# Phosphorus in agriculture – outlook on sustainable use

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# Phosphorus research at the Department Soil and Environment

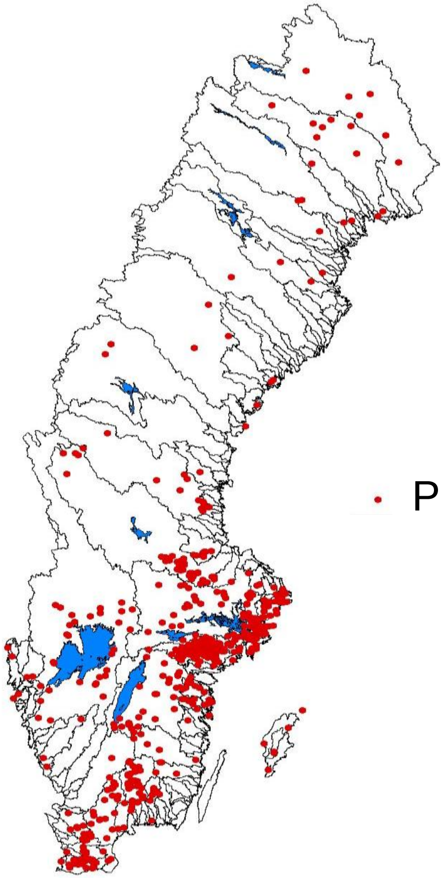
Eutrophication and mitigation

Recycling of P

P turnover in soil

# Eutrophication is a serious, unresolved problem …

**Lakes with excessive P concentrations**



• P in lakes >25 $\mu L^{-1}$



Algal blooms are frequently occurring in fresh and brackish waters

# Annual average leaching of P from arable fields over 25 years

| Field | Soil type | Annual drainage (mm) | Total P leaching (kg $ha^{-1}$) |
|---|---|---|---|
| 1 | Loam | 300 | 0.19 |
| 2 | Loam | 273 | 0.10 |
| 3 | Clay | 234 | 1.02 |
| 4 | Clay | 294 | 0.29 |
| 5 | Loamy sand | 91 | 0.07 |
| 6 | Clay | 116 | 0.27 |
| 7 | Loam | 116 | 0.02 |
| 8 | Sand | 248 | 0.29 |
| 9 | Loam | 187 | 0.23 |
| 10 | Sand | 406 | 0.09 |
| 11 | Clay | 237 | 0.65 |
| 12 | Sand | 306 | 1.47 |
| 13 | Clay loam | 240 | 0.15 |

On avarge, leaching of P from arable fields in Sweden amount to 0.4 kg P $ha^{-1}$ $yr^{-1}$

# Mitigation practices to reduce P losses

**Filling drainage trenches with with CaO**

**Growing catch-crops**

**Constructing wetlands**

**Regulating storage of manure**

The efficiency of the different measures is still under investigation

# Retention of P in constructed wetlands is limited

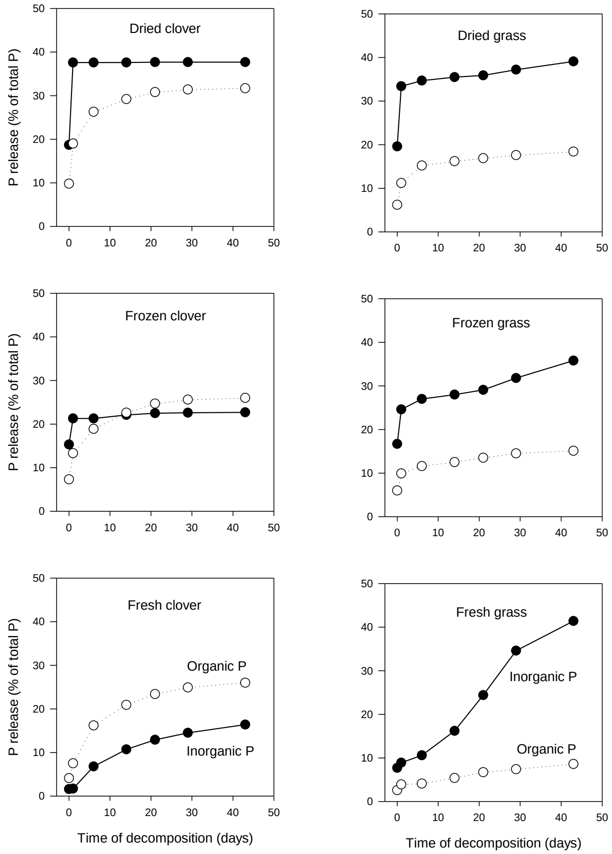

| | Total P | Particulate P | Dissolved P |
|---|---|---|---|
| | (% of load) | | |
| Retention | 36 | 24 | 9 |

Kynkäänniemi et al. 2013. JEQ 42: 596-605.

Sedimentation of particulate P is the main process for P removal but dissolved P is little affected

# Senescence of aboveground biomass contribute to P leaching

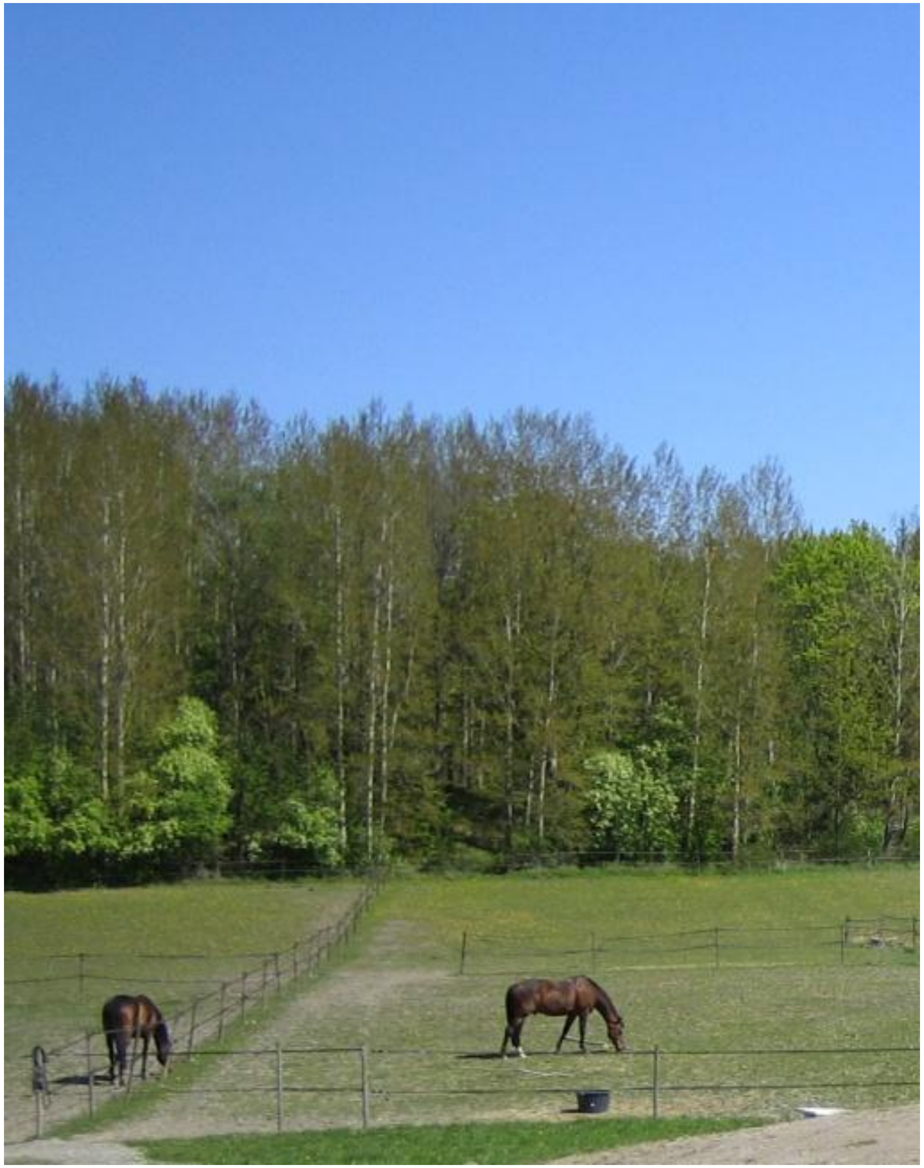
| Plant material and treatment | Initially water-extractable P | | Cumulative P release (1 month, 10$^{o}$C) | | |
|---|---|---|---|---|---|
| | $PO_4$ | Organic | $PO_4$ | Organic | Total |
| | (% of total P) | | | | |
| ***Red clover*** | | | | | |
| Untreated | 2 | 4 | 17 | 26 | 42 |
| Frost-treated | 15 | 8 | 22 | 26 | 48 |
| Dried | 19 | 10 | 38 | 31 | 69 |
| ***Ryegrass*** | | | | | |
| Untreated | 8 | 2 | 62 | 11 | 73 |
| Frost-treated | 17 | 6 | 37 | 14 | 51 |
| Dried | 20 | 6 | 38 | 31 | 69 |




Kirchmann & Wessling 2017. Acta Agric. Scand. Sect. B 67, 693-696.

