Trapping phosphorus

for a cleaner Baltic Sea

Agriculture and phosphorus load

This brochure presents novel methods for significantly decreasing phosphorus discharge from agricultural soils into waters. The solutions are based on the TraP research project.

Crops need phosphorus

Phosphorus (P) is an essential plant nutrient. Crop growth requires phosphorus but soils typically cannot supply sufficient phosphorus for plant needs.

In past decades phosphorus fertilization exceeded the amount in the harvested yields. Over-fertilization was due to high retention of phosphorus by soils originally poor in phosphorus. Otherwise, plant-available soil phosphorus remained too low to reach plant needs. Today, soil phosphorus status is better and fertilization rates of phosphorus equals plant uptake.

Some fields, including 10% of Finnish cultivated soils (25% in SW Finland), contain high concentrations of easily soluble phosphorus and are especially at risk of phosphorus leaching. These fields, with erosion-sensitive clays and many of the annually manure-amended soils should be prioritized in the nutrient loss mitigation strategy.

Soil erosion causes phosphorus discharge

Rainfall and runoff detach soil particles and transports phosphorus-containing soil to waters. This can be seen visually in turbid water. Phosphorus discharge, along with nitrogen, causes eutrophication and excessive algal growth in waters. In clay areas, erosion by water is the major reason for phosphorus losses from agricultural fields.

Eutrophication

- Nutrient enrichment is one of the biggest problems of the Baltic Sea.
- Elevated concentrations of phosphorus and nitrogen in water promote excessive growth of algae, including toxic ones.
- Agriculture causes about half of the phosphorus load of the Baltic Sea. The next largest contributors are point sources from cities.

Along with soil particle movement through runoff, dissolved phosphorus leaches from fields to waters.

Arable clay-textured soils are sensitive to erosion and phosphorus runoff associated with eroded particles contributes as much as 90% of the phosphorus load from the fine-textured Finnish fields. Phosphorus that is dissolved in water is readily available for algae. On the contrary, only a part of the phosphorus that is attached to soil particles becomes available to algae and in this sense soil-bound phosphorus is directly less harmful to water quality. Its lower availability is due to the gradual and less complete release from soil particles, leading to inefficient phosphorus use by algae. In the modeling work done in the TraP project, 16% of the particle-associated phosphorus was considered algal-available. However, under anoxic conditions potential for phosphorus release from soil particles would be higher than that.

Phosphorus has to be trapped in fields for crop use.

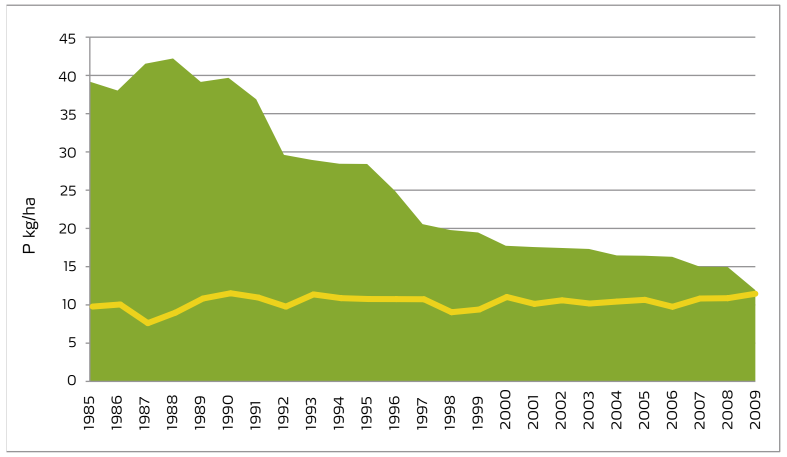
Focus on phosphorus trapping for crop use

One of the main challenges in water protection in agriculture is erosion control, because it contributes to a large part of phosphorus loading of surface waters.

Farmers need tools to retain soil, and thus phosphorus, on fields for crop use and growth.

