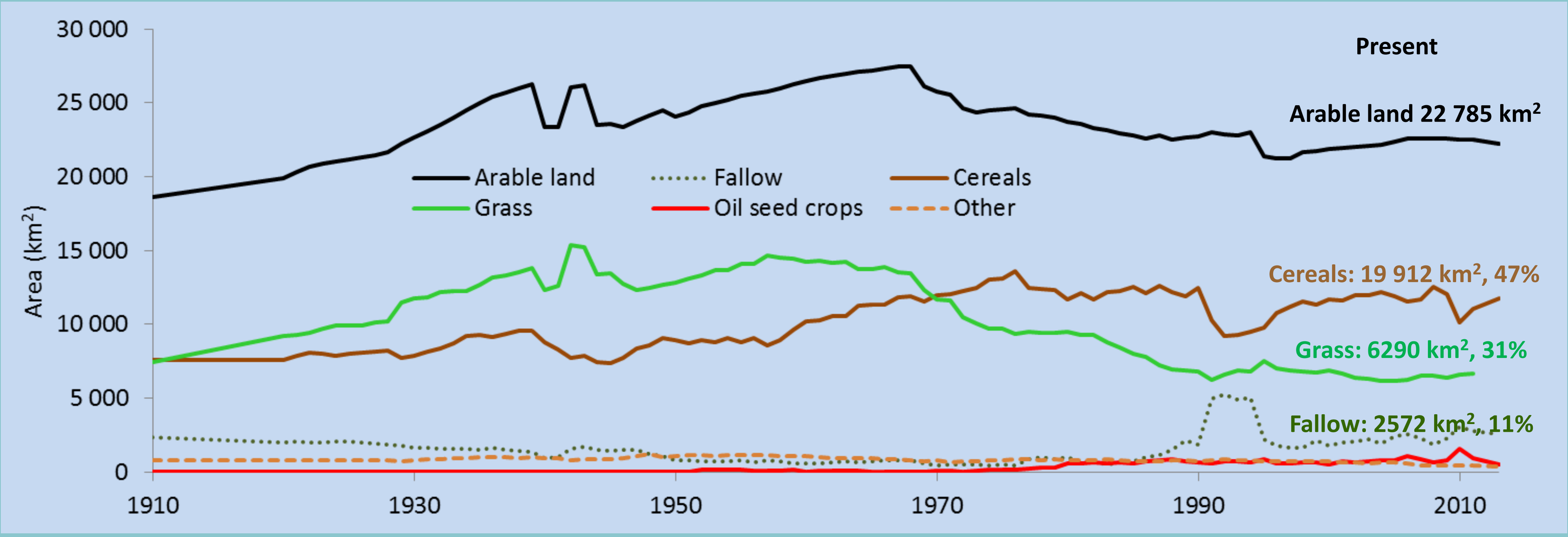
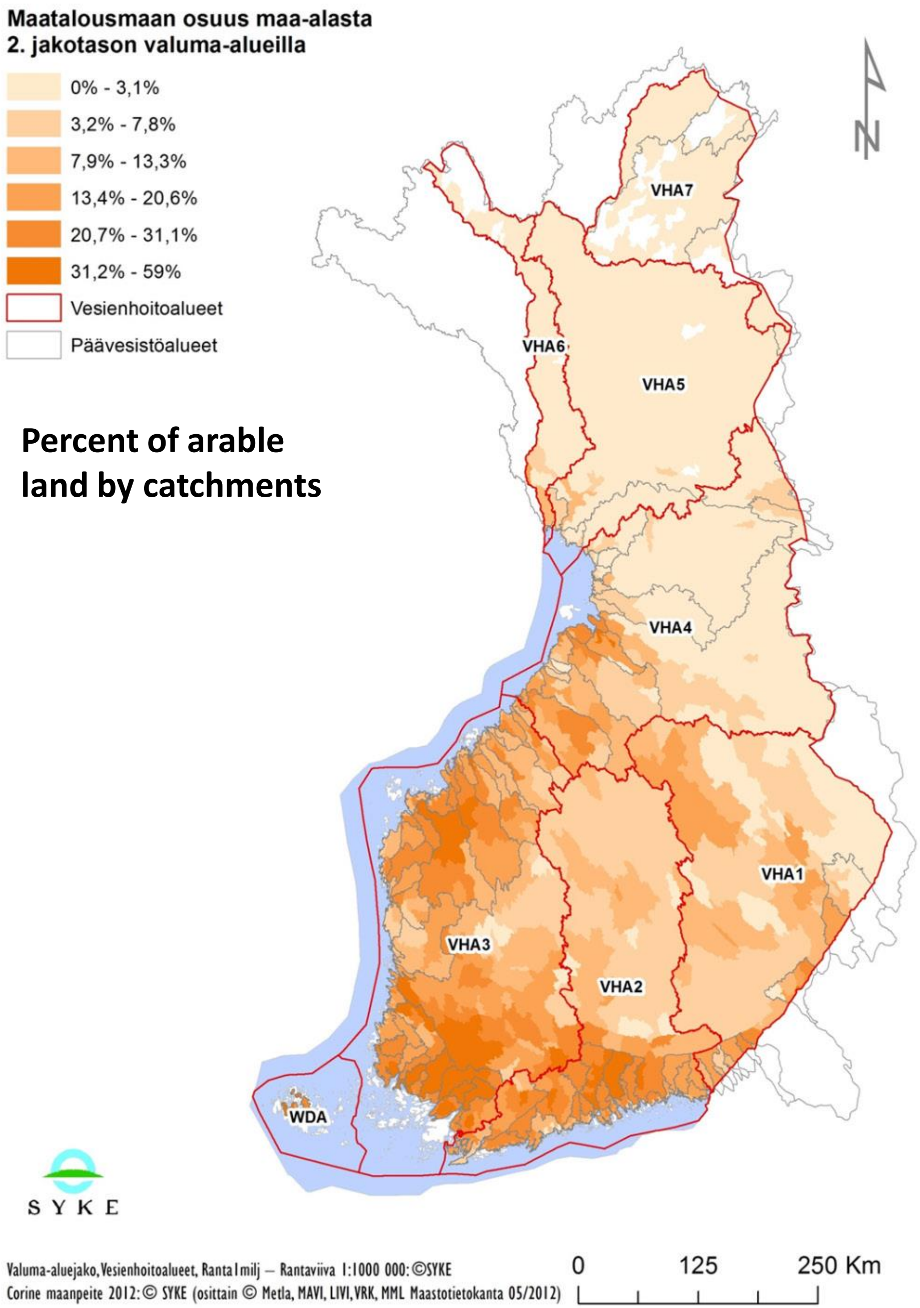
7. Agricultural load

Background

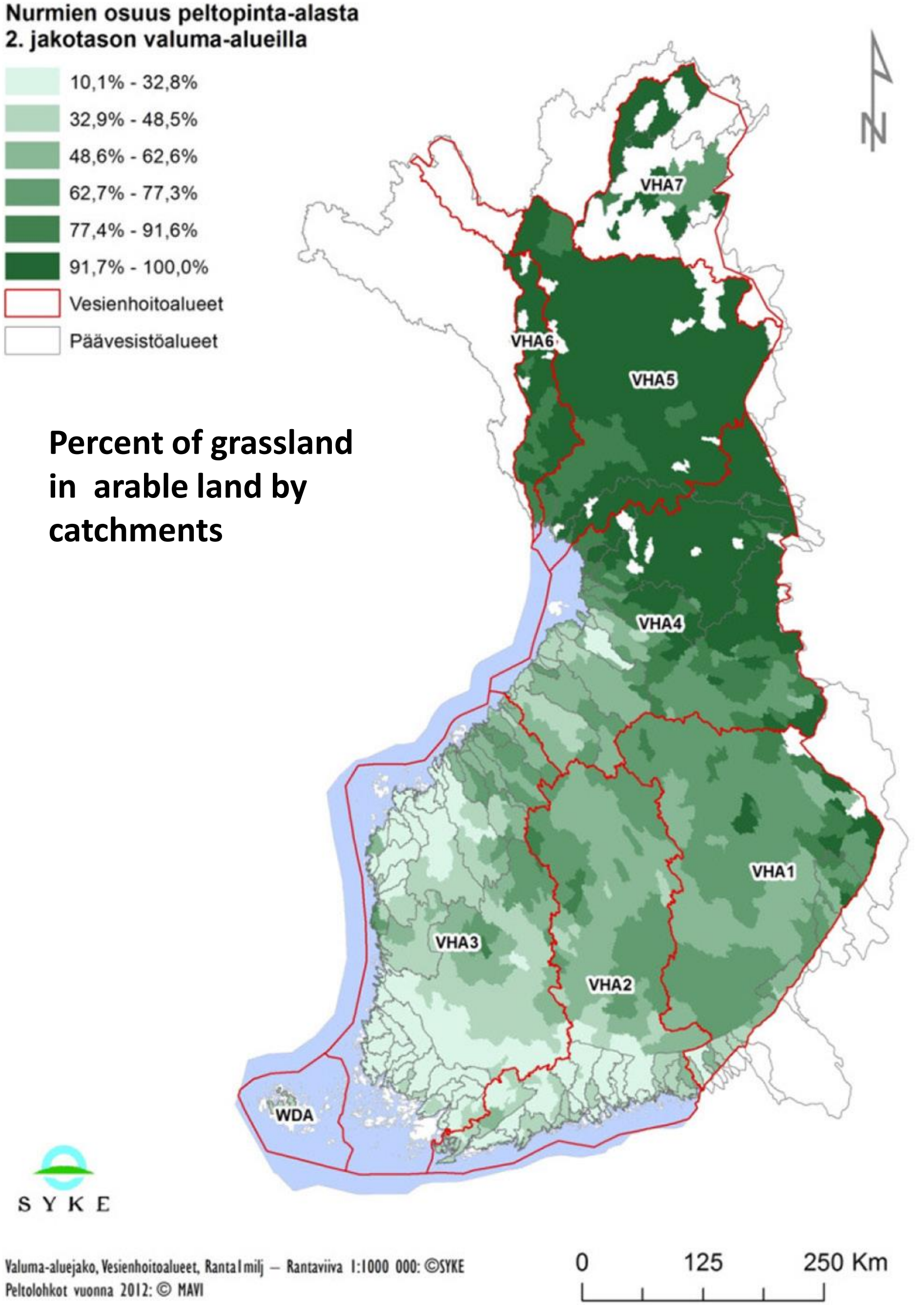
- Short productive season, unfavourable weather conditions → low yields, high costs
- Percent of GDP
  - Agriculture 2%
  - Food industry 1.6%
- Agricultural supports amount to 2 billion €
- Arable land in Finland 6.8% (EU mean 47%), i.e., 7.4% of land area
  - Southern and southwestern Finland, southern Ostrobothnia 30%
- Structural change
  - 1995: 100 000 active farms
  - Now: 51 000
  - Cereal farms 67%, animal farms 27%
  - Units increased, technology and cultivars developed
    - Average field area 42 ha
    - Average number of animals in a dairy farm 35 cows
- Clearing land for cultivation increases loading
  - Tillage, drainage, irrigation → Erosion and salinisation problems from ancient times
  - Mineralisation of organic matter increases

Development of arable land

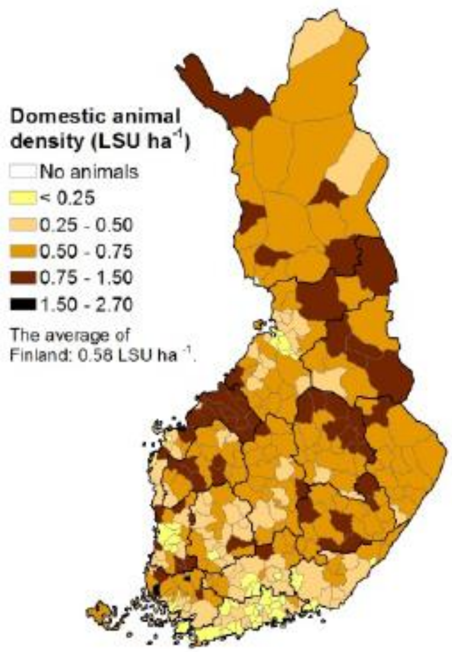


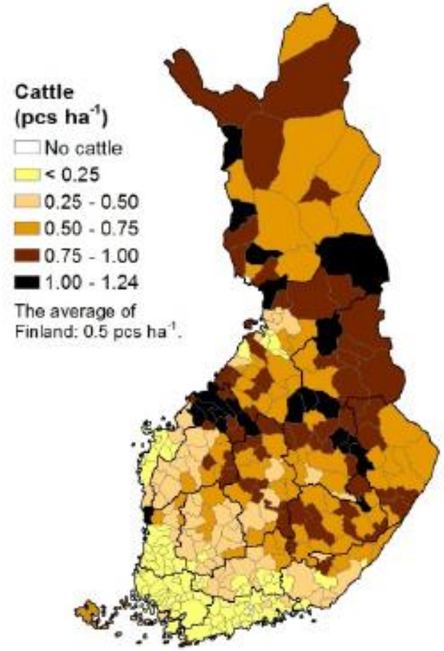


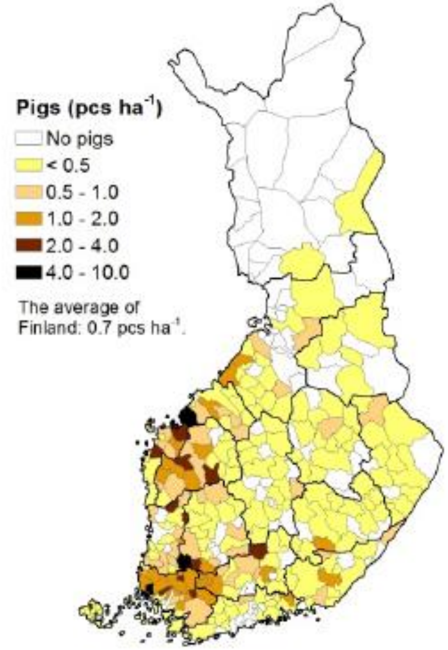
Percent of arable land by catchments



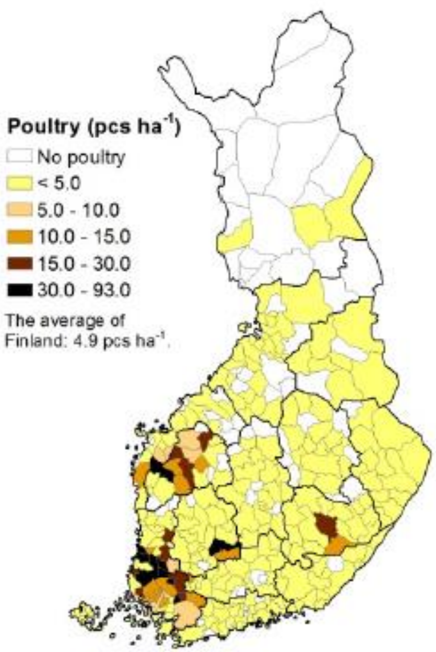
Percent of grassland in arable land by catchments

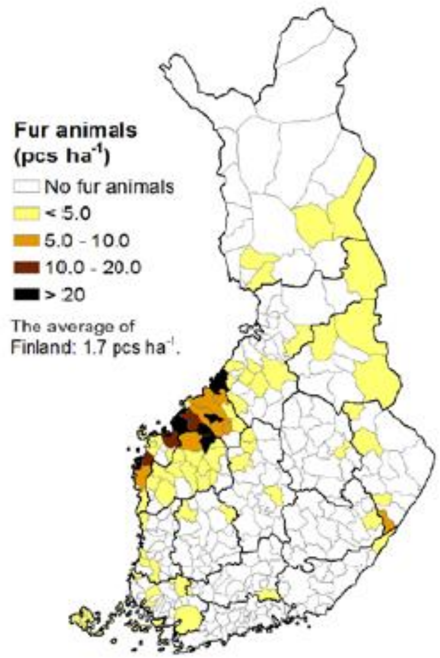


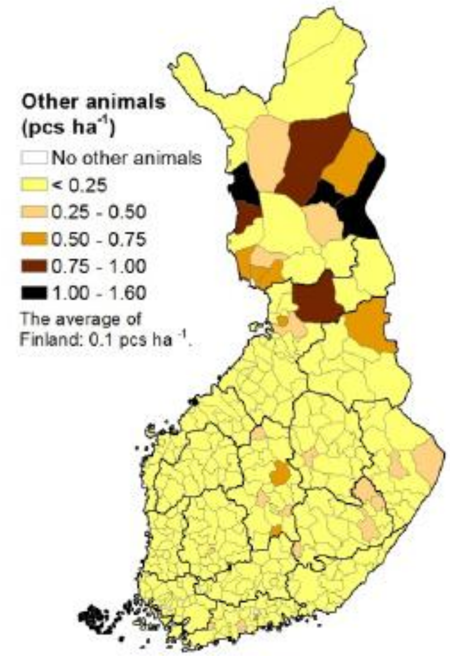




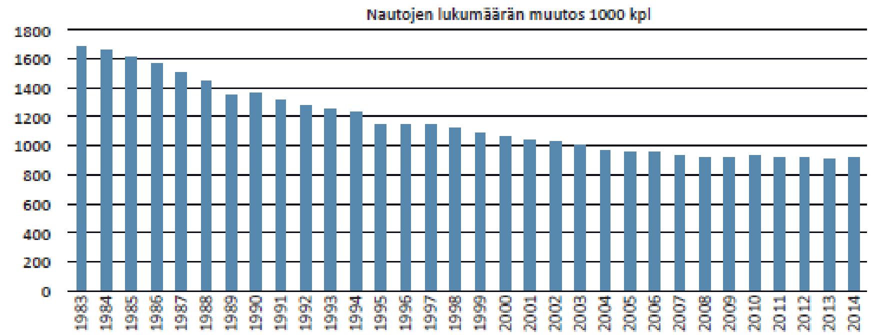
LSU = Livestock unit





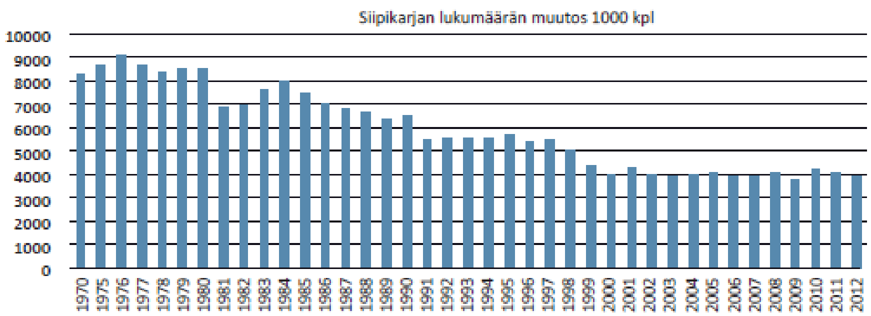


Ylivainio et al. (2014)

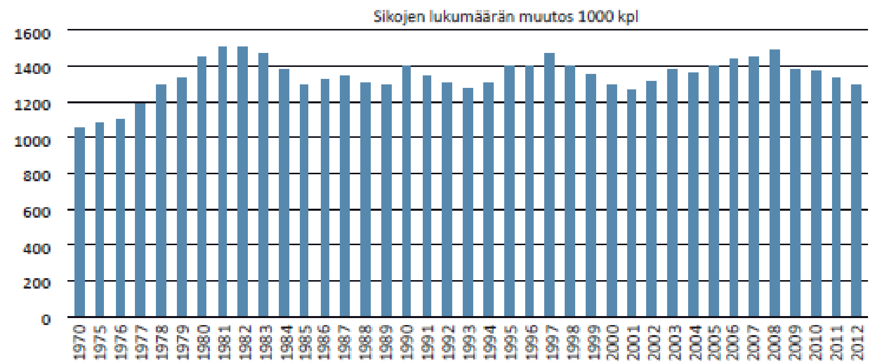


Cows

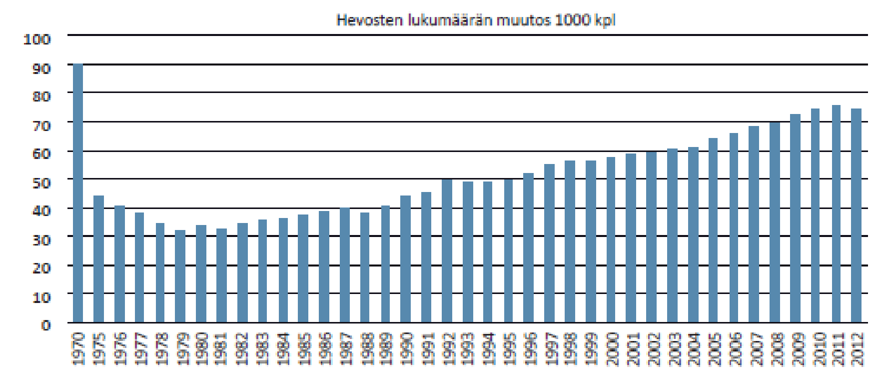
- Milk production remained about the same



Poultry



Pigs



Horses

Tattari et al. (2015)

Changes in agricultural practices

- Manure → Fertilisers
  - Before commercial fertilizers nutrient input was based on animals
    - Animals grazing in meadows and forests transported nutrients (in the form of manure) to the small cultivated area
- Specialisation and spatial differentition
- Manure has become a ”waste”
- Spreading of manure in winter forbidden
- Farmyard manure → slurry
- Open ditches → tile drainage
- Fertiliser broadcasting → incorporation in soil (into about 8 cm depth)
- Open fallow → green fallow

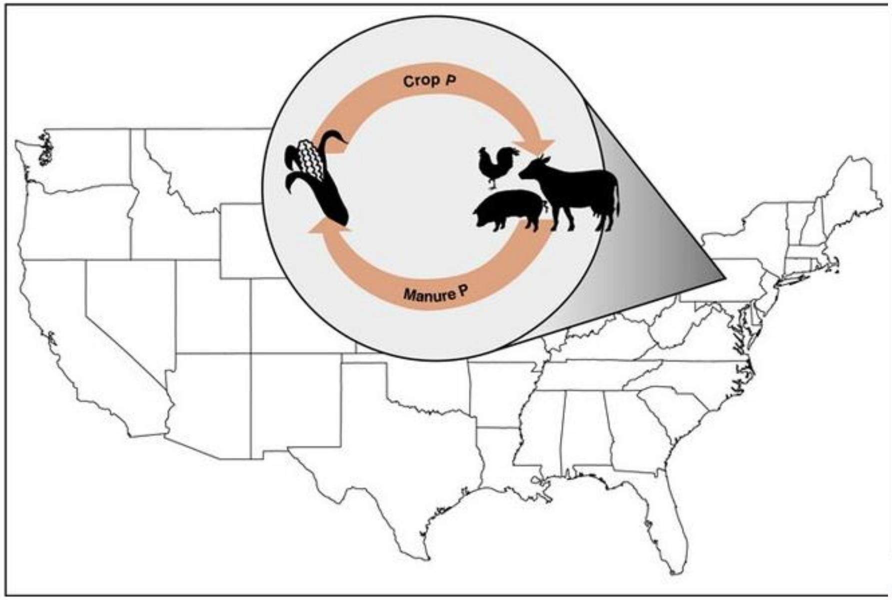


Figure 4. Before World War II, nutrient cycling was localized and sustainable within watersheds.

