Available at www.scientevents.com/proscience/

ProScience 5 (2018) 52-57

Conference Proceedings

3rd International Conference on Atmospheric Dust - DUST2018

Contribution of atmospheric deposition to soil provisioning ecosystem services in the contiguous United States: Part 2. Magnesium

Garth Groshans[1], Elena Mikhailova[1*], Christopher Post[1], Mark Schlautman[2], Michael Cope[1], Lisha Zhang[3]

[1]*Department of Forestry and Environmental Conservation, Clemson University, Clemson, SC, USA*

[2]*Department of Environmental Engineering and Earth Sciences, Clemson University, Anderson, SC, USA*

[3]*Agricultural Sciences Department, Clemson University, Clemson, SC, USA*

[*]*eleanam@clemson.edu*

Abstract

Magnesium (Mg^{2+}) deficiency commonly occurs in more than half of the global population based on dietary reference intakes set by the United States and Canada. Atmospheric deposition provides provisioning ecosystem service value to society; however, spatial distribution of atmospheric Mg^{2+} deposition varies in the United States. This study ranked the provisioning ecosystem services value of atmospheric Mg^{2+} deposition in the United States by soil order, state, and region. The total value of provisioning ecosystem services contributed from atmospheric Mg^{2+} deposition was 47M (i.g., 47 million U.S. dollars) based on a national average price (2014) of \$12.90 per U.S. ton of agricultural dolomite ($CaMg(CO_3)_2$). Regions with the highest ranked for total value of Mg^{2+} deposition were: 1) South Central, 2) West, and 3) Southeast, while the highest ranked regions based on area-normalized values were: 1) South Central, 2) Southeast, and 3) East. The highest ranked states for total value of Mg^{2+} deposition were: 1) Texas, 2) Florida, and 3) California, while the highest ranked states based on area-normalized values were: 1) Florida, 2) Louisiana, and 3) Texas. The results of this study show the importance of assessing atmospherically deposited Mg^{2+} ions for the ecosystem services framework. The potential impacts on society from this research including adding atmospheric Mg^{2+} deposition to the ecosystem services framework and increasing the betterment of health and well-being for the global population.

Keywords: Agriculture, Dolomite, Fertility, Fertilization, Food security, Land use, Magnesium, Market failure, Soil inorganic carbon (SIC), STATSGO

ISSN: 2283-5954
Selection and peer-review under responsibility of DUST2018 Scientific Committee

DOI:10.14644/dust.2018.009

1. Introduction

Magnesium is a life-supporting good, which plays an important role in soils, plants, and human nutrition (Cakmak, 2013). As an essential mineral macro-nutrient it is required by plants for growth of "sink" organs (e.g., roots, shoot tips, and seeds), which growths can be significantly affected by a low supply of magnesium in the soil (Hermans et al., 2005). Adequate magnesium nutrition is also important for grazing animals, since a low magneisum supply in soils may induce hypomagnesemia or grass tetany, a potentially fatal metabolic (Cherney et al., 2002).Magnesium, the fourth most abundant mineral in the body, is an essential dietary element for humans since it is involved in several metabolic processes (e.g., ATP-dependentbiochemical reactions, synthesis of DNA, RNA expression, cell signaling at muscle and nerve levels,and glucose and blood pressure (BP) control etc.) (Rosique-Esteban et al., 2018).

For soils with magnesium deficiencies, dolomite ($CaMg(CO_3)_2$)can be used for supplementing magnesium especially in acidic soils, but it can be costly (Havlin et al., 1999). Atmospheric deposition can be a source of magnesium but its contribution to provisioning services is currently excluded from the market.Previous research by Goddard et al. (2007) quantified continental United States atmospheric wet magnesium deposition and related it to the "regulating services" with regards to the potential formation of soil inorganic carbon (SIC) stocks, but did not provide a monetary valuation of these goods and services (Brown et al., 2007). Mikhailova et al. (2018) proposed to include the atmospheric nutrient deposition in the ecosystem services assessment arguing that atmospheric deposition is not always a "public good" since it can be deposited in the soils within "private boundaries", and therefore should be considered a "private good" for which consumption is "rival" and "excludable" (Heal, 2000).

