Can gypsum mitigate eutrophication of the Baltic Sea?

Photos: Eliisa Punttila and a local farmer

Petri Ekholm

Finnish Environment Institute SYKE

12th Annual Forum of the Strategy for the Baltic Sea Region

Innovative water protection measure for agriculture – Gypsum, structure lime and other ideas

30 September 2021

Contents

- Finnish perspective on gypsum
- What is gypsum and how it works
- Pros and cons of gypsum
- Can gypsum work outside Finland

Photos: Eliisa Punttila

Background

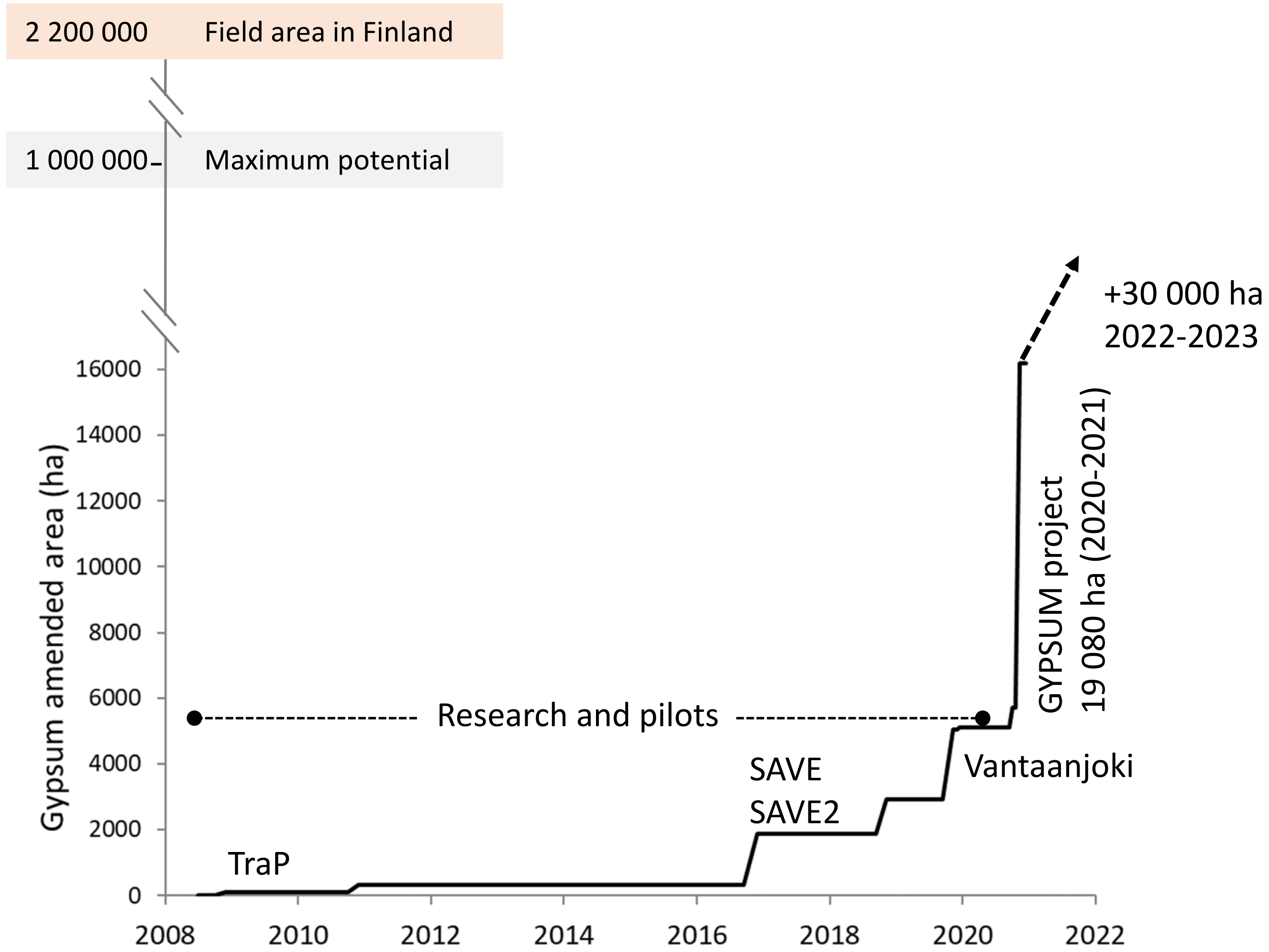
- Phosphorus load from Finland to the Baltic Sea
  - About 3500 tons per year
  - Should be decreased by 440 tons per year to meet the goals of marine strategy

