Hold Your Ground: Threats to Soil Function in Northern Great Plains Grazing Lands

By Mark A. Liebig and David Toledo

On the Ground

- Many soils throughout the northern Great Plains (NGP) of North America possess attributes that support the successful delivery of multiple ecosystem services from grazing lands.
- Anticipated changes in climate and land use in the region, however, suggest delivery of these services could be compromised in the future because of an increase in threats to soil function. These threats include soil organic matter decline, reduced physical stability, soil erosion, compaction, localized nutrient accumulation, acidification, and salinization.
- Adaptive management to conserve existing soil functions in grazing lands is necessary and includes: 1) judicious management of forage resources, 2) strategic application of management to modify vegetation composition or soil conditions, and 3) use of restoration and conservation practices known to maintain vegetation cover and protect soil.
- Management approaches to conserve soil functions in NGP grazing lands will likely require considerable adaptive capacity by land managers. Successful application of management will require timely information about soil and vegetation conditions to guide land-use decisions.

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Healthy soil is essential to the successful delivery of multiple ecosystem services. Direct contributions to primary productivity, water purification and regulation, carbon storage and regulation, nutrient cycling and provision, biodiversity, and habitat place soil at the nexus of efforts to manage land sustainably.[1]

Elevated awareness of soil's importance in promoting ecosystem health comes at a critical time. A convergence of human population growth, climate change, and continued dependence on nonrenewable energy resources has translated to a spectrum of intensified threats affecting critical soil functions through increased soil erosion, physical degradation, soil organic matter decline, acidification, salinization, and biodiversity loss.[1] Although certainly not new, these "soil threats"—when clearly identified at local scales—serve to guide management that can sustain soil functions now and in the future.[2]

Generating increased awareness of potential soil threats by geographical region and agroecosystem type is an important step to facilitate deployment of appropriate responses in a proactive manner. This forum paper seeks to briefly review soil threats to grazing lands in the northern Great Plains (NGP) of North America, along with management approaches needed to conserve soil functions in light of anticipated changes in climate and land use during the 21st century.

Regional Attributes and Outlook

The NGP of North America encompasses portions of five US states and two Canadian provinces, extending from the northern Rocky Mountains eastward along a gently sloping rolling plain to an eastern boundary representing the transition from mixed grasses of the Great Plains to tall grasses of the humid Central Lowlands.[3] Climate of the region is continental, with cold and dry winters, warm to hot summers, and limited erratic precipitation. Organic matter accumulation and calcification are dominant pedogenic processes, the outcomes of which are soils with high natural fertility and good water-holding capacity. Composition of native vegetation across the region has been shaped by drought, grazing pressure, and fire, with nonforested native vegetation dominated by a mixture of C_3 and C_4 grasses and forbs. Agriculture is the prevalent land use throughout the region, with rangeland and cropland occupying over 90% of the total land area.[4,5] Fossil energy extraction (coal, oil, and natural gas) is systemic to the region and is complemented by extensive development of renewable energy projects to harness abundant wind resources. The region is also home to the Prairie Pothole Region and numerous National Grasslands, both repositories for native vegetation, wildlife, and migratory birds.

Climate projections for the NGP through 2085 include overall warming, longer growing seasons, increased weather variability, and more extreme events.[6] These changes are currently having both beneficial and detrimental effects on NGP grazing lands and associated livestock production and are anticipated to continue based on predictions. Elevated atmospheric CO_2, coupled with warming, will increase grassland productivity, whereas warming alone will decrease the need for supplemental feed for livestock during winter months.[7] Negative effects on NGP grazing lands include lower forage quality, increased pests, pathogens and invasive plants, and greater potential for wildfires and streambank scouring. Higher temperatures throughout the region will serve to increase heat stress on livestock during summer months. Improved growing conditions, coupled with increased demand for commodity crops, is anticipated to drive grassland-to-cropland conversion in the region.[7]