In addition to erosion control, we need to focus on manure management. Due to excessive manure spreading rates, fields close to animal houses often contain far too much phosphorus for plant needs, which makes phosphorus susceptible for leaching. Manure phosphorus should be directed to those fields in which crops would truly benefit from phosphorus applications. Manure phosphorus should be fractionated for more focused use.

Yara, together with its partners, has developed gypsum-based solutions to trap phosphorus migrating from fields to waters.



Phosphorus fertilization (mineral and manure) today equals the phosphorus content of harvested yields (yellow line). Data from Finland (TNS Gallup).

Turbid runoff transports phosphorus to waters.

Gypsum traps phosphorus in fields

The TraP research project started in 2007 in order to test novel gypsum-based solutions for farm-scale phosphorus trapping. Gypsum improves soil structure and controls erosion and phosphorus losses to waters.

Gypsum improves soil structure

Gypsum dissolves and infiltrates into the soil with water, thereby improving soil structure. This in turn means that the soil can better resist rain and melting snow, markedly reducing erosion and phosphorus leakage.

In the TraP project, gypsum was spread onto fields or utilized as a precipitator component of manure phosphorus. The aim was to bind the phosphorus in fields but keep phosphorus available for crops. Additionally, the objective was to develop solutions that are readily applicable to normal farming practices without limiting production and land use, and without the need for investment in new machinery.

The solutions were tested using gypsum originating from Yara's Finnish igneous phosphate rock, treated with sulfuric acid. This gypsum is suitable for agricultural use as its concentrations of radioactive elements and heavy metals are very low.

Protection of the Baltic Sea requires new well-focused solutions on farms.

Partners of the TraP R&D project

Yara's project partners from the beginning have been the Finnish Funding Agency for Technology and Innovation (Tekes), the Finnish Environment Institute (SYKE), MTT Agrifood Research Finland, TTS Work Efficiency Institute, Luode Consulting and the Water Protection Association of the River Vantaa and Helsinki Region. Additionally, TEHO-project / the Centre for Economic Development, Transport and the Environment for Southwest Finland and the University of Helsinki and the Swedish University of Agricultural Sciences are testing the solutions.

The research has been carried out in laboratories, on fields, in catchments, and on pilot farms. The project was funded by Yara and Tekes.

In line with the EU's strategy for the Baltic Sea region

The solutions are in line with the EU's strategy for the Baltic Sea region according to which best practices in agriculture should be put into effect without reducing the productivity or competitiveness of farming.

Gypsum-based solutions give farmers the possibility of continuing farming according to best practices even on vulnerable soils. Gypsum could be a measure to use in the interim period while high soil phosphorus contents are being driven down by low phosphorus applications to a level which is no longer a risk for phosphorus discharge.

New solutions are required for the continuation of farming without transporting nutrient loads to the Baltic Sea.

Treated field at the Baltic Sea.

Measuring weir.

Up to 60 percent lower particulate P emissions

MTT, SYKE and TTS studies demonstrate the efficacy and applicability of gypsum. According to field results, gypsum has the potential to decrease particle-bound phosphorus discharge by 60%.

Field gypsum

MTT obtained strong evidence for gypsum impact

MTT Agrifood Research Finland studied erosion and P (phosphorus) mobility during two winter periods after gypsum application. The results showed that P concentrations in runoff from an annually tilled clay soil could be significantly reduced by gypsum.

The research was conducted in Jokioinen, SW Finland, on two fields that were autumn-tilled to a depth of 20 cm or 10 cm. Undisturbed soil cores were retrieved in May 2009 and 2010 from fields that in September 2008 were amended with gypsum at rates of 3 or 6 tn/ha, and from control areas that did not receive any amendment or received ground limestone. The soil cores were subjected to indoor rainfall simulations in which rainfall intensity and duration, slope of the soil surface and soil moisture were controlled. Soil test P and pH levels of the studied soils were typical on average for Finnish agricultural fields. Soils were slightly acid (pH 6.5) with moderate soil test P (10-15 mg P-Ac/l).