Use of cover/catch crops without harvesting is not an option to reduce P leaching

# Horse paddocks were identified as hot spots for P losses



Excretion area (5%)

HORSE PADDOCK

Animal density (9 LSU $ha^{-1}$)

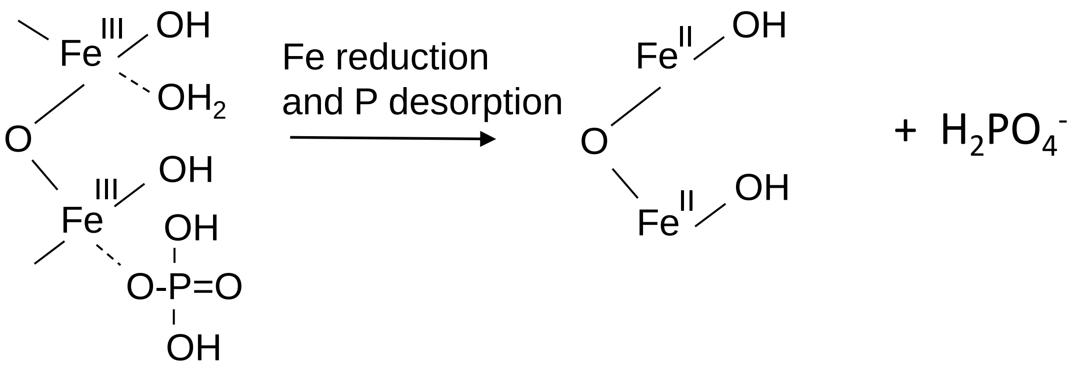
Feeding area 3%

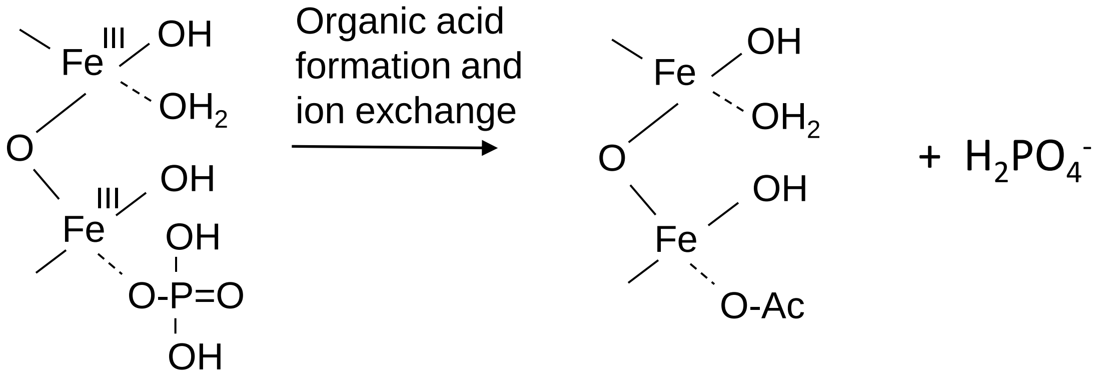
Number of horses: > 400 000
Number of paddocks: 34 000 ha
P leaching: 1.2 kg P $ha^{-1}$
N leaching: 95 kg N $ha^{-1}$

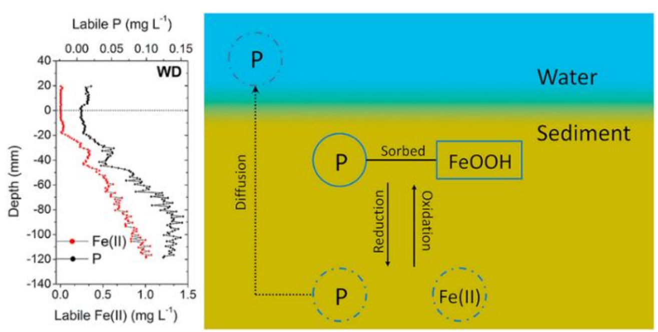
Parvage et al. 2015. Ecosys. Agric. Environ. 201, 101-110.
Parvage et al. 2015. J. Environ. Managem. 147, 306-313.

Horse paddock leak 3 times more P and 5 times more N than arable land

# Short intensive rain causes high P losses by runoff and leaching



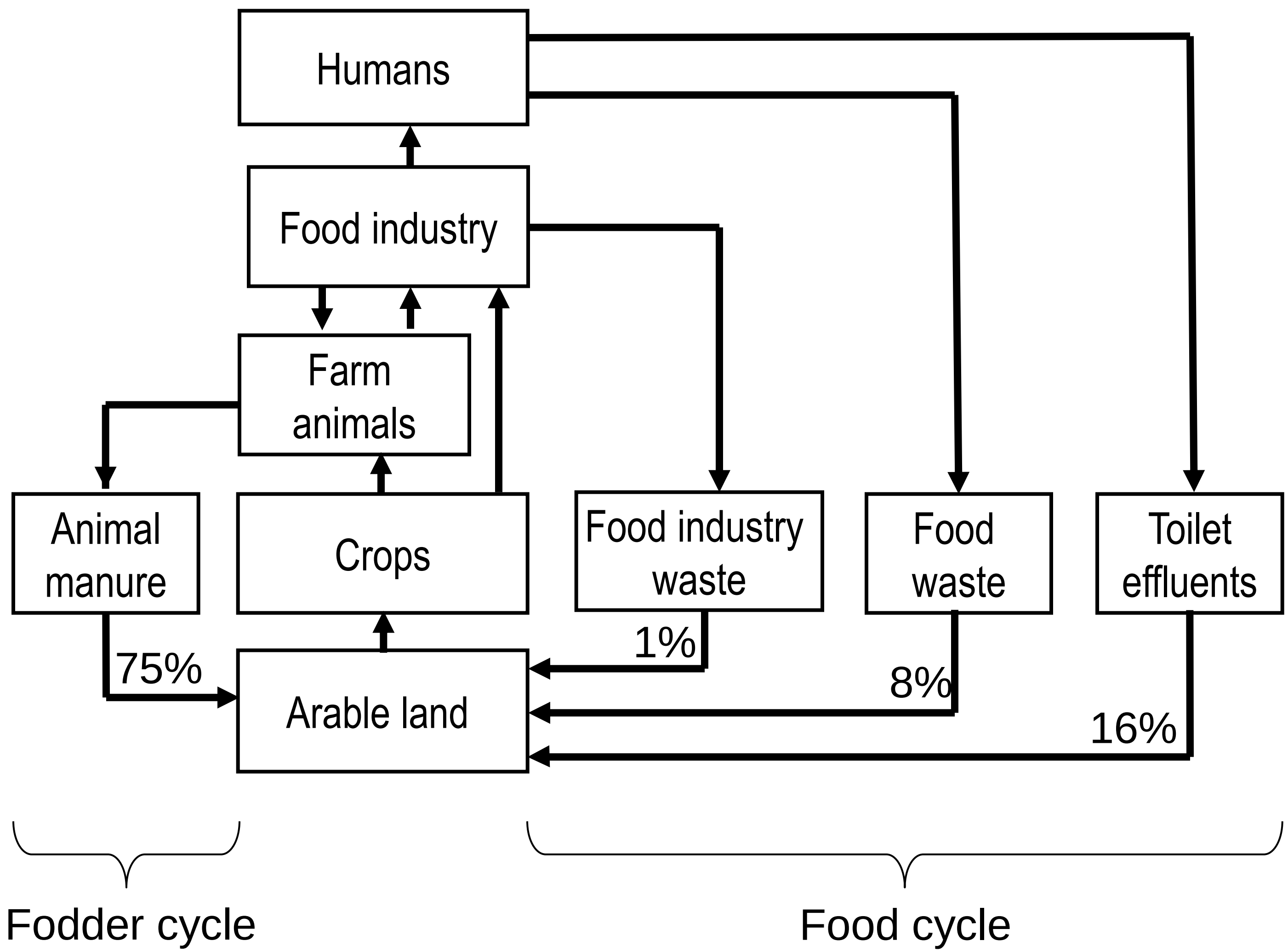




Gao et al. 2016. Environ. Pollut. 219, 466-474.

