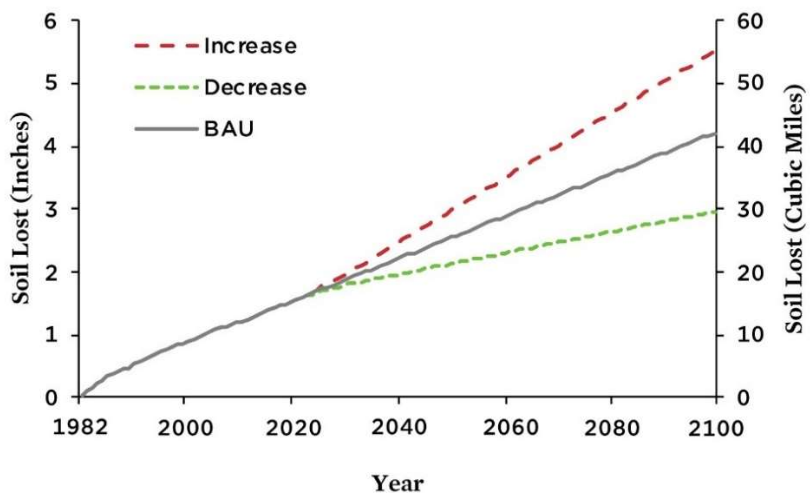
- **Scenario 2—Increased erosion:** In this case, we assumed that erosion rates would increase linearly over the next 15 years, back to their 1982 levels (seven tons per acre per year; the highest levels reported in the NRI). This increase would be due to a combination of more damaging land management practices, land use change, and exacerbated erosion rates because of climate change.

- **Scenario 3—Reduced erosion due to improved farming practices:** For this case, we assumed that erosion rates could be reduced by half (relative to 2015) over the next 15 years (reaching a rate of 2.3 tons per acre per year). This decrease would be slightly lower that the average decrease in rates observed from 1982 to 2015 (2.41 tons per acre per year). Such rate reductions may be possible given the relatively low rates of adoption of conservation practices to date (Table 2) and the reported effectiveness of these practices.[16]

Our analysis shows that additional average soil loss on US croplands by 2100 could range from about 1.5 inches to more than five inches, with the business-as-usual projection at nearly three inches (Figure 5). This is in addition to the approximately 1.5 inches lost, on average, since measurements began in 1982. As these estimates are national averages, it is important to realize that some areas would be less eroded, whereas others would be much more severely eroded relative to their starting points.

For perspective, 300 mm (12 inches) is considered to be a relatively deep topsoil. To help visualize and comprehend the magnitudes involved, we note that cumulative soil loss on US croplands from 1980 through 2100 could be enough to fill some of the nation's most popular lakes (such as Lake of the Woods, 19 cubic miles [mi^3]; Lake Champlain, 36 mi^3; and Lake Tahoe, 36 mi^3).

Figure 5. Scenarios for Soil Loss on US Cropland, 1982–2100



Estimated changes in national average soil losses on croplands due to wind and water erosion are shown for three erosion-rate scenarios—increase, decrease, and business as usual (BAU)—in inches (left) and cubic miles (right).
Notes: Data from 1982 to 2015 are linearly interpolated from the NRI observations (as shown in Figure 3). Erosion rates were projected from 2015 to 2035 based on the scenarios described above. To explore the effect of time on eroded soil depth, each scenario was also projected through 2100 based on simulated 2035 erosion rates. To calculate the depth of soil lost, an average soil bulk density of 1,200 kilograms per cubic meter was used, as in Montgomery (2007b).
SOURCE: NRCS and CSSM 2018.

Recommendations

To reduce erosion and create more resilient farm and food systems, policymakers should do the following:

- **Support the USDA's NRCS to improve, maintain, and protect the monitoring, reduction, and understanding of soil erosion.** This includes continued investment in building on the critical long-term dataset provided by the NRI, as well as investment in cost-share programs that help farmers adopt erosion-reducing practices. Such programs include the popular and effective—but chronically underfunded and oversubscribed—CSP and EQIP.
- **Increase public investments, through the USDA and NSF, in research, education, and extension programs to identify and refine effective solutions for reducing erosion rates**. Many important new farming practices that reduce erosion and preserve natural ecosystems are likely to be the result of research and extension activities funded only by the public sector, which is why continued and increased public support of these efforts is essential. While the scientific literature on erosion-reducing, soil-building farming practices has grown in recent years, the field needs more research to identify and improve such practices, particularly ones tailored to different farming systems and regions across the nation. A better understanding of the interactions among climate change effects, erosion, and farm resilience is also urgently required. Extramural funding through NIFA (for example, through the Agriculture and Food Research Initiative and the Sustainable Agriculture Research and Education Program) can help equip colleges, universities, and other institutions across the country to meet these research needs through field, lab, and modeling experiments, including farmer-led research. Increased funding should also be directed to the Long-Term Agroecosystem Research Network to advance erosion monitoring and research. Likewise, the USDA Climate Hubs should be supported to accelerate knowledge-building on relationships between regional erosion rates and climate change effects.
- **Strengthen federal crop insurance to incentivize practices that reduce erosion.** Expand the definition of "good farming practices" to include science-based sustainable practices, including NRCS-approved conservation practices. Authorize the USDA's Risk Management Agency to offer discounts for farmers who adopt practices that reduce erosion and build soil health. To prevent the conversion of grasslands to croplands, expand the "Sodsaver" grassland protection to apply across the nation. Policymakers should also improve enforcement of conservation compliance and strengthen requirements for highly erodible soils.
- **Provide funding to states and Native American tribes advancing soil health programs that address erosion.** Create a new USDA program giving grants to match state and tribal government expenditures directed toward supporting farmers in increasing adoption of practices that reduce erosion.