Rainfall simulations after the first winter period after gypsum application produced water with an extremely low concentration of eroded soil and attached P. The positive effect of gypsum application was ascribed to increased electrical conductivity (salt concentration) of the soil, which promotes aggregate stability in soils naturally low in soluble salts.

The gypsum application at the rate of 6 tn/ha resulted in up to more than 70% lower particulate P and about 50% lower dissolved P concentration in runoff water.

The second rainfall simulations in 2010 showed that the effect still existed after two winter periods after gypsum application, with about 50% lower concentrations of total P in runoff as a result.

Gypsum had no effect on wheat and ryegrass yields or market quality, except that the selenium content of the crops were lower than in the control treatments.

SYKE data from the catchment support MTT results

The Finnish Environment Institute (SYKE) studied field gypsum in Nummenpää village on 100 ha, the phosphorus load of which decreased by 60% over two winters. The effect was seen as clear ponds on soils. The application rate in autumn 2008 was 4 tons per hectare. The status of plant-available phosphorus in the fields were high-medium (20 mg/l), and the clay soils were slightly acid (pH 6.5).

Gypsum reduced runoff phosphorus concentrations

After the gypsum amendment, runoff from the Nummenpää catchment was significantly less turbid than before treatment. In addition, the concentrations of phosphorus bound to eroded soil particles and those in a dissolved form remained lower. Particle-bound phosphorus was about 60% lower and dissolved phosphorus one third lower than before. In a nearby reference catchment, where gypsum was not used, no corresponding changes were found. The Finnish Environment Institute (SYKE), Luode Consulting Oy and the Water Protection Association of the River Vantaa and Helsinki Region monitored runoff quality and quantity in Nummenpää with the aid of online sensors and water sampling.

Gypsum did not negatively affect soil chemistry

Soil analyses were conducted at the site before and after gypsum amendment. Gypsum increased the concentration of e.g. calcium in soil, as desired. No change in soil phosphorus status or in other determined growth factors was found.

Sulfate may have adverse effects in lakes

Sulfate concentration in runoff was higher after gypsum amendment. As sulfate accelerates eutrophication in lakes, extensive use of gypsum in catchments discharging into sensitive lakes should be avoided. In Finland, erosive arable land tends to be located in coastal, lake-poor catchments, where gypsum has no adverse effects as the brackish water of the Baltic Sea is inherently rich in sulfate.

In Nummenpää village decreasing of the phosphorus load was seen as clear ponds on soils.

Models up-scaled field experiments

SYKE simulated gypsum amendment under the Nummenpää conditions for the period 5 Nov 2008 – 18 Jun 2010 using a dynamic field-scale model (ICECREAM) which calculates soil transport and nutrient leaching at a daily time step. The effect of gypsum was added to the model based on laboratory and field measurements which suggested decreasing surface run-off and decreasing pool of labile phosphorus. The model simulated well the effect of gypsum in three out of the four measurement periods. Where no gypsum was applied, the cumulative total P load was 3.4 kg ha^{-1} for the entire period. With gypsum amended on 91% of the field area, as was the case in Nummenpää, the load was 45% lower. According to the model, gypsum significantly reduced more total P load than direct sowing applied on spring cereal plots (88% of the field area).

Close to the reduction target for the Archipelago Sea catchment

Potential reductions of phosphorus load to the whole Archipelago Sea catchment were estimated using a VIHMA –model based on long-term empirical data collected in Finnish experimental fields. Agricultural mitigation measures for water protection, no-tillage and buffer zones were compared with gypsum treatment for clayey soils in cereals and high value crops. Where 5% of the area is treated, the potential reduction would be 12 tons of phosphorus per year (2.5 tons readily available for algae). Where the treated area is 25%, the reduction would be 36 tons (8.9, respectively). Where the treated area is 75%, the phosphorus load would decrease by a maximum 62 tons (19 tons readily available).