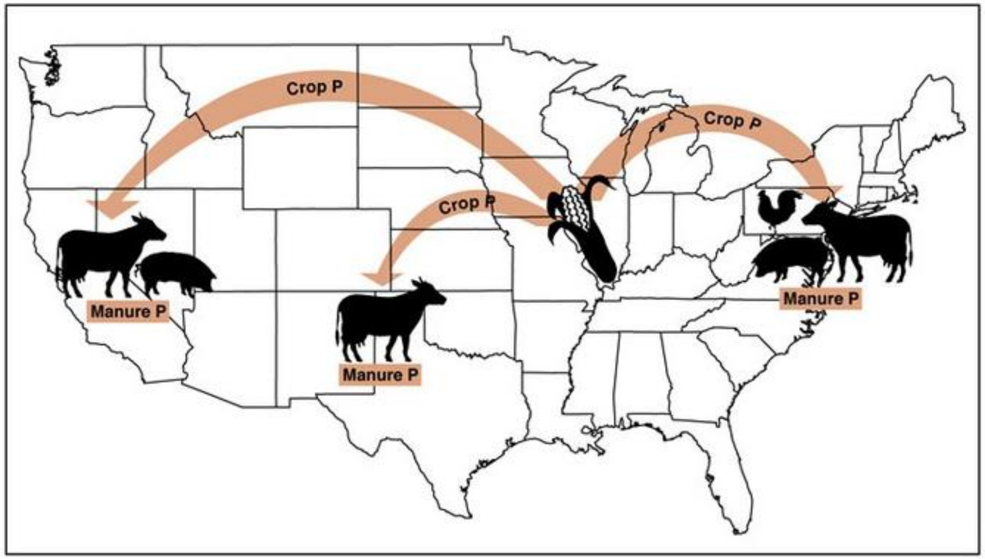


Figure 5. Since World War II, the nutrient cycle has been broken, with P tending to move from areas of grain production to areas of livestock production on a national level.

http://extension.psu.edu/plants/nutrient-management/educational/soil-fertility/managing-phosphorus-for-agriculture-and-the-environment

Spreading slurry in 1969

Winter-time spreading was forbidden by implementation of the Nitrates directive (1998)

Soil test in use in Finland

- Developed in 1947–1950 (Vuorinen & Mäkitie 1955)
- Viljavuuspalvelu Oy (currently Eurofins) established in 1952
  - Also other labs
- Soil test starts with the extraction of dry soil by
  - Acid ammonium acetate (0.5 M CH_3COONH_4, 0,5 M CH_3COOH, pH 4.65)
- Followed by the analysis of elements from the extractant
- Soil test analysis required by the Finnish agri-environmental programme (started in 1995)
- No commonly used analysis for N
  - Nitrogen release depends on mineralisation
- Analysis of inorganic N
  - Spring determination can be used in adjusting fertilising
- N sensor

Photo: Saara Kirjalainen, Ignacio Gonzáles, Elina Röman

Viljavuusluokkaleimat			
Huono	Välttävä	Hyvä	Arvel. korkea
Huononlainen	Tyydyttävä	Korkea	

Optimal fertilising

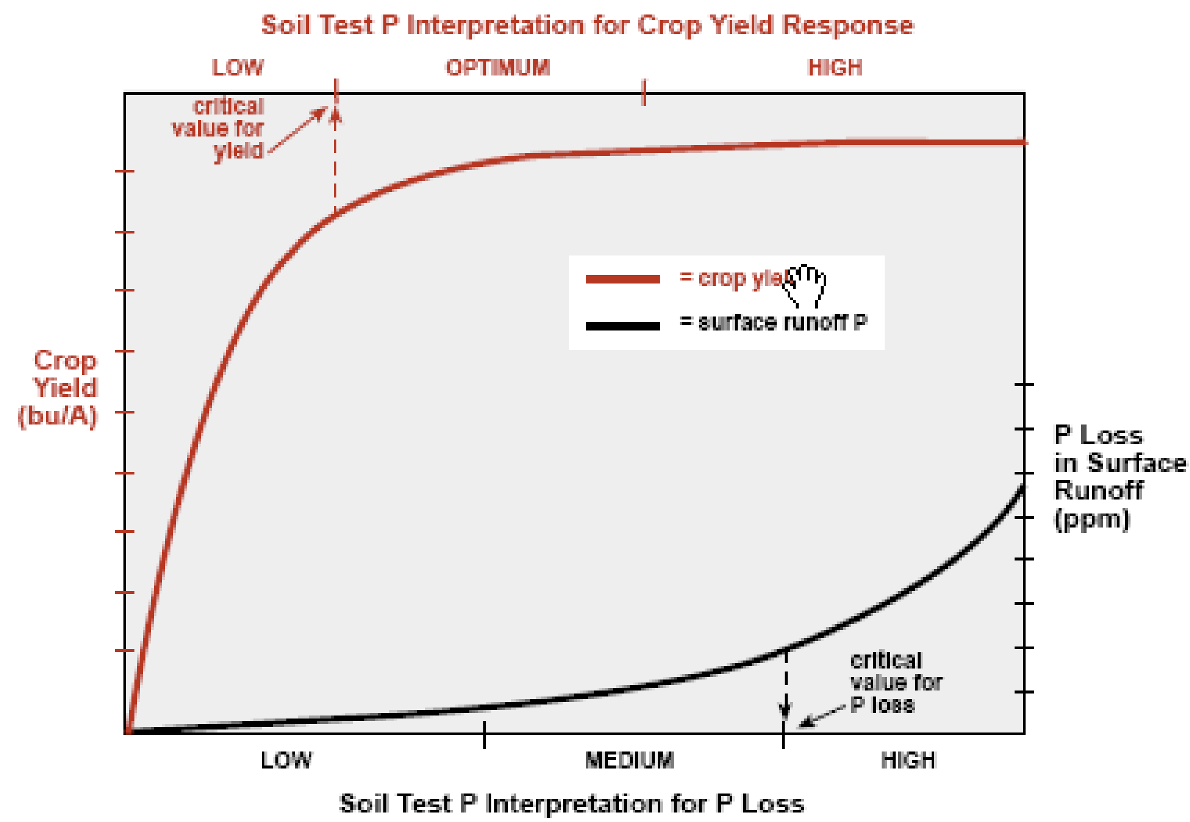


Figure 9. As soil P levels increase (x axis, above), so do crop yields and the potential for P loss in surface runoff. No direct relationship can be assumed to exist, however, between the soil test P interpretations for crop response (upper scale) and those for P loss (lower scale).

http://pubs.cas.psu.edu/FreePubs/pdfs/uc162.pdf

Use of fertilizers and manure and soil-test P

Crop uptake

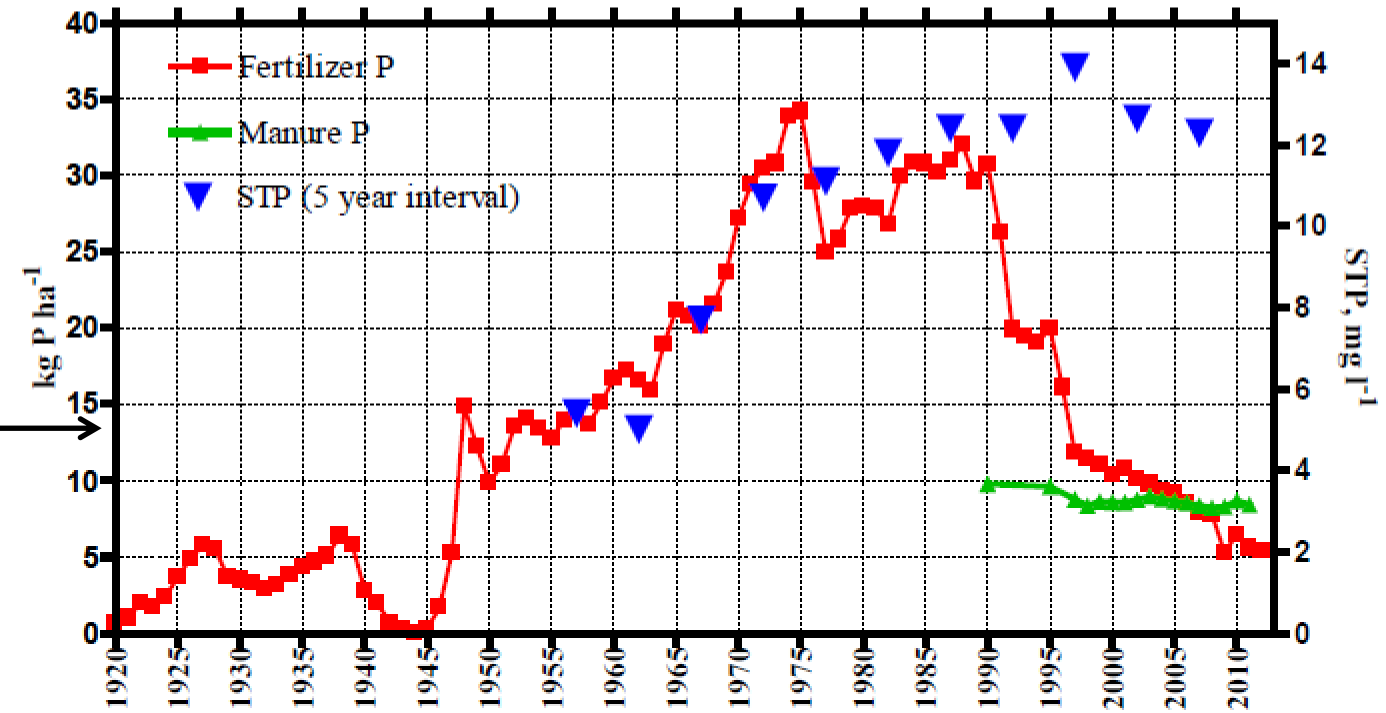


Figure 1. Sales of mineral P fertilizers to farms in Finland between 1920 and 2011 (Kekäläinen 1999, Information Centre of the Ministry of Agriculture and Forestry 2012) and production of manure P between 1990-2011 (Aakkula et al. 2010, Tapio Salo, personal communication). Development of average STP value, representing easily soluble P in the plough layer of cultivated soils, at intervals of five years during 1955-2010, is shown according to data of Viljavuuspalvelu Oy (Kurki 1963, Kurki 1972, Kurki 1982, Kähäri et al. 1987, Mäntylahti 2002, Tuloslaari 17.10.2012 http://www.tuloslaari.fi/index.php?id=41).

Ylivainio et al. (2014)

- pH of soils increased (liming)
- Soil-test P increased by 2.5 times
  - Decreased in recent years

Fertilizer recommendations

- In 1960s, the recommendation for P use: 30–60 kg ha^{-1} y^{-1}
- In 1970s, maximum average rates (35 kg ha^{-1} y^{-1}), after which recommendations were lowered
- At the start of 1990s, recommendations further lowered, short period of fertilizer tax, compulsory setaside (minumum 15% field area)
- During 1900s, 800–900 kg ha^{-1} P stored in soil in Finland (Sweden: about 700 kg ha^{-1} P)
    - P concentration increased by at least one third

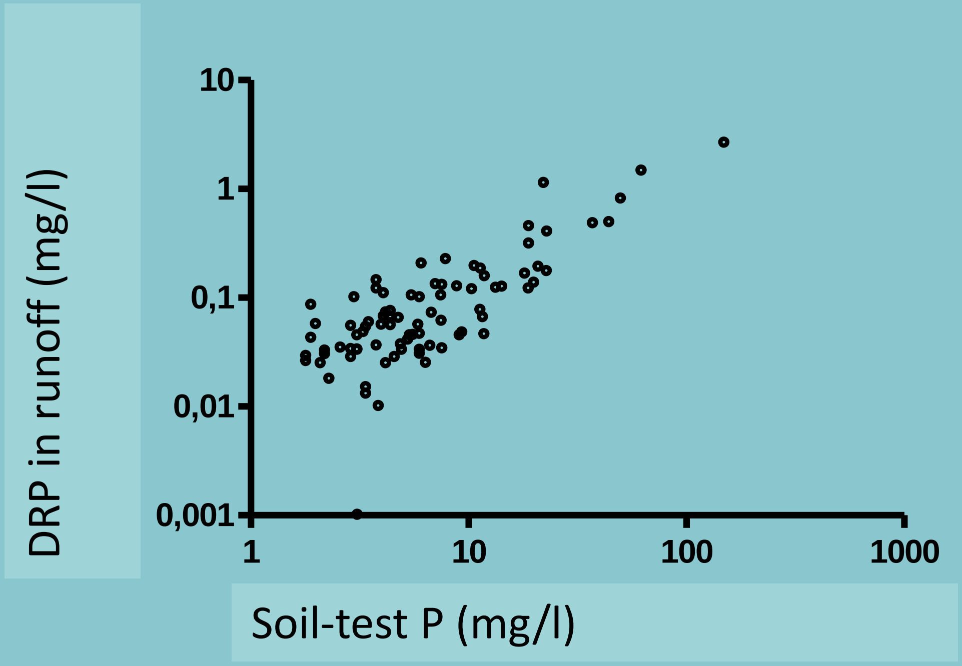
kg ha^{-1} y^{-1}	Recommendation for barley (soil class fair)
1984	40
1991	30
1995	20-28
2007	22
2017	16

Source: Uusitalo et al. (2007)

Phosphorus fertilization: A meta-analysis of 80 years of research in Finland

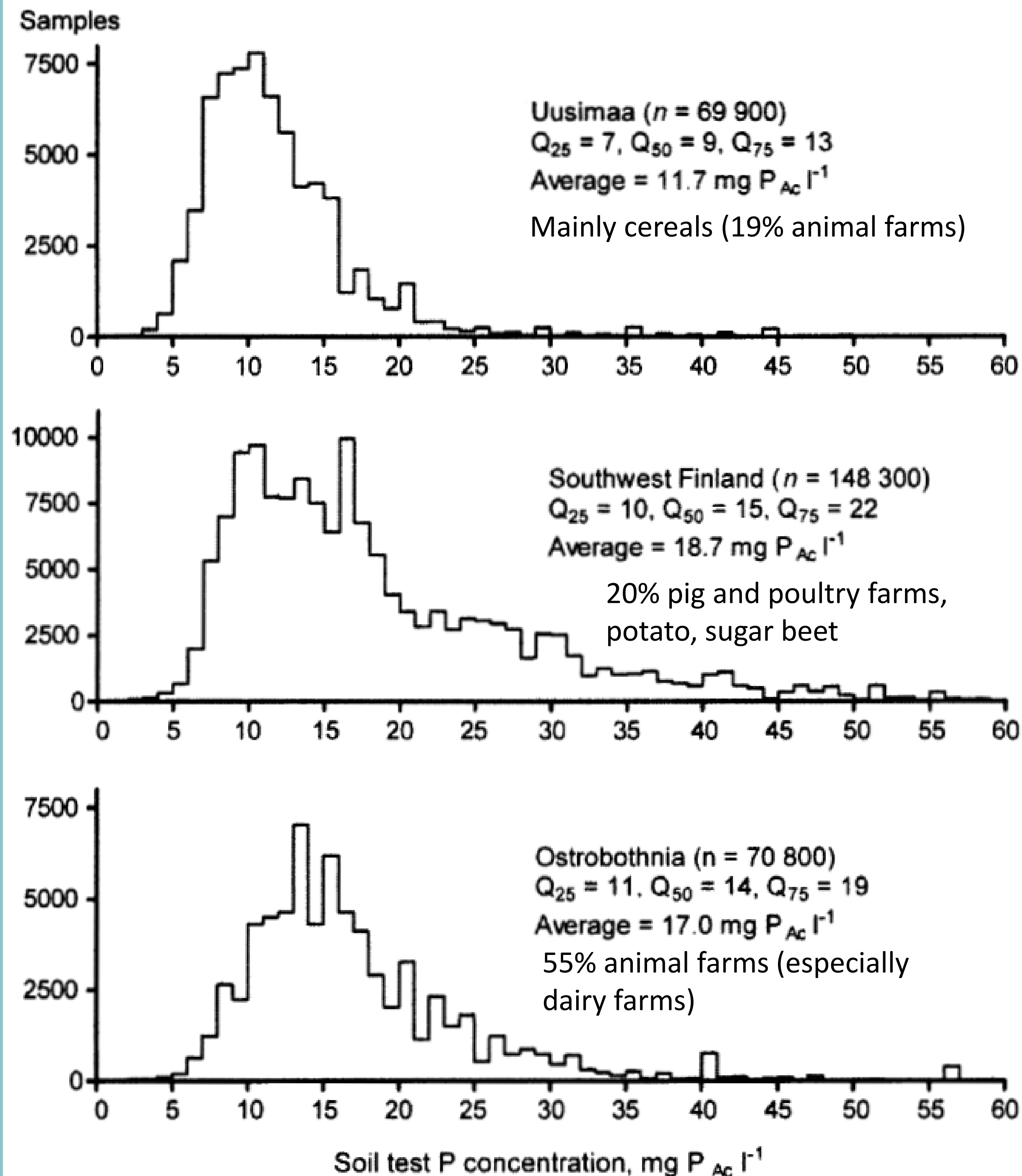
- Meta-analysis of 400 short- and long-term fertilizer trials in Finland (1927–2007, Valkama et al. 2009)
- P rates 6–100 kg ha^{-1}
- P fertilization increased crop yields (by an average of 11%) compared to the control (fertilized with N and K)
- Yield increase
  - Clay soils 5% (low rates sufficient)
  - Coarse mineral soils 10% (higher rates needed)
  - Organic soils 15%
- Threshold soil-test P after which no effect
  - Clay soils: independent on STP
  - Coarse mineral soils <10 mg l^{-1}
  - Organic soils <8 mg l^{-1}
- Conclusion: P fertilizing can be further decreased in Finland

The concentration of DRP in runoff increases with soil-test P

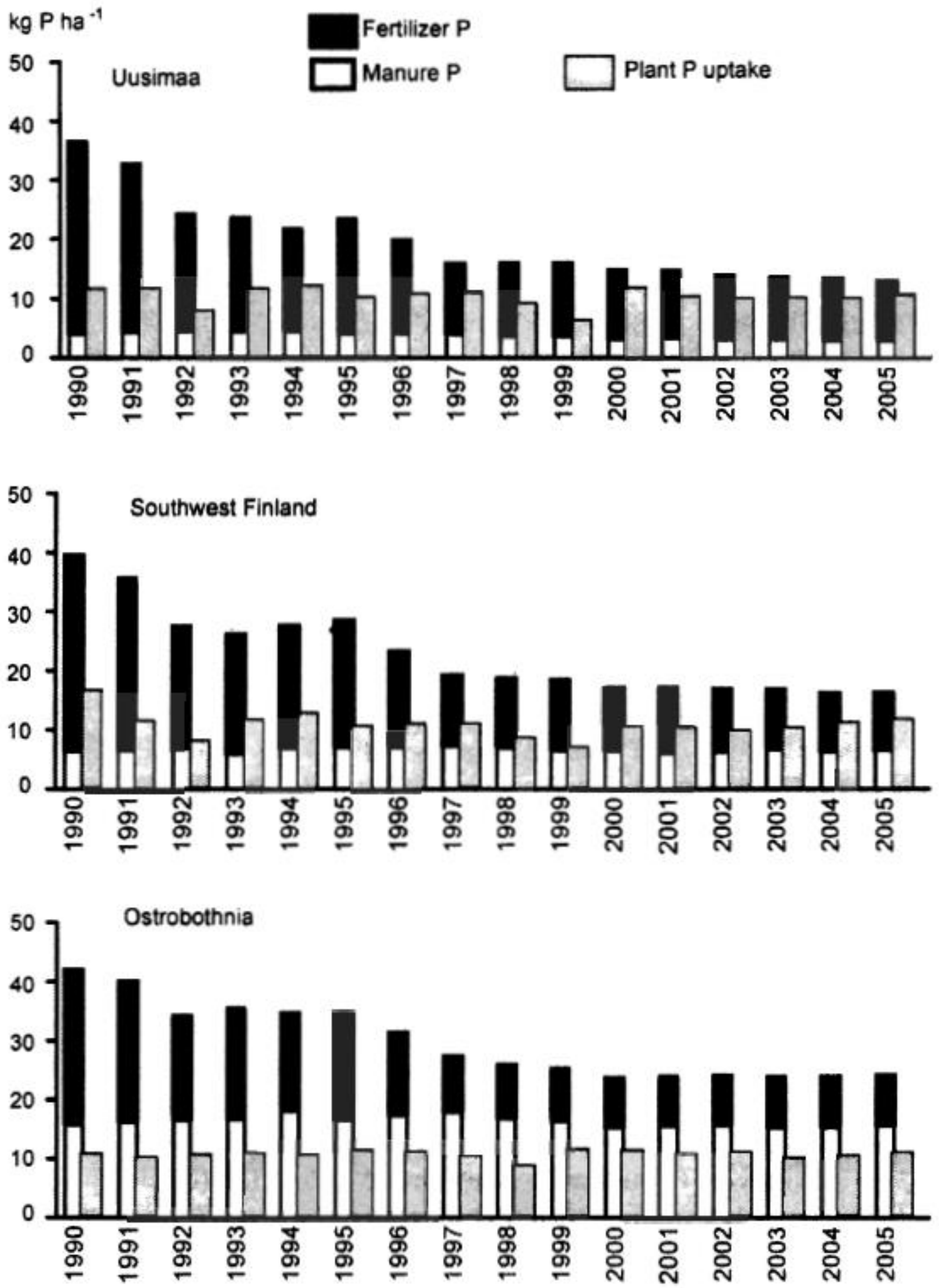


$$\boldsymbol{DRP = 0.021STP - 0.015}$$

Uusitalo & Jansson (2002)
Uusitalo ym. (2008)



