EPHEMERAL GULLIES: TO TILL OR NOT TO TILL?

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1. Introduction

Ephemeral gully erosion is now recognized as a significant, if not dominant, source of sediment from agricultural lands worldwide. Ephemeral gullies are typically plowed in and tilled across annually or more frequently, thus restoring the original swale and allowing erosion processes to become reactivated. Mechanized tillage redistributes soil from convex areas to swales in amounts that may exceed soil losses due to water erosion (Van Oost et al., 2006). This 'conveyer belt' repeatedly resupplies concentrated flow zones with erodible material, potentially exacerbating the long-term impacts of ephemeral gully erosion on losses of soil material and crop productivity, as topsoil thickness is reduced not only in the location of the gullies themselves, but across entire fields.

Gordon et al. (2007) have extended the basic theoretical framework of the Ephemeral Gully Erosion Model (EGEM, Woodward, 1999) by refining existing components, incorporating additional components, and adapting the model to operate within the USDA Annualized Agricultural Non-Point Source model (AnnAGNPS, Bingner et al., 2003). Models of ephemeral gully erosion such as EGEM, and now AnnAGNPS, limit the depth of an ephemeral gully channel to the tillage depth or depth to a less-erodible layer (e.g. fragipan). Once evacuated to this depth (through incision and headcut development and migration), channel widening by sidewall erosion dominates and erosion decreases.

We hypothesize that by routinely introducing additional topsoil to areas susceptible to concentrated runoff, via tillage and repair of ephemeral gullies, soil losses will significantly increase over long time periods. The objective of this study is to use a recently developed ephemeral gully erosion model to test this hypothesis.

2. Methods and Data

2.1. Ephemeral gully technology

The ephemeral gully model can be conceptually presented as follows (see Gordon et al., 2007). For a given runoff event, a hydrograph is constructed at the edge or outlet of a field, and the flow rate at a given location within the field is proportional to the upstream drainage area, which depends upon the length of the gully. Thus flow is unsteady in time and spatially varied. Once the flow rate at the mouth of the field exceeds the erosion threshold of the soil, incision is initiated in the form of a headcut. This headcut first incises (scours) down to the tillage depth, an erosion-resistant layer. It then migrates upstream at a rate proportional to the flow rate. The distance the headcut travels defines the ephemeral gully length, which may not exceed a maximum length calculated as a function of the size of the field. The width of the gully downstream of the headcut and sediment transport, whether limited by sediment supply or flow capacity, is proportional to flow rate. Since flow is unsteady and spatially varied, the headcut migration rate, gully width, and rates of sediment entrainment, transport, and deposition vary accordingly in time and space. Erosion processes cease at any given location once the flow rate at that location drops below this same soil erosion potential. Following the runoff event, the field may be re-tilled, thus obliterating the developed gully and reactivating initial erosion processes at the field outlet. If tillage does not occur, the physical characteristics of the existing gully are carried forward in time until another runoff event occurs, which may or may not modify the gully.

2.2. Study locations

Comprehensive datasets for ephemeral gully erosion containing measured input data, including measured soil erodibility factors, currently are not available. A literature review was conducted to determine: (1) locations where ephemeral gully erosion has been reported to contribute significantly to total soil losses; and (2) measured parameter values that may be used to compile complete input datasets for select locations. See Gordon et al., 2007 for model input requirements. Four study sites were chosen for simulation and include Belgium, Mississippi, Iowa, and Georgia.

2.3. Simulations

Ten years (1992 to 2002) of simulations were limited to five months per year (May 1 to September 1, 153 days), representing an approximate summer growing season. Field size (5.0 ha) and soil roughness (Manning's n = 0.40) were held constant throughout all simulations. In the first scenario, a tillage event (conventional moldboard plowing to 0.275 m, considered to be the maximum ephemeral gully depth) is simulated at the start of each growing season (May 1), which fills any ephemeral gully channel that may have developed during the previous year, and after which erosion begins at the field outlet. In the second scenario, a field is considered freshly tilled only at the start of the ten year simulation. At the end of each year, gully dimensions and

IV International Symposium on Gully Erosion. J. Casalí and R. Giménez (Eds.)
 ISBN 978-84–9769-198-7

erosion rates are recorded and carried over into the next growing season. These gullies are never filled by tillage and are allowed to freely develop over a ten year period.