Finnish programme to enhance the effectiveness of water protection

- Funded by the Ministry of the Environment
- Field plot and catchment-scale studies on the performance of
  - GYPSUM
    - Reducing nutrient load by spreading gypsum on a large scale on arable lands in the catchment area of the Archipelago Sea
  - STRUCTURE LIME
  - FIBER
    - Investigating the use of structure lime and fibre sludge as means of water protection, and provision of guidance on their use

WATER PROTECTION PROGRAMME

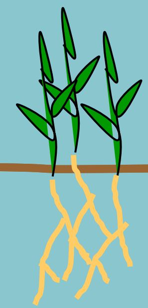
Gypsum – From laboratory to large-scale measure



Photos: Petri Ekholm, Eliisa Punttila, Pasi Valkama

How gypsum works?

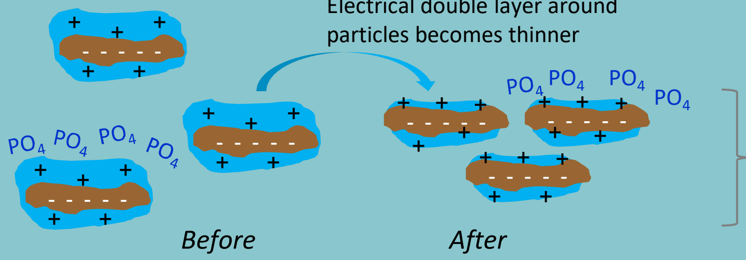
4 t/ha



Increase in S,
decrease in Se

Ionic strength of soil solution increases

Ca^{2+} SO_4^{2-}, gypsum more soluble than lime



Particles can come closer
→ aggregation
→ less prone to erosion
→ less particulate phosphorus to water

- Dissolved P will also be reduced, P being available to plants
  - Increase in ionic strength, precipitation or co-sorption with Ca
- Organic C
  - Ca acts as a bridge linking clay and organic matter (OM), formation of insoluble Ca-OM complexes, flocculation of Ca-OM complexes
- No effect on pH (unlike lime, $CaCO_3$)

Pros and cons of gypsum amendment

☺ Immediate effect

- About 50% reduction in
  - Runoff turbidity
  - The losses of
    - Suspended solids, particulate phosphorus
- Some reduction in the losses of
  - Dissolved phosphorus, dissolved organic carbon

☺ Suitable for large field areas

- Fine-textured soils
- No major agronomical restrictions
- Allows time for slower measures to work (legacy phosphorus)

☺ Several gypsum sources

- Phosphogypsum, flue-gas desulfurization gypsum, natural gypsum, recycled gypsum
- Must be free from harmful substances and not contain too much phosphorus

☺ No negative effect on the quality or quantity of yield

- Farmers have reacted positively
- Lots of calcium (777 kg/ha) and sulfur (622 kg/ha)
- Soil structure may improve

☺ No harmful effects on riverine biota (sulfate)

- Mussels, mosses, fish tested

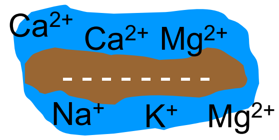
Pros and cons of gypsum amendment

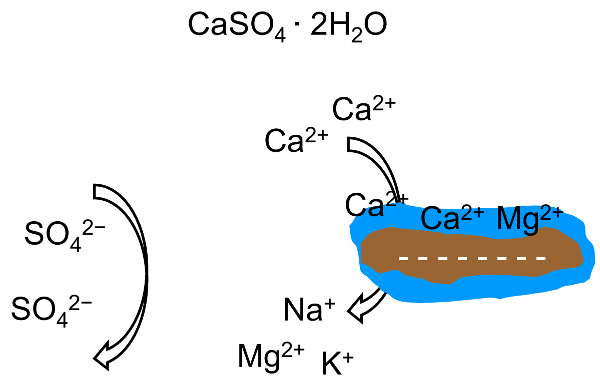
! Should be used with care in

- Catchments upstream of lakes
    - Sulfate may accelerate eutrophication of lakes and reservoirs
- Soils low in magnesium or potassium
    - Cation exchange reactions
- Ground-water areas (if leaky soils)
    - Groundwater legislation
    - Moderate increase in sulfate harmless to humans and structures
- Natura 2000 sites

☹ Selenium in crops decreases at first

😐 Temporary impact (about 4–5 years)





Can gypsum work in other Baltic Sea countries?

