Soil weathering in relation to soil acidification and sustainable forestry in Sweden

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Cecilia Akselsson

Department of Physical Geography and Ecosystem Science

Lund University
Weathering – the most important natural factor for counteracting acidification, and important for plant nutrition

Chemical weathering leads to release of base cations and counteracts acidity.

Ex: $3 \text{KAlSi}_3\text{O}_8 + 2\text{H}^+ + 12 \text{H}_2\text{O} \rightarrow \text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2 + 6 \text{H}_4\text{SiO}_4 + 2 \text{K}^+$
Acidification
The environmental objectives of Sweden

Reduced climate impact

A protective ozone layer

A safe radiation environment

A varied agricultural landscape

A magnificent mountain landscape

Clean air

A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos

Good quality groundwater

Natural acidification only

Zero eutrophication

Thriving wetlands

A good built environment

A non-toxic environment

Flourishing lakes and streams

Sustainable forests

A rich diversity of plant and animal life

A balanced marine environment, flourishing coastal areas and archipelagos.

Good quality groundwater.
History

-1967:
  - Ulf Lundin, fishery expert in Uddevalla, contacted Svante Odén, SLU: fish death and low pH in lakes!
  - Svante Odén had time series of precipitation chemistry. He found out that pH had decreased substantially in 20 years.

-1967: Article named “Nederbördens försurning” in DN. About increased acidification of precipitation due to S emissions, leading to acidified surface waters and fish death

-1979: UN/ECE Convention on Long-Range Transboundary Air Pollution!

-Critical loads (Kritisk belastningsgräns) defined 1988

-1999: Gothenburg protocol, target year: 2010

-2012: Revised Gothenburg protocol
Acid rain - Sources and acidification processes

Sources

Sulphur

Forestry

Nitrogen

Transportation
Acid rain – sources and acidification processes

*Sulphur*

Main source of S: Combustion of coal and oil. Also industries, ships, etc.

\[
S + O_2 \leftrightarrow SO_2 \\
SO_2 + O_2 \leftrightarrow 2 \text{ SO}_3 \\
SO_3 + H_2O \leftrightarrow 2 \text{ H}^+ + \text{SO}_4^{2-}
\]
Acid rain – sources and acidification processes

*Oxidized nitrogen (NO*$_x$*)

Main source of NO*$_x$*: Traffic

\[
\begin{align*}
N_2 + O_2 & \leftrightarrow 2 \text{ NO} \\
2 \text{ NO} + O_2 & \leftrightarrow 2 \text{ NO}_2 \\
2 \text{ NO}_2 + H_2O & \leftrightarrow H\text{NO}_2 + H^+ + NO_3^- \\
\end{align*}
\]
Acid rain – sources and acidification processes - *Reduced nitrogen (NH$_3$)*

Main source of NH$_3$: Fertilizers

\[
\text{NH}_3 + \text{H}_2\text{O} \leftrightarrow \text{NH}^4+ + \text{OH}^-
\]

\[
\text{NH}_4^+ + 2 \text{O}_2 \leftrightarrow 2 \text{H}^+ + \text{NO}_3^- + \text{H}_2\text{O}
\]
Acid rain – sources and acidification processes

Surt vatten kommer från markytan.

Joner förs längre ned i marken eller ut i sjöar och vattendrag.

(Från www.capensis.se)
Acid rain – sources and acidification processes

Effects

- Low pH and high concentrations of toxic aluminium
- Negative effects on fish and other water living organisms
- Risk of negative effects on vegetation
- Increased leaching of nutrients important for trees (e.g. Mg and K) which can lead to nutrient imbalance
- Increased leaching of heavy metals (e.g Cd and Pb)
Present situation and trends

Photo: Cecilia Akselsson
What does the environmental objective say?

“The acidifying effects of deposition and land use must not exceed the limits that can be tolerated by soil and water. In addition, deposition of acidifying substances must not increase the rate of corrosion of technical materials located in the ground, water main systems, archaeological objects and rock carvings.” (Riksdagen)

Clarifications (preciseringar):
- Deposition of S and N should’n't exceed what soils and water can take (avoiding harmful effects)
- The effect of landuse should be counteracted by adapting forest management to site conditions
- Lakes and strams should reach good status without liming
- Soil acidification should not accelerate corrosion or harm biodiversity
What does the environmental objective say?