Two processes may explain the fast release of dissolved P under anoxic conditions

# Recycling of P

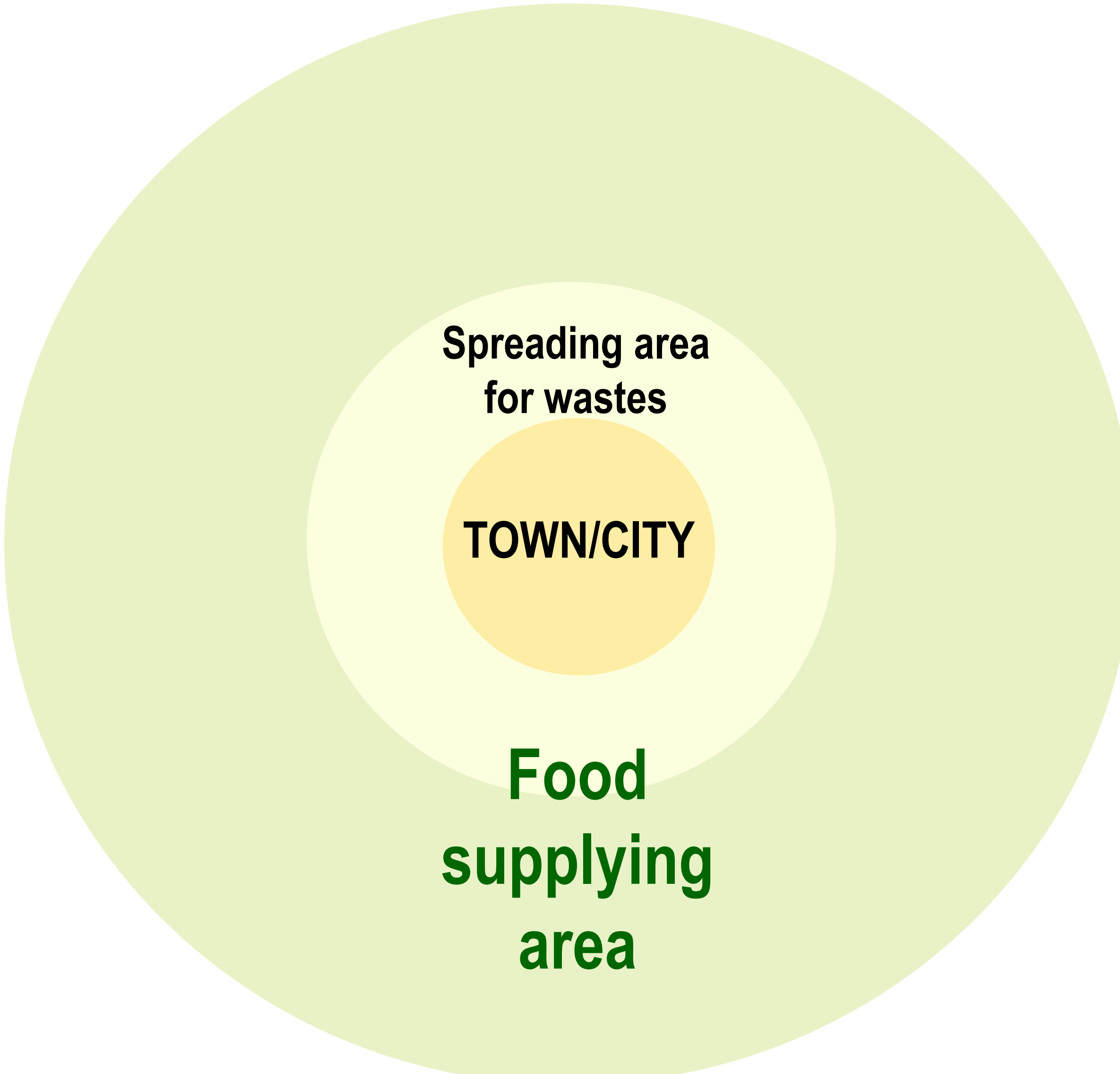
# Flows of P through organic wastes in Swedish society




Lammel & Kirchmann 1995. Fert. Soc. Proc. No. 372.

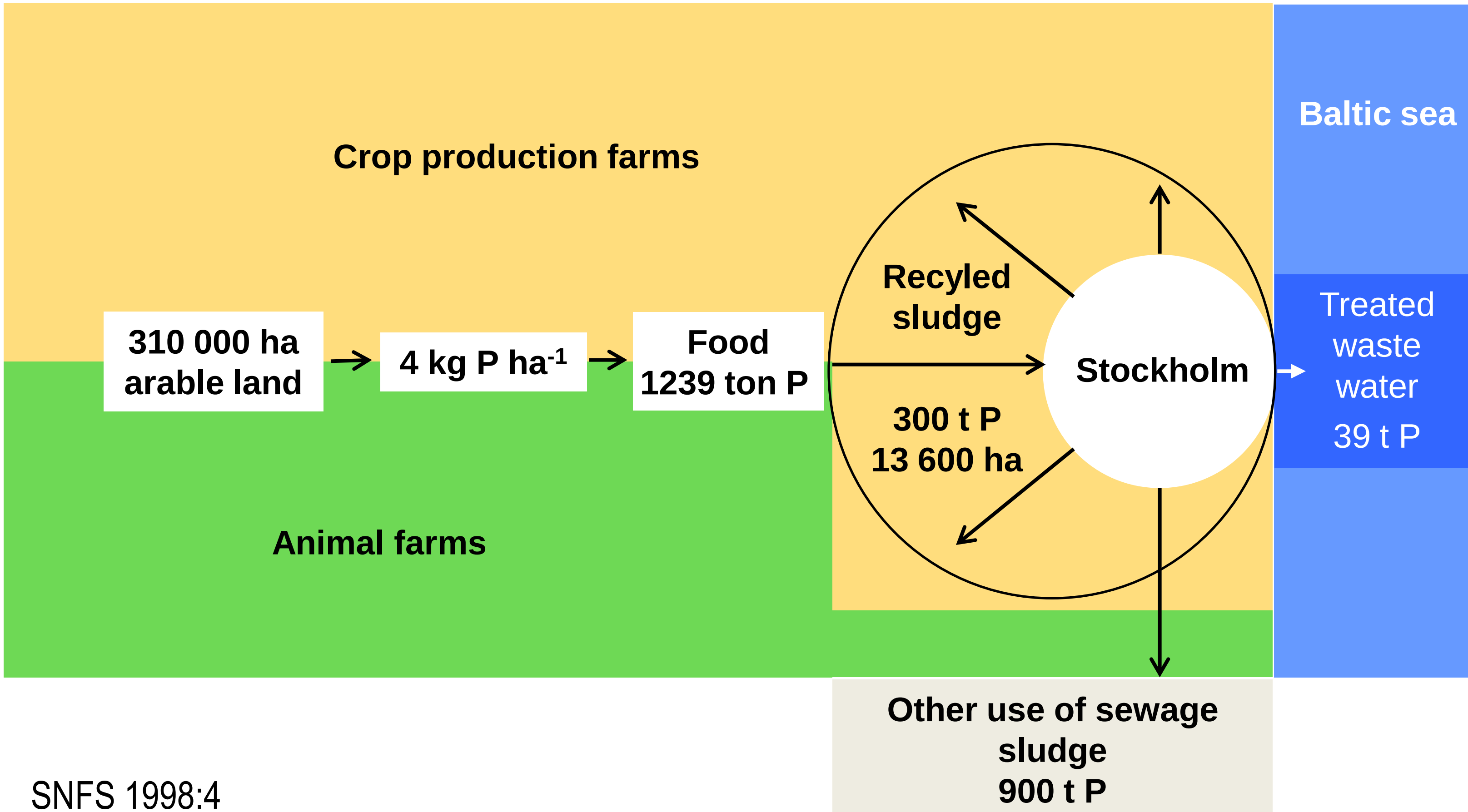
About 25% of P removed by crops annually is present in food wastes and toilet effluents

# Urbanisation leads to nutrient gathering in towns/cities




Towns/cities are supplied with food from remote, large cropland areas.
Wastes are mainly returned to areas adjacent to towns/cities

# Annual P flows to and from Stockholm City




SNFS 1998:4

Kirchmann, 1998. KSLAT 7, 145-156

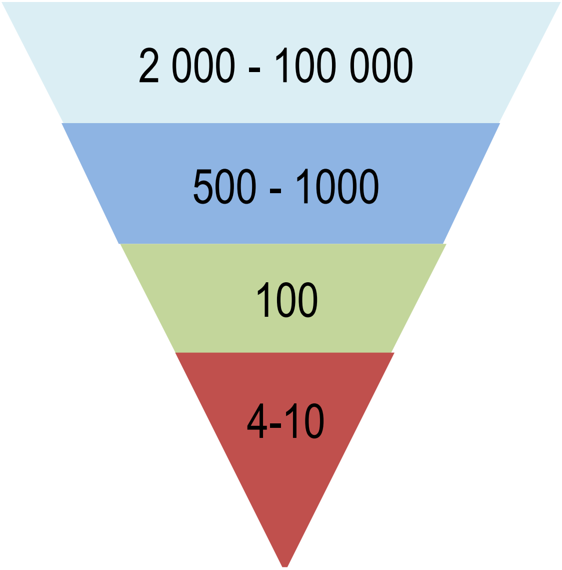
Käppala, 2010. Environmental report 2008. http://www.kappala.se

