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Impacts of Cover Crops and Crop Residues on Phosphorus Losses in Cold Climates: A Review

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Background

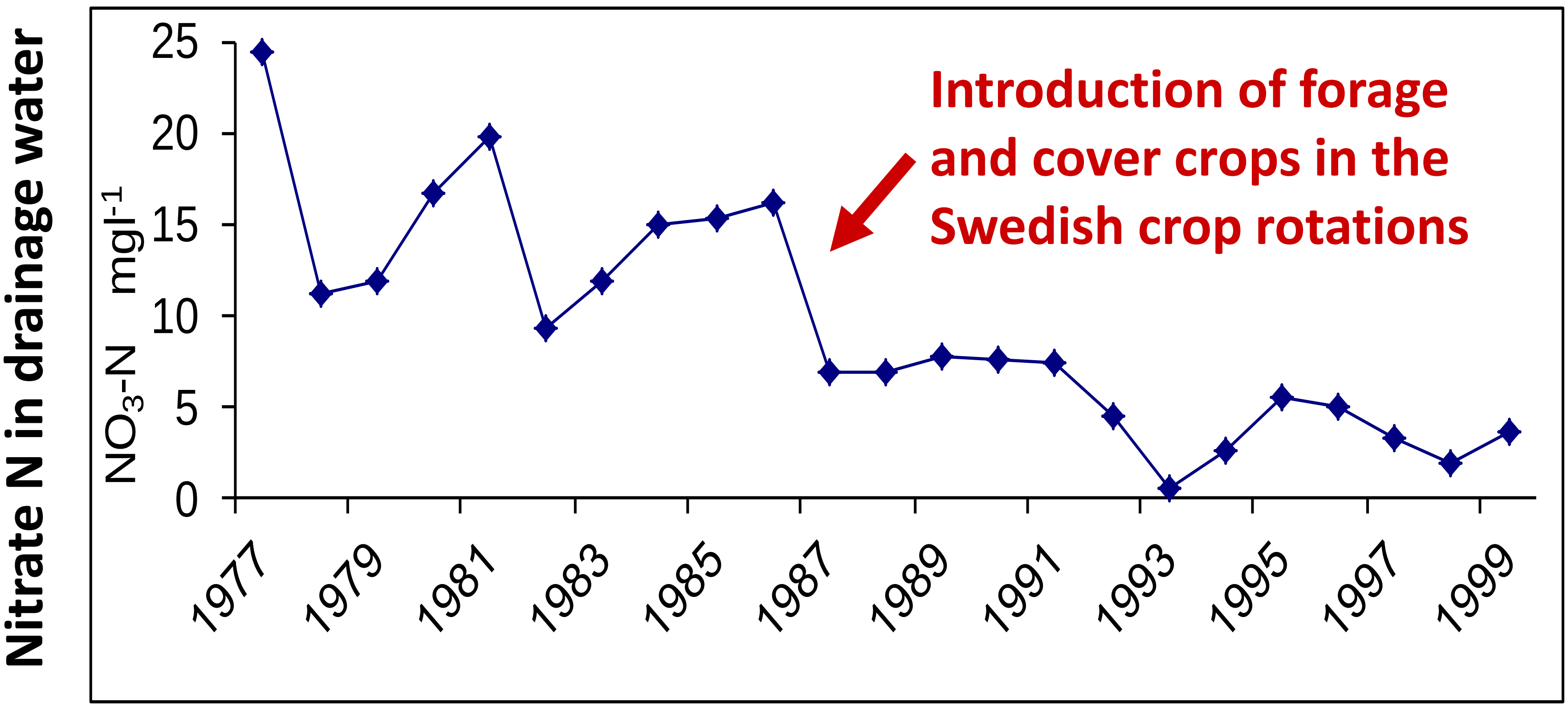
- **Sustainable agriculture** is the efficient production of safe, high quality **agricultural products**, in a way that protects and improves the **natural environment**, the **social and economic conditions** of farmers, their employees and local communities, and safeguards the **health and welfare of all farmed species** (Sustainable Agriculture Initiative Platform, 2010).

- **Crop management** (including management of cover crops and crop residues) is an essential component to achieve agricultural sustainability.