Increased global demand for energy is projected to expand development and export of fossil and renewable resources in the NGP throughout the 21st century.[8] The Williston and Powder River Basins, which comprise parts of Wyoming, Montana, North and South Dakota, Manitoba, and Saskatchewan, contain some of the world's largest reserves of coal, oil, and natural gas.[8] Recent advances in fossil energy extraction technology are expected to expand development of oil and gas exploration from deep shale deposits, while growth in wind energy development in the region is also expected to accelerate as demand for renewable energy resources increase. Effects of energy extraction and development on grazing land ecosystem services are negative because surface coal mining, oil and gas drilling, and wind tower placement disrupt landscapes through mine spoil redistribution, road construction, and physical infrastructure development (i.e., drilling/tower pads, pipelines, and transmission lines).[9]

Threats to Soil Functions

Increased demands for food and energy, coupled with anticipated changes in climate, have the potential to elevate soil threats in NGP grazing lands. General categories of threats—expressed as likely, possible, and unlikely—were developed for seven soil outcomes with established linkages to key soil functions: soil organic matter decline, reduced physical stability, soil erosion, compaction, localized nutrient accumulation, acidification, and salinization (Table 1).[2] Relevant literature to support category assignments can be found in the Appendix.

Agricultural Intensification

Future demand for food, feed, fiber, and fuel is anticipated to drive intensification in land use toward greater provision of agricultural products, especially in regions with favorable growing conditions. For NGP grazing lands, demand for animal-derived protein could increase stocking rates. This would likely lead to more extensive use of rangelands to meet the forage needs of livestock. Poorly timed hoof action, coupled with a reduction in surface cover, can degrade soil physical condition as reflected through increased compaction and decreased physical stability. If not carefully managed, such impacts on near-surface soil conditions can contribute to increased soil erosion and soil organic matter loss. Furthermore, high numbers of livestock in small areas (e.g., water sources, shelters) can contribute to concentrated nutrient inputs to soil through accumulated feces and urine[10] (Table 1). In the absence of basic cations (Ca^{2+}, Mg^{2+}, and K^{+}) to buffer pH change, nitrogen loss from nutrient-rich areas can contribute to increased acidification.[11]

Conversion of grazing lands to rainfed crop production is well documented to contribute to soil organic matter loss and decreased aggregate stability. Another likely, though long-term outcome of grassland conversion is increased soil acidification given common use of ammoniacal sources of fertilizer nitrogen in crop production systems.[12] Increases in soil erosion, compaction, and nutrient accumulation with cropland conversion are possible, although use of no-till and precision nutrient management can mitigate potential impacts. Increases in salinization with cropland conversion are also possible depending on landscape hydrology and water-use dynamics of selected crops[13] (Table 1). Higher temperatures and erratic precipitation patterns throughout the region will likely increase heat stress on cool-season crops within the NGP region. Shifts in land use could contribute to dynamic transitions between cropland and grassland or adaptive responses within a single land use (e.g., forage production during years when it is too dry for a grain crop).[14]

Energy Extraction and Development

Among drivers affecting land use in the NGP, energy extraction and development is projected to have the most consistent negative effects on soil condition (Table 1). As grazing lands are "engineered" to accommodate energy extraction, production and transmission, removal and redistribution of soil will lead to at least temporary deterioration of soil physical conditions, increased erosion, and soil organic matter loss. Removal of vegetation cover will contribute to the same outcomes in areas of direct impact, with tapering effects

Table 1. Qualitative rankings of soil threats associated with agricultural intensification, energy extraction and development, and climate change (direct and management-dependent effects) in northern Great Plains grazing lands