SCB 2010. Statistiska Meddelande MI 22 SM 1201

Conclusion: No equitable re-distribution of nutrients through organic wastes

# Water and P contents in urban organic wastes

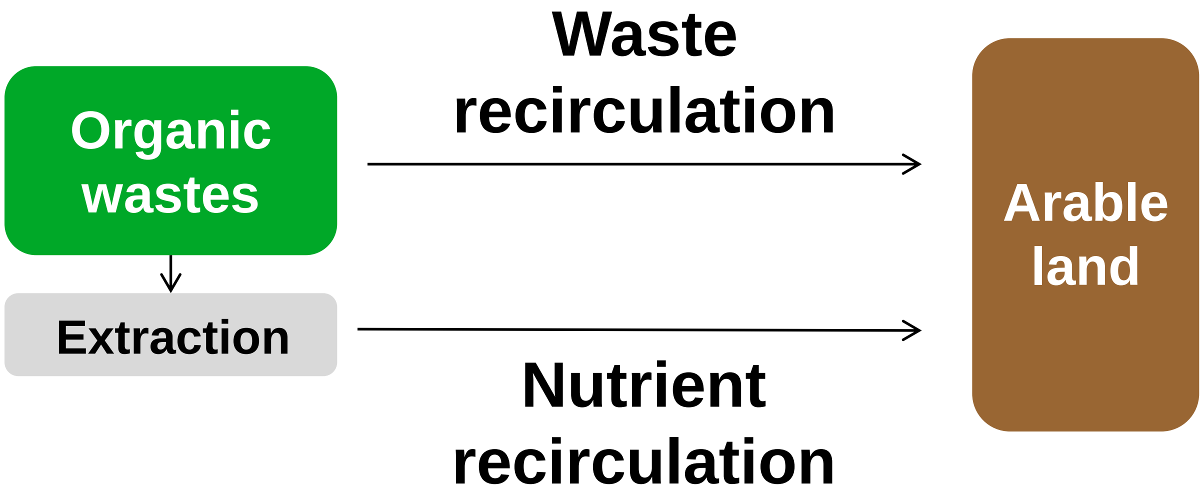
| Product | (% water) | (% P in wet weight) |
|---|---|---|
| Sewage water | 99 | 0.001 |
| Human urine | 99 | 0.05 |
| Biogas residues | 90-95 | 0.075 |
| Compost | 55-65 | 0.15 |
| Sewage sludge | 70-90 | 0.7 |
| *Ash from sewage sludge* | 1-3 | 9 |
| *Ammonium phosphate* | <1 | 22 |



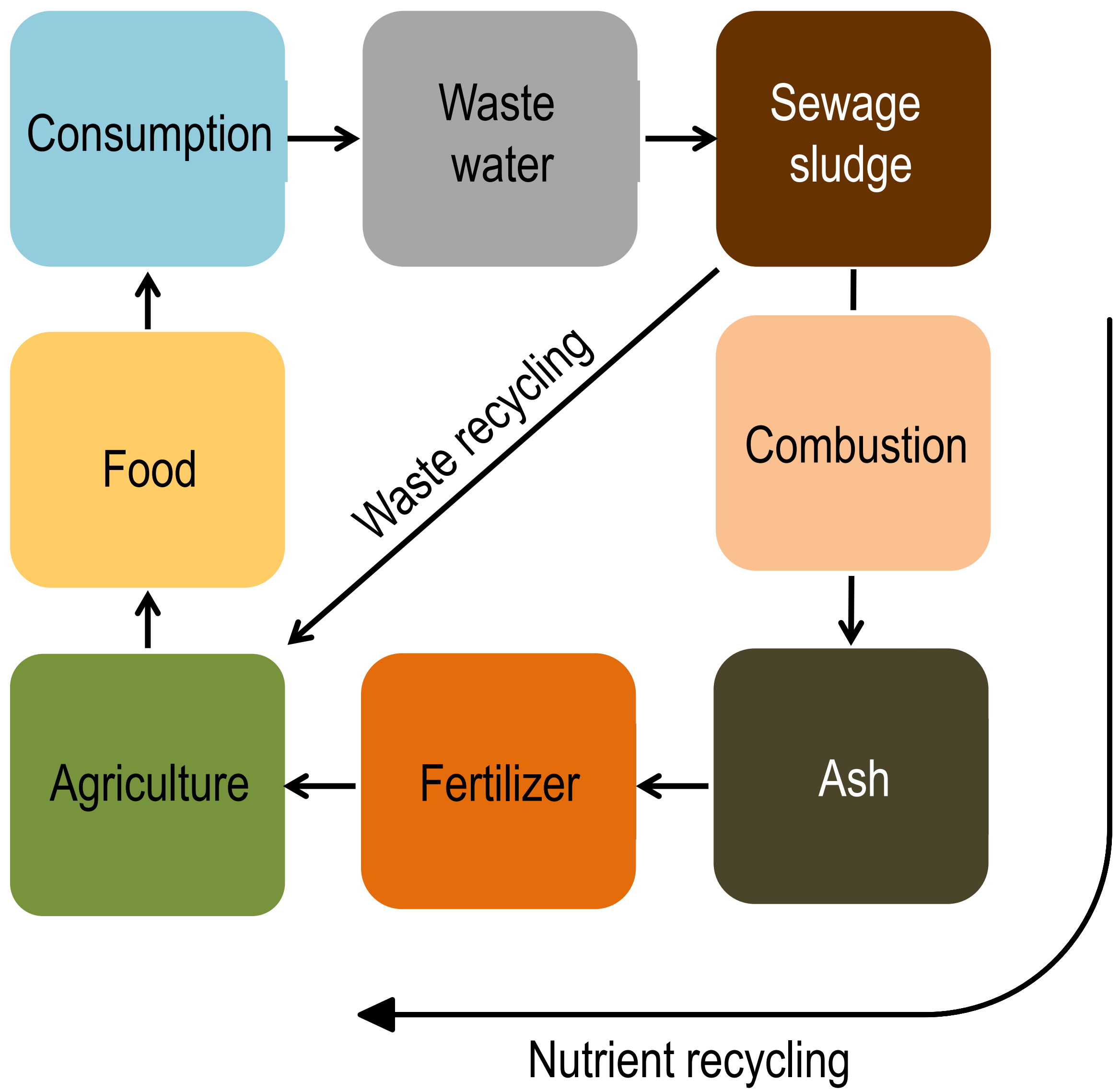

The weight over nutrient (P) hierachy in organic wastes

Large amounts of wastes need to be transported due to low nutrient and high water content

# Two ways to close the plant nutrient loop in society



# Closing the food cycle through nutrient extraction from wastes




The conceptual idea is to recycle nutrients rather than organic wastes

# Ashes as a P resource

Ash from sewage sludge (Fe-precipitated)

7-13% P

Ash from sewage sludge (Al-precipitated)

7-13% P

Ash from offals

16-18% P

Ash from slaughterhouse waste

16-18% P

Fe-ore waste

ca 3% P

Apatite

12-16% P

Ashes of sewage sludge have similar P contents as apatite

# Fertilizer production from sewage sludge

Sewage treatment plant

Sewage sludge

Sludge combustion

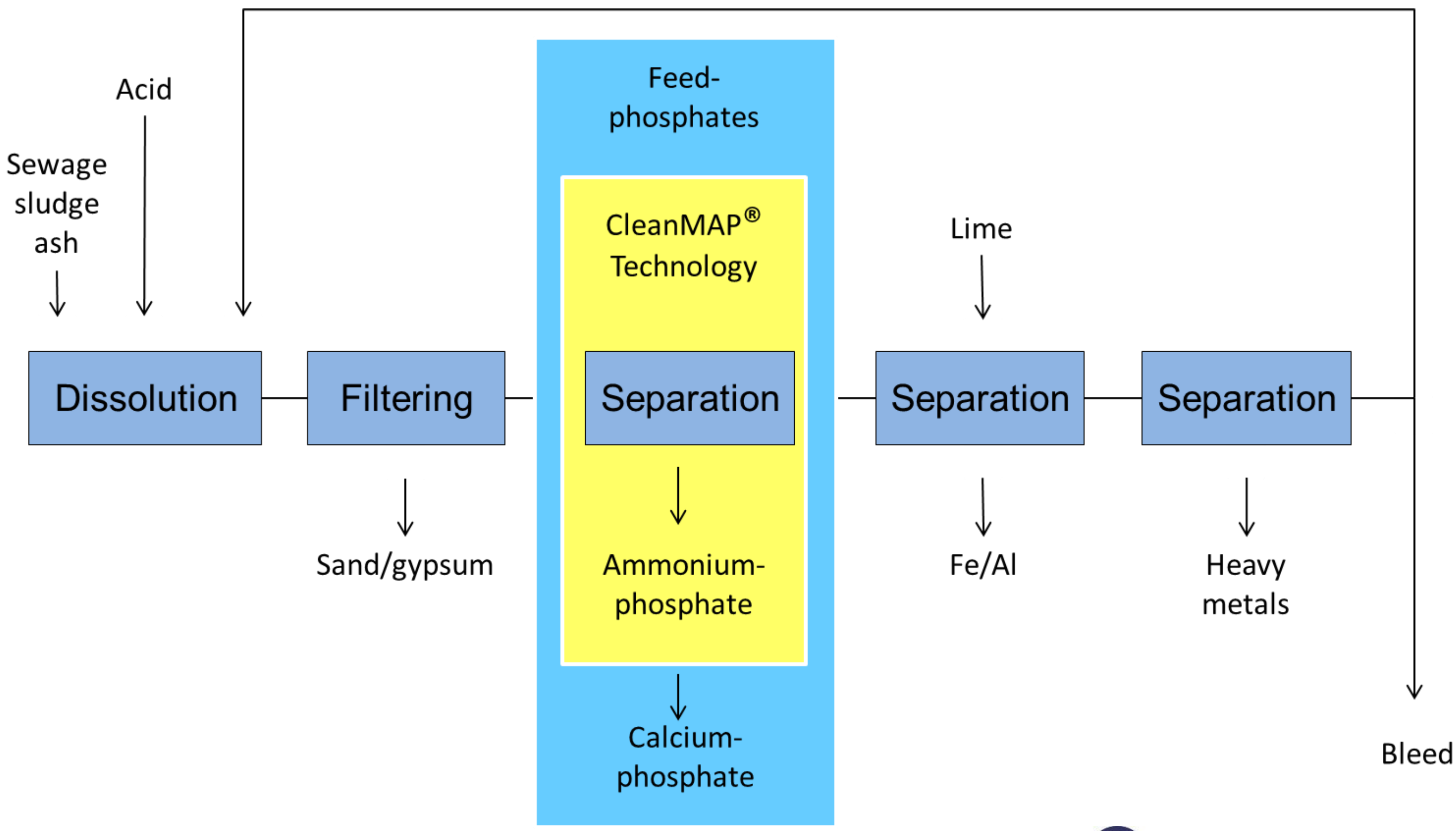
Ash from sewage sludge

'EasyMining' process

Ammonium phosphate (< 1 mg Cd $kg^{-1}$ P)

