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Gypsum amendment of fields as a water protection measure in agriculture

Gypsum amendment of fields brings a much-needed boost to water protection in agriculture. This information package explains the implementation and impact of gypsum amendment, in the light of research and practical experiences.

SAVE *– Saving the Archipelago Sea by applying gypsum to agricultural fields is a joint research project between the University of Helsinki and the Finnish Environment Institute (2016–2018), funded by the Ministry of the Environment. The study is based on an extensive pilot, carried out by the SAVE project in collaboration with the NutriTrade project (2015–2018) funded by the EU Central Baltic programme.*

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Water protection solutions in agriculture

Agriculture provides livelihoods for farmers, food for society, and beautiful rural landscapes for citizens. However, the environment is being burdened by nutrients and soil running off fields into water bodies. These cause eutrophication and turbidity in water bodies. The leaching of phosphorus is strongest from fields susceptible to erosion, or that have abundant phosphorus reserves. Such fields can be found in the river basin of the Archipelago Sea. The fields of Southwest Finland are one of the major sources of nutrient load listed by HELCOM (Baltic Marine Environment Protection Commission – Helsinki Commission).

Farmers have been making efforts to reduce the nutrient load in agriculture for over 20 years. However, the means used, such as protection strips combined with fertilisation restrictions, have not been sufficiently effective to reduce the phosphorus load. Additional water protection should be sought using means that are suitable for the widest possible area of arable land and easily implemented among other farm work.

Gypsum amendment as a water protection measure is simple to implement and feasible for large-scale use. It supports current measures for reducing phosphorus leaching and accelerates the achievement of the related goals. Gypsum has a direct impact on leaching, which improves the state of coastal waters. As a non-productive investment, it is also eligible for support through agricultural subsidy programmes.

Gypsum has long been known as a soil conditioner, whose active mechanism has been understood for almost a hundred years. The effect of gypsum on the soil's ability to bind phosphorus and limit its leaching into water has been studied for the last 10 years in Finland. In 2016, an extensive pilot project carried out in Southwest Finland involved a detailed investigation of the preconditions for the large-scale use of gypsum, and the potential risks.

The gypsum amendment of fields is now ready for large-scale use in order to enhance water protection in agriculture. The method is suitable for over 500,000 hectares of arable land in Finland located in the river basins of water bodies flowing into the Bothnian Sea, the Archipelago Sea and the Gulf of Finland. Gypsum amendment is easy to implement and the desired water protection impact can be achieved with a small amount of gypsum; 4t/ha. The reductive effect of gypsum on phosphorus leaching is currently thought to last around five years.

With gypsum amendment, the gypsum load flowing into the Baltic Sea can be reduced immediately and at low cost. No adverse effects, due to the sulfate contained in gypsum, have been observed in the river environment. Due to the water protection benefits of gypsum amendment, it can easily be made eligible for the EU's agricultural subsidies. This would enable the rapid removal of the agricultural sector's nutrient loading of the Archipelago Sea from HELCOM's list of the most burdensome emission sources.

This information package describes the use of gypsum as a water protection method. The content is based on both previous research and the results and practical experiences of the SAVE project. It is intended to help those involved in implementing agricultural water protection measures as well as others working at the related issue.

WHAT IS GYPSUM?

Gypsum is calcium sulfate with two bonded crystal water particles; it has the chemical formula $CaSO_4 \cdot 2H_2O$. Gypsum occurs in nature as a mineral which can be mined, but also an industrial by-product. It can also be easily recycled. When the gypsum's origin is known and it is confirmed that its contents are pure, it is safe for use in agriculture.

In Finland, gypsum is available as a by-product of the phosphoric acid industry from Siilinjärvi. Gypsum is formed through a process whereby locally mined apatite is dissolved in sulfuric acid. Because apatite from Siilinjärvi contains no heavy metals or radioactivity, the gypsum generated by its process is safe to use.

HOW GYPSUM WORKS IN SOIL?

Gypsum can be used for the rapid reduction of phosphorus leaching from fields, since it begins to take effect immediately as it dissolves into the soil. This is due to the increase in the ionic strength of the soil.

When gypsum is spread on soil, water in the soil makes it dissolve into calcium and sulfate ions. The increased ion strength compresses the electrical double layer surrounding the soil particles. The soil particles get closer together and form larger microparticles. Calcium also forms bridges between soil particles. In addition, the phosphorus can bind more tightly to the surface of soil particles, reducing the amount of phosphorous released into soil water. However, the phosphorus remains available to plants as before.