Influence		Responses	Soil Threats						
			Soil organic matter decline	Reduced physical stability	Soil erosion	Compaction	Localized nutrient accumulation	Acidification	Salinization
Agricultural Intensification		Increased stocking rates and/or more extensive grazing	Possible	Possible	Possible	Likely	Likely	Likely	Possible
		Grassland-to-cropland conversion	Likely	Likely	Possible	Possible	Possible	Likely	Possible
Energy Extraction and Development		Road/Pad development	Likely	Likely	Likely	Likely	Possible	Unlikely	Possible
		Minespoil redistribution	Likely	Likely	Likely	Likely	Possible	Possible	Possible
		Decreased vegetation cover	Likely	Likely	Likely	Likely	Unlikely	Possible	Possible
Climate Change (Direct Effects)		Increased CO_2	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely	Likely	Unlikely
		Overall warming	Likely	Possible	Possible	Unlikely	Unlikely	Unlikely	Unlikely
		Greater frequency of extreme weather	Possible	Possible	Likely	Unlikely	Unlikely	Unlikely	Unlikely
		More variable soil water availability	Possible	Possible	Possible	Possible	Unlikely	Unlikely	Possible
Climate Change (Management Dependent)	Change in Natural Disturbance Regime	Decrease in prescribed fire	Unlikely	Unlikely	Possible	Unlikely	Possible	Unlikely	Unlikely
		Increased wildfires	Possible	Possible	Possible	Unlikely	Possible	Unlikely	Unlikely
		Altered plant community composition	Possible	Possible	Possible	Unlikely	Possible	Unlikely	Unlikely
		Accumulation of plant litter	Possible	Unlikely	Unlikely	Unlikely	Likely	Unlikely	Unlikely
	Invasive Plants	Shift in plant composition and dominance	Possible	Possible	Possible	Unlikely	Possible	Unlikely	Possible
		Change in above- and below-ground structure	Likely	Possible	Possible	Unlikely	Possible	Unlikely	Possible
		Woody plant encroachment	Likely	Likely	Likely	Unlikely	Likely	Unlikely	Unlikely

on soil properties with increasing distance from roads, pads, and pipelines. Salinization is possible with vegetation removal and through redistribution of saline or sodic minespoil on the soil surface. Establishment of invasive plant species in areas disturbed by energy development can also alter soil properties (reviewed below). Negative effects on soil condition from energy extraction and development, however, are tempered somewhat by the fact that direct impacts will be limited to a relatively small proportion of the grazing landscape.

Climate Change

Potential climate change effects on soil are complex. Direct effects of anticipated changes (e.g., elevated CO_2, overall warming, extreme weather, and variable moisture availability) interact in ways that can accentuate or negate potential soil threats. Moreover, because plant and soil responses are tightly linked in agroecosystems, management can have similar confounding effects on eventual outcomes affecting soil function.

When considered in isolation, direct effects of climate change on soil threats in NGP grazing lands are mixed (Table 1). Increased atmospheric CO_2 is unlikely to directly affect soil functions, though increased soil acidification and mineral weathering is likely in the long term. Overall warming will serve to increase soil temperatures, and accordingly, carbon mineralization. Increased respiration, without a proportional return of carbon to the soil, will likely result in reduced soil organic matter with possible cascading effects of reduced aggregate stability and increased soil erosion. Greater frequency of severe weather, as reflected by intense precipitation or wind events, is likely to contribute to increased soil erosion. Associated threats to soil from severe weather include possible declines in near-surface aggregate stability and soil organic matter. Soil threats from more variable soil water availability are strongly linked to aboveground biomass dynamics. Limited soil water during persistent drought will constrain plant growth, with associated decreases in vegetation cover and carbon inputs to soil. Accordingly, decreases in soil organic matter and near-surface aggregate stability are possible during drought, along with increases in soil erosion and compaction. Increased frequency of wet–dry cycles in soil with shallow ground water could facilitate salt uplift in the absence of adequate plant growth, thereby increasing salinization.

Landowner management decisions have affected the natural disturbance regime of NGP grazing lands through decreased occurrence of fire and altered grazing management practices. The combination of climate and management has altered plant community composition and contributed to the accumulation of plant litter, each with subsequent effects on various soil threats (Table 1). A potential increase in prescribed fires can reinstate the natural disturbance regime with positive effects on plant species composition and nutrient distribution.[15] Return of charred litter may contribute to spatially heterogeneous distribution of nutrients on affected rangelands.

Shifts in plant composition and dominance, change in above- and below-ground structure, and woody plant encroachment are strongly related. National Resources Inventory data suggests that much of the NGP has been invaded by Kentucky bluegrass (*Poa pratensis*) and some woody invasive species are beginning to encroach into parts of this region as a result of increased water availability, longer growing season, and lack of disturbance.[16] The mechanisms leading to soil threats associated with these changes may vary but will ultimately decrease plant cover and affect vegetation distribution and biodiversity in rangelands, with long-term effects of soil organic matter decline, decreased near-surface structural stability, and increased soil erosion. Woody plant encroachment will also increase the prevalence of accumulated nutrients around woody plant clusters, fostering spatially heterogenous nutrient landscapes in NGP rangelands.[17] Increased heterogeneity in rangelands has been associated with increased levels of biodiversity.[18]