New technologies to treat ashes can produce high value inorganic fertilizers

# Diagram of the EasyMining process for sewage sludge ash




EasyMining Sweden
- changing phosphate production
www.easymining.se

Completely water-soluble ammonium and/or Ca-phosphates are produced.
No water evaporation during the process is required.
In-going chemicals become useful components of products

# Comparing extracted P with sewage sludge P

| Characteristics | P extracted from ash | P in sewage sludge |
|---|---|---|
| Plant availability | 100 % water-soluble | 10% water-soluble |
| Pollutants | Very low metal content, sterile, no organics (< 1 mg Cd $kg^{-1}$ P) | Metals, organics, etc. (20-30 mg Cd $kg^{-1}$ P) |
| Transportation | Low cost (26% P in ammonium phosphate) | High cost (<1% P in sewage sludge) |
| Use in agriculture | Substitution of rock phosphate and P fertilizer | Low fertilizer value |

The most important advantage of extracted P is a higher product value than of sludge P

# Hypothesis

Despite environmental efforts improving sewage sludge quality, urban organic waste recycling is limited by inherent causes.

**Sustainable nutrient cycling .......**

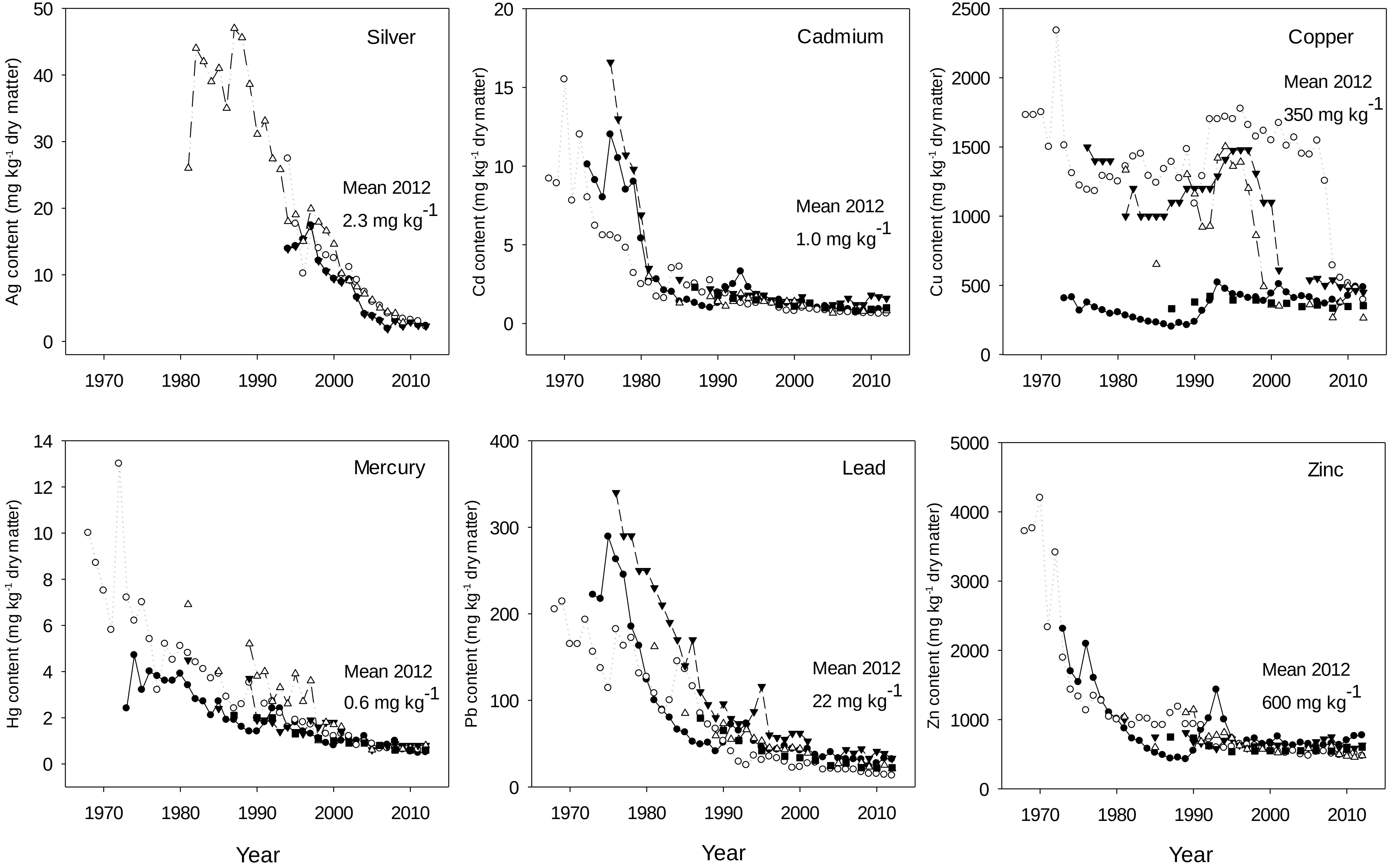
**may not be achieved through recycling of organic wastes,**

**….. but through recycling of nutrients extracted from wastes.**

Kirchmann et al. 2017. Ambio 46, 105-112.

Ashes will play a major role for nutrient recycling

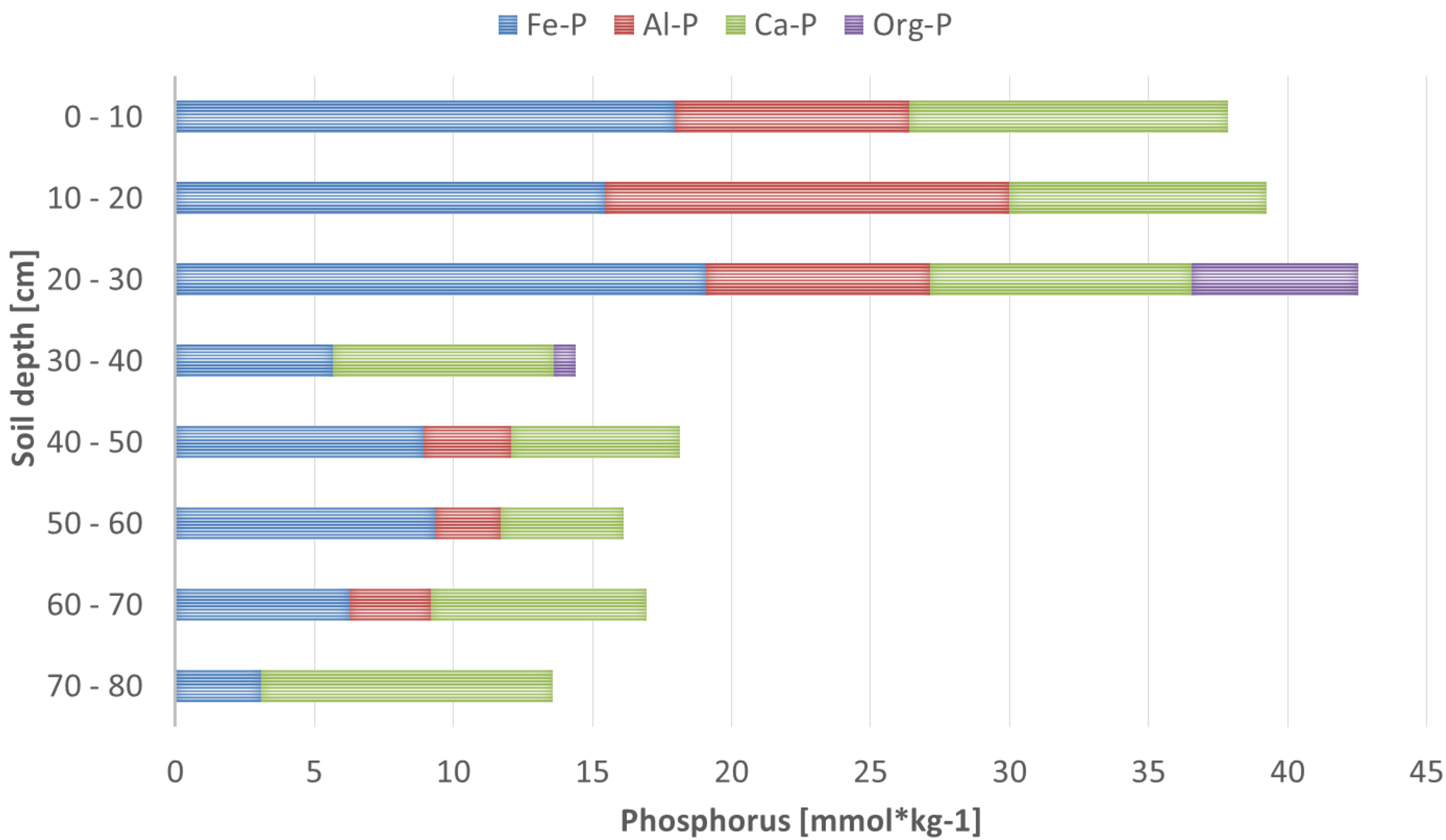
# Metal contents in Swedish sewage sludge over time