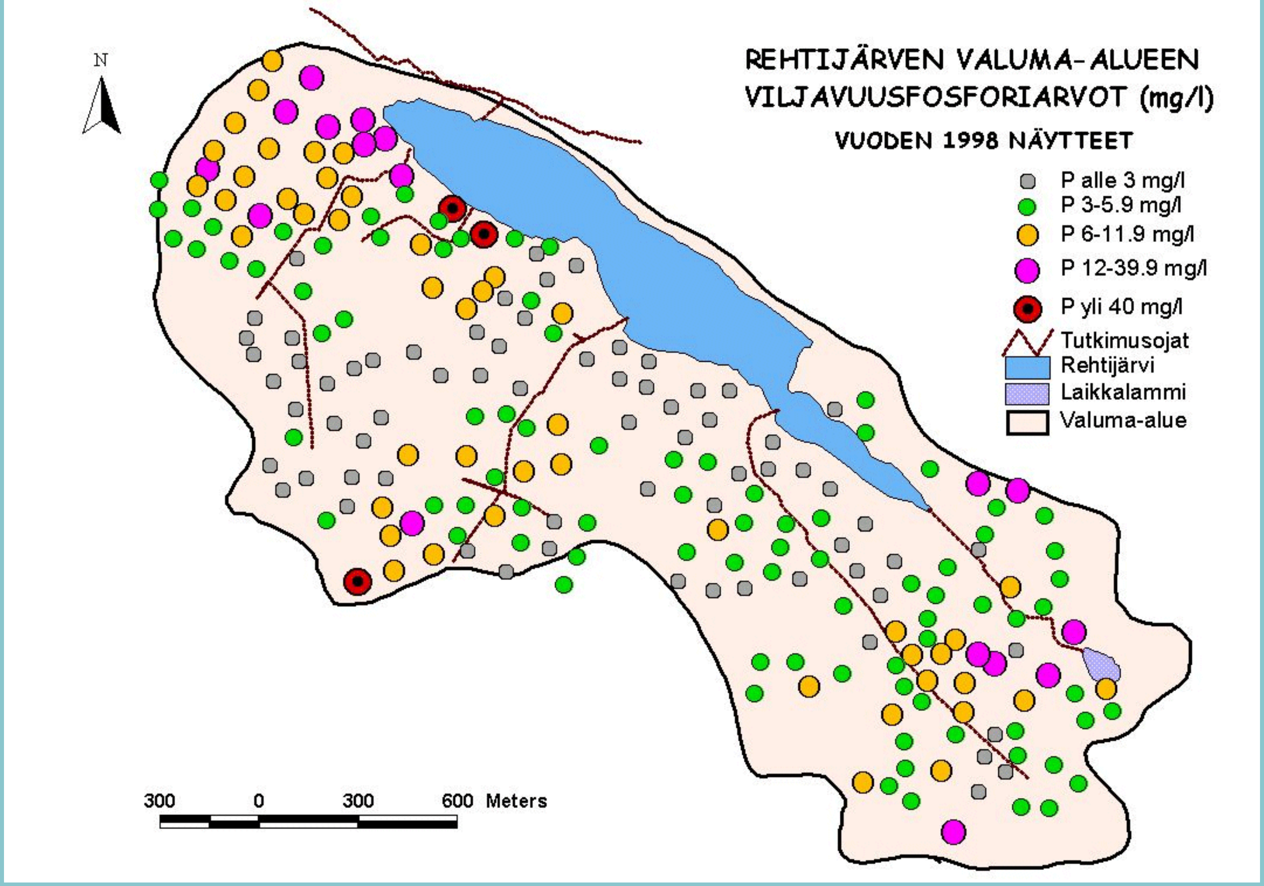
Uusitalo et al. (2007)



Uusitalo et al. (2007)

Soil-test P in the catchment of Lake Rehtijärvi (Jokioinen)

STP mg/l	Area km^2	Loss kg/y
< 3	0.75	4.5
3-6	0.80	10.8
6-12	0.50	13.5
12-40	0.17	13.3
> 40	0.03	5.0



50% of DRP loss originates from less than one fifth of the field area

Map: Närvänen A & Jansson H
Source: Eila Turtola, MTT

Estimating agricultural load

Lysimeters, experimental fields

Small catchments

Agricultural rivers

m^2, ha

0.1–10 km^2

100–1000 km^2

- Models: Icecream, Coup, FLUSH…
- Expert systems: VIHMA

- SWAT, INCA…

- Vemala

Lysimeters and experimental fields

- Help to understand processes
- Experimental design and set-up crucial
- Results apply only the experimental site
  - Generalisation requires a high number of studies performed in different conditions + replicates
- No knowledge on catchment processes

An example

- ^{33}P on top of soil monolites (diameter 0.295 m , depth 1.18 m), artificial precipitation weekly (Djodjic et al. 1999)
  - Percolating water contained more P in a clay soil than in a sandy soiil Sa
  - P was transported by macropore flow without being sorbed to soil

The Aurajoki experimental field†

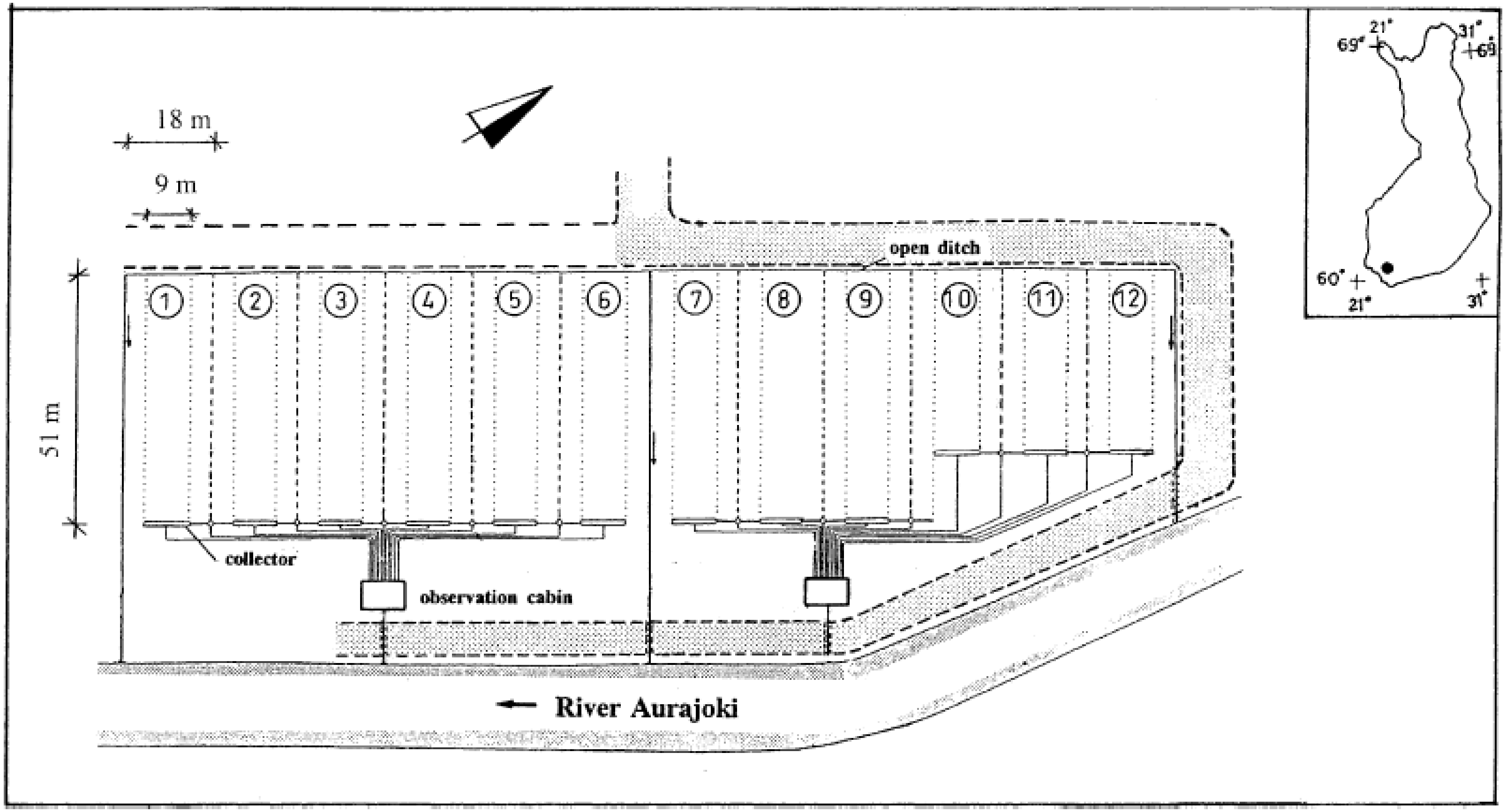
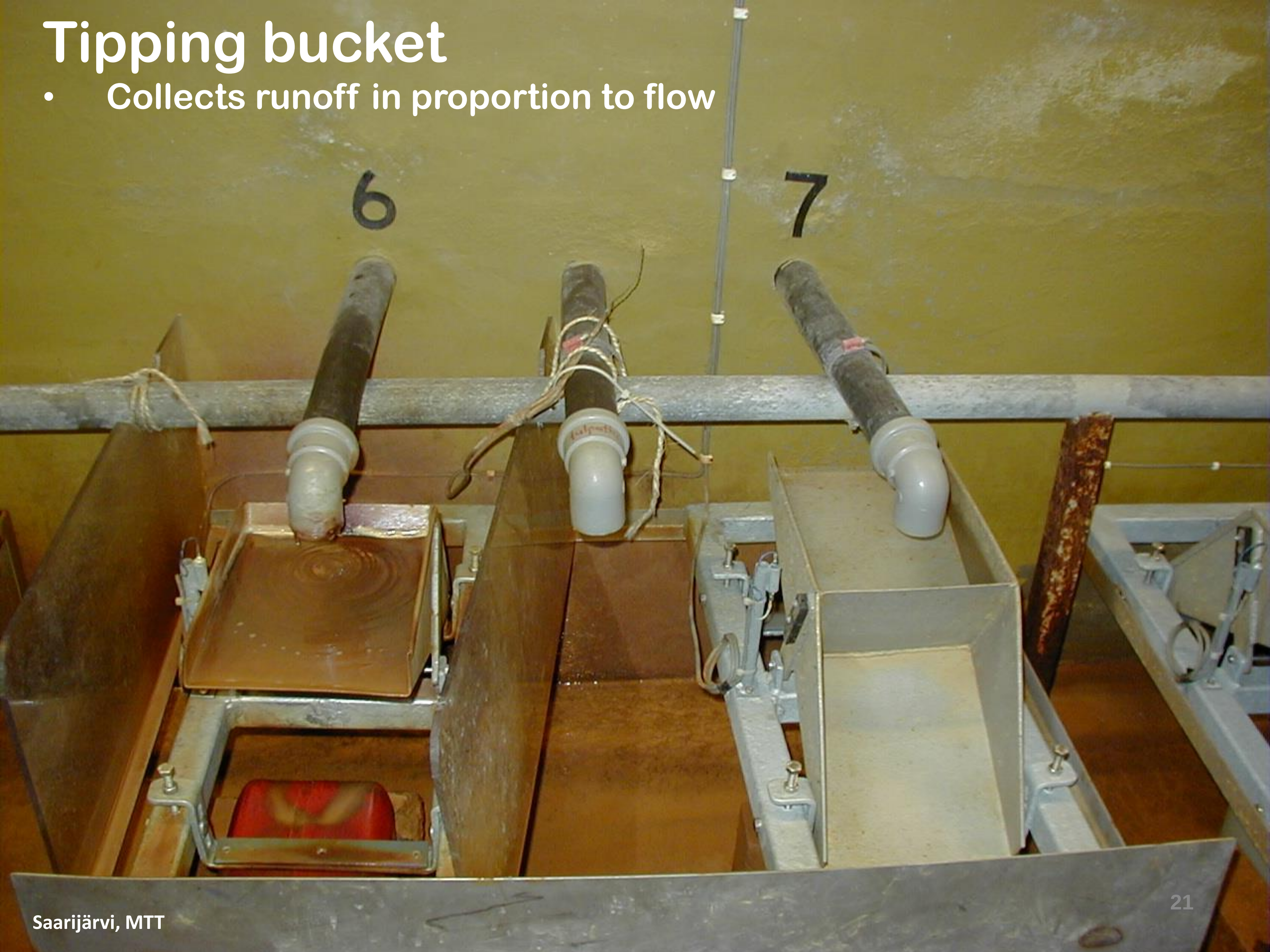


Fig. 1. Layout of the Aurajoki experimental field.

Tipping bucket

- Collects runoff in proportion to flow



Saarijärvi, MTT

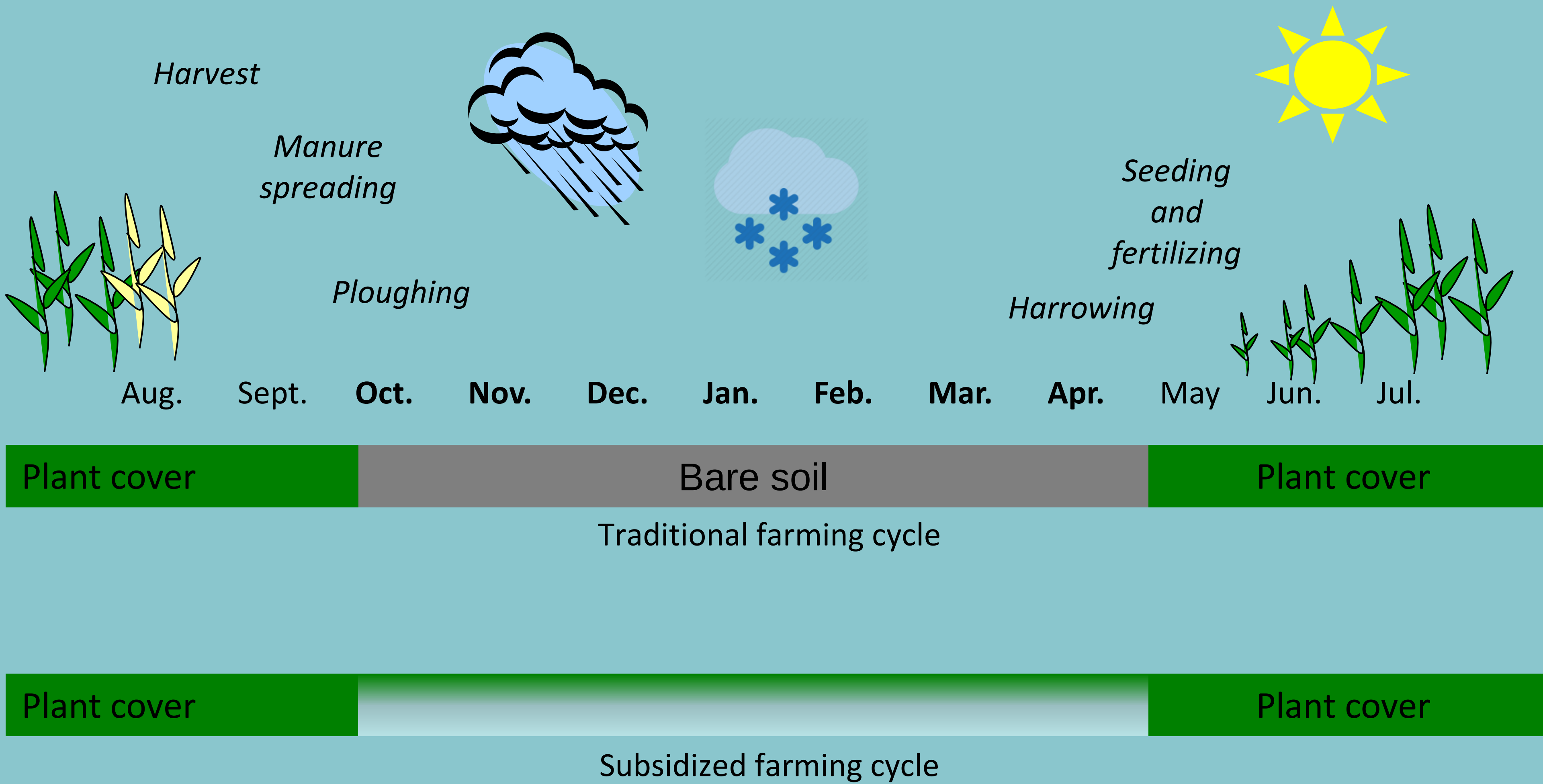
Effect of season on the losses of P and N

- **Fertilizer trial in 16 field plots (grass, fine sand, 3 years, Turtola & Kemppainen 1998)**

Treatment	N (kg km^{-2} y^{-1})	P (kg km^{-2} y^{-1})
No fertilizers	1300	73
Slurry in autumn	6200	1600
Slurry in winter	19 100	5400
Slurry in spring	2300	420
NPK fertilizer in spring	2400	400

  - **17% and 59% of P in manure spread in autumn and spring, respectively, was flushed away**
  - **11% and 33 % for N**

Annual farming cycle



A plough and a cultivator

A plough

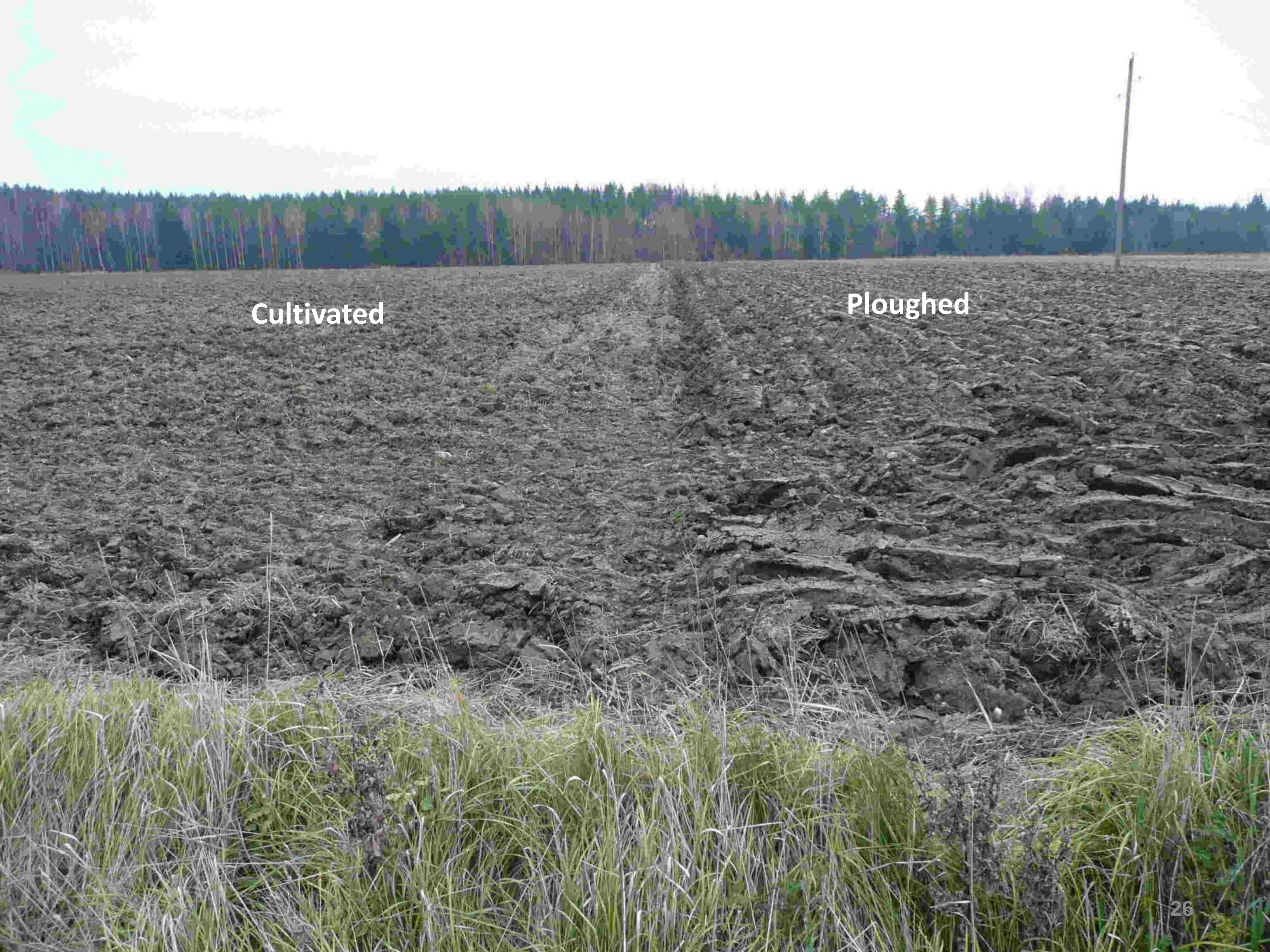
A cultivator

Two harrows

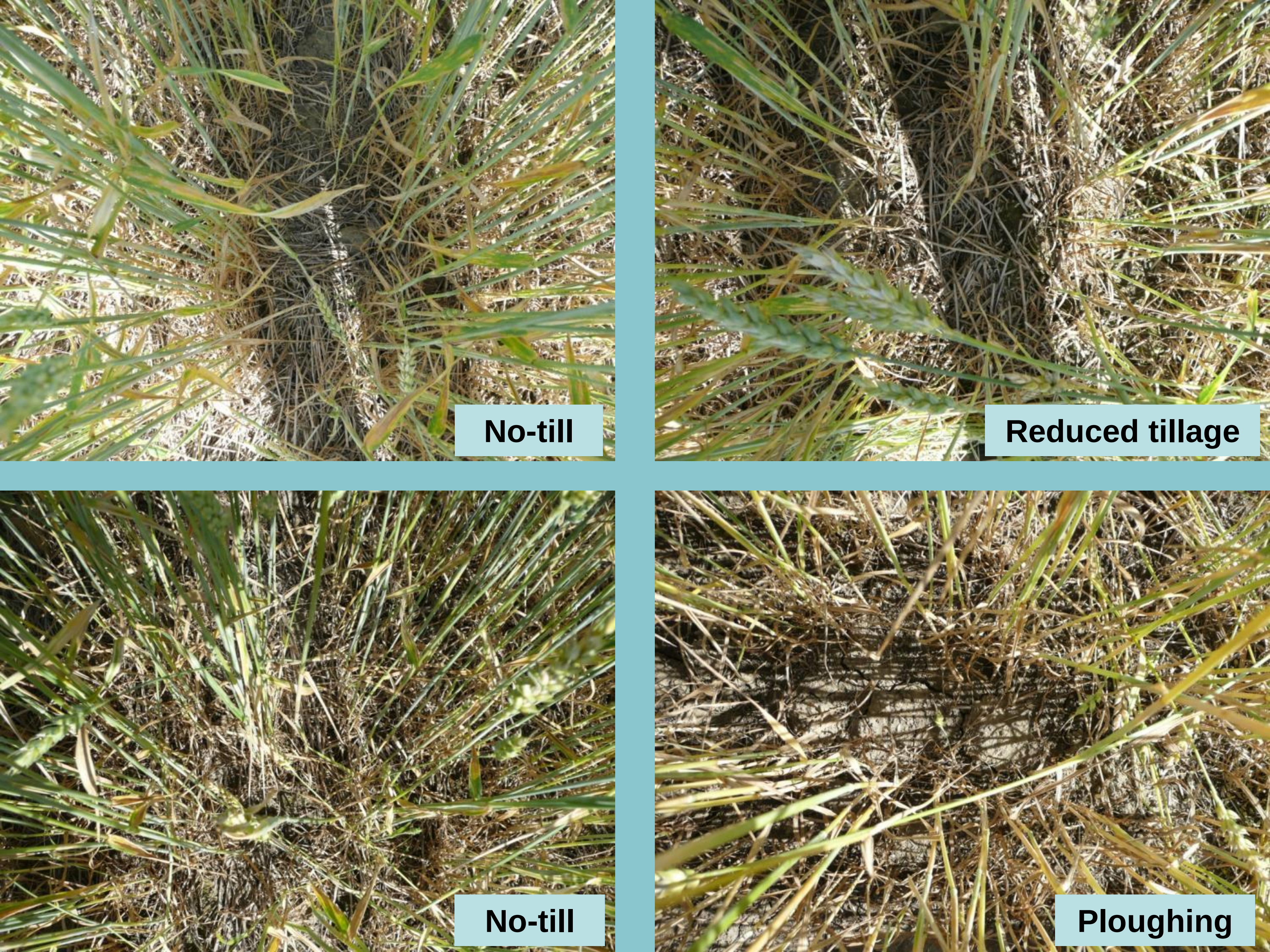
A spring-tooth drag harrow (joustopiikkiäes)