Approaches to Mitigate Soil Degradation

Mitigating soil degradation from anticipated threats to NGP grazing lands will require increased awareness of management's role to affect land sustainability and an ability to adapt to dynamic conditions. Sustainability of land (i.e., the capacity to generate ecosystem services over time) is expressed through its resistance to degradation and its resilience, which refers to the capacity of land to recover from degradation. While resistance and resilience are largely a function of inherent attributes of soil, topography, and climate, management plays a crucial role in determining how soil responds to external stressors. Whether from agricultural intensification, energy extraction and development, climate change, or some combination thereof, strategic application of context-specific management can serve to buffer soil from change, thereby allowing producers to "hold their ground" during challenging times.

Maintaining or increasing plant cover on grazing lands is perhaps the most fundamental management outcome that can minimize soil change from anticipated threats.[7] Keeping the ground covered with living biomass and adequate amounts of litter offer benefits to soil through physical protection, carbon inputs, and modulated temperature and moisture fluctuations. Maintaining plant cover, however, can be especially challenging given the inherently high spatial and temporal variability of biomass production on grazing lands throughout the NGP.[7] Accordingly, managing forage resources conservatively would serve to reduce the likelihood of soil degradation from limited plant cover. However, undesirable shifts in vegetation composition caused by changes in climate or land use may require management changes resulting in temporary reductions in vegetation cover, such as targeted grazing, prudent use of fire and concurrent utilization of multiple livestock species. Areas with intensive livestock impacts may require rest, reseeding, or conversion to pasturelands through targeted use of perennial forages or annual cover crops to capture available nutrients or ameliorate near-surface structural damage from hoof action.

Minimizing negative outcomes from the conversion of rangelands to other land uses relies on landscape-tailored efforts that align land use with land potential to ensure conversions are done as efficiently as possible.[19] Though anticipated to be limited in scope, targeting land conversion to the most appropriate land type should consider inherent attributes of soil and topography along with broader ecosystem services across landscapes, thereby guiding the physical footprint of conversion to locations with the least negative impacts over the long term. Grazing lands converted to energy extraction and development will require restoration efforts to reestablish vegetation and protect soil in disturbed areas,[20] whereas lands converted to rainfed pastures or crop production necessitate application of conservation practices to minimize soil degradation. Though land-use conversions are typically associated with a focus on near-term benefits at the expense of longer-term considerations, additional income streams for producers may offer opportunities to develop multiple enterprise synergies found in integrated agricultural systems.[19]

Collectively, nuanced responses to anticipated soil threats in NGP grazing lands would require monitoring and considerable management flexibility. Adaptive management has been upheld as a promising approach to manage the complexity associated with matching forage production variability over time with livestock demands.[21] For grazing lands converted to rainfed crop production, adoption of dynamic cropping systems can optimize production, economic, and resource conservation goals through annual decisions that leverage crop sequencing opportunities within regionally adapted crop portfolios.[22] As expected, use of these flexible management approaches is inherently information intensive, requiring producers to assimilate multiple streams of data to arrive at timely responses to external stressors or production opportunities. Central to the selection of appropriate responses will be the availability of information addressing the status of the soil resource.

A Critical Role for Assessments

Anticipated changes to NGP grazing lands underscore the importance of conducting periodic assessments of the soil resource to guide flexible management. Fortunately, recent interest in soil health assessments applicable to rangelands has ushered in a wealth of indicator recommendations and associated interpretation criteria[23,24] while complementing well-established soil-associated protocols specific to rangeland health assessments.[25,26]

Stand-alone soil assessments and soil assessments that are part of larger assessment and monitoring frameworks on grazing lands should contribute to improved decision-making, and ultimately, an improved soil resource.[23,27] It is likely that ecosystems will not react to management as previously expected in the NGP because of changes in land use and expected changes in climate.[7] Accordingly, tailoring the timing and spatial extent of assessment and monitoring activities to capture outcomes from weather-related events or land use disturbances will be an important step toward developing proactive management approaches. Equally important will be the need for "listening places" specific to grazing lands,[28] whereby soil assessments are repeated frequently over the period of decades to document longer-term soil property dynamics.