Environmental efforts have significantly reduced metal contents in sewage sludge over time


P turnover
in soil

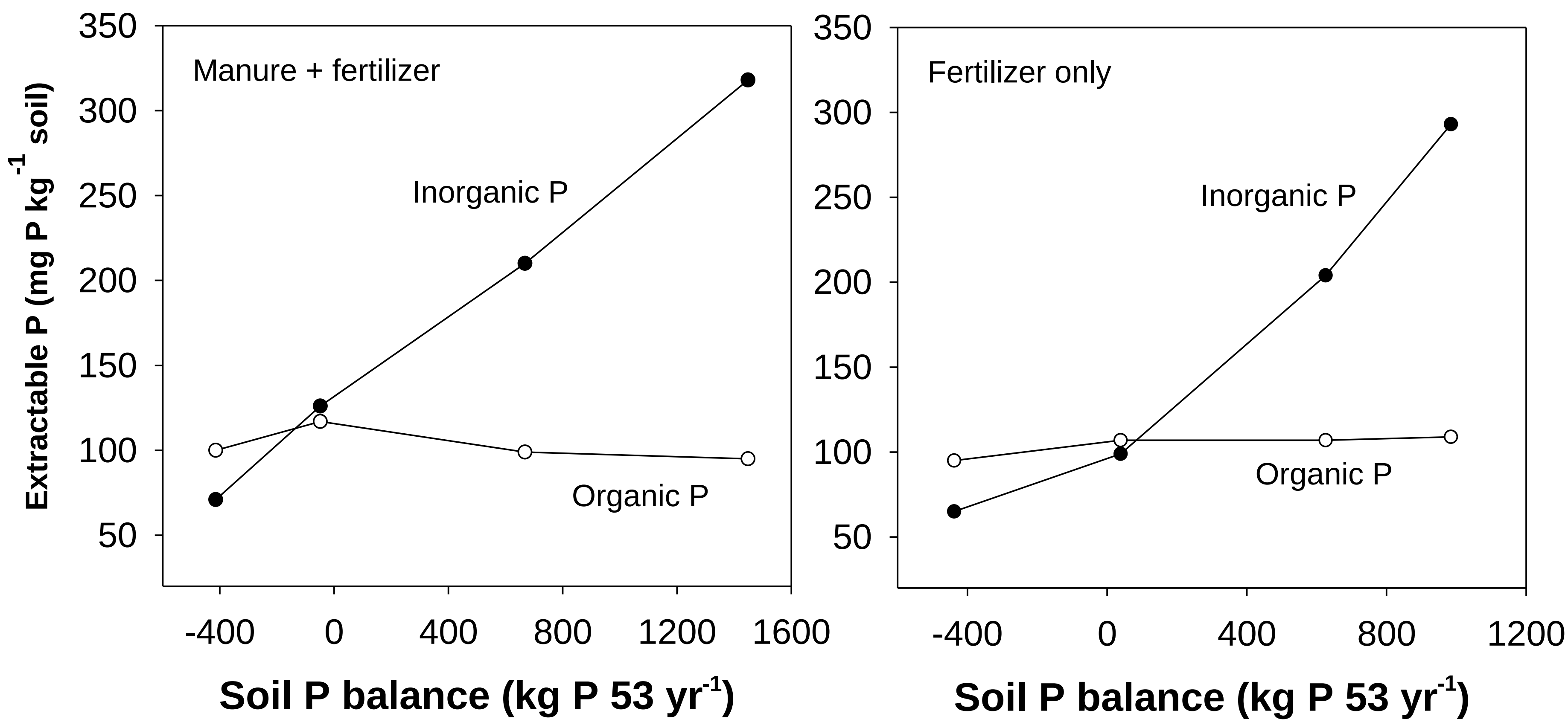
# P-speciation in a sandy profile based on XANES analysis




Schmieder et al. 2017. Geoderma (submitted)

Fe-bound P was dominating in the topsoil and apatite in the lower subsoil

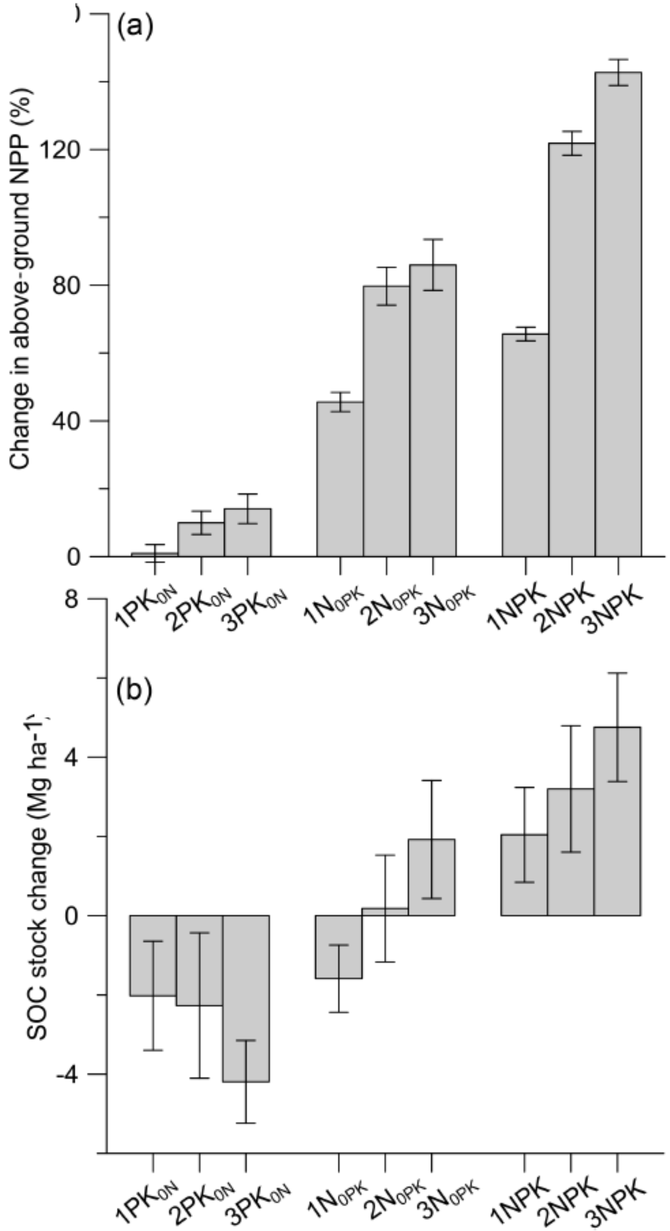
# Changes in organic and inorganic P in topsoils upon depletion and accumulation after 53 years (site Fjärdingslöv)




Ahlgren et al. 2013. Soil Use and Management, 29, 24-35.

Organic P in soil is not increased through large applications of inorganic P over time

# Phosphorus fertilization under nitrogen limitation




Poeplau et al. 2016. Biogeosciences 13, 1119-1127

High rates of P and K fertilization have a negative effect on SOC stocks in the absence of N

# Resumé

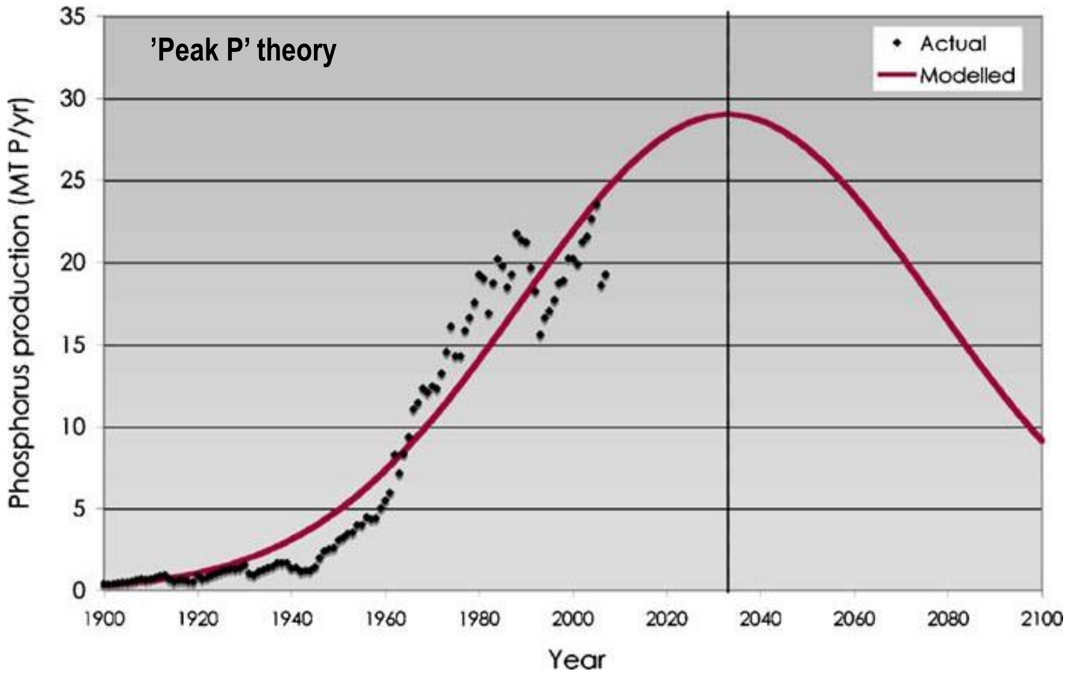
- A wide range of P mitigation practices are currently applied.
  Still, efficient methods to reduce leaching of dissolved P from soil are lacking.