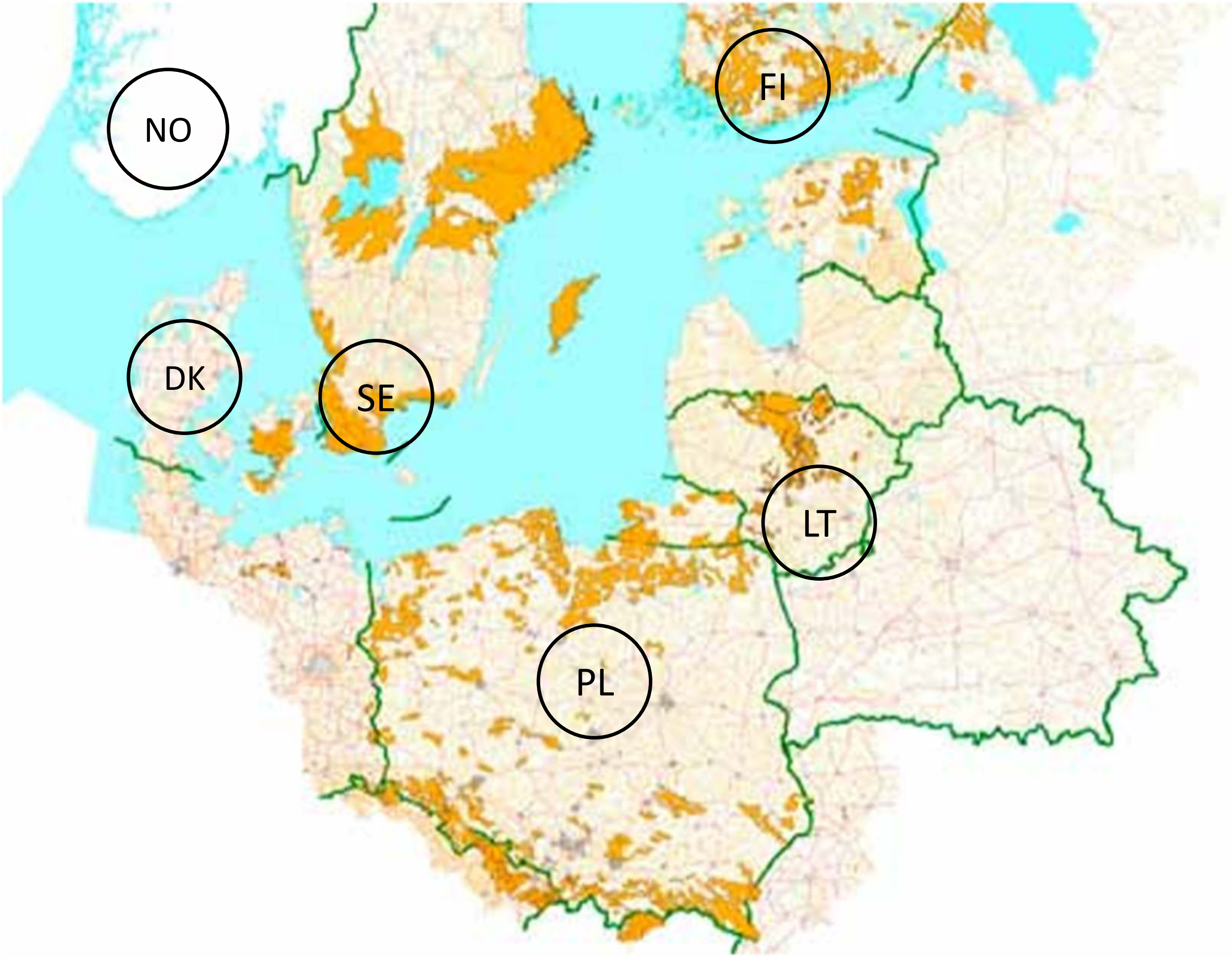


Figure 4. Clayey areas identified as FAO soil class Cambisol with EU soil map.