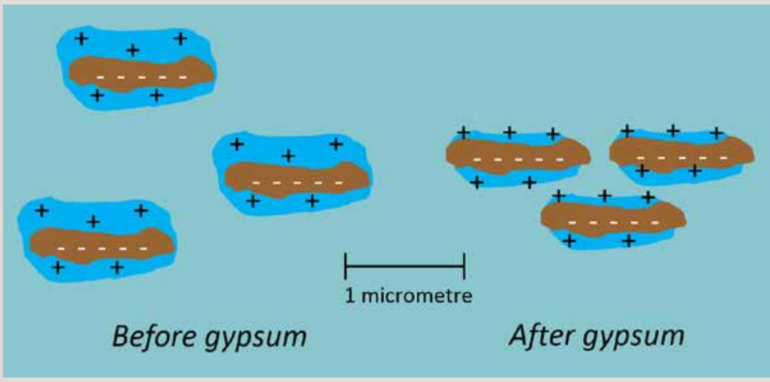
THE EFFECT OF GYPSUM ON NUTRIENT LEACHING FROM FIELDS

Gypsum amendment significantly reduces erosion and the leaching of both dissolved reactive phosphorus and particulate phosphorus which is bound to the soil. Dissolved phosphorus can be directly used by algae. Particulate phosphorus only affects eutrophication when it dissolves in water.

The increased ionic strength in soil due to gypsum also reduces the run-off of dissolved organic carbon. In addition, as erosion reduces, less carbon bound to soil leaches into water bodies. Like phosphorus and nitrogen, carbon is an important factor in eutrophication. To improve the soil structure and mitigate climate change, carbon should be bound to fields rather than escaping into water bodies.

Gypsum is a white, powdery substance (Photo: Janne Artell)

Newly spread gypsum looks like a thin layer of snow on the surface of a field (Photo: Eliisa Punttila)



The surfaces of negatively charged soil particles have a layer of positively charged ions. Gypsum condenses the electronic double layer and the particles are compacted. (Picture: Petri Ekholm)

A manure spreader (in the picture) or lime spreader can be used to spread gypsum. (Photo: Janne Artell)

HOW IS GYPSUM SPREAD?

Gypsum amendment is easy. Gypsum is spread from lime or manure spreader. Research findings suggest that 4 t/ha of gypsum is sufficient dose to achieve effective water protection. Gypsum should be spread after the harvest and before tilling. It is suitable for all tilling methods: ploughing, light tilling and no-till farming. From the water protection perspective, the best result is achieved if the field is tilled lightly after spreading, because the gypsum then mixes more evenly into the soil and is less likely to leach from the surface.

No-till sowing should not be carried out directly after gypsum spreading, because the ionic strength of the field's surface may temporarily rise so high that it hampers germination. Gypsum can be spread on stubble fields in the autumn if the farmer is planning no-till sowing in the spring. Gypsum should not be spread on snow or frozen ground, because the gypsum may then be washed away by meltwater or rain before dissolving into the soil.

In order to prevent soil compaction, gypsum should be spread during a dry period, if possible. It is recommended to be spread fairly soon after being delivered to a farm. If necessary, gypsum can be stored at the side of the field, protected from wind and rain by a tarpaulin, for example. This will prevent the gypsum from spreading into the environment and avoid the hardening of the pile's surface. The hardening of the gypsum could hamper, and affect the evenness of, spreading.

CAN GYPSUM AMENDMENT BE REPEATED?

The current information indicates that the impact of gypsum amendment on water quality lasts around five years. The duration of gypsum amendment's effect on the Savijoki river pilot area is being monitored through continuous measurements and water and soil samples until at least 2020. This will provide additional information on when the gypsum amendment should be renewed. If the gypsum amendment is repeated, the suitability of each plot should be reviewed in the same way as for the first round of amendment.

FARMERS' EXPERIENCES OF GYPSUM SPREADING

A total of 55 farmers were involved in a gypsum-spreading pilot carried out in the Savijoki river basin in Lieto and Paimio in the autumn of 2016. The farmers ordered the gypsum through an agricultural retailer. Most of the spreading (80% of the farms) was done through a contractor, and the rest with the farms' own equipment. After gypsum amendment, 58% of the fields were subject to light tilling, 33% were ploughed and 9% were left untilled. Nine out of ten of the farmers estimate that the different stages of gypsum amendment – delivery, gypsum storage and transport around the farm, and spreading – went well. More than 70% considered the method well suitable for use between other farm works at field. On individual farms, difficulties arose due to the capacity of the related fields, later-than-expected threshing, and windy weather. The success of the large-scale pilot was promoted by long spells of dry and fair weather in the autumn of 2016. The experiences of farmers were gathered through surveys and joint events between 2016 and 2017.