- Nutrients in wastes from densely populated areas can be recycled as inorganic fertilizers in future.

- There are strong indications that Fe-bound P is responsible for temporarely high leaching losses of P.

# Scarcity of rock phosphates came into focus in 2008

In 2009/10, a ‘peak phosphorus’ theory was discussed.




Cordell et al. 2009. Global Environmental Change 19, 292-305.

Peak P was estimated to occur around 2035

# World reserves of rock phosphate

| Country | Economically exploitable apatite (million tons) | |
|---|---|---|
| | 2008 | 2016 |
| China | 4,100 | 3,100 |
| USA | 2,200 | 1,100 |
| **Morocco + W.S.** | **5,700** | **50,700** |
| Russia | 200 | 1,300 |
| Tunisia | 100 | 100 |
| Brazil | 260 | 320 |
| Jordan | 900 | 1,200 |
| Kazakhstan | - | 260 |
| Israel | 180 | 130 |
| Egypt | 100 | 1,200 |
| South Africa | 1,500 | 1,500 |
| Australia | 82 | 1,100 |
| Saudi Arabia | 25 | 680 |
| Togo | 30 | 30 |
| Senegal | 50 | 50 |
| Other countries | 890 | 1,000 |
| **Total** | **15,000** | **68,000** |

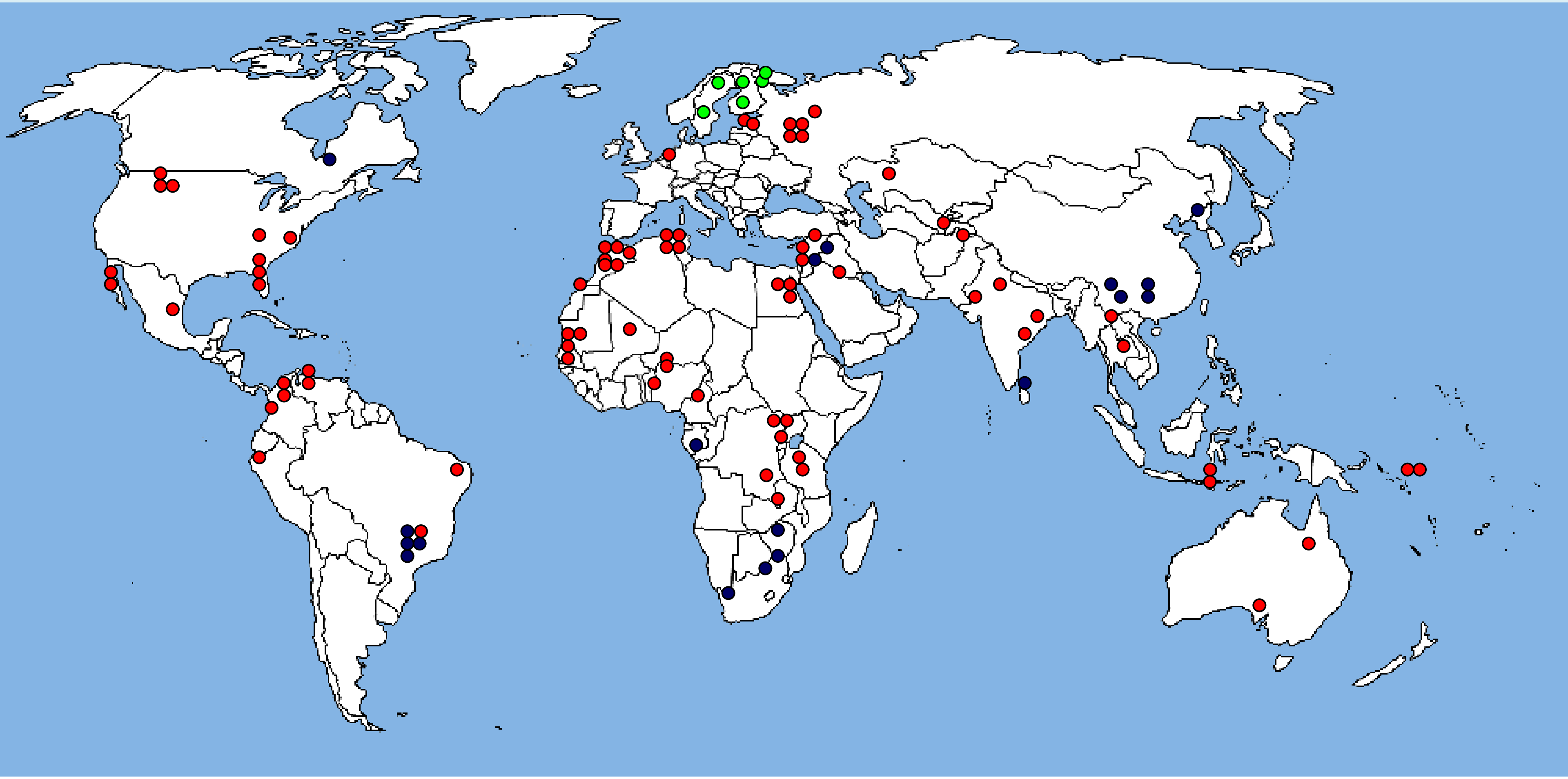
USGS 2017. https://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/mcs-2017-phosp.pdf

The ‘peak P’ theory was dismissed after USGS estimates on world P resources increased

# Open mining of sedimentary apatite at Khouribga, Morocco


Tenfold higher P deposits were reported from Morocco/West Sahara since 2014

# Abundance of cadmium in phosphate deposits



| | | |
|---|---|---|
| Low cadmium | < 10 mg | $Cd\ kg^{-1}\ P$ |
| Medium cadmium | 10 -50 mg | $Cd\ kg^{-1}\ P$ |
| High cadmium | >50 mg | $Cd\ kg^{-1}\ P$ |

McLaughlin et al. 1996. AJSR 34, 1-54.

More than 75% of phosphates are marine, sedimentary deposits containing Cd

# Cadmium contents in phosphate deposits and P fertilizers

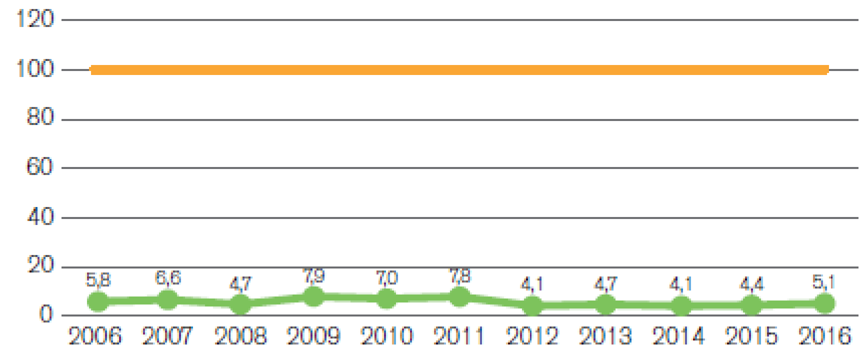
| Origin of phosphate | Cd content (mg Cd $kg^{-1}$ P) |
|---|---|
| Russia (Kola), Finland (Silinjärvi) | 1 |
| South Africa (Phalaborwa) | 23 |
| China (Yunan) | 35 |
| Syria (Eastern and Khneifiss) | 35 |
| Australia (Duchess) | 50 |
| Egypt (Quseir) | 61 |
| Morocco (Khouribga) | 80 |
| Israel (Arad) | 85 |
| Tunesia (Gafsa) | 108 |
| Israel (Zin) | 228 |
| Morocco (Boucraa) | 240 |
| Christmas Island | 275 |
| USA (North Carolina) | 311 |

McLaughlin et al. 1996. AJSR 34, 1-54.

| Cadmium in 90 European P fertilizers (mg Cd $kg^{-1}$ P) | |
|---|---|
| Mean | 83 |
| Median | 87 |
| P90 | 168 |
| P95 | 185 |

Nziguheba & Smolders 2008. Sci.Total Environ. 390, 53-57.