The objective of this study was to assess and rank the contribution of atmospheric magnesium (Mg^{2+}) deposition to soil provisioning ecosystem services within the contiguous United States (U.S.) by state and region. A monetary valuation of total (wet plus dry) atmospheric calcium (Mg^{2+}) deposition was calculated based on an average U.S. price of $12.90 in the year 2014 per U.S. ton of agricultural dolomite ($CaMg(CO_3)_2$)(USGS, 2016).

2. Materials and methods

2.1 Total atmospheric Mg^{2+} deposition

Maps of annual atmospheric total deposition of Mg^{2+} (kg ha^{-1}) for the years 2000 through 2015 were downloaded from the National Atmospheric Deposition Program website (NADP, 2018) in Grid format (Table 1). Details on sample collection, laboratory methods, quality control, and calculations for annual atmospheric total deposition of Mg^{2+} at field sites can be found in several open-source publications using the NADP website (NADP, 2018). A detailed explanation of the NADP mapping methodology can be found in Schwede & Lear (2014). Briefly, estimates of annual atmospheric total deposition of Mg^{2+}at field sites are spatially interpolated to a continuous raster (gridded) map layer using inverse distance weighting (IDW).

Table 1. Data sources and descriptions (adapted from Goddard et al., 2007)

Data layer	Description	Source
Mg^{2+} deposition	Inverse Distance Weightingmaps in ArcGIS® Grid format – 2500 m resolution	http://nadp.slh.wisc.edu/NTN/annualmapsByYear.aspx
Loess	Gridded 0.1° × 0.1° from maps from the U.S. Geologic Survey	Lineback et al., 1983; Miller et al., 1988; Holbrook, et al., 1990; Gray et al., 1991; Hallberg et al., 1991; Denne et al., 1993; Whitfield et al., 1993; Swinehart et al., 1994

2.2 Loess distribution

Loess distribution was mapped using 0.1 × 0.1° gridded map layers derived from U.S. Geological Survey (USGS) maps (Lineback et al., 1983; Miller et al., 1988; Holbrook et al., 1990; Gray et al., 1991; Hallberg et al., 1991; Denne et al., 1993; Whitfield et al., 1993; Swinehart et al., 1994) by Kohfeld and Harrison (2001). This map layer depicts the approximate boundaries of loess deposition (Table 1).

2.3 Data analyses

A map of the annual mean total atmospheric deposition of Mg^{2+} (kg ha^{-1}) over the study period was computed using the Cell Statistics script in ArcGIS® 10.4 (ESRI, 2016). Summary statistics of this map were computed for each of the contiguous United States using the Zonal Statistics script in ArcGIS® 10.4 (ESRI, 2016). The annual mean atmospheric total deposition of Mg^{2+} (kg ha^{-1}) over the study period for each state wasthen converted to U.S. dollars per area (i.e., hectare) and U.S. dollars in Microsoft Excel using the following equations:

$$\$/ha = (Mg^{2+} deposition, kg/ha) \times \frac{184.4\ kg\ CaMg\ (CO_3)_2}{24.305\ kg\ Mg^{2+}} \times \frac{1\ lb_m}{0.45359\ kg} \times \frac{1\ U.S.\ ton}{2000\ lb_m} \times \frac{\$\ price}{U.S.\ ton\ CaMg\ (CO_3)_2} \quad (1)$$

$$\$/ha = (price\ per\ area\ from\ eqn. 1) \times (area\ in\ ha) \quad (2)$$

Note that the price values calculated in U.S. dollars and dollars per ha represent the money that would be required simply to purchase agricultural dolomite ($CaMg(CO_3)_2$) based on an average price of \$12.90 per U.S. ton of $CaMg(CO_3)_2$ in U.S. in 2014(USGS, 2016). The values reported would not cover other important costs, such as the equipment, fuel, and labor that would be required to incorporate the magnesium amendments into the soil, nor any external costs associated with mining the dolomite etc. (Groshans et al., 2018). The reported values also assume that all magnesium being deposited onto the soils by deposition remains in the soil and is not subject to losses due to runoff, erosion, groundwater recharge, etc. Lastly, it is important to take note that the original sources of magnesium in the deposition is not accounted for in our analyses, there likely is some amount of magnesium recycling and redistribution that occurs both spatially and temporally across the U.S. (Goddard et al., 2007).