MONITORING WATER QUALITY IN THE SAVIJOKI RIVER

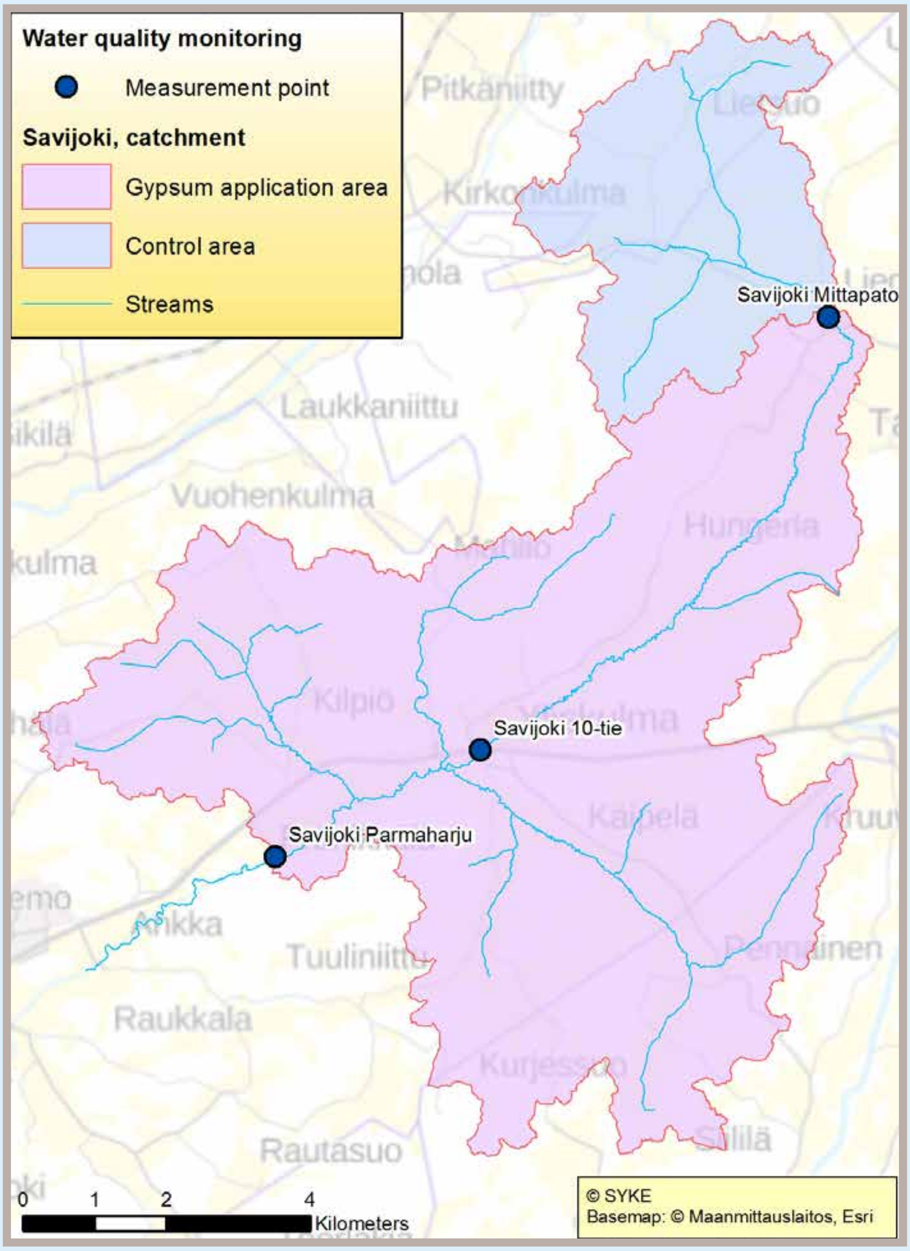
The Savijoki river, which is a tributary to the Aurajoki river, was monitored before and after the spreading of gypsum, using sensors and manually gathered samples at three observation sites between 2016 and 2018. The size of the research area is 82km2, 43% of which is arable land. The total area of gypsum-treated plots is 1,500ha (18% of the total area, 42% of the arable land). The headwaters of the Savijoki river serves as a control area in which no gypsum has been spread.