Tattari et al. 2012. Mapping erosion- and phosphorus-vulnerable areas in the Baltic Sea Region – data availability, methods and biosecurity aspects. MTT Report 65.

doi:10.2489/jswc.73.1.22A

FEATURE

Gypsum as a soil amendment to enhance water quality by reducing soluble phosphorus concentrations

David Kost, Joe Nester, and Warren A. Dick

It is said that lakes are born to die. As soon as a lake basin is formed, either slowly by glacial action as for the Great Lakes or rapidly by the New Madrid earthquake for Reelfoot Lake, Tennessee, in 1811 to 1812 (USGS 2012), it fills with water. It then begins to accumulate sediments and nutrients, including phosphorus (P), that increase productivity. This ultimately results in the lake basin filling with sediments and organic materials. The Maumee River drainage basin (area of 21,050 km^2 [8,132 mi^2]) on the western edge of Lake Erie occurs primarily in Ohio but also includes parts of Indiana and Michigan (figure 1). The basin has high agricultural productivity, with approximately 80% of the land devoted to row crop corn (*Zea mays* L.) and soybeans (*Glycine max* [L.] Merr.). The Maumee River drains into the shallow western basin of Lake Erie and contributes most of the sediment and one-third of soluble P that enters Lake Erie.

Runoff from agricultural fields often contains excessive P that impacts water bodies in a process called cultural eutrophication (National Academy of Sciences 1969). Beginning in the 1950s, Lake Erie was strongly affected by cultural eutrophication (Verduin 1969). In the 1960s there were large blooms of the cyanobacterium ("blue-green algae") *Microcystis* and the attached green alga *Cladophora*. *Microcystis* and other cyanobacteria produce toxins that can harm humans and other animals that contact or ingest tainted water.

Beginning in the 1960s, strong efforts were expended to reduce P input to the lake. These included banning phosphates (PO_4) from detergents, upgrading the treatment of sewage and other point sources of P, and adopting conservation tillage in agriculture to reduce erosional input of P attached to soil particles. These practices resulted in decreased blooms during the 1970s.

The return of cyanobacterial blooms to the western Lake Erie basin around 1995 implicated nonpoint sources, including agricultural runoff, as sources of P entering the lake. Since 1995, there has been a bloom in the western basin each year. In 2011, the city of Toledo, Ohio, spent several thousand additional dollars per day treating water affected by cyanobacterial blooms. In 2013 the entire surface of the lake was covered with algal blooms, and in August of 2014, a toxic bloom in western Lake Erie led to a two-day drinking water ban in Toledo. Although considered less severe in 2016 than in some recent years, the algal blooms caused by *Microcystis* cyanobacteria are still clearly evident (figure 1).

Drainage of water from fields via tile is extremely important in managing fields in the Maumee River watershed because of the cool humid climate and high water tables. Without subsurface (tile) drainage, row crop agriculture would be extremely limited. There is a clear connection between tile flow and nutrient movement from fields. Smith et al. (2015) have reported that treating only surface water runoff would not achieve the goal of 41% reduction in P loading into Lake Erie. In the St. Joseph River watershed, a tributary of the Maumee River, 48% of the total P and 49% of the soluble P losses from fields occurred through tile flow.

Gypsum is a good source of calcium (Ca) and sulfur (S) for plant nutrition and has several uses as a soil amendment including alleviating subsoil acidity, ameliorating

Figure 1

(a) Maumee River watershed and (b) *Microcystis* cyanobacteria bloom in western Lake Erie on September 20, 2016 (NOAA 2016).

(a)

(b)

David Kost is a research associate, Ohio Agricultural Research and Development Center, Ohio State University, Wooster, Ohio. Joe Nester is director of Nester Ag, Bryan, Ohio. Warren A. Dick is professor emeritus, Ohio Agricultural Research and Development Center, Ohio State University, Wooster, Ohio.