3. Results and discussion

Atmospheric Mg^{2+} deposition provides a substantial monetary value to the U.S. and it was evaluated by state and region using an accounting framework adapted from Groshans et al. (2018). Atmospheric Mg^{2+} deposition provides goods (e.g., Mg^{2+}, etc.) and services (e.g., provisioning, etc.) for agricultural benefit (e.g., liming, etc.) and therefore can be evaluated using commodity prices for agricultural dolomite ($CaMg(CO_3)_2$). The total provisioning ecosystem value of atmospheric magnesium deposition was \$47M (i.e., 47 million U.S. dollars) based on an average 2014 price of \$12.90 per U.S. ton of dolomite ($CaMg(CO_3)_2$). The value of average annual Mg^{2+} deposition varies at the country scale by state and region.

3.1 The value of average annual total Mg^{2+} deposition at the country scale by state and region (2000-2015)

The highest ranked states for value of total Mg^{2+} deposition were: 1) Texas (\$7.37M), 2) Florida (\$2.53M), and 3) California (\$2.31M), where the value shown in parentheses for each state are based on the price of agricultural dolomite. The top three states with the highest area-normalized total mean annual values were:1) Florida (\$0.18 ha^{-1}), 2) Louisiana (\$0.13ha^{-1}), and 3) Texas (\$0.11 ha^{-1}) (Fig. 1). The highest ranked regions for value of total Mg^{2+} deposition were: 1) South Central (\$10.7M), 2) West (\$9.89M), and 3) Southeast (\$8.75M), while the highest ranked regions based on area-normalized total Mg^{2+} deposition values were: 1) South Central (\$0.09 ha^{-1}), 2) Southeast (\$0.08 ha^{-1}), and 3) East (\$0.07 ha^{-1}) where again the values in parentheses are based on dolomite.

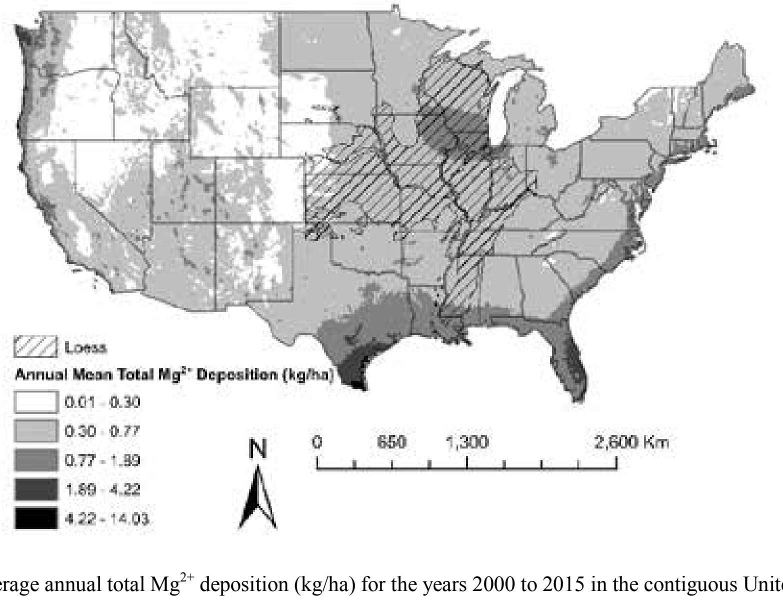

Fig. 1. Average annual total Mg^{2+} deposition (kg/ha) for the years 2000 to 2015 in the contiguous United States

Atmospheric magnesium deposition can be a significant source of a life-supporting nutrient, which is important in achieving one of the 17 United Nations (UN) Sustainable Development Goals (Millennium Ecosystem Assessment, 2005): “2. End hunger, achieve food security, and improve nutrition and promote sustainable agriculture.” Given a global population of 7.6 billion people, and a recommended daily intake of 420 mg per person per day of magnesium, it would require at least 3192 metric tons/day of magnesium to ensure that every person is able to meet their daily magnesium requirement.