The research plot includes forest, inhabited areas and fields that have been cultivated in various ways. The fields have different soil types, of which clay is the most common. The diversity of the area creates an additional challenge when evaluating water quality, but represents an opportunity for examining the method's effectiveness in a mosaic of varying conditions. The effects of gypsum amendment on water quality have previously been investigated in a smaller river basin (the TraP project) and several laboratory tests.

EFFECT OF GYPSUM AMENDMENT ON NUTRIENT LEACHING

Solid matter. During the first autumn rains, there was a perceivable change in the turbidity of the runoff water. According to sensor measurements, the gypsum reduced the amount of solid matter running off the treated fields by around half in the first two years. Gypsum amendment therefore markedly reduces the amount of solid matter that causes turbidity and settles on the bottom of water bodies.

Particulate phosphorus. The leaching of particulate phosphorus was reduced in proportion to the leaching of solids. A reduction of around 50% has therefore been achieved so far by the SAVE project, and one of 60% by the TraP project. The comparison must take account of the fact that no precise figures can be obtained for major land use to the extent practiced in the Savijoki river basin with varying field characteristics.



The research area extends to the municipalities of Lieto, Paimio and Aura. The water quality measurement points are shown in the map. (Picture: Juha Riihimäki)

The meandering Savijoki river, close to the lowest measuring point on the Parmaharju Ridge in Lieto (Photo: Janne Artell)

Dissolved phosphorus. Laboratory tests and previous field tests have shown that gypsum reduces the leaching of dissolved phosphorus. There is also a theoretical basis for the phenomenon. A reduction of around 25% was achieved by the TraP project. The impact of the SAVE project could not yet be assessed, because the dissolved phosphorus content of the relatively rarely taken manual samples varied too much within the research area. Greater precision will be achieved by 2020, when the number of observations has increased.

Organic carbon. The increased ionic strength in soil due to gypsum reduces the runoff of dissolved organic carbon. On this account, gypsum has been trialled as a means of reducing organic carbon leaching in Australia. In the Savijoki river pilot project, gypsum significantly reduced the leaching of organic carbon. The precise reduction percentage cannot yet be calculated because, unlike particulate phosphorus, dissolved organic carbon also runs off non-agricultural land in large amounts. Gypsum reduced the leaching of carbon bound to soil by around 50%.

Calcium, magnesium and potassium. Gypsum contains calcium, which is absorbed by the surface of soil particles. It can also displace other cations in the soil, such as magnesium and potassium, which can be released into soil water. In the Savijoki river, it was found that calcium and soluble sulfate leached in mostly equivalent amounts. Only a relatively small portion of the calcium therefore remained on the surface of the soil particles. There was a slight increase in the runoff of other cations.

SULFATE CONTENT OF THE SAVIJOKI RIVER

The sulfate content of gypsum was considered a key risk factor in gypsum amendment. Sulfate is a naturally occurring substance that is abundant in sea water, for example. Being highly soluble, it also leaches off fields over a period of years. After gypsum spreading, the Savijoki river had an average sulfate content of 32 mg/l (Parmaharju), compared to 11 mg/l before spreading. In the first rains after spreading, sulfate concentrations briefly rose to 320 mg/l, but did not exceed 100 mg/l at any time thereafter.