A disc harrow

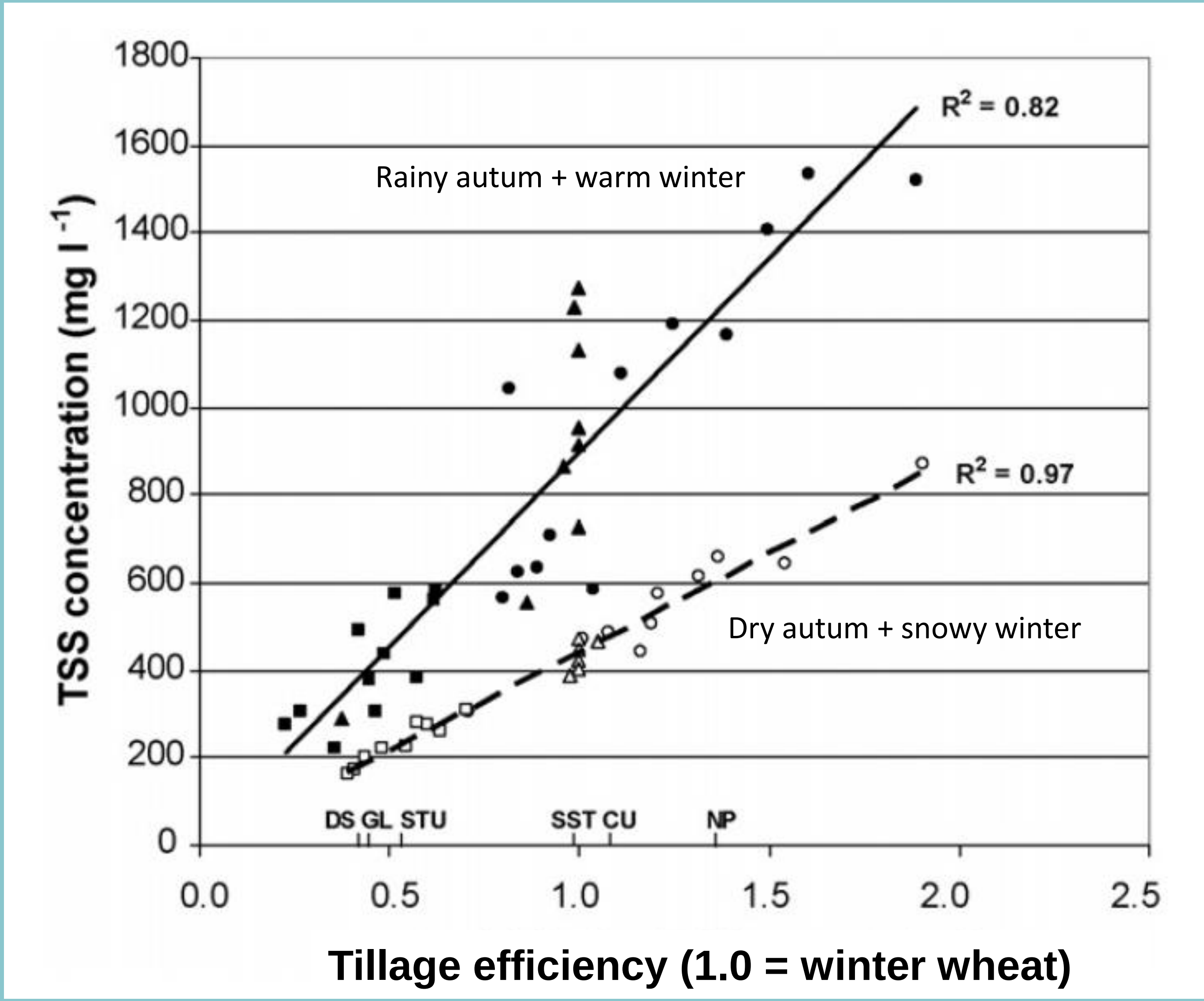
No-till: soil prepared only by a seed furrow cutting plough share


Cultivated
Ploughed

- Area of autumn ploughed fields
    - 12 000 – 13 000 km^2 (start of the 1990s)
    - 5 100 km^2 (2010)
- No-till
    - 1600 km^2 (7% cultivated area in 2009)


No-till
Reduced tillage
No-till
Ploughing

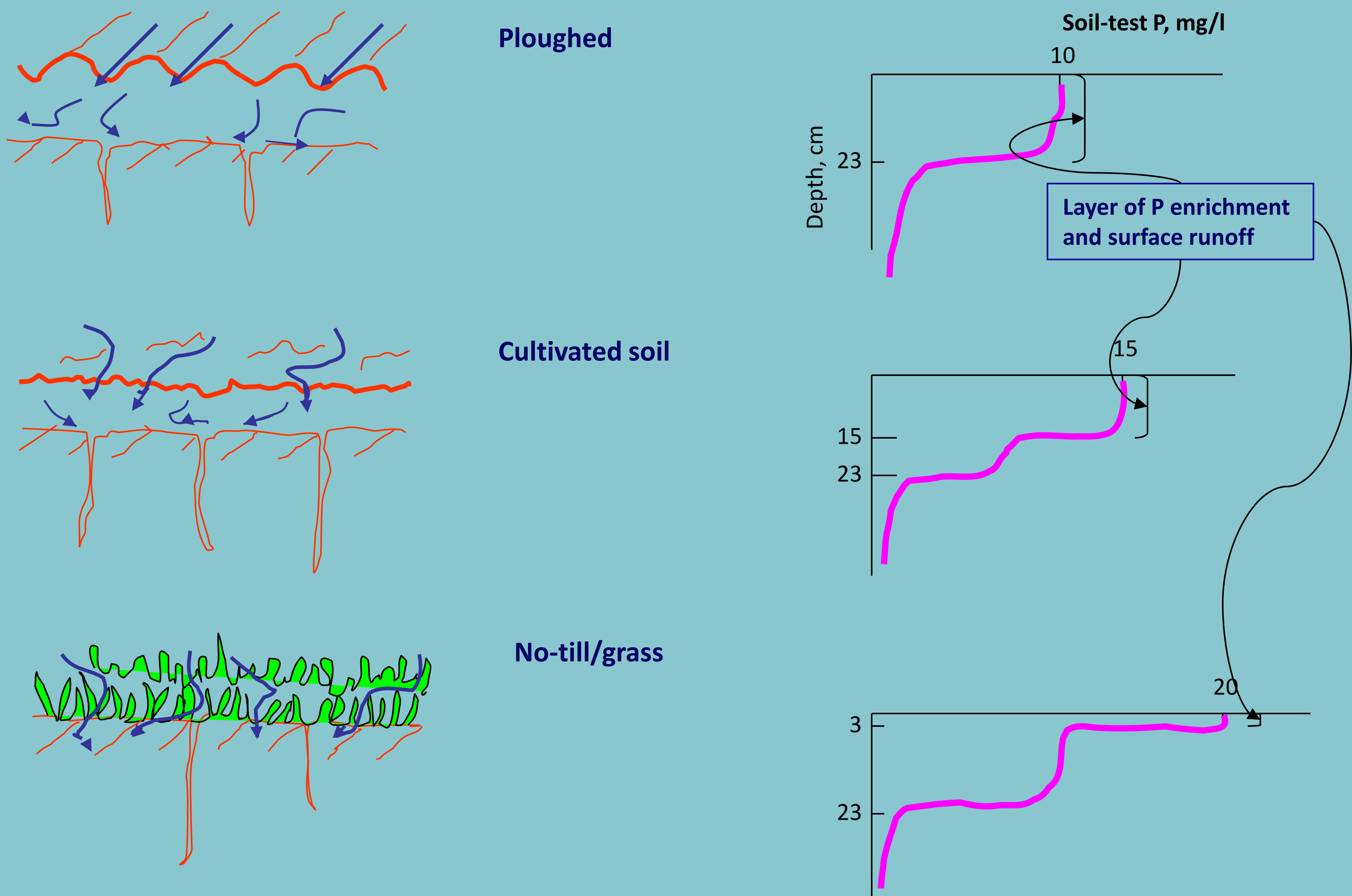
Effect of mild vs. normal winters on TSS concentration in runoff



DS = direct sowing (no-till)
GL = grass ley
STU = stubble
SST = shallow stubble cultivation
CU = cultivation
NP = normal ploughing

Puustinen ym. (2007)

Phosphorus enrichment in top soil

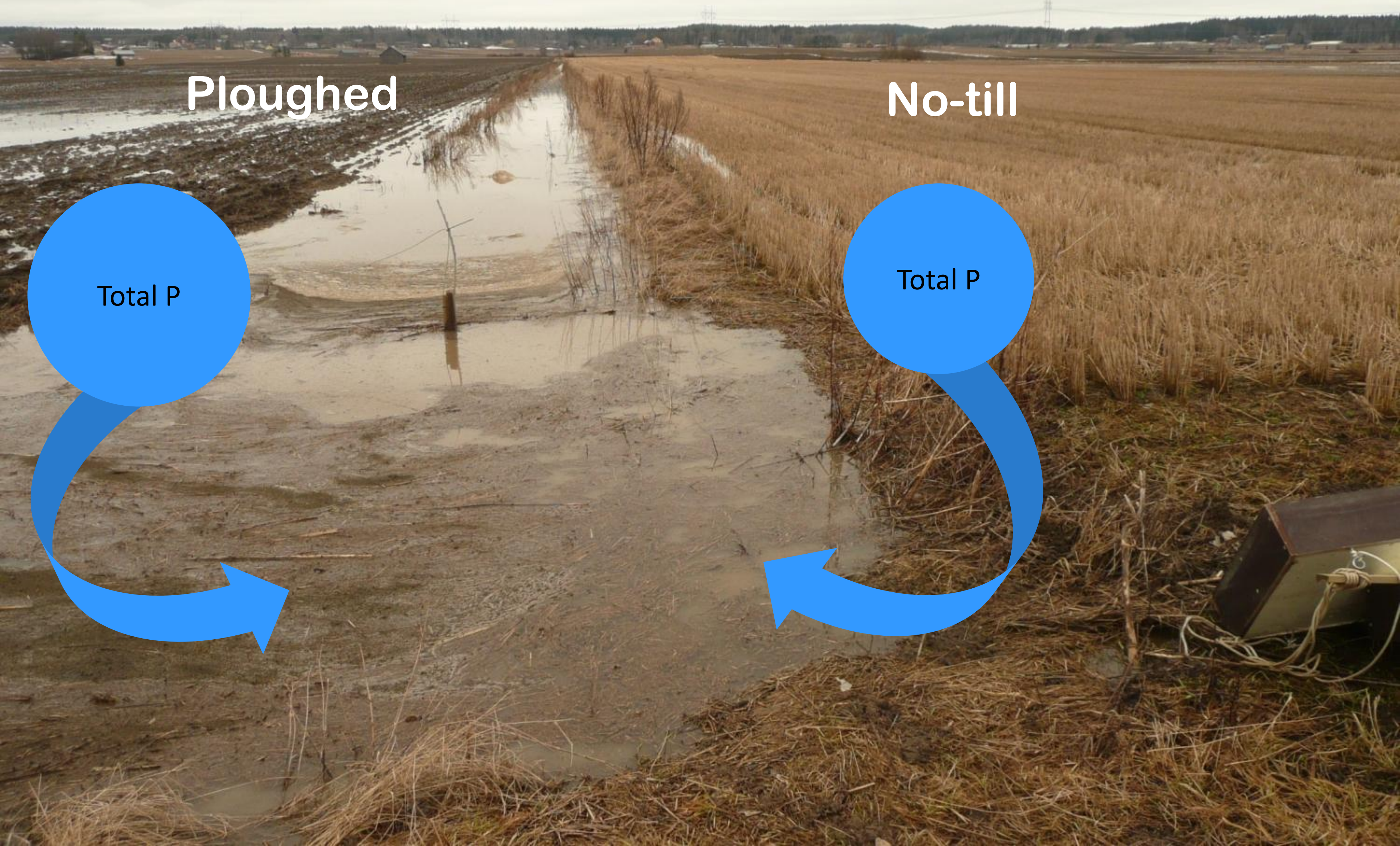


Fertilizers and plant residues left in a thin top soil layer

- Sorption sites will be filled by P and organic matter (competition)

Dia: Eila Turtola

Phosphorus loss from fields

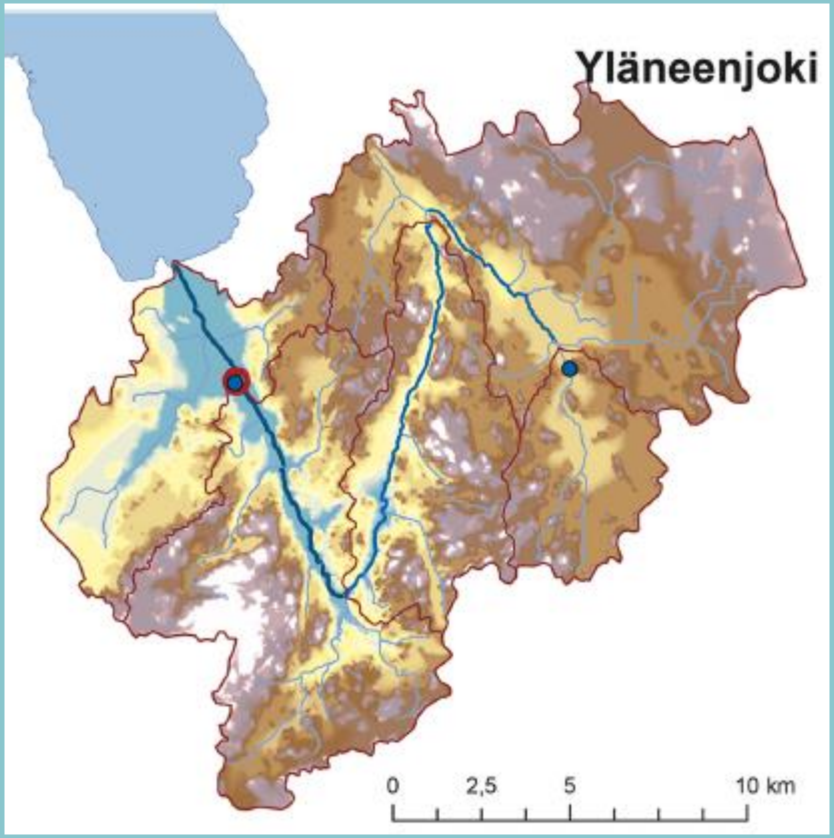


Phosphorus loss from fields

Are DRP losses increased in Finland?

The Yläneenjoki

- 233 km^2, 28% field, animal husbandry
- Change in P forms (Rankinen et al. 2015)
    - 1991 → 2011
  - The share of DRP in total P
    - 15% → 25%
  - The share of PP in total P
    - 75% → 65%
  - TSS load reduced by 31%
  - Reduced tillage increased especially on low to moderately erosive fields



Winter green cover

Agri-environmental support system

- Support paid for 20%, 40%, 60% and 80% plant cover
- At least 20% of field area has to have a genuine plant cover in winter
    - Grass
    - Perennial garden plants
    - Stubble
    - Catch crops
    - Winter crops
    - Fallow (green or stubble)
- Only 20% of field can be under reduced tillage in allocation area III (green)

Allocation area III

- Support increases (stronly) till 80% plant cover
- From 20% to 80%, the plant cover has to be ”genuine”

Other areas

- Support lower and increases moderately till 60% plant cover

Small catchments

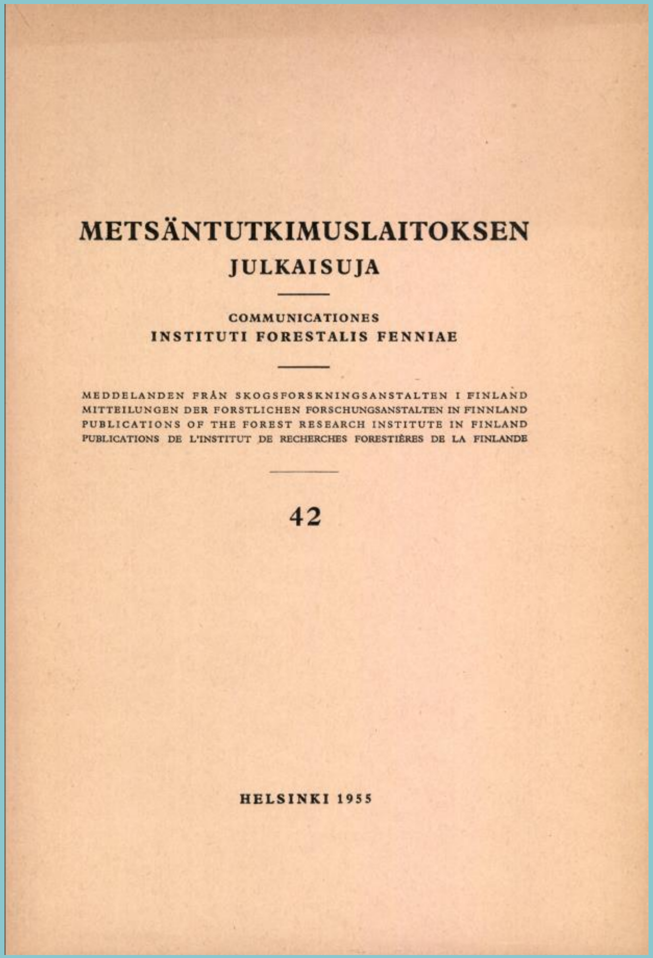
- The network of small catchments established in 1957 for hydrological monitoring
- In 1962: water quality monitoring started
  - SYKE: 24
  - Luke: 13
  - No lakes in the catchment (0.07–122 km^2)
  - Agricultural catchments (*n* = 4) dominated by crop production (number of animals low)
    - Hovi†, Savijoki, Löytäneenoja, Haapajyrä + 2 mixed areas
- Runoff from water level and measuring weir, manual sampling, automatic sampling, sensors
- Processes cannot be identified
- Enables the estimation of specific loads
  - A common method to estimate diffuse load (esim. kg km^{-2} y^{-1})
  - Annual mean load under average hydrological conditions for a specific land use/land cover under specific climate
  - Applicability to other scale, areas and conditions?

Savijoki (Aurajoki)

Kirsti Granlund, SYKE

The first study on agricultural nutrient load in Finland

- Viro (1953)
- Monthly water samples from the lower reaches of the Vuoksi, Kymijoki, Kokemäenjoki, Oulujoki and Kemijoki + from rain water
- Soil in the catchment dictates the element concentrations in river water
  - Fine soils cultivated, correlation between cultivated areas and water quality
- Geology dictates the cation content
- TSS concentrations largest during spring and autumn floods
- A soil layer of 0.0056 mm annually transported to the sea
  - After the latest ice age 5.1 cm
- Transport so small that the fertility of soil will remain unchanged for long


METSÄNTUTKIMUSLAITOKSEN
JULKAISUJA

COMMUNICATIONES
INSTITUTI FORESTALIS FENNIAE

MEDDELANDEN FRÅN SKOGSFORSKNINGSANSTALTEN I FINLAND
MITTEILUNGEN DER FORSTLICHEN FORSCHUNGSANSTALTEN IN FINNLAND
PUBLICATIONS OF THE FOREST RESEARCH INSTITUTE IN FINLAND
PUBLICATIONS DE L'INSTITUT DE RECHERCHES FORESTIÈRES DE LA FINLANDE

42

HELSINKI 1955

Specific load from crop production

- Small agricultural catchments (little animal husbandry)
  - 1981–1997 (Vuorenmaa ym. 2002)
    - **110 (60–141) kg km^{-2} y^{-1} P, 1500 (1400–1700) kg km^{-2} y^{-1} N**
    - 14 (9.9–18) kg km^{-2} y^{-1} DRP
  - N:P ratio about 14
- Agricultural rivers
  - Clayey catchments in southern Finland (little animal husbandry)
  - 1981–1997 (Vuorenmaa ym. 2002):
    - 140 (130–160) kg km^{-2} y^{-1} P 1800 (1100–2300) kg km^{-2} y^{-1} N
- Acid sulfate soils
  - P load smaller (28 kg km^{-2} y^{-1} P), N (2200 kg km^{-2} y^{-1} N) load higher
  - Acid sulfate soils account for some 16% of field area in Finland
- The load from other soil types poorly known

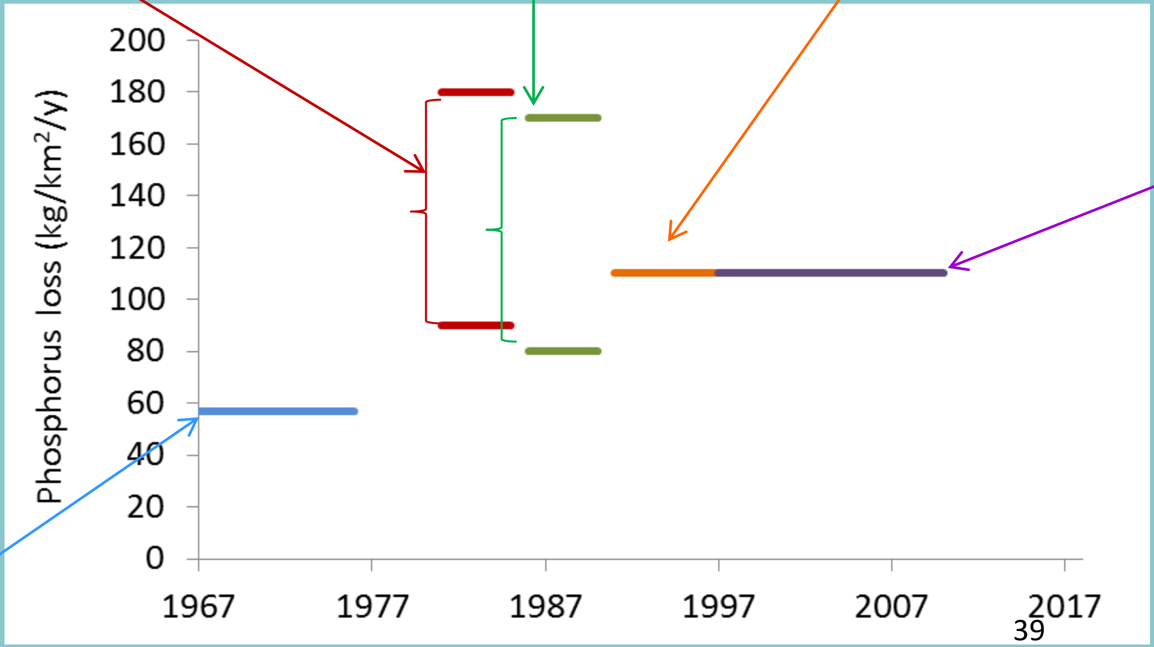
How reliable are the loss estimates?