Although anticipated soil threats imply evaluation criteria favoring soil assessments, a soil-based methodology of grazing lands will be insufficient.[27] As many soil properties are slow to change, surrogates of soil condition will be needed to address short-term dynamics. Fortunately, soil-vegetation associations are particularly strong in grazing lands,[26] allowing for the use of aboveground criteria to effectively guide management. Coupled use of vegetation attributes and select soil properties may have the greatest benefit to land managers in assessing effects of soil threats and outcomes of management.[27]

Conclusions

Improving soil conditions in NGP grazing lands in the face of anticipated land use and climate change represents a serious challenge for land managers. Likely or possible soil threats from these changes have the potential to degrade soil conditions and compromise the delivery of critical ecosystem services in this important ecological and agricultural region. Because restoration of soils in the region is inherently slow, efforts should be made to conserve existing soil functions. Achieving this will likely require the adoption of flexible management paradigms given the complexity of interactions among external stressors. Timely information about soil and vegetation conditions will be essential to successfully deploy management that protects the soil resource.

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Appendix A Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.rala.2018.11.003.

References

1. Schulte, R.P.O., F. Bampa, M. Bardy, C. Coyle, R.E. Creamer, R. Fealy, C. Gardi, B.B. Ghaley, P. Jordan, H. Laudon, C. O'Donoghue, D. Ó'hUallacháin, L. O'Sullivan, M. Rutgers, J. Six, G.L. Toth, and D. Vrebos. 2015. Making the most of our land: managing soil functions from local to continental scale. *Frontiers in Environmental Science* 3:1-14.
2. Bünemann, E.K., G. Bongiorno, Z. Bai, R.E. Creamer, G. De Deyn, R. de Goede, L. Fleskens, V. Geissen, T.W. Kuyper, P. Mäder, M. Pulleman, W. Sukkel, J.W. van Groenigen, and L. Brussaard. 2018. Soil quality – A critical review. *Soil Biology & Biochemistry* 120:105-125.
3. Padbury, G., S. Waltman, J. Caprio, G. Coen, S. McGinn, D. Mortensen, G. Nielsen, and R. Sinclair. 2002. Agroecosystems and land resources of the northern Great Plains. *Agronomy Journal* 94:251-261.
4. Statistics Canada, . Census of Canada. Statistics Canada Advisory Services Available at: www.statcan.gc.ca.
5. USDA Census of Agriculture, 2012. Agriculture Census. Available at: United States Department of Agriculture, National Agricultural Statistics Servicewww.agcensus.usda.gov2012.
6. Shafer, M., D. Ojima, J.M. Antle, D. Kluck, R.A. McPherson, S. Petersen, B. Scanlon, and K. Sherman. 2014. Ch. 19: Great Plains. In: Melillo JM, Richmond TTC, & Yohe GW, editors. Climate change impacts in the United States: the third national climate assessment. U.S. Global Change Research Program. p. 441-461.
7. Derner, J., D. Briske, M. Reeves, T. Brown-Brandl, M. Meehan, D. Blumenthal, W. Travis, D. Augustine, H. Wilmer, D. Scasta, J. Hendrickson, J. Volesky, L. Edwards, and D. Peck. 2017. Vulnerability of grazing and confined livestock in the Northern Great Plains to projected mid- and later-twenty-first century climate. *Climatic Change* , https://doi.org/10.1007/s10584-017-2029-6.
8. U.S. Energy Information Administration, . North Dakota – State Energy Profile Analysis. Accessed at: https://www.eia.gov/state/analysis.php?sid=ND.
9. Allred, B.W., W.K. Smith, D. Twidwell, J.H. Haggerty, S. W. Running, D.E. Naugle, and S.D. Fuhlendorf. 2015. Ecosystem services lost to oil and gas in North America. *Science* 348:401-402.
10. Augustine, D.J., D.G. Milchunas, and J.D. Derner. 2013. Spatial redistribution of nitrogen by cattle in semiarid rangeland. *Rangeland Ecology & Management* 66:56-62.