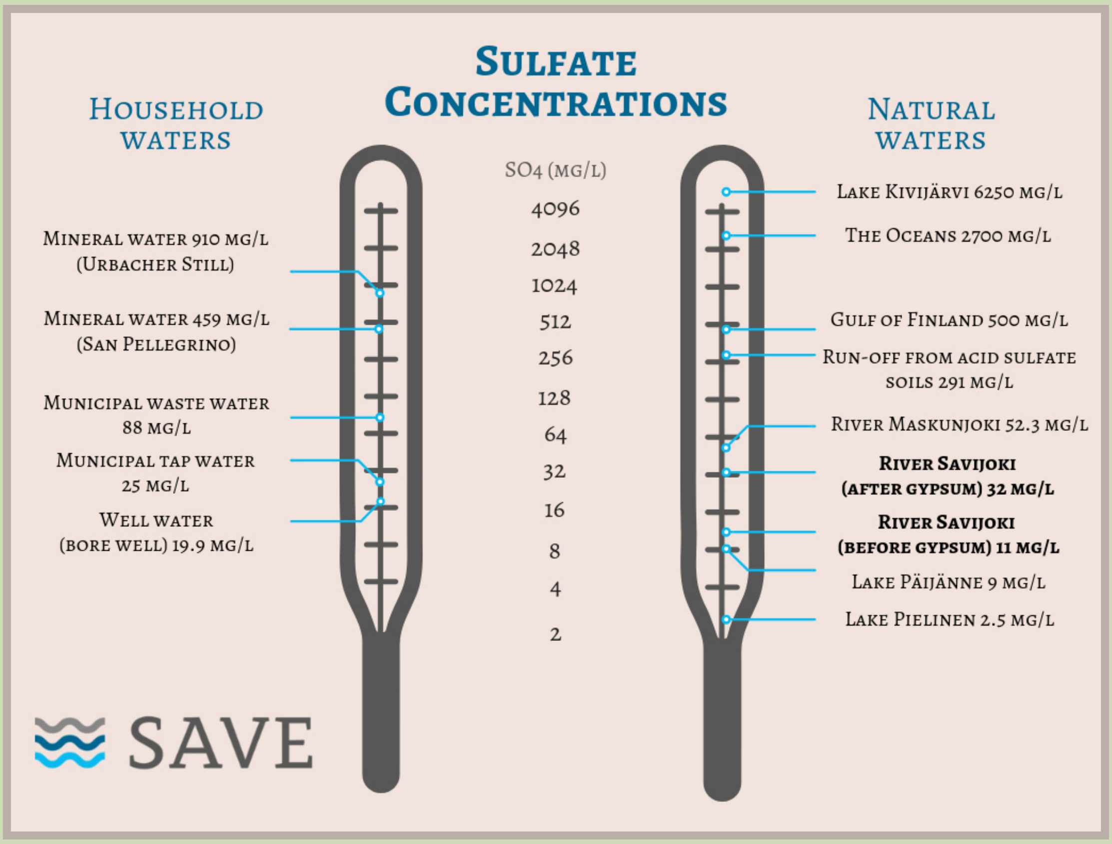
EFFECTS ON THE AQUATIC ENVIRONMENT

The SAVE project involved an investigation of the effects of large-scale gypsum amendment on the biota of small watercourses, and sulfate tolerance tests were carried out in a laboratory. Few previous studies have been conducted involving similar concentrations. The measured sulfate concentrations were found to have no adverse effects on the behaviour or occurrence of adult thick-shelled river mussels, or the survival of their larvae. Neither was any effect observed on fish stocks (including the reproduction of trout) or in the growth of antifever fontinalis moss. Further findings on the effects of gypsum amendment on trout reproduction will be obtained from the gypsum spreading project of the Vantaanjoki river between 2018 and 2019.

Upon entering a lake, water with leached sulfate can increase the release of phosphorus from the bottom and thus accelerate eutrophication (the so-called internal load). Gypsum is therefore not recommended for use in lake basins – with the exception of flow-through lakes, which have very short water retention times. The effect of sulfate on bottom sediments was evaluated in a study by the Turku University of Applied Sciences, which was carried out in collaboration with the SAVE project. Flowing waters tend to be oxygenous, with low quantities of material settling on the bottom. The risk of significant phosphorus release into river bottom sediments is therefore low: this view is also supported by the monitoring of water quality in the Savijoki river.

COULD GYPSUM END UP IN GROUNDWATER?

Because the sulfate and calcium contained in gypsum easily runs off with water, it can end up in groundwater after being filtered through soil strata. Gypsum is not therefore recommended for use in groundwater formation areas, although moderate concentrations of sulfate or calcium are not detrimental to humans or infrastructure. Samples were taken from seven wells located close to the gypsum-treated plots in the Savijoki pilot area. There was no change in the sulfate or calcium levels of the well water, aside from that of one well. It is suspected that surface water had run off into the well, because there had been a significant increase in nitrate, which is not contained in gypsum.



Sulfate levels in domestic and natural waters (Figure: Petri Ekholm & Samuli Puroila)

Crops on the pilot-area plots during the summer after gypsum spreading (Photo: Riikka Mäkilä)

MONITORING OF SOIL AND CROPS

The SAVE project monitored crops and the soil on 30 plots before and after gypsum spreading. Basic tests and microbial activity evaluations were carried out on soil samples, and Eurofins' extensive plant and selenium analyses on crop samples. In addition, the farmers in the area were asked for supplementary observations.