The effect of sampling strategy

Weekly sampling in spring, biweekly in autumn, a few samples in other seasons, i.e. about 15 y^{-1} + 30–50 automatically taken samples (Rekolainen et al. 1995)

12 samples in wet periods (Rekolainen 1989)

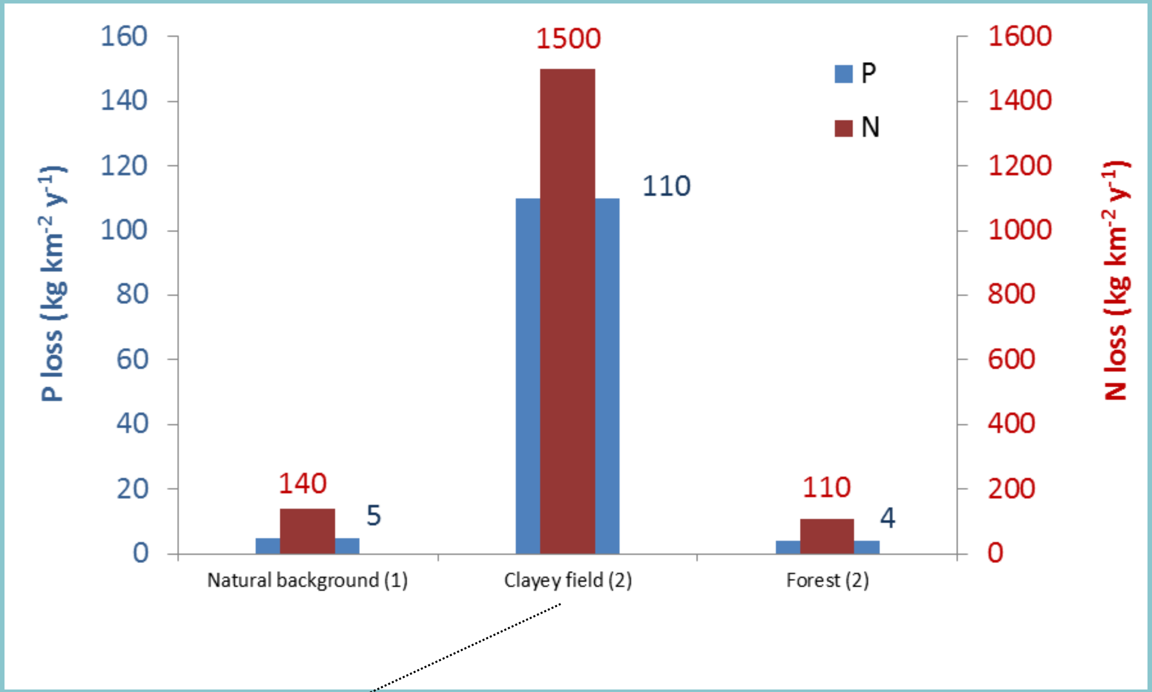
The same (Vuorenmaa et al. 2001)



23-58 samples (Tattari et al. 2017)

12 monthly samples (Kauppi 1979)

Specific losses from land uses



1 = Mattsson et al. (2003), 2 = Vuorenmaa et al. (2002)

Small agricultural catchments on clayey soils in southern Finland (animal husbandry in minor role)

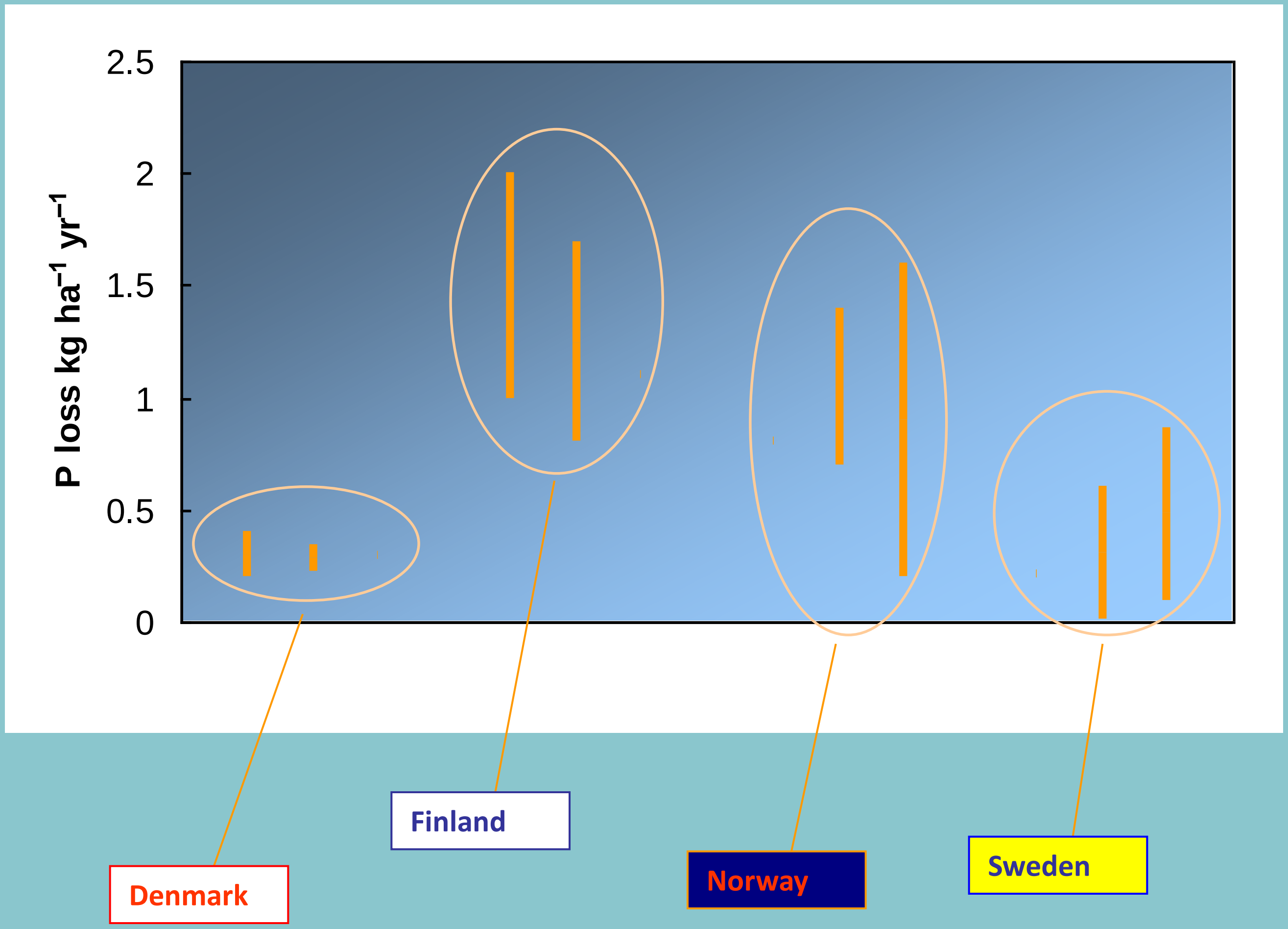
The load from other soil types is less well known, except from…

Acid sulfate soils (about 16% of Finnish agricultural soils)

28 kg km^{-2} y^{-1} P

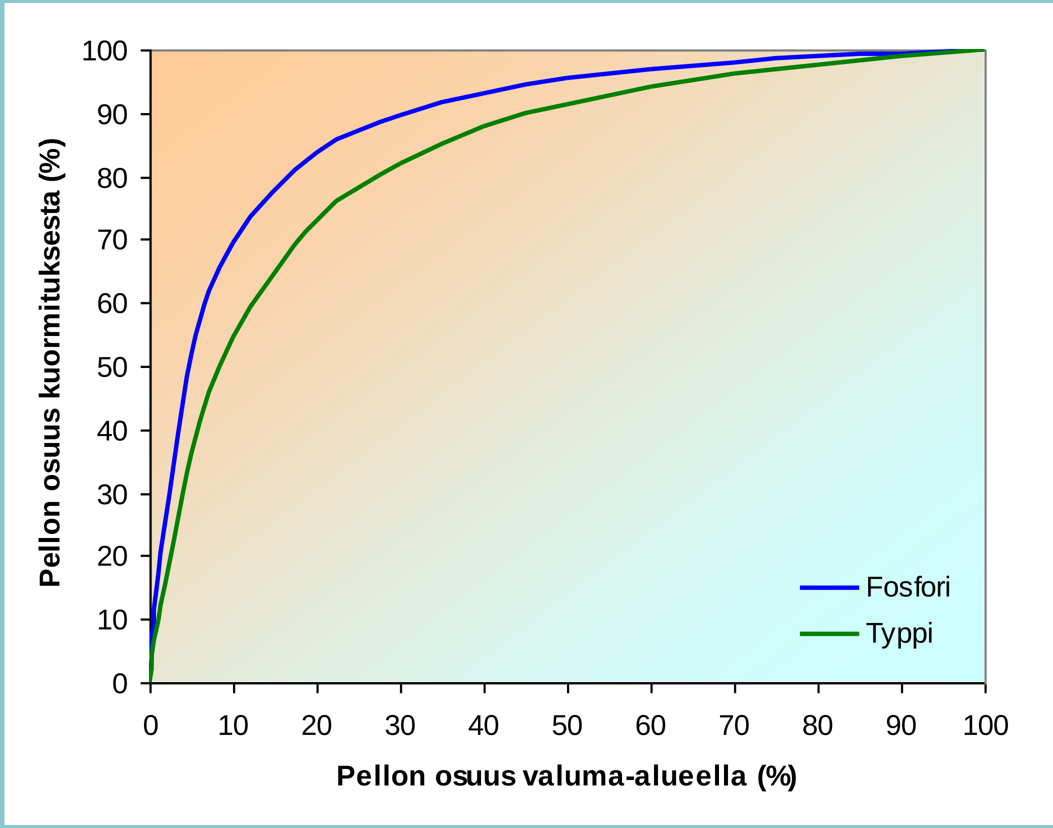
2200 kg km^{-2} y^{-1} N

Specific phosphorus loss in Nordic countries



Svendsen LM, Kronvang B (1991), Rekolainen et al. (1997), Vagstad et al. (2000, 2001), Ulén et al. (2007), Heckrath et al. (2008)

Effect of field percentage on nutrient load (a simplification)



Assumption: non-agricultural land forested

Reducing agricultural load

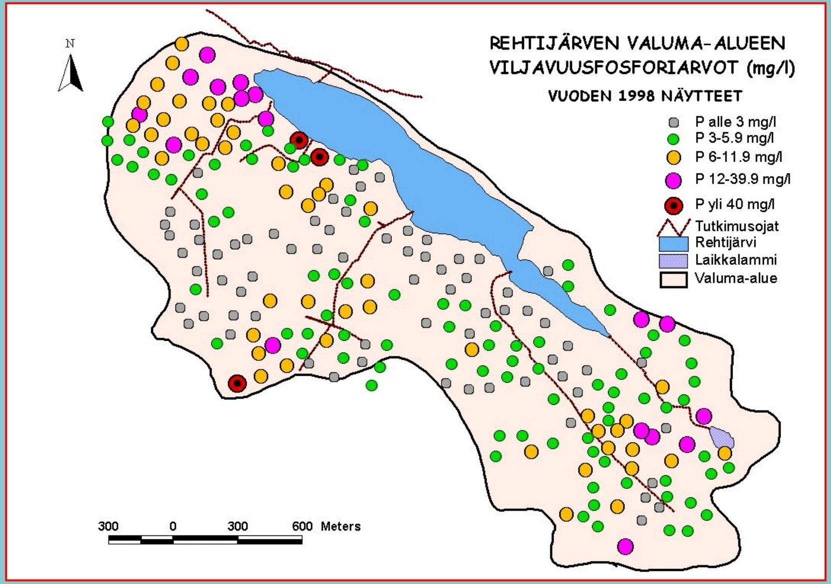
- Reducing nutrient losses
  - Fertilizing/feeding
  - Manure management
  - Improving soil structure/health, farming and tillage techniques
- Capturing the losses
  - Settling ponds and wetlands
  - Filter strips, riparian zones
  - Chemical treatments
- Structural changes

Fertilizing

- Fertilizers return the nutrients removed by yield
  - Secures good quality and quantity of yield
- Based on soil test and experience (a realistic target yield)
- Spreading type (incorporation, broadcasting)
- Accounting for the nutrients in manure
- Green fertilizing: making use of biological N fixation
- Precision farming
  - Yield monitored by aid of aerial photos, GPS positioninig, N-sensor…
- 49% of cultivated fields in Finland: P fertilizer hardly increases yield for grasses and cereals
  - Southwestern Finland: 73%, Åland: 76% (Ylivainio et al. 2014, Lemola et al. 2015)

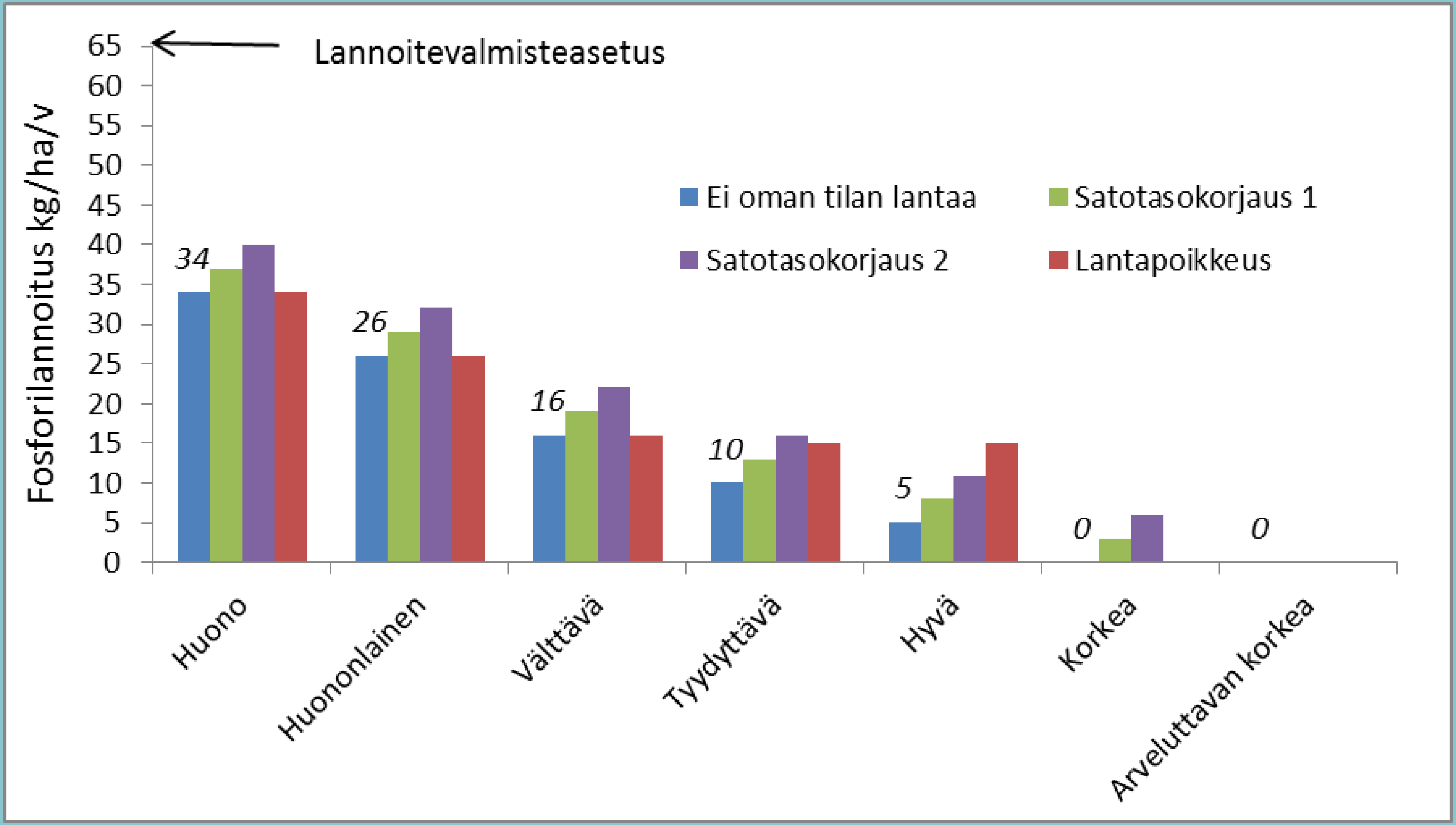
Rehtijärvi Revisited

The loss of DRP after 10 and 30 years with annual P balances of 0 kg/ha or –5 kg/ha



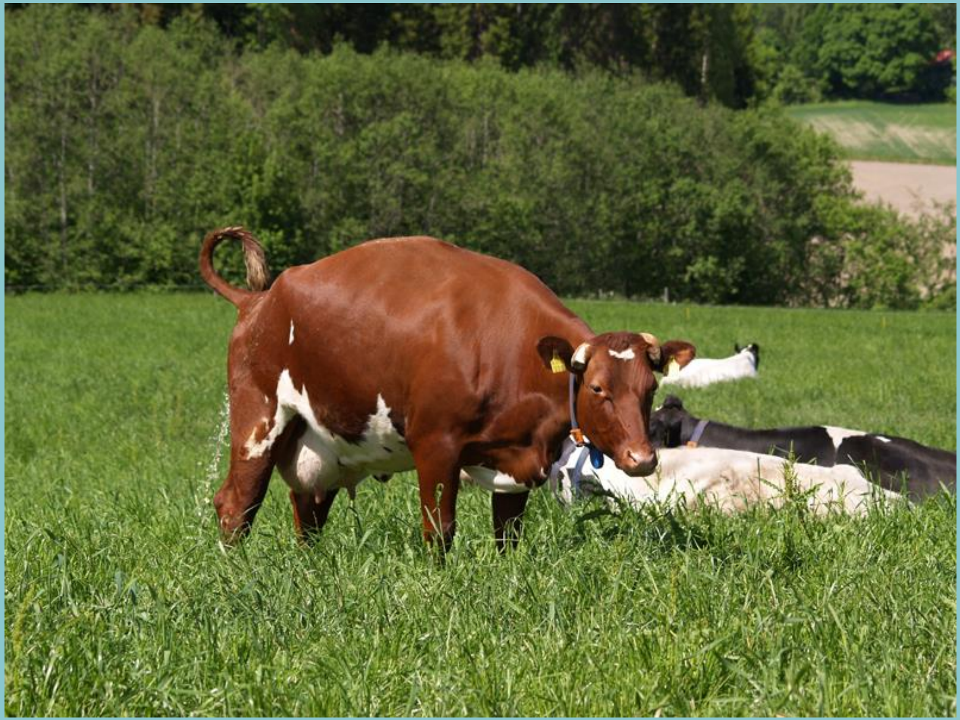
Soil-test P	Area	P loss "now"	P loss after 10y		P loss after 30y	
mg/l	ha	kg/y	Balance 0 kg/ha	Balance -5 kg/ha	Balance 0 kg/ha	Balance - 5 kg/ha
< 3	75	4.5	3.7	3.1	2.4	1.2
3-6	80	10.8	8.8	8.0	5.9	4.1
6-12	50	13.5	11.0	10.2	7.3	5.7
12-40	17	13.3	10.8	10.2	7.2	6.0
> 40	3	5.0	4.0	3.8	2.7	2.3
Sum	225	47.1	38.3	35.3	25.5	19.3

P fertilizer restrictions in the Finnish agri-environmental programme



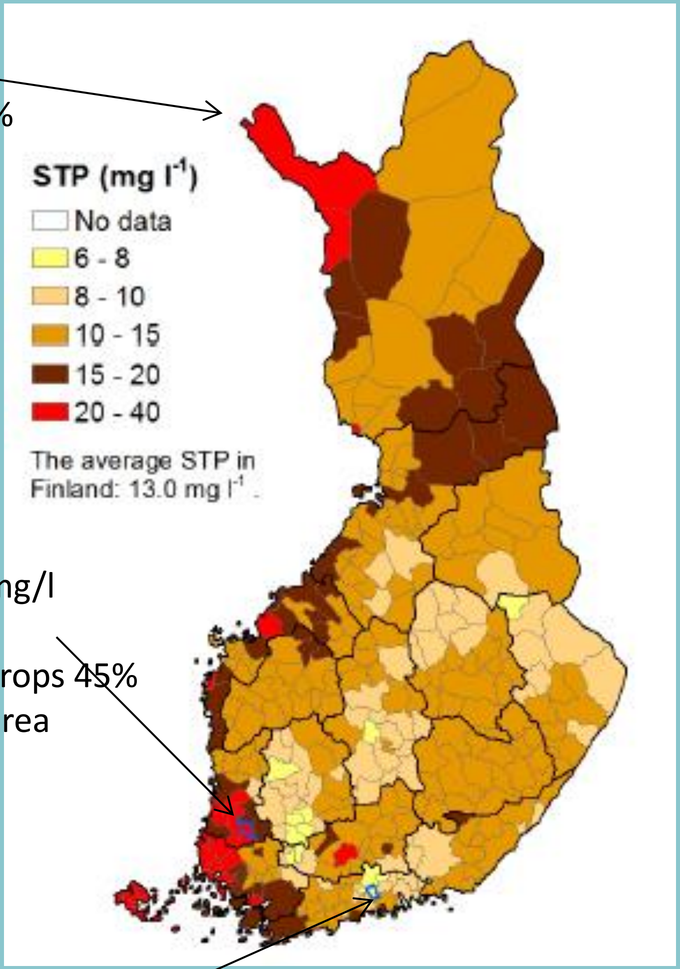
For cereals, oil seed plants and legumes