Manure gypsum

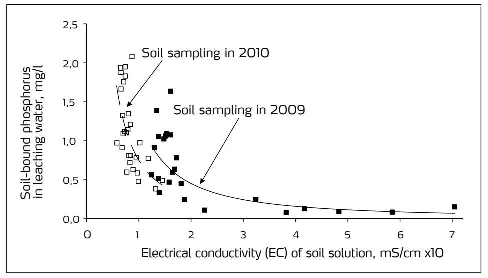
In the gypsum treatment of manure the dissolved phosphorus in slurry will settle onto the bottom of the slurry storage tank together with the solids. Sedimentation of dissolved phosphorus is achieved using a Gypsum-MgO –based precipitate, which is mixed with the slurry in the tank. Following treatment, the liquid fraction from the upper part of the tank can be spread on fields where phosphorus fertilization is not required. The phosphorus-rich solid fraction can be transported to fields located further away where phosphorus requirements are often higher.

The results of farm studies indicate that 70–90 % of the phosphorus in pig and cattle slurry settles in the solid fraction through gypsum treatment. In cattle slurry approximately half and in pig slurry a third of the original slurry volume ends up as the P-rich solid fraction.

Calculations by TTS show that it is possible for the farmer save around € 0.5 per ton on slurry transport costs through gypsum treatment. In Yara's field experiments the nutrient use efficiency for plant growth was good for both slurry fractions, and the nitrogen from the liquid fraction was taken up by the plants better compared with untreated slurry.

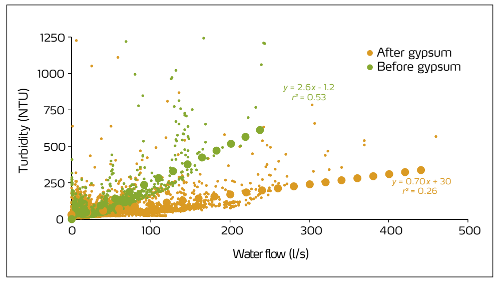
According to TTS, both gypsum field spreading as well as slurry treatment can be performed using normal agricultural machinery.

Jokioinen



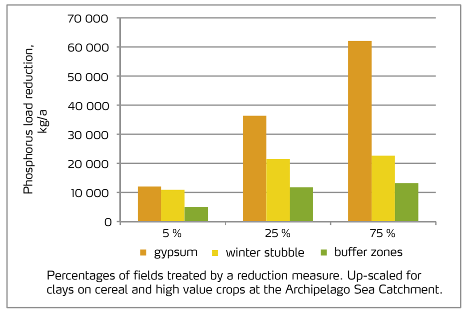
Gypsum increases the electrical conductivity (EC) of soil solution. If the EC-index is maintained between 2-3, phosphorus transportation from soils is minimal.

Nummenpää

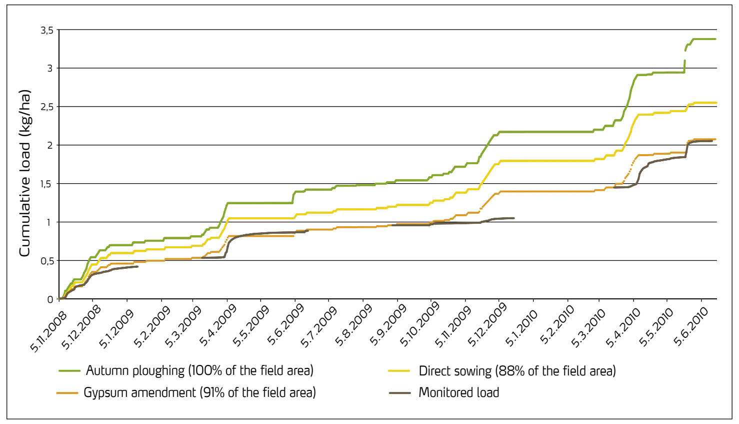


After the gypsum amendment, runoff turbidity was appreciably lower especially during the peak flow events. The data consist of more than 11 000 turbidity values recorded by an automatic sensor (YSI600 OMS).