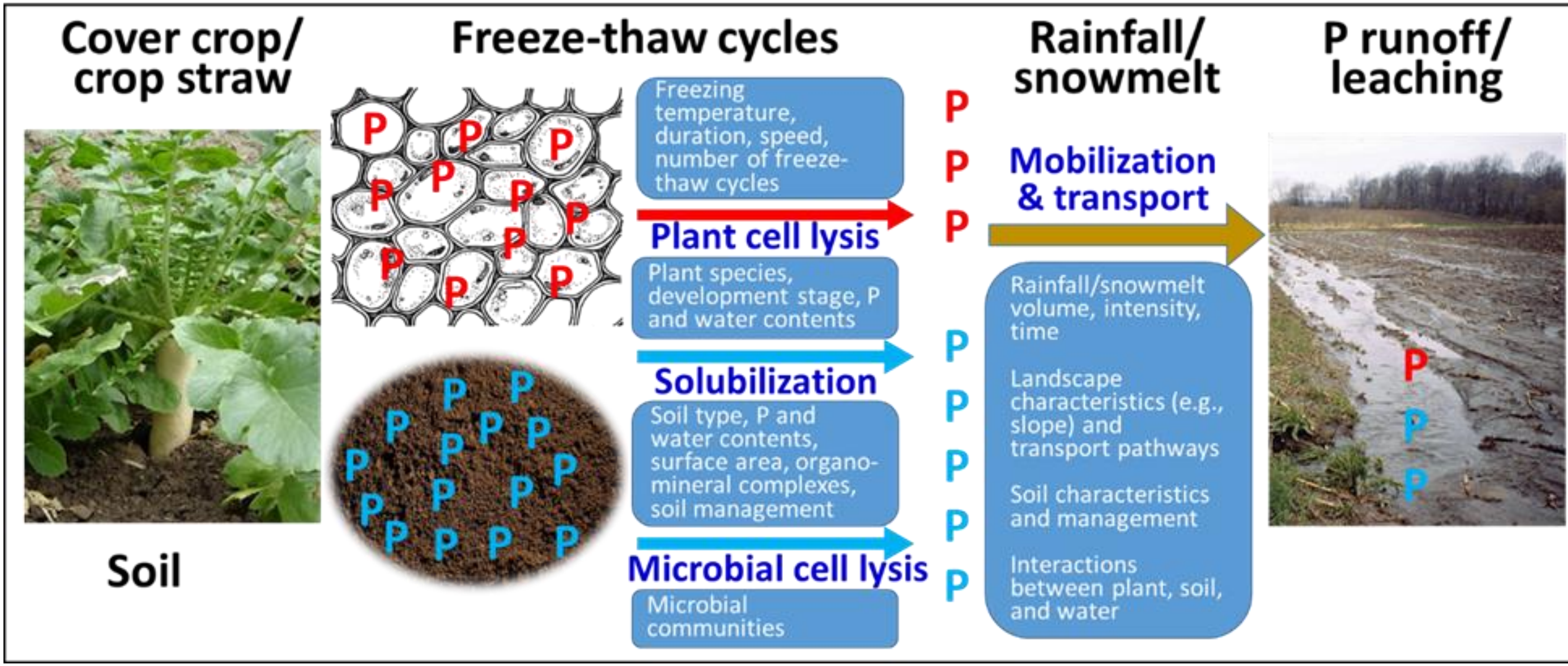
Benefits of using cover crops and crop residues during non-growing seasons

Cover crops and crop residues help to improve soil fertility, prevent soil erosion and reduce nitrogen leaching.

E.g. success in reducing N leaching (Bergström 2011)



BUT in cold climates, cover crops and crop residues after freeze-thaw can become a source of phosphorus (P) loss to water



Freeze-thaw effects on dissolved P transfer from vegetation and soil to water. Major processes are indicated with arrows and influential factors are given in boxes.

Lakes are sensitive to P!!!

Review objectives

- Clarify the impacts of cover crops and crop residues on water quality in cold climates;

- Discuss the drivers and the importance of cover crops and crop residues in P losses under various bio-geo-physical conditions; and

- Shed light on the future research needs for crop management in cold climates.