HOW DOES GYPSUM AFFECT SOIL?

Gypsum dissolves rapidly in soil, which was reflected in higher sulfur concentrations and conductivity values in a fertility analysis carried out during the summer following the gypsum spreading. Sulfate binds weakly to soil, as shown by the clear reduction in sulfur levels in a soil analysis in the following year. Some calcium from the gypsum remains in the cation exchange sites, displacing the magnesium and other cations from the particle surfaces. Gypsum spreading has no effect on the phosphorus state or pH value of the soil.

The impact of gypsum on soil structure was not investigated during the SAVE project, but responses to the farmer survey included references to improved soil structure. The effect of gypsum on the soil's microbiology was investigated in the year following the spreading of gypsum. There were no differences between the microbiological activity of the soil in the treated and untreated plots.

HOW DOES GYPSUM AFFECT CROPS?

Gypsum has no effect on the suitability of soil phosphorus for plants, and no changes were observed in phosphorus concentrations in crops. Sulfate in gypsum has been found to impair the absorption of selenium by plants during the first year after gypsum spreading (TraP project). This should be noted during selenium fertilisation or in the feeding of animals if the crops in question are used as animal feed. However, no declines in selenium were observed in the case of the Savijoki river; concentrations were generally low in the region. It has also been suggested that gypsum reduces the absorption of boron, but no support has been found for this claim. The sulfur content of the crop rose in the gypsum-treated plots.

FARMERS' OBSERVATIONS OF FIELDS

The survey indicated that none of the farmers in the Savijoki river area observed impaired yields or adversely affected soil due to the gypsum. Individual farmers estimated that the gypsum's effect on yields was positive. Most could not detect any effect on yields. Soil improvements were reported by farmers who either ploughed or light-tilled their fields in particular – about one-third of them believed that the gypsum had a positive effect on the soil. A few farmers also believed that the gypsum had improved the soil in the case of non-tilling. A third observed a certain degree of compaction in the fields due to spreading work, and a quarter noted that some ruts had been left. However, no major problems arose with regard to gypsum spreading and most experienced no problems at all.

WHERE CAN GYPSUM BE USED?

Gypsum is particularly suitable for reducing phosphorus runoff on clay soils. Regional targeting is recommended with regard to the method. Around 540,000 hectares of the drainage basins of the Bothnian Sea, Archipelago Sea and Gulf of Finland, or around a quarter of Finland's entire arable area, are potentially suitable for the spreading of gypsum. The parts of the drainage basins in which gypsum spreading is recommended are shown in yellow on the map. Organic farming is being carried out on around 10% of the suitable arable area.