Models



Where 75% of the area is treated, the phosphorus load would decrease by a maximum 62 tons a year (19 tons readily algal-available).



According to the model, gypsum significantly reduced more total P load than direct sowing applied on spring cereal plots (88% of the field area).

Cultivation

In soil cultivation, fields are tilled in order to prepare the seedbed and to control weeds and plant diseases. Soil tillage disturbs soil structure and makes soils vulnerable to soil erosion, i.e. particle movement from fields. Erosion along with water runoff leads to nutrient discharge.

Fertilization is plant nutrition. Although nutrients are given according to crop needs, not all nutrients are taken up by roots. Part of the nutrients leak.

Nutrient leakage can be controlled by

- minimizing soil tillage
- avoiding soil compaction by heavy machinery to maintain water infiltration capacity and minimize surface runoff
- spreading fertilizers according to plant needs by adjusting rate and timing
- placing fertilizers and manure below soil surface
- improving soil structure and phosphorus retention by gypsum

Gypsum spreading

Soil amendment by gypsum is soil improvement, in which soil physical and chemical characteristics are modified for better phosphorus retention.

Gypsum is calcium sulfate (dihydrate), which can be spread on the soil surface like lime after harvest. Gypsum is spread on unfrozen soils, where it dissolves and improves soil aggregation and electrical conductivity for better phosphorus retention and thus reduces phosphorus leakage.

In Nordic conditions like Finland, 90% of the phosphorus load caused by agriculture is generated before and after the growing season. Therefore, application in the fall is most efficient for reducing leakage during the coming winter, although spring is an option, too.

It is not necessary to apply gypsum every year. Once every three or four years at a rate of 4 tons per hectare is enough. Based on current understanding, during the two first years about one third of sulfate is leached downward to a soil depth below 20 cm, where it still controls phosphorus leakage through the subsoil. Studies to monitor longevity effects are still in progress.

Gypsum soil application

- has no effect on land use or cultivation practices
- is most advantageous for addressing more erosion sensitive soils with high phosphorus content
- also binds manure phosphorus into cultivated soils
- needs further examination for yield selenium content and soil potassium and magnesium indices

Phosphorus trapping

Phosphorus is trapped in soils by mechanisms which do not decrease its plant availability. Gypsum increases soil electrical conductivity and ionic strength. This causes better phosphorus retention capacity by soil particle surfaces and lower phosphorus concentration in soil solution which means less leaching. The phosphorus status remains unaffected, however.

Tiny soil particles are attached to form aggregates which are less easily removed by water runoff. Particles stay on fields, and waters in ponds and ditches are much less turbid.

Gypsum spreading is the first abatement measure which binds phosphorus by:

- maintaining plant availability of phosphorus
- reducing transportation of both particle-bound phosphorus and dissolved phosphorus at the same time

Impact on phosphorus load

At the catchment scale and based on on-line monitoring, gypsum spreading decreased phosphorus load by 60%.

Phosphorus load reduction, up-scaled for the entire catchment of the Archipelago Sea, was at best 70 tons a year if all clays with cereal and high value crops were treated with gypsum (near 0.1 million ha).

Impact on waters

Waters are less turbid. Gypsum reduces the concentrations of phosphorus in runoff. This controls nutrient enrichment in waters (eutrophication).

Reduced nutrient enrichment causes less algal growth and water bodies are less eutrophicated. This means clearer waters and less toxic algal blooms.

Due to increased sulfate losses, the method is not recommended for lake catchments. In lake-poor coastal catchments, sulfate originating from gypsum is not harmful as sea water contains a lot of sulfates.