Review method

WEB OF SCIENCE

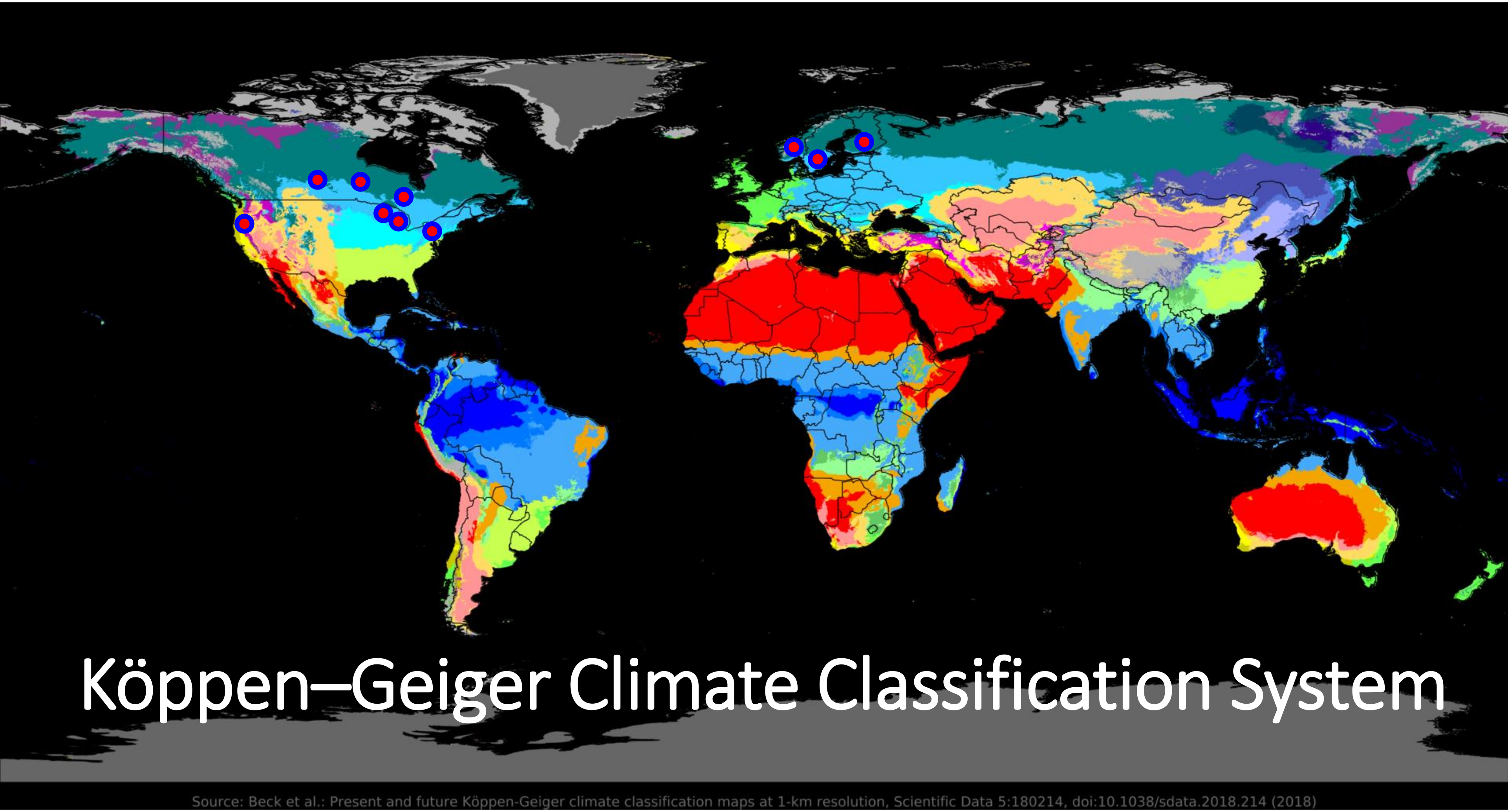
- **Web of Science database** — “Advanced Search”:

TS= ((crop OR residue OR plant* OR veget*) AND (fall OR autumn OR winter OR freez* OR frost OR season*) AND (phosphorus OR phosphate)) AND TI=(leach* OR runoff OR run-off OR drain* OR releas* OR water quality) NOT TI=("treatment plant" OR urban OR city OR roof* OR forest* OR wetland OR catchment* OR watershed* OR reservoir OR lake OR river OR highway).*

Where, TS means topic, which includes title, key words, and abstract of an article, and TI means title.