4. Conclusions

Soil provisioning ecosystem services are impacted by the atmospheric input of magnesium (Mg^{2+}) ions. Annual atmospheric deposition of Mg^{2+} ions furthers the liming of soil; however, deposition spatially varies in the United States. For example, the South Central and West regions have high Mg^{2+}deposition due to proximity to the ocean. Some fraction of the deposited Mg^{2+} will be available for plant uptake. This study ranked the provisioning value of soil ecosystem services of atmospheric Mg^{2+} deposition from 2000 to 2015 within the contiguous United States by state and region. The total provisioning ecosystem value of atmospheric magnesium deposition was $47M (i.e., 47 million U.S. dollars) based on an average 2014 price of $12.90 per U.S. ton $CaMg(CO_3)$. Calculating global terrestrial soil nutrient pools and fluxes requires an understanding of the dynamic nature of atmospheric Mg^{2+} deposition. The atmosphere is traditionally viewed as a “public good” outside of market evaluation, but it can be a source of nutrients deposited to the soils within privately-owned lands in different geographic regions.

5. Acknowledgements

This study was based on data from the National Atmospheric Deposition Program (NRSP-3). Clemson University provided funding for this study. Technical Contribution No. 6671 of the Clemson University Experiment Station. This material is based upon work supported by NIFA/USDA, under projects: SC-1700541.

References

Brown T.C., Bergstrom J.C., Loomis J.B. (2007). Defining, valuing, and providing ecosystem goods and services. Natural Resources Journal 47, 29-376.

Cakmak, I. (2013). Magnesium in crop production, food quality and human health. Plant and Soil 368, 1-4.

Denne J.E., Luza K.V., Richmond G.M., Jensen K.M., Fishman W.D., Wermund G. (1993). Quaternary geologic map of the Wichita 4° × 6° Quadrangle, United States. Map NJ-14. In: Richmond GM et al. (eds.) *Quaternary Geologic Atlas of the United States*. Misc. Invest. Ser. Map I-1420. USGS, Denver, CO.

Cherney J.H., Mikhailova E.A., Cherney D.J.R. (2002). Tetany potential of orchardgrass and tall fescue as influenced by fertilization with dairy manure or commercial fertilizer. Journal of Plant Nutrion, 25(7), 1501-1525.

ESRI. (2016). ArcGIS Desktop: Release 10.4. Redlands, CA: Environmental Systems Research Institute.

Goddard M.A., Mikhailova E.A., Post C.J., Schlautman M.A. (2007). Atmospheric Mg^{2+} wet deposition within the continental United States and implications for soil inorganic carbon sequestration. Tellus, 59B, 50-56.

Groshans G.R., Mikhailova E.A., Post C.J., Schlautman M.A., Zurqani H.A., Zhang L. (2018). Assessing the value of soil inorganic carbon for ecosystem services in the contiguous United States based on liming replacement costs. Geoderma (In review).

Gray H.H., Bleuer N.K., Lineback J.A., Swadley W.C., Richmond G.M., Miller R.A., Goldthwait R.P., Ward R.A. (1991). Quaternary geologic map of the Louisville 4° × 6° Quadrangle, United States. Map NJ-16. In: Richmond GM, Fullerton DS (eds.) *Quaternary Geologic Atlas of the United States*. Misc. Invest. Ser. Map I-1420. USGS, Denver, CO.

Hallberg G.R., Lineback J.A., Mickelson D.M., Knox J.C., Goebel J.E., Hobbs H.C., Whitfield J.W., Ward R.A., Boellstorf J.D., Swinehart J.B., Dreezen V.H. (1991). Quaternary geologic map of the Des Moines 4° × 6° Quadrangle, United States. Map NK-15. In: Richmond G.M. et al. (eds.) *Quaternary Geologic Atlas of the United States*. Misc. Invest. Ser. Map I-1420. USGS, Denver, CO.

Havlin J.L., Beaton J.D., Tisdale S.L., Nelson W.L. (1999). *Soil Fertility and Fertilizers: An Introduction to Nutrient Management*. 6th Edition. Prentice Hall, Upper Saddle River, NJ, 499 pp.

Heal G. (2000). *Nature and the Marketplace: Capturing the Value of Ecosystem Services*. Washington, D.C., Covelo, California.