Manure



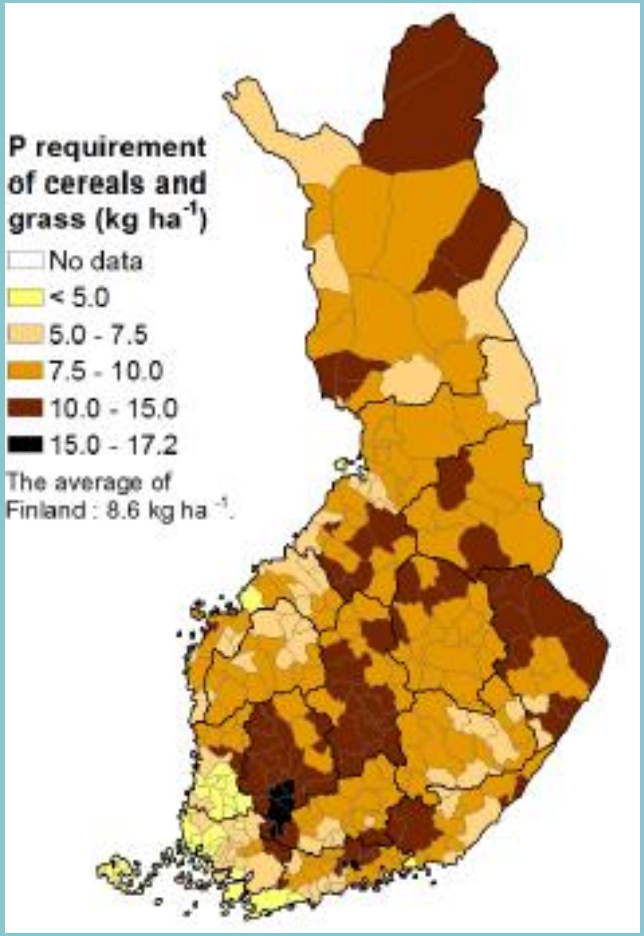
Soil test P in Finland

Enontekiö
- Field 0.47 %



Köyliö 39.3 mg/l
- Poultry
- Special crops 45% of field area

Pornainen 6.7 mg/l
- Few animals

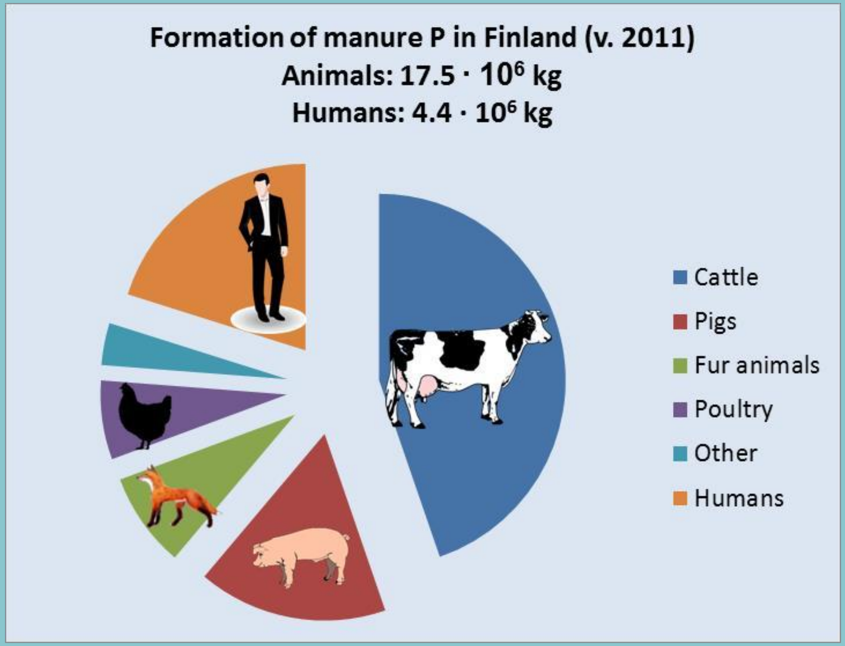


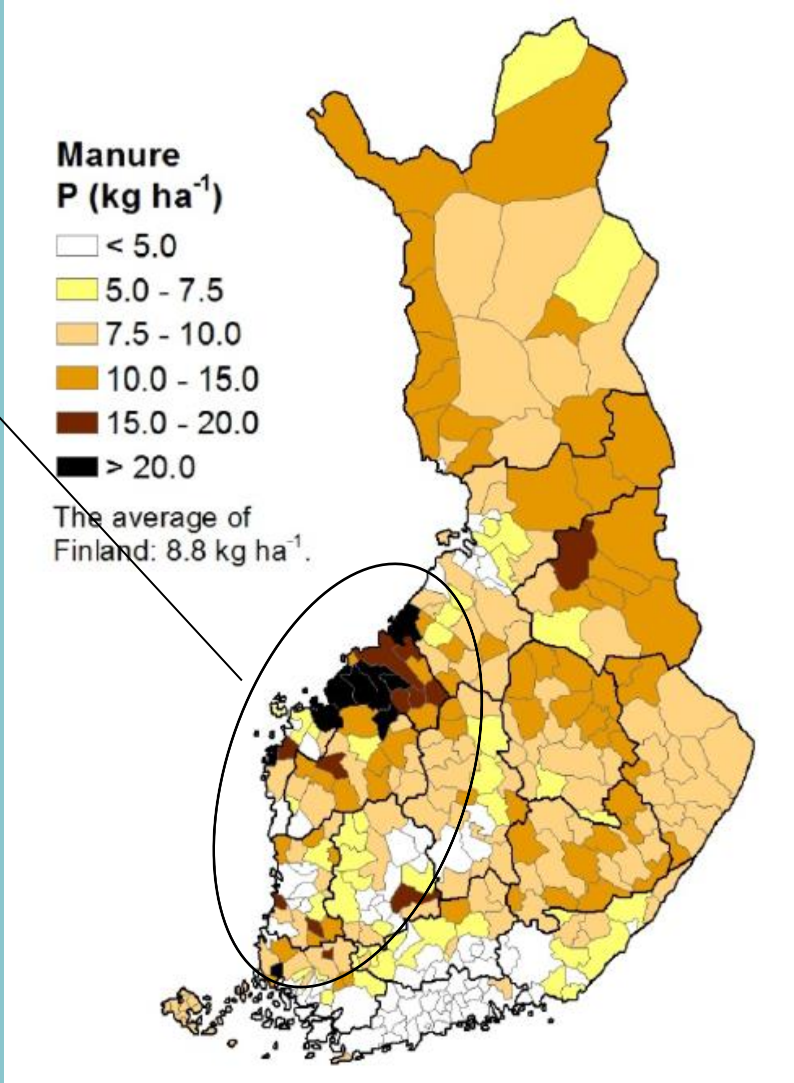
Köyliö vs. Valtimo
- 12% vs. 82% field area reacts to P

Ylivainio et al. (2014)

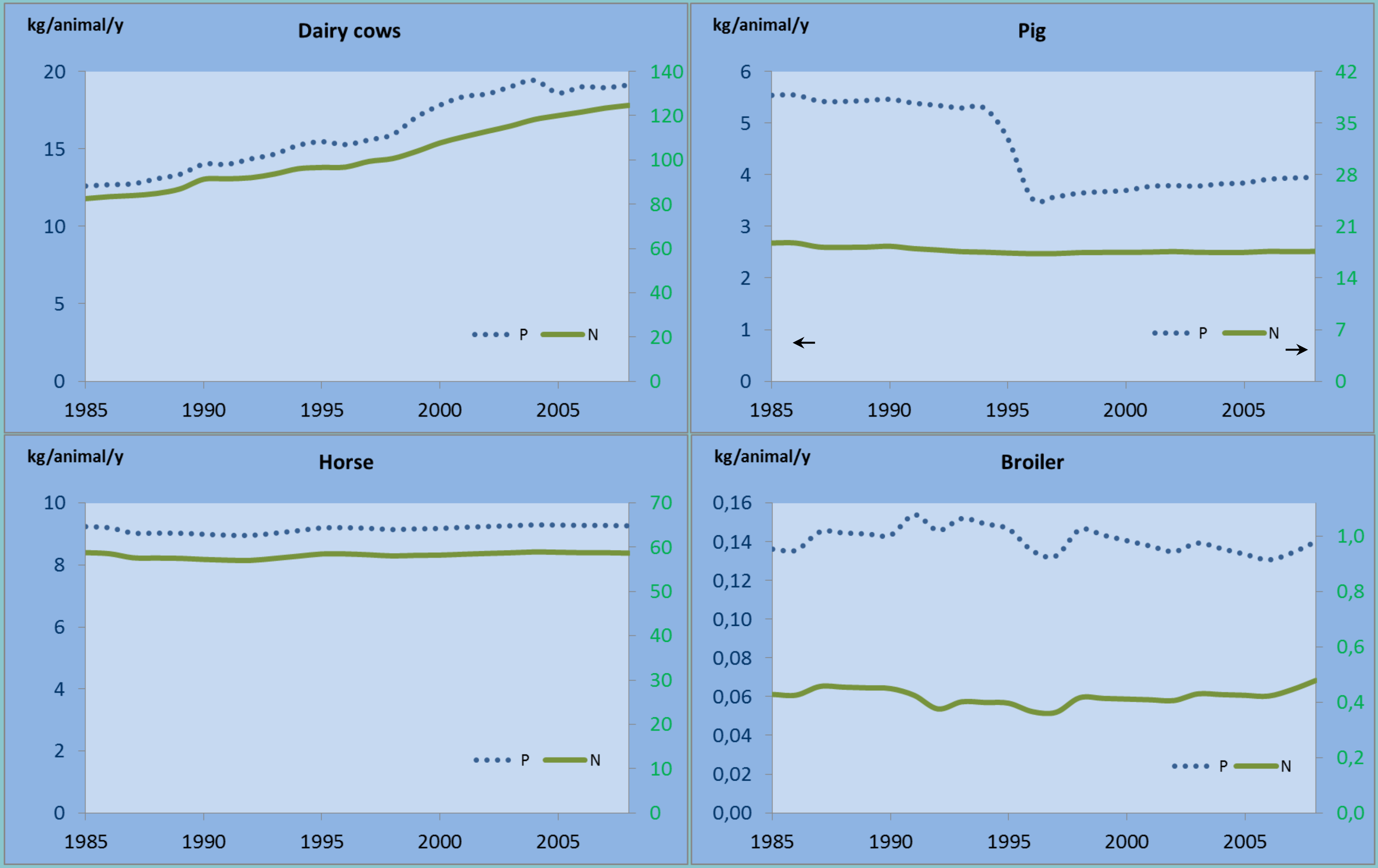
Manure formation

42% of manure P is produced in Osthrobothnia

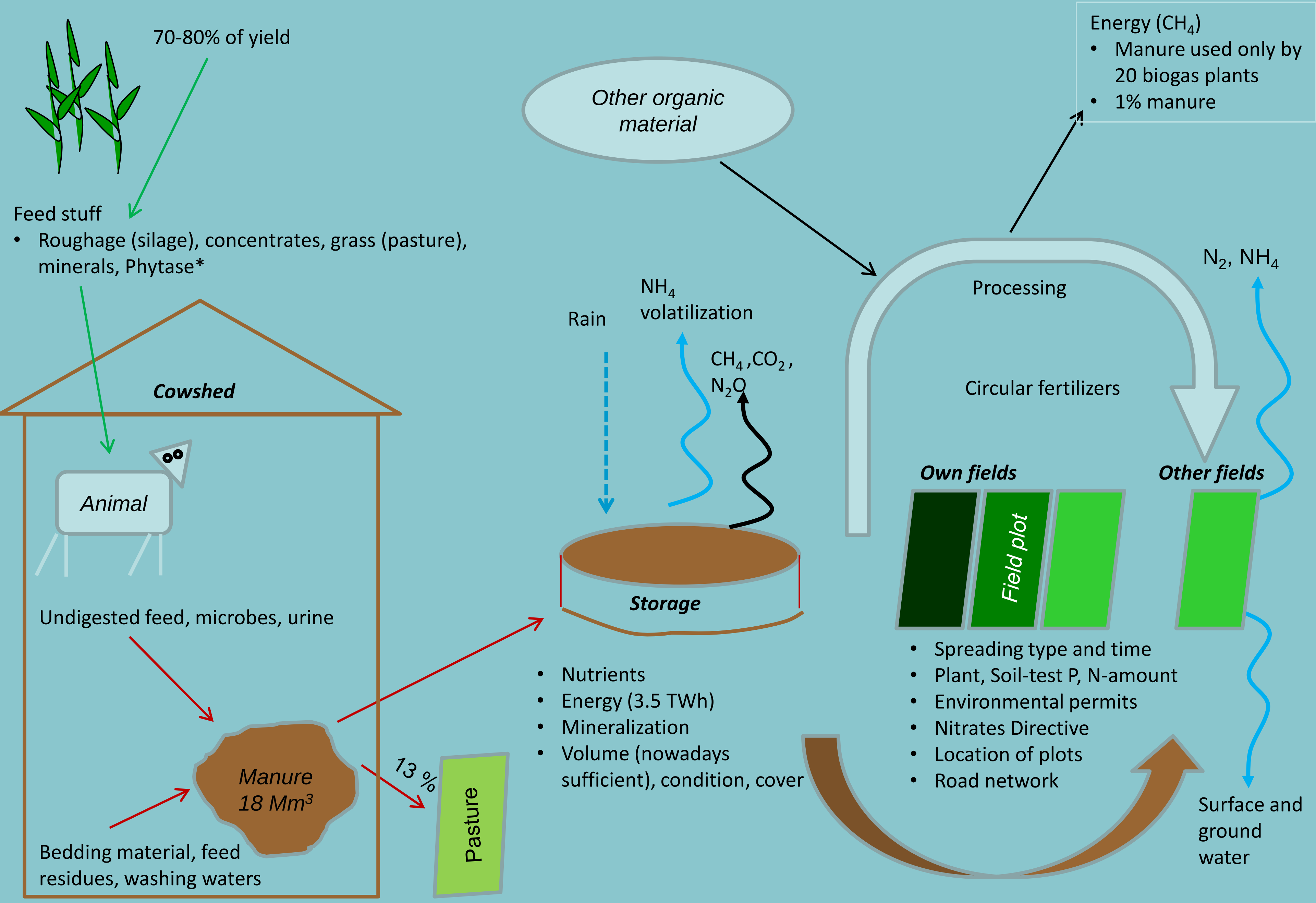




Nutrients in manure by animals



Data: Jouni Nousiainen (LUKE)

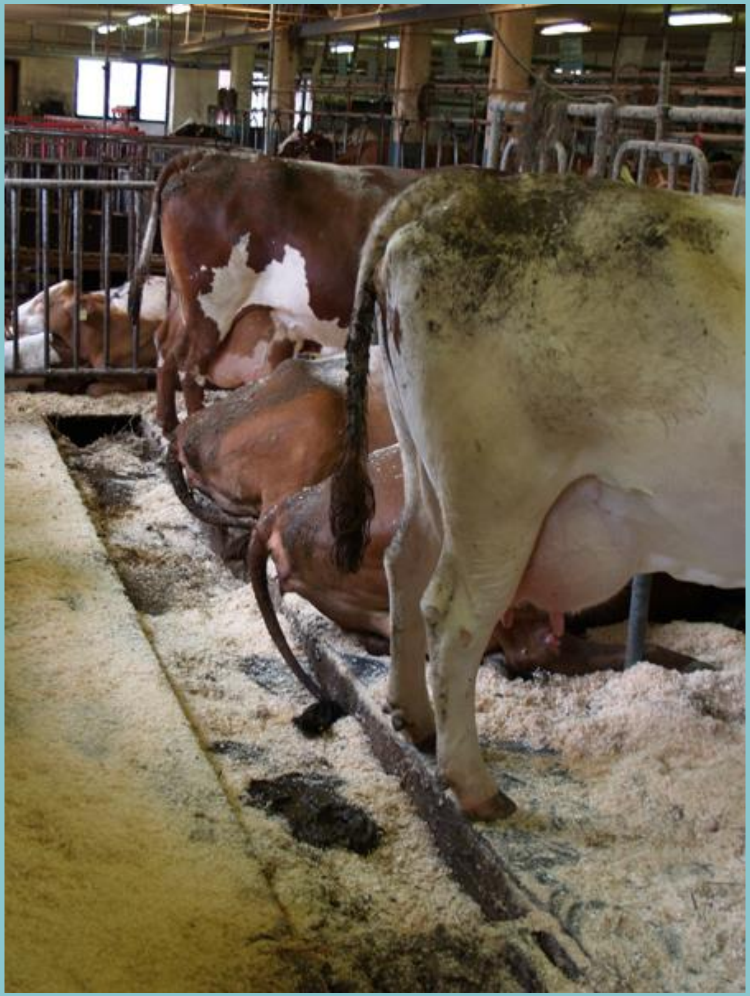


*Inositol P / Phytic acid
- Partly digested by cattle, very little by nonruminants
- Bound more tightly to soil than inorganic orthophosphate

Manure nutrients

- P mostly in an inorganic form
  - Solubility to water
    - Less than ⅓ (fur animals)….80% (cattle)
    - Fur animals feed on fish and side products of meat and fish industry (P originates from bone)
- Solubility of manure N 25–90 %
  - (1) Inorganic N, (2) N becoming available in the first year, (3) residual effect
  - Inorganic N available to plants, unless is volatilised or lost by runoff
- Manure may give higher yields than mineral fertilizers
  - Organic matter enhances soil structure
- But
  - Nutrient concentration varies
  - N/P in manure: 2/1 – 4/1 vs. in plant uptake 4/1 – 9/1
  - All nutrients not immediately available
  - Spreading challenging, transport expensive (mainly poultry manure exported)
- Manure spread on all fields in Finland: 8.8 kg/ha/y
- Plant need 8.6 kg/ha/y (95% target yield)
- Yet, 5.6 kg/ha/y fertilizers given
- If manure were spread only to plots needing P, manure would account for 82% of the P amount needed in the next 20 years (Lemola et al. 2015)

Tie stall (parsinavetta), solid manure

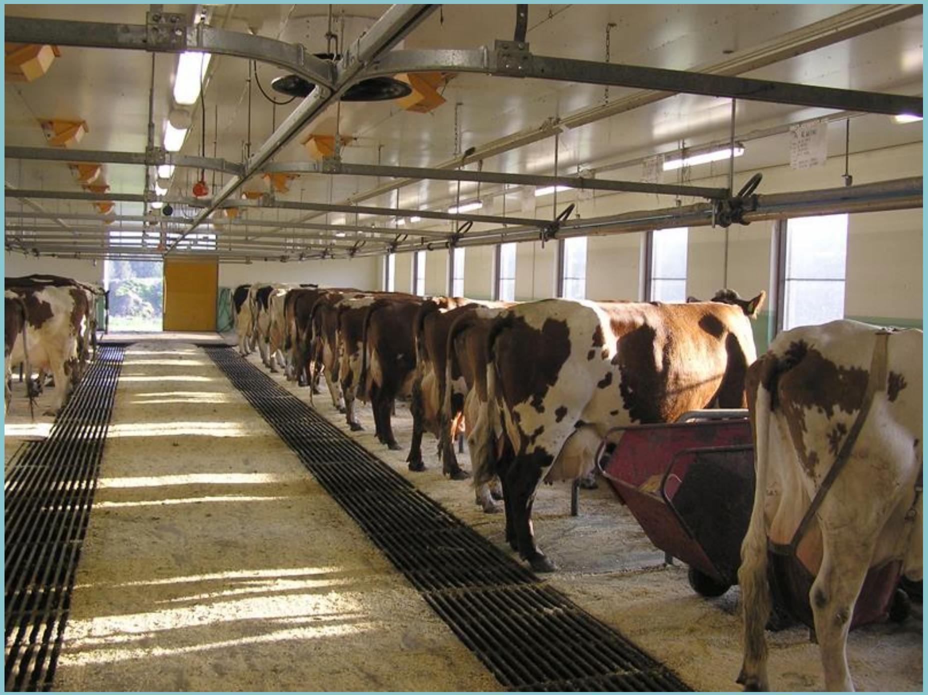


Photos: Sakari Alasuutari, TTS Tutkimus

Tie stall + exercise yard (jaloittelualue)

- **Cattle chained from neck**
- **About half of cattle**
- **Decreasing in popularity**
- **Solid manure most common**

Tie stall, liquid manure



Solid manure (kuivike-/kuivalanta) = faeces + urine + bedding material (straw, sphagnum peat, sawdust)

Liquid manure/slurry (lietelanta) = faeces + urine + washing waters (95% water)

Loose housing (pihatto), solid manure

Photo: Sakari Alasuutari, TTS Tutkimus

- Animals can move freely between stalls, feeding area and dunging passage
- Increasing in popularity (especially in large units)
- Liquid manure most common

Exercise farms may form hot spots of loading

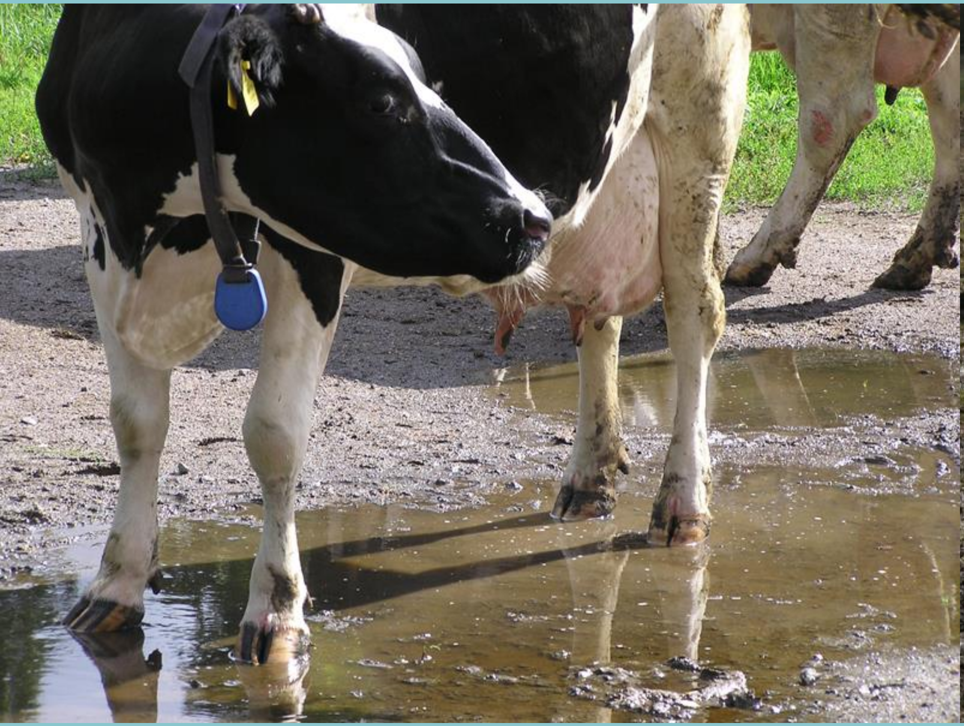


Photo: Sakari Alasuutari, TTS Tutkimus, Aaro Närvänen, Luke

Manure scraper (lantaraappa) in loose housing, note the patterned dunging passage (lantakäytävä)

Manure scraper in loose housing

Manure scraper in loose housing with slatted floor (rakolattia)

Piggeries usually produce liquid manure

Photo: Sakari Alasuutari, TSS Tutkimus

Storage of manure

1. Liquid manure storage pits

$$
\begin{array}{ccccc}
 & & & & NH_3 \text{ in the air} \\
 & & & & \updownarrow \\
\text{Urea and organic matter} & \leftrightarrow & NH_4^+ + H_2O & \leftrightarrow & NH_3 + H_3O^+
\end{array}
$$

Less water, ammonium volatilization and smell

Photo: Sakari Alasuutari, TTS Tutkimus

Storage of manure

2. Solid manure storage

3. Field heap (Kuivalantapatteri)

- ”Remote storage, has to be reported to the municipality
- At least 100 m from watercourses, main drains or wells
- 5 m from ditches
- Compact ground + cover
- Not permitted on flood-risk fields and ground water areas (Nitrates Directive)

Photos: Sakari Alasuutari, TTS Tutkimus

Spreading manure

Slurry broadcasting (hajalevitys)

- The most common method (has to be covered (mullattava), unless spread on vegettaion

Trailing hose (letkulevitys)

Liquid manure efore harrowing (covering) and seeding in spring

On stuble in spring

With hose on grass (after the first cut in summer)

Injection of liquid manure in soil (quite rare) into 6-10 cm depth reduce P losses

Photos: Sakari Alasuutari, TTS Tutkimus

Precision spreader of solid manure

Sakari Alasuutari, TTS Tutkimus

Dairy

Sakari Alasuutari, TTS Tutkimus

Treatment

- See sparse population

Grass and silage

Grass

- In organic farming part of rotation
- In animal farms, grass used as fodder (pasture, silage…)
  Säilörehun osuus kasvanut, kuivaheinänteko vähäistä
- In cereal farms grass used as green fertilizing
- Less erosion, more dissolved P

Preservation of grass fodder

- Hay poles → AIV silos → hay bales
- A.I. Virtanen (1920s, Nobel 1945): fresh grass packed anaerobically, adjusted at pH4 with hydrochloric acid/sulphuric acid -> retards microbial degradation
- 1970s: formic acid
- Liquid (puristeneste) 2 g l^{-1} N; 0.5 g l^{-1} P, pH 4.3, BOD_7 200 x raw wastewater
- Predrying about 20 years ago, no liquid, pH not so low, because microbial growth restricted by dryness
- Mid-1980s: bales (pyöröpaali)