Published August 2, 2018

Journal of Environmental Quality TECHNICAL REPORTS

WASTE MANAGEMENT

Meta-Analysis of Gypsum Effects on Crop Yields and Chemistry of Soils, Plant Tissues, and Vadose Water at Various Research Sites in the USA

David Kost, Ken J. Ladwig, Liming Chen, Tom M. DeSutter, Leo Espinoza, L. Darrell Norton, Dan Smeal, H. Allen Torbert, Dexter B. Watts, Richard P. Wolkowski, and Warren A. Dick*

Abstract

Gypsum has a long history as a soil amendment. Information on how flue gas desulfurization (FGD) gypsum affects soil, water, and plant properties across a range of climates and soils is lacking. We conducted a meta-analysis using data from 10 field sites in the United States (Alabama, Arkansas, Indiana, New Mexico, North Dakota, Ohio, and Wisconsin). Each site used three rates each of mined and FGD gypsums plus an untreated control treatment. Gypsum rates included a presumed optimal agronomic rate plus one rate lower and one rate higher than the optimal. Gypsum was applied once at the beginning of each study, and then data were collected for 2 to 3 yr. The meta-analyses used response ratios (R) calculated by dividing the treatment value by the control value for crop yield or for each measured element in plant, soil, and vadose water. These R values were tested for their significance with z values. Most R values varied only slightly from 1.00. Gypsum significantly changed more R values from 1.00 for vadose water than for soil or crop tissue in terms of numbers of elements affected (11 for water, 7 for soil, and 8 for crop tissue). The highest R value for soil was 1.57 (Ca) which was similar for both mined and FGD gypsum, for crop tissue was 1.46 (Sr) for mined gypsum, and for vadose water was 4.22 (S) for FGD gypsum. The large increase in Ca and S is often a desired response to gypsum application. Lowest R values occurred in crop tissue for Mg (0.89) with FGD gypsum and for Ni (0.92 or 0.93) with both gypsums. Although some sites showed crop yield responses to gypsum, the overall mean R values for mined gypsum (0.987) and for FGD gypsum (1.00) were not significantly different from 1.00 in this short-term study.

Core Ideas

- Meta-analysis was used to evaluate gypsum treatments at 10 sites within the United States.
- Response ratios were calculated for crop yields and chemistries of soil, plants, and water.
- Crop yields showed both positive and negative results to gypsum treatments.
- Most R values for elements varied only slightly from 1.0, meaning no treatment effect.
- Concentrations of elements in samples were below levels of environmental concern.

Gypsum ($CaSO_4 \cdot 2H_2O$) is a quality source of Ca and S and has many beneficial uses in agriculture (Wallace, 1994). The most fundamental agricultural use for gypsum is to provide Ca and S for plant nutrition, and this occurs any time gypsum is used as a soil amendment. Some additional uses of gypsum include (i) remediating sodic soils by displacing Na with Ca (Mao et al., 2016); (ii) ameliorating subsoil acidity (Shainberg et al., 1989; Sumner, 1993) by displacing Al^{3+} with Ca^{2+} followed by the Al^{3+} combining with SO_4^{2-} from gypsum to form a less toxic entity; (iii) serving as an electrolyte source to promote rainwater infiltration and percolation and reduce soil swelling, dispersion, and crusting (Oster, 1982; Shainberg et al., 1989; Dontsova and Norton, 2002); and (iv) reducing water-soluble P coming off of fields (Watts and Torbert, 2009, 2016; Torbert and Watts, 2014; King et al., 2016). These effects have the potential to improve soil and water quality and also crop yields. The sustainable use of flue gas desulfurization (FGD) gypsum was recently summarized from a group of 10 papers published in a special section of this journal (Watts and Dick, 2014). Two other recent and relevant reviews on the use of gypsum as a soil amendment were authored by Wang and Yang (2018) and Zoca and Penn (2017).

Increasing volumes of FGD gypsum have become available for agricultural use due to electricity-producing utilities installing forced oxidation scrubbers that produce byproduct gypsum. The USEPA has published a brochure that describes agricultural uses of gypsum, specifically FGD gypsum, as a soil amendment (USEPA, 2008). The USDA-NRCS has also published a national standard related to appropriate use of gypsum for different purposes (USDA-NRCS, 2015). To date, 20 states have included the standard for applying gypsum as a soil amendment for promotion of this practice in their state (USDA-NRCS, 2018). However, continued widespread adoption of FGD gypsum by farmers and regulatory personnel requires documentation of its effectiveness and safety.