Reduction targets for the Baltic Sea

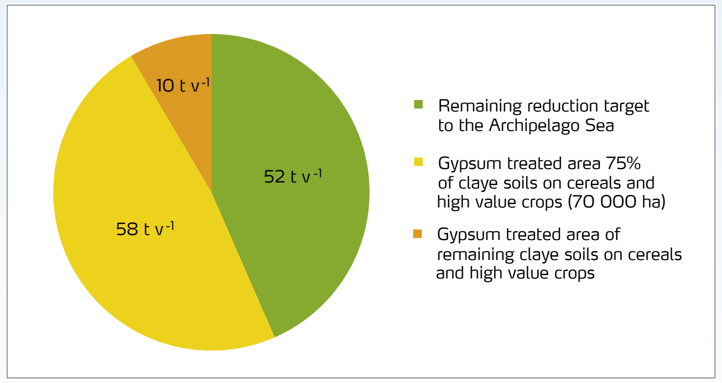
Reduced phosphorus load retards eutrophication and complies with the targets set by the EU and the national governments of the Baltic Sea States.

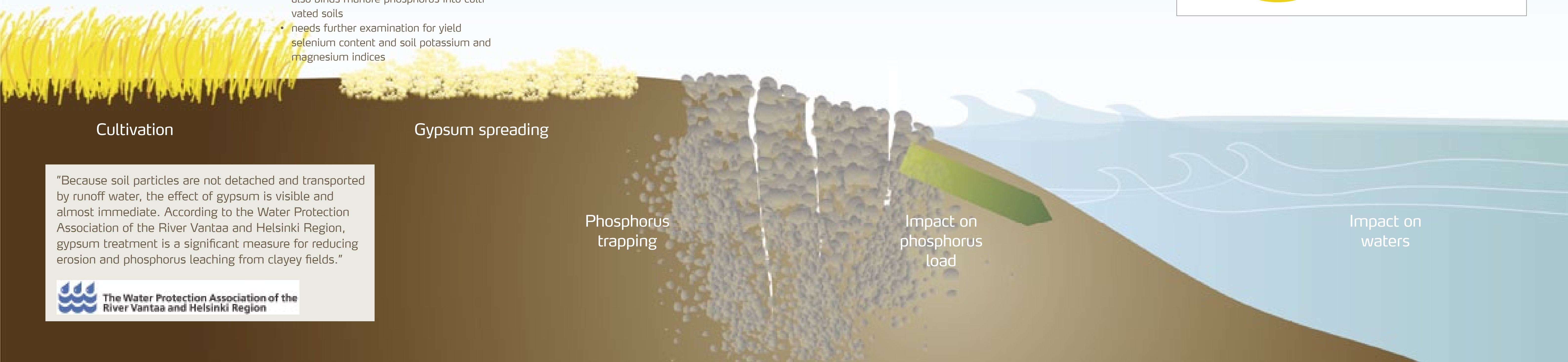
For the Archipelago Sea, Finland has set a reduction target of 120 tons a year. Gypsum treatment has the potential to meet 70 tons of this target, i.e. near 60%.

Similarly, the phosphorus reduction targets to the Baltic Sea agreed by HELCOM for Sweden are 229 and for Estonia 220 tons a year.

New solutions are required in order to maintain farming on vulnerable soils of the Baltic Sea region.

Phosphorus reduction shares by gypsum from the reduction target set to the Archipelago Sea (120 tn/a)





"Because soil particles are not detached and transported by runoff water, the effect of gypsum is visible and almost immediate. According to the Water Protection Association of the River Vantaa and Helsinki Region, gypsum treatment is a significant measure for reducing erosion and phosphorus leaching from clayey fields."

The Water Protection Association of the River Vantaa and Helsinki Region

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Photos: Sakari Alasuutari, Petri Ekholm, Kimmo Lehtonen, Liisa Pietola, Pasi Valkama.

About Yara

Yara International ASA is a global company specializing in plant nutrition and industrial solutions. As the world's largest supplier of mineral fertilizers, Yara helps provide food and renewable energy for a growing world population. Our products are also used to cleanse the air and eliminate toxic gas. The company is based in Norway and has about 7,600 employees with operations in more than 50 countries.

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