Source: Kirsi Saarijärvi (LUKE)

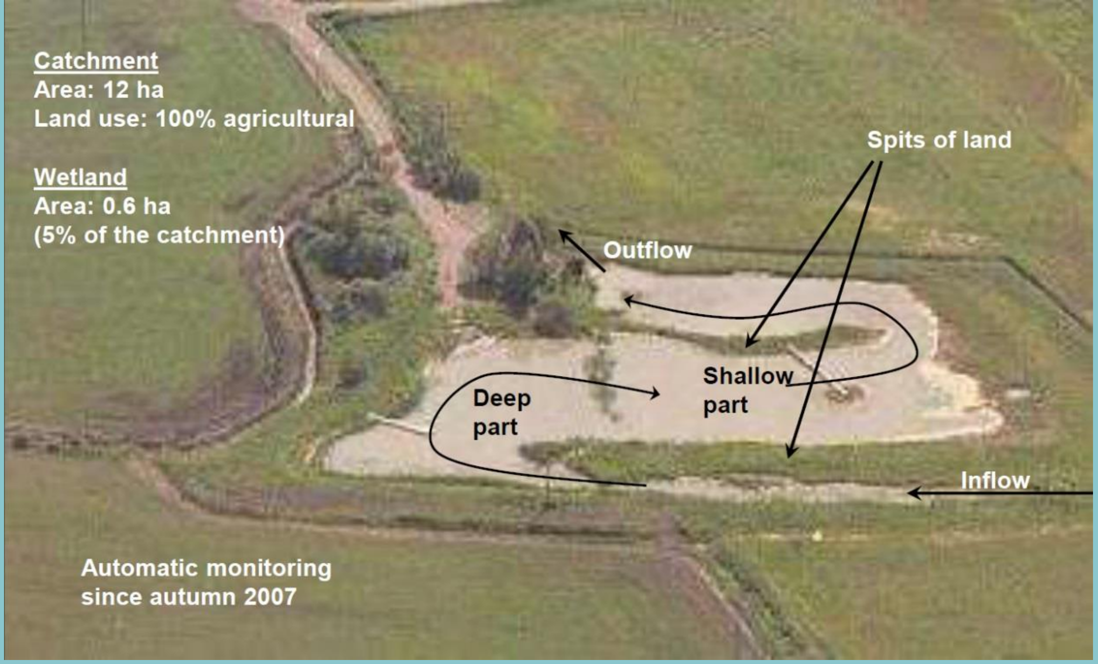
Pasture

Photo: Sakari Alasuutari, TTS Tutkimus

Constructed wetlands

"*Wetland is like a spong retaining water flow and filtering nutrients*" WWF

- **Natural wetlands largely drained**
- **In Finland, more than 1000 wetlands constructed with agri-environmental subsidies + other wetlands**
- **Recipe for a good wetland**
  - **Surface area 1–2% of the catchment area**
  - **Water detention time long (>1 d)**
  - **Incoming water rich in nutrients, i.e. field percentage of the catchment at least 30%**
  - **Water spreads evenly on all areas (no by-pass flow)**
  - **Includes a flood plain so that detention time does not decrease linearly with increasing flow**
  - **Is established in a "natural" location in the catchment**
  - **Outside field: minimize excavation outside, on the field: remove surface soil**
  - **Deep open areas and shallow areas**



The Hovi wetland

- Constructed in 1998 (Vihti)
- Receives the runoff from the above Hovi small agricultural catchment (100% field)
- Wetland 0.6 ha, catchment 12 ha (5% of the catchment)
- Well monitored
- Removes PP, DRP, TSS and N

Rantamo-Seitteli – The largest constructed wetland in Finland

0.28 km²

In the western shore of Lake Tuusulanjärvi

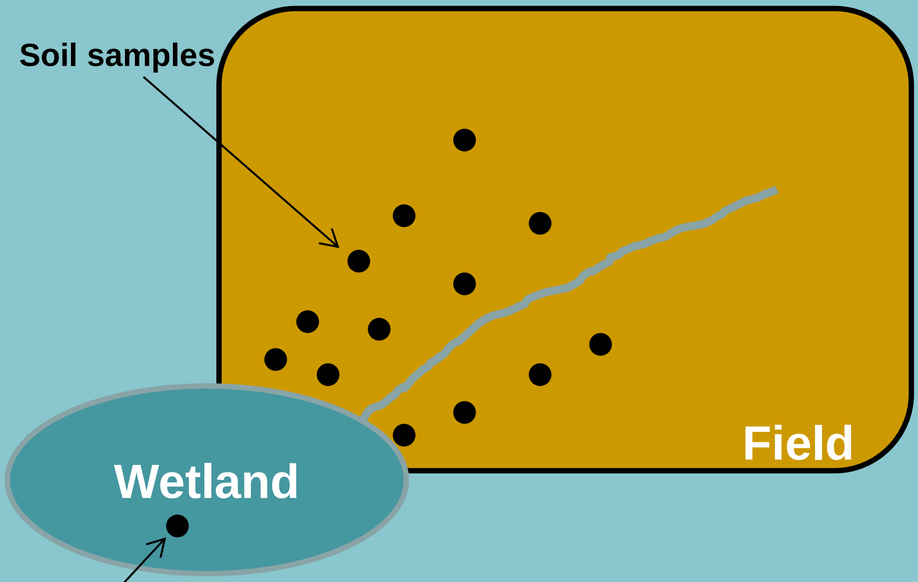
tos: Tero Taponen, Uudenmaan ELY

What can happen in wetlands?

- Flow velocity decreases
  - Increases sedimentation and allows time for different processes
  - Settling ponds ”harmless”
- Water filtered through vegetation
  - Particulate matter trapped
- Nutrients taken up (and released) by biota, bacteria and biofilms
  - Roots transport O_2 to sediment
- Mineralisation
  - Denitrification
- Adsorption-desorption
- Retention in three wetlands (Koskiaho et al. 2003)
  - TSS:−5–72%
  - TP: −6–67%
  - DRP:−33–33%
  - TN: −7–40%
  - NO_3-N: −8–38%
  - NH_4-N: −50–57%

A study on five Finnish wetlands

Laakso et al. (2016)



- P was released by desorption from eroded soil
- Clay and Al ja Fe oxides were removed most easily (*selective erosion*)

→ Wetland received matter that had a higher ability to bind P than the parent soil

- P concentration in field soil and wetland sediment the same, but soil contained more Al-bound P and sediments Fe-bound P
- In anaerobic sediments, Fe-bound P is released and may be transported downstream (*iron and sulfate reduction*)
- The Hovi wetland had a lot of Al-bound P, which enhances the binding in anaerobic conditions
- Wetland sediments had a higher S concentration than parent soil (*sulfate reduction*)
- If sediment was returned to field (recommendation by the Ministry of Agriculture and Forestry), upon its oxidation and drying new Fe oxide surfaces would be formed that would efficiently bind P

→ Wetland sediment lowers the P status of field soil

Multifunctional wetland in Nummela

Wahlroos et al. 2016

- Chain of two wetlands in urban parks
  - Nummela Niittu (1.5 ha, fishless)
  - Nummela Gateway (0.4 ha, 0.1% of its 550 ha catchment)
- Urban and agricultural catchment
- Multiple beneficial ecosystem services
  - Storm-water management
  - Compared to lawn landscape
    - A higher biodiversity with increased resilience
    - A lower maintanence and more valuable habitats for amphibians and birds
    - A higher carbon binding
- Self-establishment of vegetation
- Retention
  - TSS: 15%
  - TP: 10%
  - NO_3-N: 7%

Local effectiveness vs. national effectiveness

- **National monitoring data**
  - **TP (kg/km^2/y) = 10.4 + 1.15 Field% - 0.81 Lake% (Röman et al. 2018)**
- **Field area in Finland: 22 590 km^2 → 7.4% of land area**
- **Lake%: 10**
  - **TP load: 3300 t/y**
- **How much should Lake% increase to reduce the agricultural TP load by 10% (330 t/y)?**
  - **Lake% 10 → 11.3, i.e. by 4523 km^2**
- **Assuming a mean wetland area of 0.5 ha, about 950 000 wetlands should be constructed**
- **Verification**
  - **The Hovi wetland (0.6 ha) received 21.3 kg TP in 2013-2014 and removed 11.6 kg of it (54%), i.e. 967 kg/km^2/y (Koskiaho et al. 2015) → 68 300 wetlands**

Buffer strips and riparian zones

- Water act requires a 0.6 m edge (piennar) between field and a ditch
- Buffer strip: 1-3 m
- Buffer/riparian zone: on average at least 15 m wide
  - Untilled
  - Unfertilized
  - Perennial plant cover
  - No pesticides
  - Mowed annually, residues collected
  - Grazing permitted
- For example: sloping fields, flooded plots, river banks, ground water areas, areas with a risk to landslides

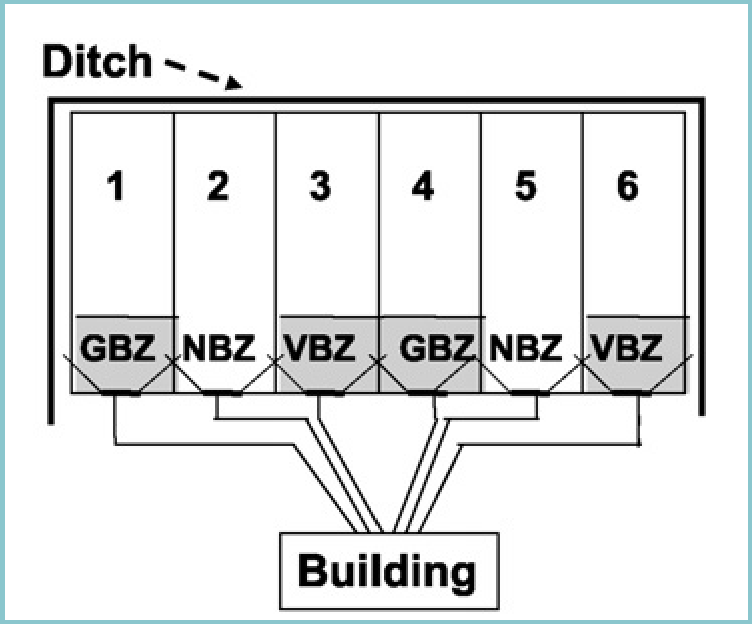
Photo: A. Närvänen, Luke

Riparian zones

- Current area 110 km^2
- Control erosion especially in sloping fields
  - Removes soil material from surface runoff
  - Effect on grasses and no-till plots?
- Usually do not remove dissolved P, but may
- Increase dissolved P
  - P liberated from vegetation upon freezing and thawing
  - Concentrations high especially in winter and spring
  - Vegetation has to be removed (except when trees)
    - Removes nutrients and their enrichment in top soil
- N is mostly transported via drainage flow
  - Effect on N small
- Decreases the active cultivated area
- The plants in riparian zone have more root volume, use more water and decrease surface runoff
- With aging the soil stucture improves, except when used for grazing

The Lintupaju experimental field

Uusi-Kämppä et al. (2010)



GBZ = Grass buffer zone
NBZ = No buffer zone
VBZ = Natural vegetation buffer zone

Farming practise	**Decrease (+ = increase) in losses as compared to no buffer zones plots**			
	TSS	PP	DRP	TP
Autumn ploughing	>50 % GBZ VBZ	~45 % GBZ VBZ	+7 % GBZ +60 % VBZ	36 % GBZ 28 % VBZ
Pasture (grass)	>10%	~10 % GBZ VBZ	18 % GBZ 36 % VBZ	13 % GBZ 21 % VBZ
No-till	>20%	~25 % GBZ VBZ	5 % GBZ 29 %* VBZ	14 % GBZ 23 % VBZ

*Infiltration imporves

$Fe_2(SO_4)_3$ addition to ditch water

Photo: Aaro Närvänen, MTT

Fe-Ca-granules

Gypsum treatment of agricultural fields

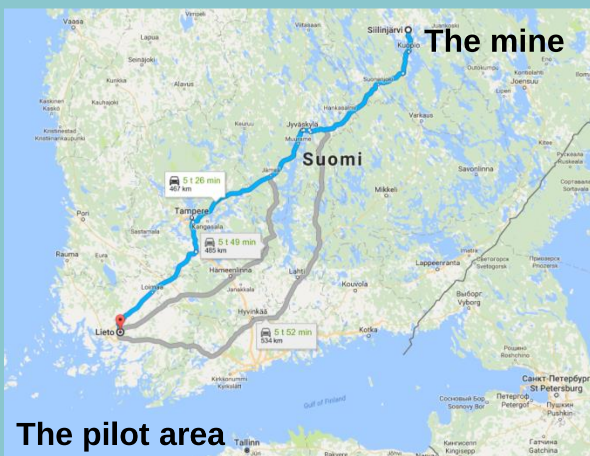
Photos: Pasi Valkama

Photo: Janne Artell


Apatite mine in Siilinjärvi


Gypsum formed as a side-product


Pilot area: the River Savijoki



The mine
The pilot area

144 lorries transported 6.27 million kg gypsum


55 farms taking part in the pilot


Gypsum spread on 1530 hectares of fields in autumn 2016

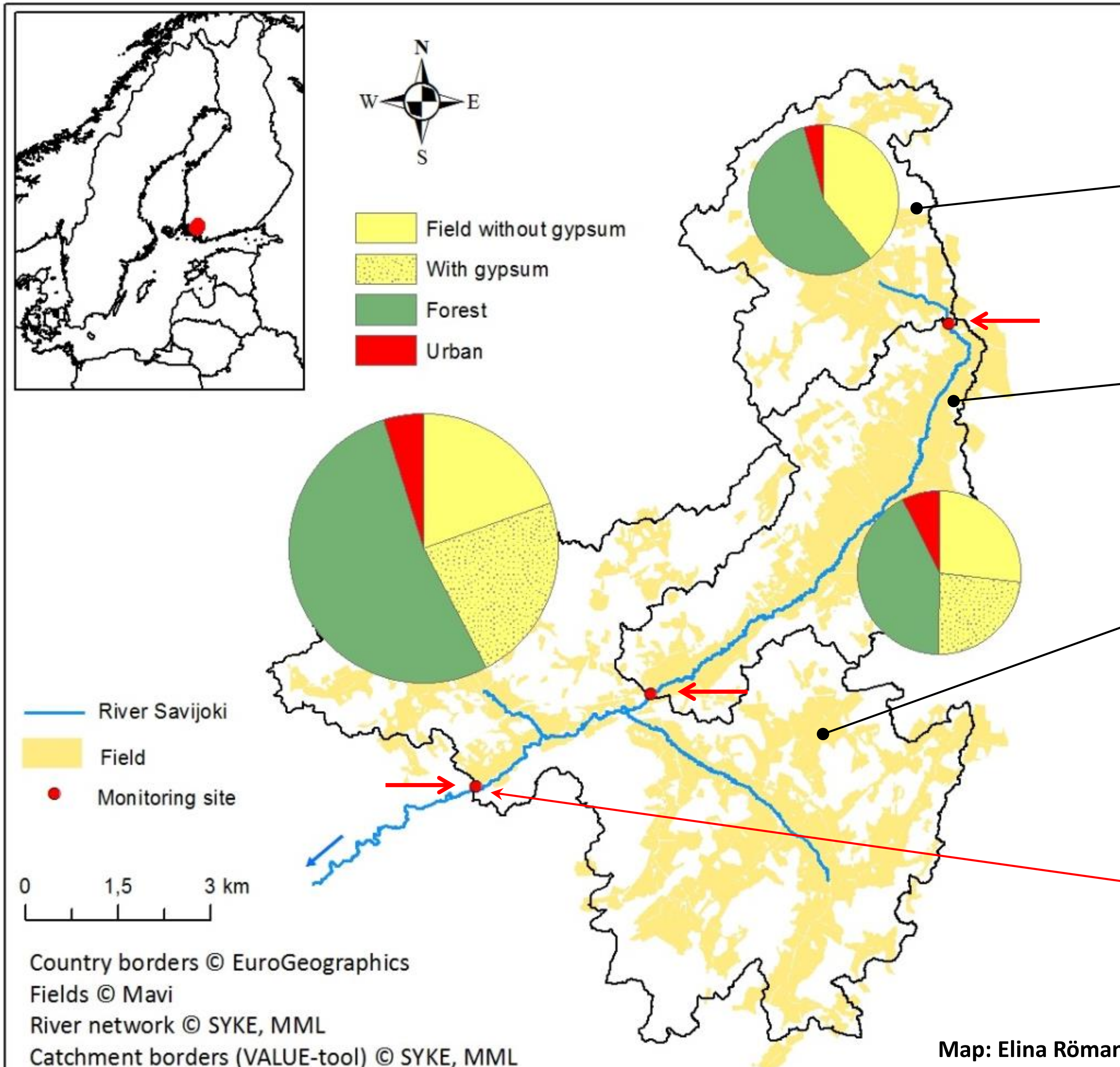

A hint of gypsum (4000 kg/ha)

Photos: Janne Artell, Eliisa Punttila, Petri Ekholm

Spreading gypsum on 16.9.2016 (Salon seudun sanomat, Elina Lahti)

https://youtu.be/6vlzlpc5ls4

Pilot area: the Savijoki



1. CONTROL AREA 15 km²
Fields 39%, no gypsum

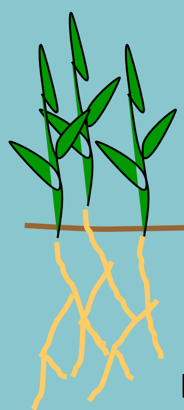
2. UPPER GYPSUM AREA 18 km²
Fields 50%, of which
47% amended with gypsum

3. LOWER GYPSUM AREA 49 km²
Fields 41%, of which
54% amended with gypsum

82 km²
43% fields, of which
43% amended with gypsum

How gypsum ($CaSO_4 \cdot H_2O$) works?

Crop yield & Cultivation
- Soil structure may improve
- S for plants
- Lower Se uptake



$CaSO_4 \cdot 2H_2O$

Surface runoff
- Less particulate P and dissolved P
- No effect on N
- More SO_4^{2-}, Ca^{2+} (other cations?)

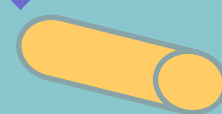
→ Gradual weakening of the effect (4–5 years?)

Dissolution
$Ca^{2+} + SO_4^{2-}$

Increase in ionic strength
- Electrical double layer around soil particles suppressed
- Particles come closer, form larger aggregates and become less sensitive to erosion
- Desorption of P reduced

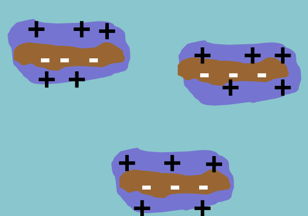
Unlike lime ($CaCO_3$) does not affect pH