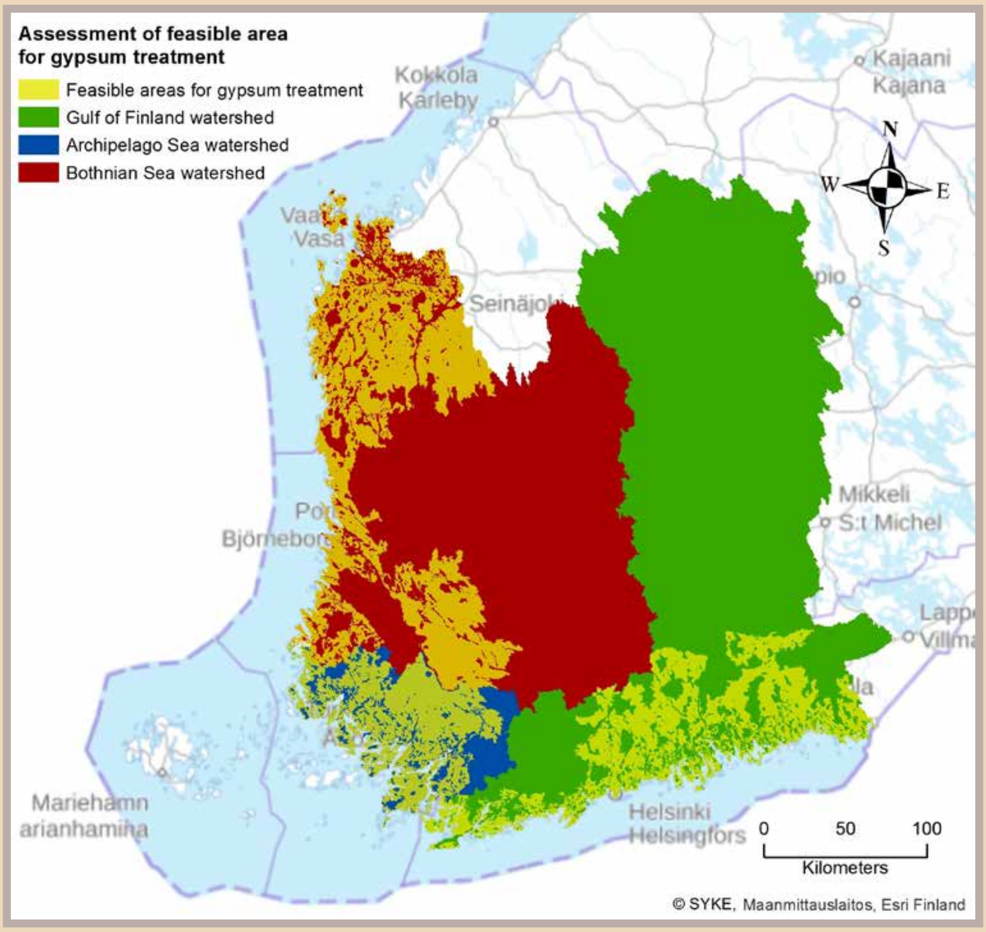
The potential area was estimated by excluding the areas where gypsum amendment is not recommended due to issues such as the sulfate content of gypsum. Sulfate is not harmful after entering the sea, since sea water is naturally rich in sulfate. On the other hand, in lake-basin areas gypsum should not be used until information can be gained on how strongly sulfate runoff affects the sulphur content of bottom waters especially in lakes with slow water exchange. A rise in sulfate levels could increase the release of phosphorus from lakebed sediments and accelerate eutrophication. In addition, gypsum is not recommended for use in or near Natura areas. In groundwater areas, careful consideration should be given to the use of gypsum, as for other agricultural activities such as the spreading of slurry. Furthermore, gypsum is not recommended for use in acidic sulfate soils either, where it has only a negligible effect on the runoff of phosphorus.

WHAT MUST BE TAKEN INTO ACCOUNT AT FARM LEVEL?

According to the EU organic farming regulation, natural gypsum can be used in organic farming but industrially produced gypsum (such as Siilinjärvi gypsum) cannot.

Gypsum is not recommended for use in fields that have a deficiency of potassium or magnesium and are correspondingly rich in calcium. The addition of calcium displaces potassium and magnesium from the surfaces of soil particles, highlighting the imbalance between their various cations. Gypsum does not affect the acidity of arable land. If there is an acidity problem in a field, it is recommended to be treated with lime before using gypsum as a means of water protection. If a well is located in the gypsum spreading area, a protected zone should be left around the well.

Gypsum produced as a by-product of the phosphoric acid industry contains a small amount of phosphorus (e.g. 0.2% in Siilinjärvi gypsum). The farmer may choose to take this into account when determining the amount of phosphorus fertilisation. However, the fertiliser restrictions associated with environmental compensation take no account of the amount of phosphorus contained in gypsum.



Around 540,000 hectares of arable land is suitable for gypsum amendment in Finland. The use of gypsum in agriculture is safe in the yellow areas on the map. (Picture: Juha Riihimäki)

Drainage basin	Suitable area for gypsum spreading, ha	P-load reduction, t/y	P-load reduction target, t/y
Bothnian Sea	240 000	132	60
Archipelago Sea	150 000	98	100
Gulf of Finland	150 000	83	170
Total	**540 000**	**312**	**330**

Arable area suitable for gypsum amendment, annual phosphorus load reduction due to gypsum amendment and the objectives of the Finnish Marine Strategy by drainage basin

MAJOR POTENTIAL IN MARINE PROTECTION

Gypsum amendment is an important opportunity from the perspective of protecting the Baltic Sea. In Finland, gypsum amendment could reduce the phosphorus load reaching the Baltic Sea by 300 tonnes a year. Such a major reduction would help achieve the phosphorus reduction targets set by the HELCOM Baltic Sea Action Plan and the Finnish Marine Strategy. If gypsum amendment were also introduced in Sweden, Denmark and Poland, for example, an annual reduction of 1,500 to 2,000 tonnes would be achieved. In the long term, such a major reduction would begin to affect the condition of the entire Baltic Sea.