3. Results and Discussion

3.1. Long-term erosion rates

Erosion rates (sediment delivery to the gully mouth, Mg ha^{-1} yr^{-1}) for simulated ephemeral gullies over the ten-year time period were 326% greater on average when the gullies are filled annually by tillage as opposed to those gullies left untilled. These erosion rates do not include sheet and rill erosion. When gullies are filled in by tillage, erosion processes are reactivated and erosion potential is maximized, as the entire channel may be eroded again. In this case, cumulative erosion rates are continuously increasing (Fig. 1c). In contrast, after several storms, gullies left untilled generally approach some maximum dimension related to the size of the field, the erodibility of the soil material, and the frequency and magnitude of runoff events. Once these dimensions are attained, erosion potential is minimized and erosion rates are greatly reduced, as cumulative rates of erosion increase only slightly due to gully widening or the removal of deposited material from the gully bed. In Belgium, cumulative erosion rates for the two tillage scenarios diverge after six years of simulation and for a ten year period, the untilled gullies conserve 3.1 Mg ha^{-1} yr^{-1} of soil material. For the remaining study sites, cumulative erosion amounts diverge after the first year or two and over a ten-year period in Mississippi (Fig. 1), Iowa, and Georgia, no-till soil conservation rates amount to 7.6, 7.7, and 9.0 Mg ha^{-1} yr^{-1}, respectively.

3.2. Implications for ephemeral gully management practices

The negative effects of tillage with regard to ephemeral gully erosion further demonstrate the advantages of soil conservation technologies such as no-till planting and installation of best management practices (BMPs). No-till practices increase the stability of the soil, allow for greater retention of moisture, and promote residue cover that protects the soil from detachment by raindrop impact, and the beneficial hydrologic impacts of no-till agriculture have been shown to increase over time (Dabney et al., 2004). Installation of BMPs such as grassed waterways in concentrated flow zones has been shown to reduce flow erosivity and induce deposition, thereby preventing erosion of natural drainageways by ephemeral gully incision (Fiener and Auerswald, 2003).

When ephemeral gullies are present, land managers should acknowledge the implications of repairing ephemeral gullies during tillage and consider alternate approaches to mitigating ephemeral gully erosion and ensuring the long-term productivity of their land.

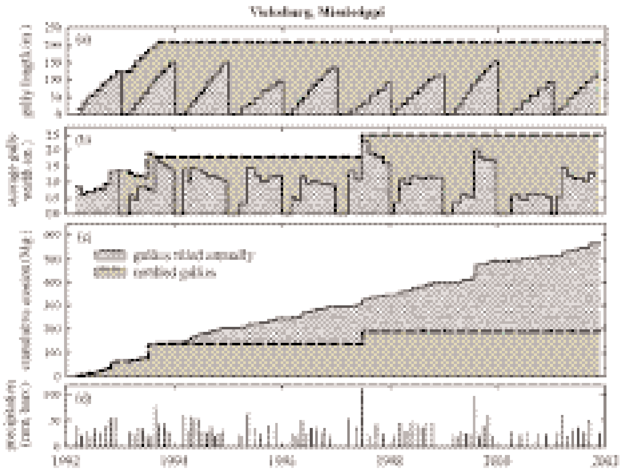

Fig. 1. Time evolution of (a) ephemeral gully length (m), (b) ephemeral gully width (m), and (c) cumulative erosion (Mg) for annually tilled and untilled gullies resulting from (d) rainfall events producing concentrated flows exceeding the soil's critical shear stress at Vicksburg, Mississippi. Note that gully dimensions and erosion rates are identical during the first simulation year.

4. Conclusion

While the perceived magnitude of ephemeral gully erosion may be masked after gullies are repaired, the action of plowing in these channels reduces topsoil thickness and crop productivity over a much wider area than the channel itself. This study demonstrates that filling ephemeral gullies on an annual basis during tillage operations may be more destructive than realized. These results should provide land managers an additional incentive for adopting soil conservation practices such as no-till.

Acknowledgements: This work was funded by the USDA-ARS.

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