Leakage through the soil

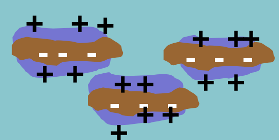


Drainage flow

Ground water

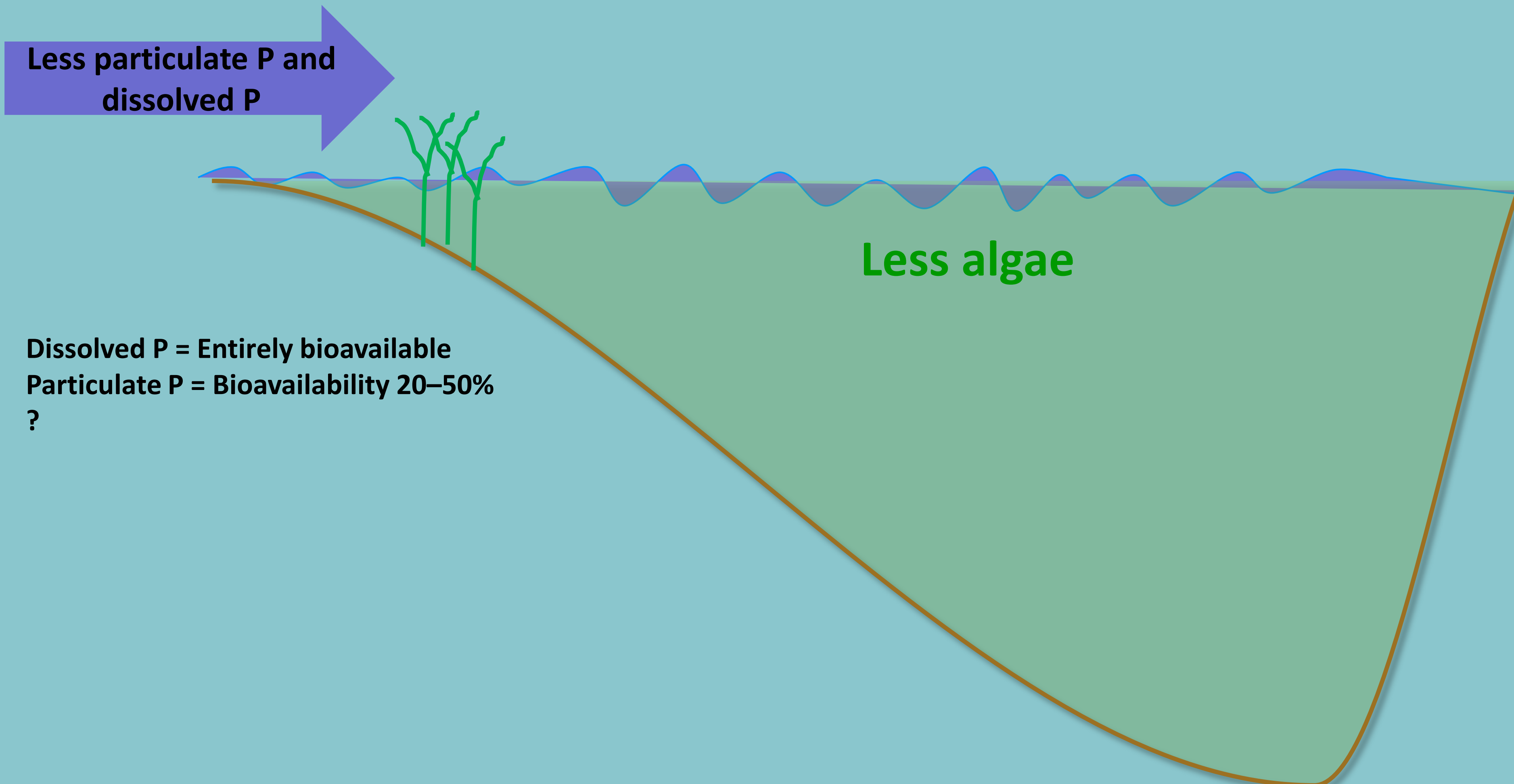


Before gypsum



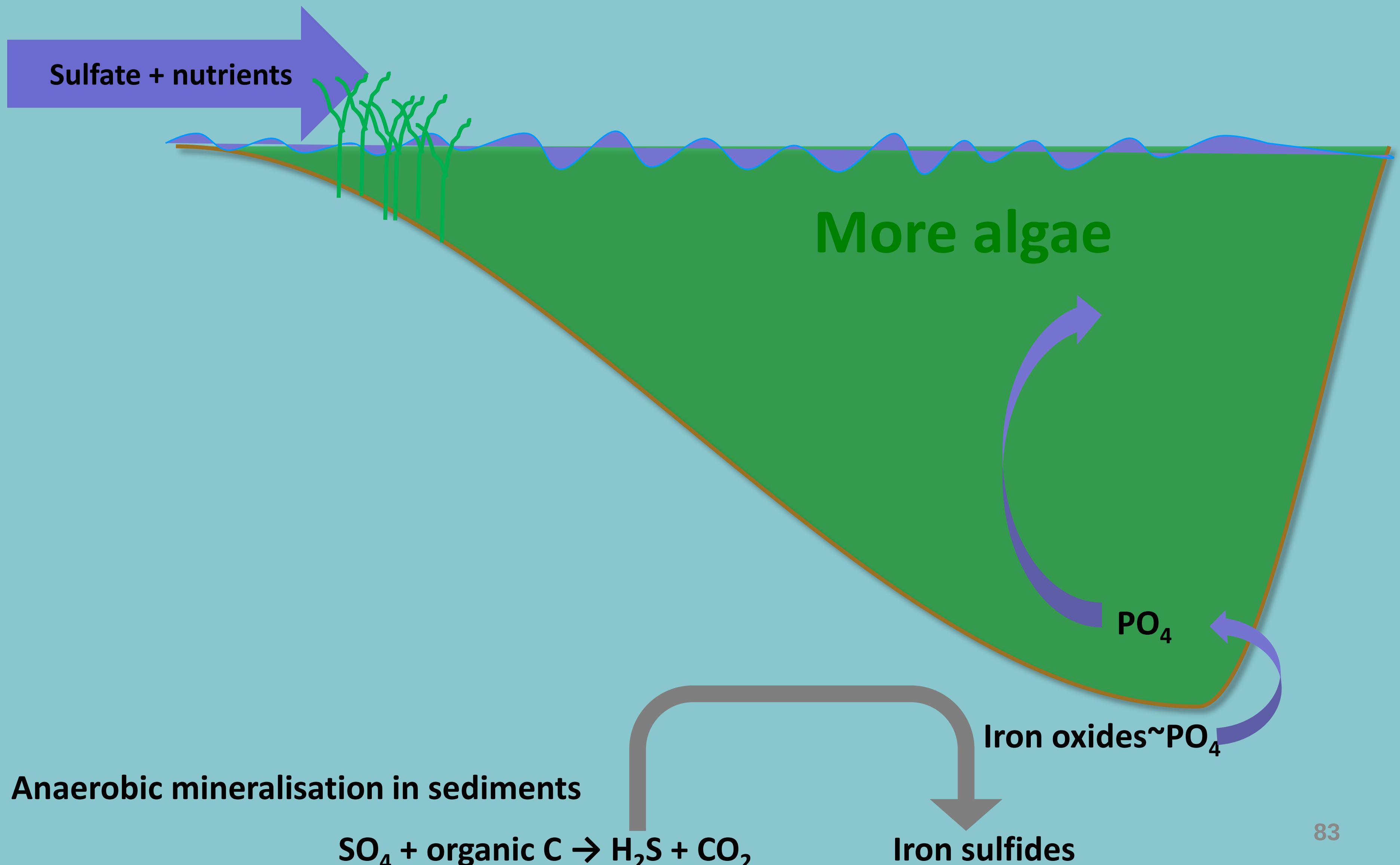
After gypsum

Desired effect



Dissolved P = Entirely bioavailable
Particulate P = Bioavailability 20–50%
?

Major restriction:
No gypsum in catchments with lakes



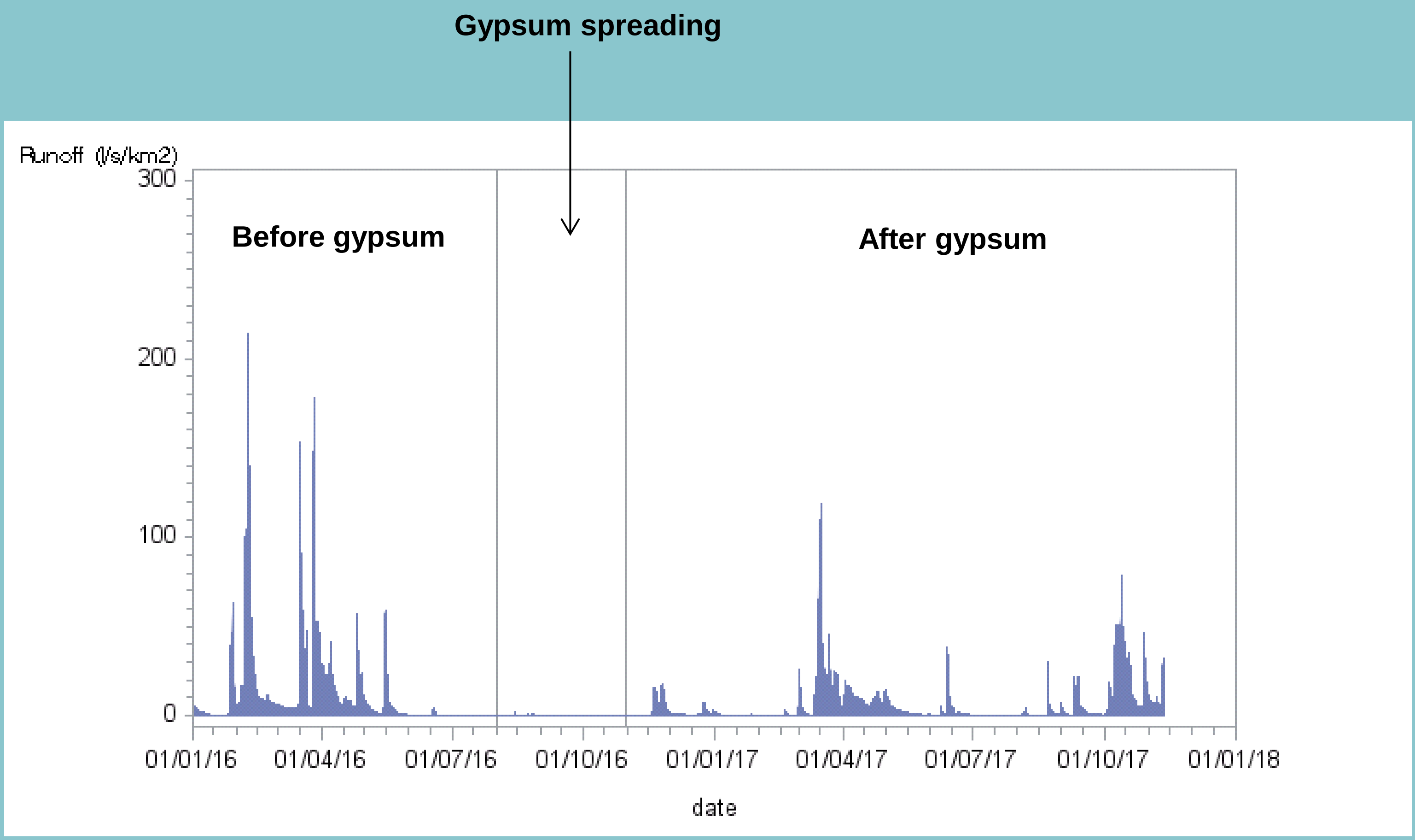
Immediate effect

Treated with gypsum

Not treated

Photos: Janne Artell and a local farmer

Runoff in the Savijoki



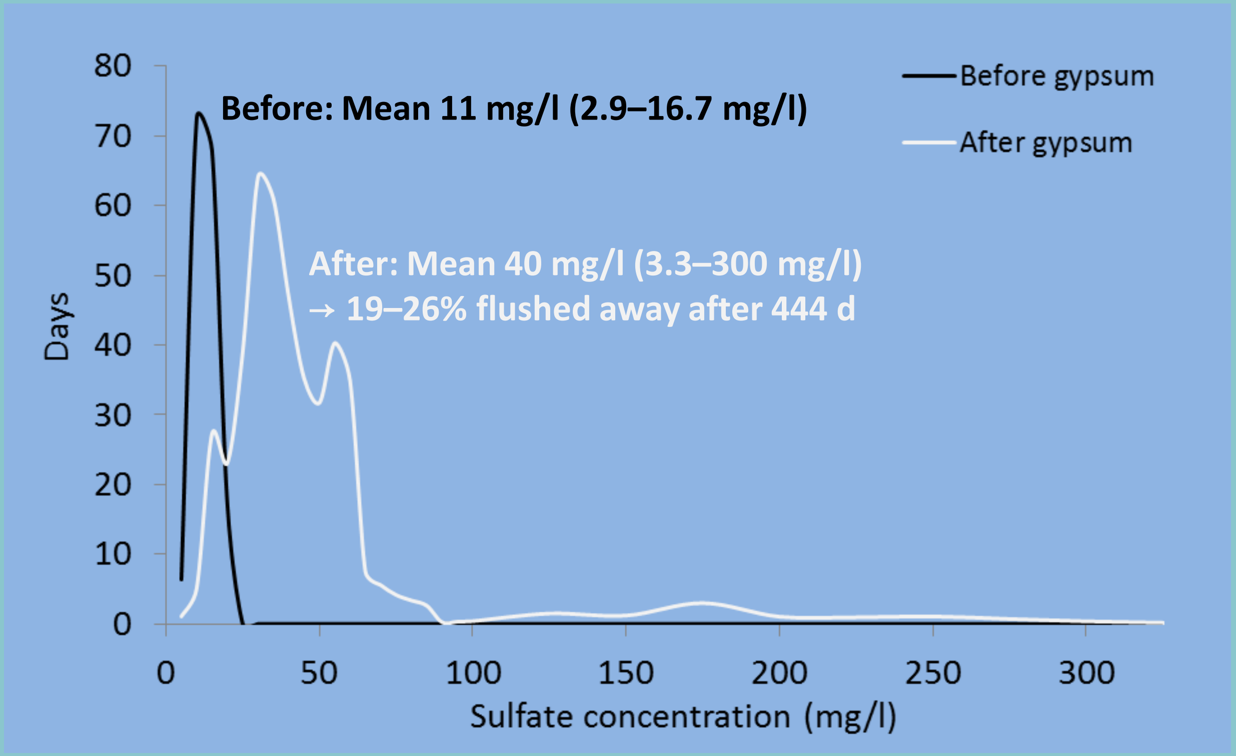
Loss of particulate P
Before and after the gypsum amendment

Area	Before gypsum 19.2.–31.7.2016 = 164 d (112 mm)		After gypsum 1.11.2016–18.1.2018 = 444 d (320 mm)		Gypsum fields	
	g km^{-2} d^{-1}	% larger than the control	g km^{-2} d^{-1}	% lower than the control	g km^{-2} d^{-1}	% lower than the control
Control	206		500			
Gypsum area – upper	330	+60	385	−23	252	−50
Gypsum area – lower	286	+39	389	−22	294	−41

Before gypsum
- **The loss of particulate P larger in the gypsum area than in the control area, despite the relatively similar characteristics**

After gypsum
- **Reduction in the losses at least 41%, potentially much higher**

Sulfate concentration in the Savijoki



- **At this pace, gypsum would be washed away in 5–6 years**
- **How long does the gypsum effect last?**

Potential side effects

Concern	Test	Anticipated effect
Thick-shelled river mussel (*Unio crassus*)	Behaviour of adults in SO_4 exposure (lab)	None
	Survival of glochidium larvae in SO_4 exposure (lab)	None
	Survey of abundance in the pilot area	None
Common water moss (*Fontinalis antipyretica*)	Growth in SO_4 exposure (lab)	None
Diatoms	Biomass and species on an articial surface in the pilot area	None
Fish assemblage	Abundance by electrofishing	None
Trout eggs (*Salmo trutta*)	Incubation with egg cylinders in the pilot area	Results not yet available
Ground water	Water quality in 7 wells	None
Phosphorus release	Sediment incubations in SO_4 exposure (lab)	Results not yet available
Soil chemistry	Analysis of top- and subsoil	None
Soil biology	Not studied	?

Thanks to: Hanna Arola, Heikki Hämäläinen, Krista Rantamo, Johanna Salmelin, Jukka Syrjänen (University of Jyväskylä)

Antti Kaseva et al. (Turku University of Applied Sciences)

Jukka Aroviita, Tiina Laamanen, Matti Leppänen, Maria Rajakallio, Jarno Turunen (SYKE)

Rami Laaksonen, Niclas Perander (Nixplore)

Potential BONUS effects?

- Appears to decrease the losses of dissolved organic carbon
- May reduce anionic pesticides
- Decreases the need to use P fertilisers in the long run

Farmer survey

87% of the farmers responded to a questionnaire

- **78% would use gypsum, if it were subsidized by the agri-environmental support scheme**
- **72% considered that local people sympathised with gypsum use**
- **70% would recommend gypsum to other farmers**
- **56% considered that gypsum is an easy agri-environmental measure**
- **6% experienced problems in gypsum spreading**

BUT: the autumn 2016 was perfect (= dry) for gypsum amendment

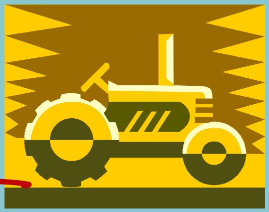
Soil structure/health

- Affects yield and thereby indirectly nutrient load
    - Yield increases → higher share of nutrients to plants
- Affects erosion

Soil structure decreased
- 40% of fields rented
    - Rented fields may be located far → farming activities made under unoptimat conditions,
- Fundamental improvements expensive

Rotation, grass, fallow
- Perennial, deep-rooted plants
- Organic matter build-up

Organic matter
- Binding of water increases
- Aggregates becomen stronger



Good aggregate and pore structure
- Infiltration rapid
- Soil tolerates wetness (not eroded, crusted or siltated)

Good aggregate and pore structure
- Plants take efficiently nutrients
- The better the yield, the higher amount of organic matter left in soil

Liming ($CaCO_3$)
- Ionic strength and cation composition
- Acidity decreased
- Improves biological activity, P availability and aggregate structure

Soil compaction
- Traffic on wet soils
- Surface runoff increases

Biological activity
- Earth worms loosen the soil and improve aggregate structure
- Microbial activity increase aggregate stability

Functioning drainage
- Macropores emptied rapidly
- Nutrient uptake by plants improved
- Risk of soil compaction reduced

Modified from Laura Alakukku

ELSEVIER

Agricultural Water Management 28 (1995) 295–310

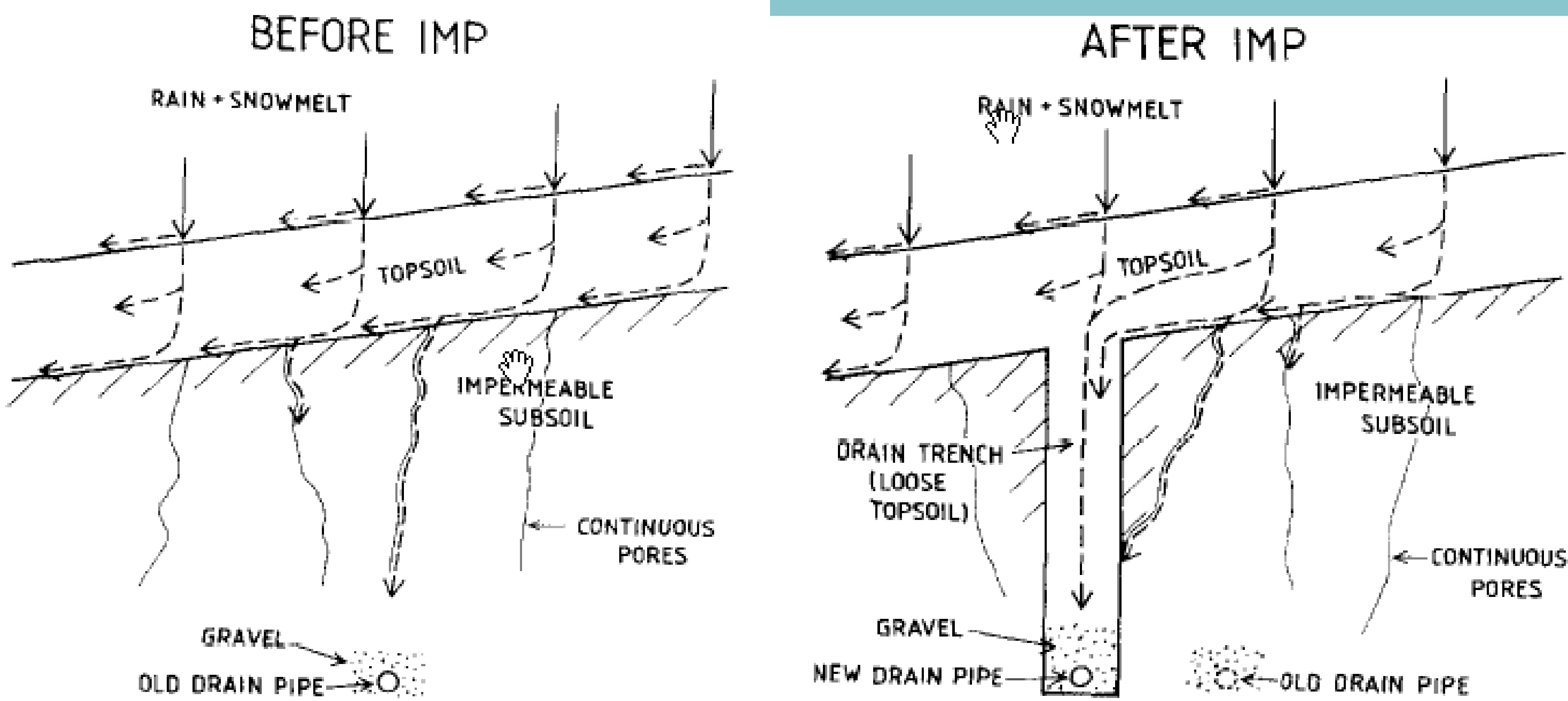
Agricultural water management

Influence of improved subsurface drainage on phosphorus losses and nitrogen leaching from a heavy clay soil

E. Turtola [a,*], A. Paajanen [b]

[a] Institute of Crop and Soil Science, Agricultural Research Centre of Finland, FIN-31600 Jokioinen, Finland
[b] Research Station for Ecological Farming, FIN-51900 Juva, Finland

Accepted 12 January 1995



References

Djodjic F, Bergström L, Ulén B, Shirmohammadi A. 1999. Mode of Transport of Surface-Applied Phosphorus33 through a Clay and Sandy Soil. Journal of Environmental Quality 28:1273-1282.

Koskiaho J, Ekholm P, Räty M, Riihimäki J, Puustinen M, 2003. Retaining agricultural nutrients in constructed wetlands – experiences under boreal conditions. Ecological Engineering 20:91–105.

Koskiaho J, Siimekselä T, Puustinen M. 2015. Maatalouden vesiensuojelukosteikkojen tehokkuusseuranta automaattilaitteistojen avulla. Vesitalous 4/2015: 35-40.

Laakso J, Uusitalo R, Yli-Halla M. 2016. Phosphorus speciation in agricultural catchment soils and in fresh and dried sediments of five constructed wetlands. Geoderma 271:18-26.

Lemola, Uusitalo, Sarvi, Ylivainio, Hyväluoma, Turtola 2015. Fosforin käytön vaikutus Suomen peltomaiden fosforitilaan – 20 vuoden skenaariot eri lannoitusstrategioilla. Pro Terra. No. 67 / 2015. VIII Maaperätieteiden päivien abstraktit.

Puustinen, M., Koskiaho, J., Peltonen, K., 2005. Influence of cultivation methods on suspended solids and phosphorus concentrations in surface runoff on clayey sloped fields in boreal climate. Agr. Ecosyst. Environ. 105, 565-579.

Puustinen M, Tattari S, Koskiaho J, Linjama J. 2007. Influence of seasonal and annual hydrological variations on erosion and phosphorus transport from arable areas in Finland. Soil & Tillage Research 93:44-55.

Puustinen M, Turtola E, Kukkonen M, Koskiaho J, Linjama J, Niinioja R, Tattari S. 2010. VIHMA—A tool for allocation of measures to control erosion and nutrient loading from Finnish agricultural catchments. Agric Ecosyst Environ 138:306–317.

Rankinen K, Gao G, Granlund K, Grönroos J, Vesikko L. 2015. Comparison of impacts of human activities and climate change on water quantity and quality in Finnish agricultural catchments. Lands Ecol.

Röman E, Ekholm P, Tattari S, Koskiaho J, Kotamäki N. 2018. Catchment characteristics predicting nitrogen and phosphorus losses in Finland. River Res Applic. 2018:1-9.

Tattari S, Puustinen M, Koskiaho J, Röman E, Riihimäki J. 2015. Vesistöjen ravinnekuormituksen lähteet ja vähentämismahdollisuudet. Suomen ympäristökeskuksen raportteja 35.

Tattari S, Koskiaho J, Kosunen M, Lepistö A, Linjama J, Puustinen M. 2017. Nutrient loads from agricultural and forested areas in Finland from 1981 up to 2010 – Can the efficiency of undertaken water protection measures seen? Environ Monit Assess 189: 95.

Turtola E, Kemppainen E. 1998. Nitrogen and Phosphorus Losses in Surface Runoff and Drainage Water after Application of Slurry and Mineral Fertilizer to Perennial Grass Ley. Agricultural and Food Science in Finland,7:569-581.

Turtola E, Kemppainen E. 1998. Nitrogen and Phosphorus Losses in Surface Runoff and Drainage Water after Application of Slurry and Mineral Fertilizer to Perennial Grass Ley. Agricultural and Food Science in Finland,7:569-581.

Uusi-Kämppä J, Jauhiainen L. 2010. Long-term monitoring of buffer zone efficiency under different cultivation techniques in boreal conditions. Agriculture, Ecosystems and Environment.

Uusitalo R, Jansson H. 2002. Dissolved reactive phosphorus in runoff assessed by soil extraction with an acetate buffer. Agriculture and Food Science Finland. 11:343-353.

Uusitalo R, Turtola E, Grönroos J, Kivistö J, Mäntylahti V, Turtola A, Lemola R, Salo T. 2007. Finnish trends in phosphorus balances and soil test phosphorus. Agricultural and Food Science 16: 301-316.

Valkama ym. 2009. Phosphorus fertilization: A meta-analysis of 80 years of research in Finland. Agriculture, Ecosystems and Environment 130:75-85.

Vuorinen J, Mäkitie O. 1955. The method of soil testing in use in Finland. Agrogeol. Publ. 63:1–44.

Ylivainio K, Sarvi M, Lemola R, Uusitalo R, Turtola E. 2014. Regional P stocks in soil and in animal manure as compared to P requirement of plants in Finland. MTT reports 124.

Viro PJ. 1953. Loss of nutrients and the natural nutrient balance of the soil in Finland. Metsätiet. tutkimuslait. julkaisuja 42.1.

Virtanen AI. 1933. The AIV Method of Processing Feeds. Empire J. Exper. Agric. 1:143–155.

Wahlroos O et al. 2016. Urban wetland parks in Finland: improving water quality and creating endangered habitats. I nternational Journal of Biodiversity Science, Ecosystem Services & Management. 11:46-60.

.