INCLUSION TO THE CURRENT PHOSPHORUS POLICY

In Finland, attempts have been made to reduce agricultural phosphorus leaching by preventing the runoff of solid matter and limiting the amount of phosphorus fertilisation in fields which have higher phosphorus levels. However, phosphorus leaching from fields with high phosphorus levels only reduces in the long run, when excess phosphorus is removed from the soil along with the crop. On the other hand, stepping up anti-erosion activities is costly. With gypsum amendment, a reduction in phosphorus runoff can be achieved faster and more cost-effectively than with current means.

COSTS OF GYPSUM AMENDMENT

Because gypsum amendment does not reduce yields or the arable area, it does not result in loss of income for farmers. In addition, no equipment investments are required, since gypsum can be spread using existing equipment. The costs of gypsum amendment have been ascertained in the Savijoki river pilot and earlier projects, all of which involved the use of Siilinjärvi gypsum. The total cost of the process was around EUR 220 per hectare. Transportation from Siilinjärvi to the farms accounted for about 60% of the cost. The remainder is divided between the material and the costs incurred at the farm.

COST-EFFECTIVENESS

The cost of gypsum amendment in proportion to its ability to reduce the phosphorus load in agriculture is around EUR 60 to 70 per kilogram of phosphorus reduced. Such a benchmark can help in finding the most advantageous ways of reducing the phosphorus load in agriculture. Existing means of reducing the phosphorus load, such as the addition of protection strips and wetlands, would be considerably more expensive.

HOW TO PROMOTE GYPSUM AMENDMENT?

There are good grounds for using public funds to promote the gypsum amendment of fields, since the resulting load reduction would directly benefit society through the improved condition of water bodies.

- Gypsum amendment should be linked to agricultural support schemes, such as the scheme for non-remunerative agricultural investments.
- The EU's agricultural policy should promote the use of gypsum for water protection in the Baltic Sea region.
- HELCOM should add gypsum amendment to its list of recommended measures.
- Research into the effectiveness, feasibility and acceptability of gypsum amendment should be promoted in the Baltic Sea countries.

FARMERS' VIEWS ON GYPSUM AMENDMENT

If gypsum amendment were covered by the agricultural support scheme, most farmers who participated in the Savijoki river pilot project thought that they would use the scheme. The experiment was positive for many of them and they would be ready to recommend the use of gypsum to others.

GOVERNMENT KEY PROJECT

MEASURE BACKED UP BY SCIENCE AT CATCHMENT LEVEL

Erkki Aura began to study the impact of gypsum on clay erosion in the early 2000s. His experiments were followed by Kemira GrowHow's laboratory tests and the TraP project in 2007–2010, in which rain simulation tests were carried out in a laboratory and a 100-hectare pilot was performed in Nurmijärvi. The effects were monitored by the TraP Follow up project. At the same time, the implementation of gypsum amendment was tested alongside farmers in the TarVeKe project. The TEHO project involved examining the impact of gypsum addition on soil characteristics, and investigating the spreadability of gypsum. In gypsum pilots performed for the SAVE and NutriTrade projects, the suitability of gypsum amendment was tested for large-scale use. In 2018, a new gypsum spreading project began in the Vantaanjoki river basin in Uusimaa.

GYPSUM PILOT IN THE SAVIJOKI RIVER BASIN

The Savijoki river gypsum pilot assessed the suitability of gypsum amendment for large-scale use in improving the condition of the Archipelago Sea and the entire Baltic Sea. A total of 55 farmers in Southwest Finland were involved in the project, in which gypsum was spread over more than 1,500 hectares of arable land in autumn 2016.

Projects and financiers: The SAVE Project (2016–2018), funded by the Finnish Ministry of the Environment, and the NutriTrade project funded by the EU Interreg Central Baltic (2015–2018). SAVE is part of the government's key project of circular economy.

Parties implementing the projects: University of Helsinki and the Finnish Environment Institute

Partners: John Nurminen Foundation, Natural Resource Institute Finland, Yara, Baltic Sea Action Group, the agricultural producer associations MTK and SLC, Southwest Finland ELY Centre, Luode Consulting, Lounais-Suomen vesiensuojeluyhdistys, University of Jyväskylä, Turku University of Applied Sciences, Nixplore, ProAgria and Eurofins

SAVE
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