To strengthen the resiliency of the nation's agricultural and rural communities, an increased, more equitable, and renewed investment in reducing soil erosion is urgently needed. Federal policies and programs have a critical role to play in establishing educational, financial assistance, research, and technical assistance initiatives to support farmers in reducing erosion, building soil health, and securing more resilient and equitable farm and food systems.

Marcia DeLonge *is research director and senior scientist in the UCS Food and Environment Program.* ***Karen Perry Stillerman*** *is senior analyst in the program.*

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ENDNOTES

1. The NRCS (2009) has estimated that the amount of nitrogen and phosphorus lost in avoidable eroded soil adds up to $11.92 per acre per year (assuming the implementation of practices that can reduce erosion by 8.6 tons per acre per year).

2. Water cleanup costs associated with avoidable eroded soils were estimated to be $4.93 per ton. Assuming an estimated 8.6 tons avoidable erosion per acre per year, this amounts to $42.40 per acre per year (NRCS 2009).

3. See https://data.bls.gov/cgi-bin/cpicalc.pl.

4. The USDA's National Cooperative Soil Survey has identified and mapped more than 20,000 kinds of soil in the United States. See https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054278.

5. Water and wind erosion account for the majority of land degradation, although other forms of chemical and physical degradation also contribute (Eswaran, Lal, and Reich 2001).

6. Prairie strips are areas of corn and soybean fields planted with diverse native plant species with deep root systems (see https://www.nrem.iastate.edu/research/STRIPS/content/faq-what-are-prairie-strips).

7. Estimates suggest that 0.4 billion tons and 0.8 billion tons of soil were lost to wind erosion in 1934 and 1935, respectively (Cook, Miller, and Seager 2008). A modeling study assessing the period from 1932 to 1939 estimated that the Dust Bowl led to a loss of about 0.4 billion tons per year—3.3 billion tons cumulatively—throughout the full period (Cook, Seager, and Smerdon 2014). The SCS estimated that 15 percent of Great Plains acreage was severely

eroded by 1934, and by 1938, that portion had reached 40 percent (Hansen and Libecap 2004).

8. These estimates are calculated based on data in the Federal RePORTER, Version 3.41.0, for all years with data available for the Agricultural Research Service, NSF, and NIFA (2008–2016). For comparison, the nation's leading competitive grants program in agricultural sciences, NIFA's Agriculture and Food Research Initiative, had a budget of $400 million in 2018 and 2019 (OBPA 2020).

9. For more details, see https://ltar.ars.usda.gov/about.

10. For more details, see https://www.climatehubs.usda.gov/sites/default/files/Regional_Hub_Charter.pdf.

11. For example, indicators used to estimate wind erosion include soil properties, land observations, wind characteristics, and dust measurements.

12. The NRI used the empirical-based Revised Universal Soil Loss Equation model. This model provides a conservative estimate, as it does not include erosion from gullies, tillage, landslides, and riverbanks (Borrelli et al. 2017).

13. The Conservation Reserve Program, administered by the USDA's Farm Service Agency, pays farmers to remove environmentally sensitive land from production for 10 to 15 years. See https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program.

14. "Prime farmland" is defined by the NRCS as follows: "Land that has the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops. It must also be available for these uses. It has the soil quality, growing season, and moisture supply needed to economically produce sustained high yields of crops when treated and managed according to acceptable farming methods, including water management. In general, prime farmland has an adequate and dependable water supply from precipitation or irrigation, favorable temperatures and growing season, acceptable acidity or alkalinity, acceptable salt and sodium content, and few or no rocks. It is permeable to water and air. Prime farmland is not excessively erodible or saturated with water for a long period of time, and it either does not flood frequently or is protected from flooding" (SSDS 2017).

15. Ohio's surface area is 26.4 million acres (NRCS and CSSM 2018).

16. For example, cover crops are used on less than 4 percent of US cropland acres, and conventional tillage is still used on 20 percent of US cropland acres (NASS 2020). EQIP can reduce erosion rates by 8.6 tons per acre (NRCS 2009), and research has identified practices, detailed on page 4 of this report, that reduce erosion rates by more than 50 percent.

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