11. Tian, D., and S. Niu. 2015. A global analysis of soil acidification caused by nitrogen addition. *Environmental Research Letters* 10024019.
12. Tarkalson, D.D., G.W. Hergert, and K.G. Cassman. 2006. Long-term effects of tillage on soil chemical properties and grain yields of a dryland winter wheat-sorghum/corn-fallow rotation in the Great Plains. *Agronomy Journal* 98:26-33.
13. Arndt, J.L., and J.L. Richardson. 1988. Hydrology, salinity and hydric soil development in a North Dakota prairie-pothole wetland system. *Wetlands* 8(2):93-108.
14. Wienhold, B.J., M.F. Vigil, J.R. Hendrickson, and J.D. Derner. 2017. Vulnerability of crops and croplands in the US Northern Plains to predicted climate change. *Climatic Change* , https://doi.org/10.1007/s10584-017-1989-x.
15. Kral, K., R. Limb, A. Ganguli, T. Hovick, and K. Sedivec. 2018. Seasonal prescribed fire variation decreases inhibitory ability of Poa pratensis L. and promotes native plant diversity. *Journal of Environmental Management* 223:908-916.
16. USDA-NRCS, . National Resources Inventory Rangeland Resource Assessment. Available at: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/nri/results/?cid=nrcseprd1343025.
17. López-Pintor, A., A. Gómez Sal, and J.M. Rey Benayas. 2006. Shrubs as a source of spatial heterogeneity—the case of Retama sphaerocarpa in Mediterranean pastures of central Spain. *Acta Oecologia* 29:247-255.
18. Bestelmeyer, B.T. 2005. Does desertification diminish biodiversity? Enhancement of ant diversity by shrub invasion in southwestern USA. *Diversity and Distributions* 11:45-55.
19. Liebig, M.A., J.E. Herrick, D.W. Archer, J. Dobrowolski, S.W. Duiker, A.J. Franzluebbers, J.R. Hendrickson, R. Mitchell, A. Mohamed, J. Russell, and T.C. Strickland. 2017. Aligning land use with land potential: the role of integrated agriculture. *Agricultural & Environmental Letters* 2170007.
20. Gasch, C., S. Huzurbazar, and P. Stahl. 2014. Measuring soil disturbance effects and assessing soil restoration success by examining distributions of soil properties. *Applied Soil Ecology* 76:102-111.
21. Derner, J.D., and D.J. Augustine. 2016. Adaptive management for drought on rangelands. *Rangelands* 38(4):211-215.
22. Hanson, J.D., M.A. Liebig, S.D. Merrill, D.L. Tanaka, J.M. Krupinsky, and D.E. Stott. 2007. Dynamic cropping systems: increasing adaptability amid an uncertain future. *Agronomy Journal* 99(4):939-943.
23. Printz, J.L., D. Toledo, and S.C. Boltz. 2014. Rangeland health assessment: the key to understanding and assessing rangeland soil health in the Northern Great Plains. *Journal of Soil and Water Conservation* 69(3):73A-77A.
24. Derner, J.D., A.J. Smart, T.P. Toombs, D. Larsen, R.L. McCulley, J. Goodwin, S. Sims, and L.M. Roche. 2018. Soil health as a transformation change agent for US grazing lands management. *Rangeland Ecology & Management* 71:403-408.
25. Herrick, J.E., J.R. Brown, A.J. Tugel, P.L. Shaver, and K. M. Havsted. 2002. Application of soil quality monitoring and management: Paradigms from rangeland ecology. *Soil Science Society of America Journal* 94:3-11.
26. Pellant, M., P. Shaver, D.A. Pyke, and J.E. Herrick. 2005. Interpreting indicators of rangeland health, version 4. Tech. Ref. 1734-6. U.S. Denver, CO, USA: Department of the Interior, Bureau of Land Management, National Science and Technology Center, BLM/WO/ST-00/001+1734/REV05. 122 p.
27. Brown, J.R., and J.E. Herrick. 2016. Making soil health a part of rangeland management. *Journal of Soil and Water Conservation* 71(3):55A-60A.
28. Janzen, H.H. 2016. The soil remembers. *Soil Science Society of America Journal* 80:1429-1432.

Authors are USDA-ARS, Northern Great Plains Research Laboratory, Mandan, ND 58554-0459, USA (mark.liebig@ars.usda.gov, Liebig); and USDA-ARS, Northern Great Plains Research Laboratory, Mandan, ND 58554-0459, USA (Toledo).