J. Environ. Qual. 47:1284–1292 (2018)
doi:10.2134/jeq2018.04.0163

Received 24 Apr. 2018.
Accepted 18 June 2018.
*Corresponding author (dick.5@osu.edu).

D. Kost, L. Chen, and W.A. Dick, School of Environment and Natural Resources, The Ohio State Univ./The Ohio Agricultural Research and Development Center, Wooster, OH 44691; K.J. Ladwig, Electric Power Research Institute (EPRI), Palo Alto, CA 94304; T.M. DeSutter, Soil Science Dep., North Dakota State Univ., Fargo, ND 58108; L. Espinoza, Crop, Soil & Environmental Science, Univ. of Arkansas, Little Rock, AR 72204; L.D. Norton, USDA-ARS National Soil Erosion Research Lab., West Lafayette, IN 47907; D. Smeal, Plant and Environmental Sciences, New Mexico State Univ., Agricultural Science Center, Farmington, NM 87499; H.A. Torbert and D.B. Watts, USDA-ARS National Soils Dynamics Lab., 411 S. Donahue Dr. Auburn, AL 36832; R.P. Wolkowski, Dep. of Soil Science, Univ. of Wisconsin–Madison, Madison, WI 53706. Assigned to Associate Editor Peter Kopittke.

Abbreviations: CVAFS, cold vapor atomic fluorescence spectrometry; FGD, flue gas desulfurization; ICP–AES, inductively coupled plasma–atomic emission spectroscopy; L, natural log of the response ratio; R, response ratio.

Finnish studies on gypsum

Partly in Finnish

Alestalo L. 2011. Keväällä levitetyn kipsin vaikutukset suorakylvöpellolle. Laurea-ammattikorkeakoulu, Hyvinkää.

Aura E, Saarela K, Räty M. 2006. Savimaiden eroosio. MTT:n selvityksiä 118. In Finnish.

Ekholm P, Jaakkola E, Kiirikki M, Lahti K, Lehtoranta J, Mäkelä V, Näykki T, Pietola L, Tattari S, Valkama P, Vesikko Lj, Väisänen S. 2011. The effect of gypsum on phosphorus losses at the catchment scale. The Finnish Environment 33.

Ekholm P, Valkama P, Jaakkola E, Kiirikki M, Lahti K, Pietola L. 2012. Gypsum amendment of soils reduces phosphorus losses In an agricultural catchment. Agricultural and Food Science 21:279–291.

Iho A, Laukkanen M. 2012. Gypsum amendment as a means to reduce agricultural phosphorus loading: an economic appraisal. Agricultural and Food Science 21:307–324.

Iho A, Lankoski J, Ollikainen M, Puustinen M, Lehtimäki J. 2014. Agri-environmental auctions for phosphorus load reduction: experiences from a Finnish pilot. Agricultural and Resource Economics 58:205–222.

Kosenius A-K and M. Ollikainen 2018. Drivers of participation in gypsum treatment of fields as an innovation for water protection. Ecological Economics: 157:382-393.

Malmilehto S, Kaipainen R, Muurinen S. 2021. Kipsin kevätlevityksen vaikutus juurikkaan ja viljan kasvuun. Sokerijuurikkaan Tutkimuskeskus, SjT. Raportti KIPSI-hankkeelle.

Mattila T, Manka V, Rajala J. 2019. Kipsi maanparannusaineena – hyödyt ja haitat maan kasvukunnolle. Raportteja 192. Helsingin yliopisto, Ruralia-Instituutti. (In Finnish.)

Ollikainen M, Kosenius A-K, Punttila E, Ala-Harja V, Puroila S and Ekholm P. 2020. Gypsum Amendment of Arable Fields – Farmers' Experience from a Large Scale Pilot. Agricultural and Food Science.

Pietola L, 2008. Gypsum-based management practices to prevent phosphorus transportation. NJF Report, Vol 4, Nr 4.

Uusitalo R, Ylivainio K, Rasa K, Kaseva J, Pietola L, Turtola E. 2012. Gypsum effects on the movement of phosphorus and other nutrients through undisturbed clay soil monoliths. Agricultural and Food Science 21:260-278.