Hermans C., Bourgis F., Faucher M., Strasser R.J., Delrot S., Verbruggen N. (2005). Magnesium deficiency in sugar beets alters sugar partitioning and phloem loading in young mature leaves. Planta, 220, 541–549. doi:10.1007/s00425- 004-1376-5

Holbrook D.F., Gilliland W.A., Luza K.V., Pope D.E., Wermund E.G., Miller R.A., Bush W.V., Jensen K.N., Fishman W.D. (1990). Quaternary geologic map of the Vicksburg 4°x 6° Quadrangle, United States. Map NI-15. In: Richmond G.M., Fullerton D.S. (eds.) *Quaternary Geologic Atlas of the United States*. Misc. Invest. Ser. Map I-1420. USGS, Denver, CO.

Kohfeld K.E., Harrison S.P. (2001). DIRTMAP: The geological record of dust. Earth-Science Reviews 54, 81–114.

Lineback J.A., Bleuer N.K., Mickelson D.M., Ferrand W.R., Goldthwait R.P. (1983). Quaternary geologic map of the Chicago 4° × 6° Quadrangle, United States. Map NK-16. In: Richmond G.M., Fullerton D.S (eds.) *Quaternary Geologic Atlas of the United States*. Misc. Invest. Ser. Map I-1420. USGS, Denver, CO.

Mikhailova E., Cope M., Groshans G., Post C., Schlautman M., Zhang L. (2018). Contribution of atmospheric deposition to soil provisioning ecosystem services in the contiguous United States: Part 1. Calcium. DUST 2018: The International Conference on Atmospheric Dust. Villa Romanazzi Carducci, Bari, Italy. May 29-31, 2018.

Miller R.A., Maher S.W., Copeland C.W., Rheams J., LeNeathery K.F., Gilliland T., Friddell W.A., Nostrand M.S., Wheeler A.K.V., Holbrook W.H., Bush D.F. (1988). Quaternary geologic map of the Lookout Mountain 4° × 6° Quadrangle, United States. Map NI-16. In: Richmond G.M., Fullerton D.S. (eds.) *Quaternary Geologic Atlas of the United States*. Misc. Invest. Ser. Map I-1420. USGS, Denver, CO.

Millennium Ecosystem Assessment (2005). *Ecosystems and human well-being: synthesis*. Millennium Ecosystem Assessment Series. World Resources Institute, Washington, DC, p.155.

National Atmospheric Deposition Program (NRSP-3). (2018). NADP Program Office, Wisconsin State Laboratory of Hygiene, 465 Henry Mall, Madison, WI 53706. http://nadp.slh.wisc.edu/

Rosique-Esteban N., Guasch-Ferré M., Hernández-Alonso P., Salas-Salvadó J. (2018). Dietary magnesium and cardiovascular disease: A review with emphasis in epidemiological studies. Nutrients 10, 168 doi:10.3390/nu10020168.

Schwede D.B., Lear G.G. (2014). A novel hybrid approach for estimating total deposition in the United States. Atmospheric Environment, 92, 207-220.

Swinehart J.B., Dreezen V.H., Richmond G.M., Tipton M.J., Bretz R., Steece F.V., Hallberg G.R., Geobel J.E. (1994). Quaternary geologic map of the Platte River 4° × 6° Quadrangle, United States. Map NK-14. In: Richmond G.M. (ed.) *Quaternary Geologic Atlas of the United States*. Misc. Invest. Ser. Map I-1420. USGS, Denver, CO.

USGS. (2016). Minerals Yearbook, 2014: Stone, crushed [Advance Release]. U.S. Department of the Interior, U.S. Geological Survey, April 2016. 71.2 https://minerals.usgs.gov/minerals/pubs/commodity/stone_crushed/myb1-2014-stonc.pdf

Whitfield J.W., Ward R.A., Denne J.E., Holbrook D.F., Bush W.V., Lineback J.A., Luza K.V., Jensen K.M., Fishman W.D. (1993). Quaternary geologic map of the Ozark Plateau 4° × 6° Quadrangle, United States. Map NJ-15. In: Richmond G.M., Fullerton D.S. (eds.) *Quaternary Geologic Atlas of the United States*. Misc. Invest. Ser. Map. I-1420. USGS, Denver, CO.