“It is not possible to reach the environmental objective to 2020 with the decided or planned measures. The development is positive.”
Acidification status today

- 10% of Swedish lakes and 20% of the forest soils are assessed as acidified.

- In SW Sweden 50% of the lakes and forest soils are assessed as acidified.

- 200 million SEK are spent on lake liming every year

- Measurements and modelling indicate slow recovery
Reductions of emissions in Europe

 från EU-27

~80 % reduction

From EMEP, www.emep.int, april 2013
Sulphur deposition trends

(Based on data from the SWETHRO network. Modified from Pihl Karlsson et al, 2011, Env. Poll.)
Sulphur deposition trends (Arkelstorp, Skåne)

(Based on data from the SWETHRO network, IVL: Akselsson mfl, 2013)
Nitrogen deposition trends
(Västra Torup, Skåne)

(Based on data from the SWETHRO network, IVL)
Antropogenically acidified lakes

Lakes (> 1 ha) in different effect classes in the year 2010, based on there modelled pH decrease since before industrialization

(Filip Moldan, IVL, www.ivl.se/magiclibrary)
Acidification in solid soil (left) and soil solution (right)

% soil in the 2 highest acidification classes

From soil inventory, Johan Stendahl, SLU

From SWETHRO network, IVL
Acidification from forestry
Acidification from forestry

Tree growth: Uptake of base cations – BC: Ca, Mg, K. Release of H⁺.

Biomass harvesting: The BC losses and acidification becomes permanent
Acification from forestry – increased biomass harvesting

(Swedish forest agency)
Acidification from forestry

Acid rain removes base cations and acidifies...

...and biomass harvesting too.

Chemical weathering leads to release of base cations and counteracts acidity.

Ex: \[3 \text{KAlSi}_3\text{O}_8 + 2\text{H}^+ + 12 \text{H}_2\text{O} \rightarrow \text{KAl}_3\text{Si}_3\text{O}_{10} \text{(OH)}_2 + 6 \text{H}_4\text{SiO}_4 + 2 \text{K}^+\]
Acid deposition and forestry lead to losses of nutrients...

...and nutrients are necessary for all living organisms
Acidification in the perspective of Swedish rocks, soils and landforms
Acidification in the perspective of Swedish rocks, soils and landforms

(From Hess, 2013)

(From Hess, 2013)

(Photo: Jonas Åkerman)

www.sgu.se
Acidification in the perspective of Swedish rocks, soils and landforms

(Photo: Cecilia Akselsson)

(From Hess, 2013)

(Photo: Jonas Åkerman)
Acidification in the perspective of Swedish rocks, soils and landforms

(soil map from SGU)

(http://www-markinfo.slu.se/)
Chemical weathering of base cations (BC; baskatjoner) (Ca, Mg, K, Na) in forest soils for sustainable forestry: Introduction to exercise
Nutrient balance calculations

- Deposition
- BC weathering
- Leaching
- Harvest

\[ \Delta = \text{Inflow} - \text{Outflow} \]
What will happen with the base cation balance if harvesting increases?

\[ \Delta = \text{Inflow} - \text{Outflow} \]
What will happen with the base cation balance if harvesting increases?

Reduced soil pool...
What will happen with the base cation balance if harvesting increases?

...and eventually reduced leaching.
Weathering may increase as well! But to compensate it has to increase as much as the harvest losses.
What will happen if harvesting increases?

Δ = Inflow - Outflow

Another way to compensate: wood ash recycling
Net accumulation Ca

Stem harvesting   Whole-tree harvesting

Ca meq m\(^{-2}\) y\(^{-1}\)

- < -30
- -30 - -20
- -20 - -10
- -10 - 0
- > 0
Potassium (K)

Deposition  Weathering  Harvest (stem)  Leaching

K meq m² y⁻¹
< 1
1 - 3
3 - 5
5 - 7
7 - 9
> 9
Net accumulation $K$

Stem harvesting  Whole-tree harvesting

K meq/m²/yr

- < -4
- 4 - 2
- 2 - 0
- 0 - 2
- > 2
Exercise tomorrow:

- Modelling weathering rates for Ca, Mg, Na and K
- Test how temperature, moisture, mineralogy and texture affects weathering rates (e.g. what happens if temperature increases according to climate change scenarios)
- Calculate nutrient balances for Ca, Mg and K
Exercise tomorrow – The PROFILE model

Tested for use with PROFILE only