Vantaanjoen kipsihanke 2020. Loppuraportti 30.11.2020. Ympäristöministeriö.

Yli-Renko M, Rasa K. 2011. Kipsikokeilu TEHO-hankkeessa. s. 34–54. Kulmala A. (toim.) TEHO-hankkeen julkaisuja 1/2011.





Photos: Janne Artell, John Nurminen foundation, Eliisa Punttila, Pasi Valkama, a local farmer

Petri Ekholm, Finnish Environment Institute
petri.ekholm@syke.fi

Gypsum Initiative project
https://johnnurmisensaatio.fi/en/projects/gypsum-initiative/

SAVE project
SAVE – Saaristomeren vedenlaadun parantaminen peltojen kipsikäsittelyllä (helsinki.fi)

Ympäristöministeriö
Miljöministeriet
Ministry of the Environment

Ulkoministeriö
Utrikesministeriet

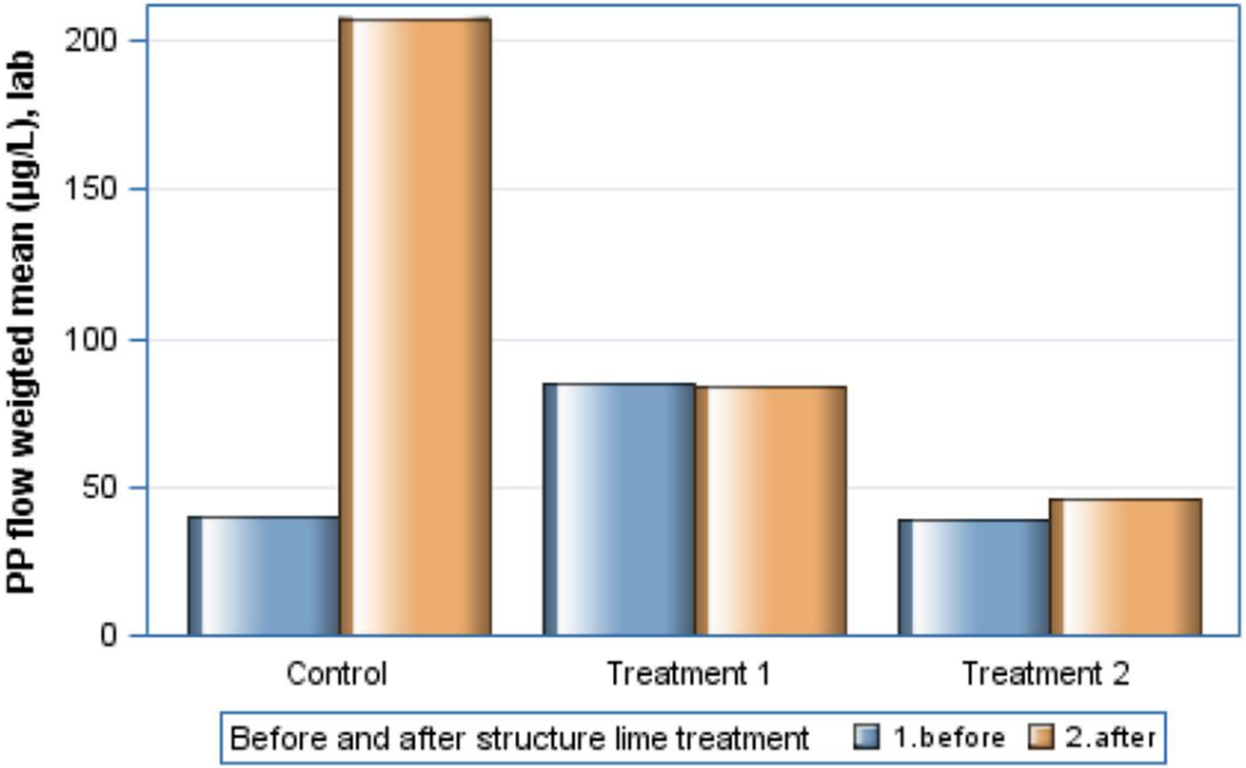
HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

SYKE

JOHN NURMINEN FOUNDATION

Finnish experiences on structure lime

Preliminary results from a catchment study



No clear change in dissolved phosphorus or dissolved organic carbon

Structure lime project, unpublished data