**Cadmium in Swedish P fertilizers (mg Cd $kg^{-1}$ P)**




Lantmännen

In marine, sedimentary P deposits, Cd-rich minerals (e.g. Zinkblende) cause contamination

# Cadmium in food - a health risk

● Exposure to levels of 30–50 µg Cd $day^{-1}$ increase the risk of bone fracture, cancer, kidney dysfunction and hypertension.

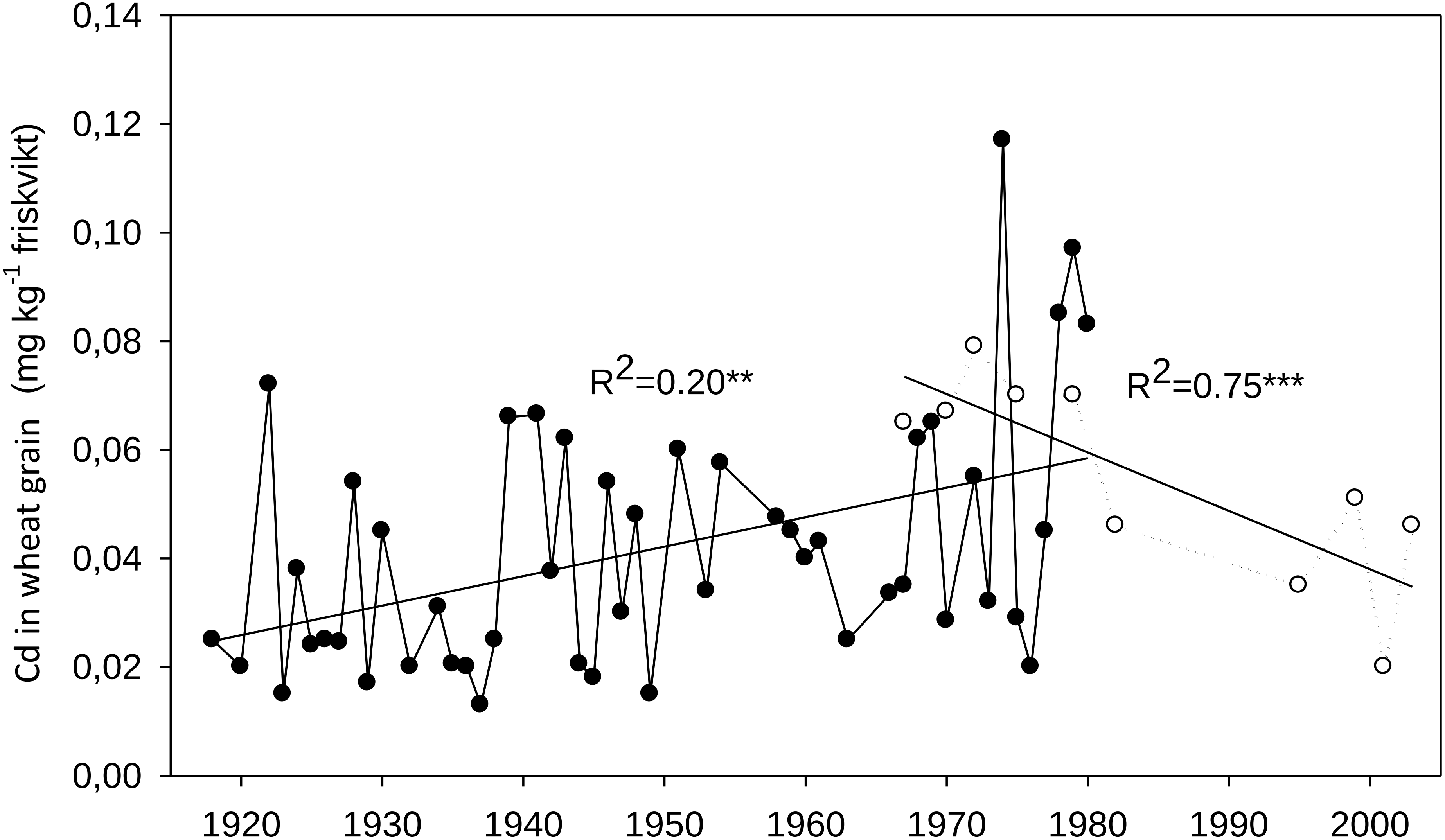
Satarug et al. (2003) Toxicology Letters 137, 65-83

● Recommendation by EFSA (2009):
*”The intake of Cd needs to be reduced from 7 to 2.5 µg Cd* $kg^{-1}$ *body weight and week”.*

EFSA 2009. European Food Safety Authority Journal 980, 1-139.

The recommendation by EFSA means a 2/3 reduction of dietary Cd intake

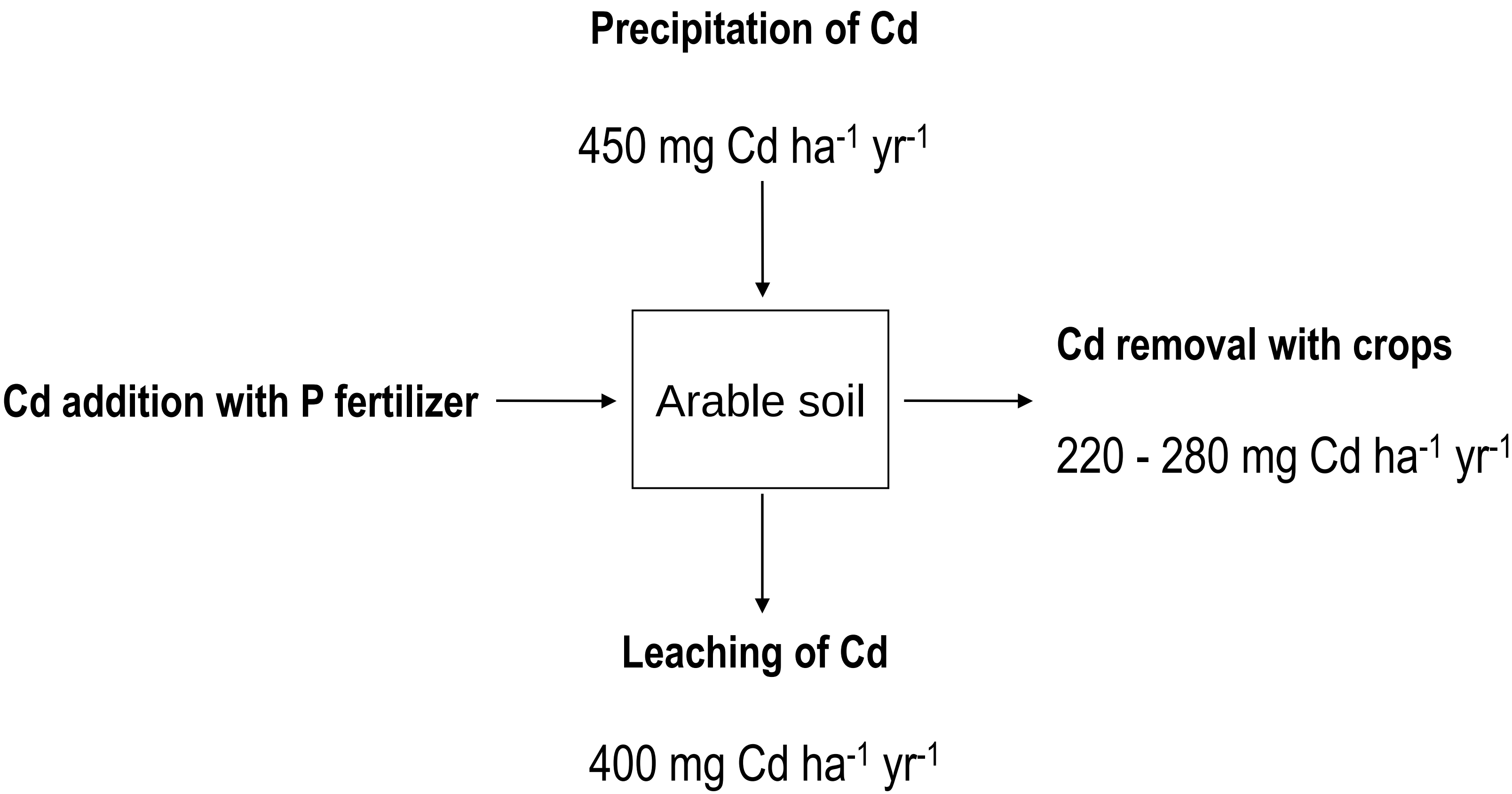
# Content of Cd in Swedish wheat from long-term field trials




Kirchmann et al. 2010. Medicinsk Geologi, 229-257.

During 60 years Cd increased in Swedish wheat but declined since the 1980th

# Soil Cd balance of Swedish arable land




Eriksson 2001. Naturvårdsverket Report 5148.
Eriksson 2009. Rapport MAT21, nr 1/2009. SLU, Uppsala.

Cd in fertilizer/manure must not exceed 10 mg Cd kg$^{-1}$ P to avoid enrichment in soil when applied at rates of 20-25 kg P ha$^{-1}$ yr$^{-1}$