- **39 studies** (mostly published and some under reviewed or unpublished work by authors)
- **Review aspects**: (1) plant biomass and total P content, (2) water extractable P in plants, (3) P release from plant materials in cold climates, (4) P runoff from cropped soils, (5) P leaching from cropped soils, and (6) P loss across scales.

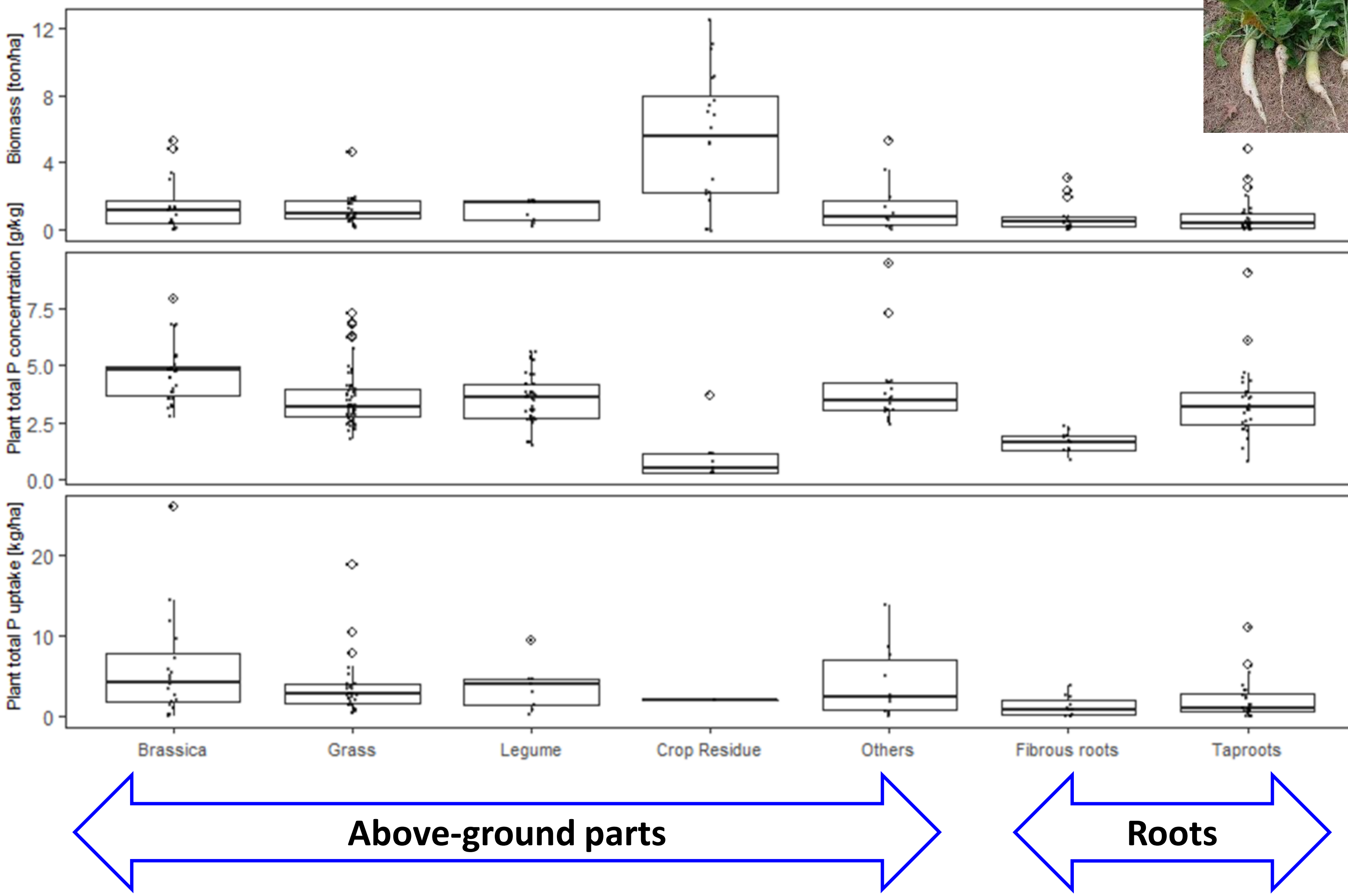
Review scope: cold climates



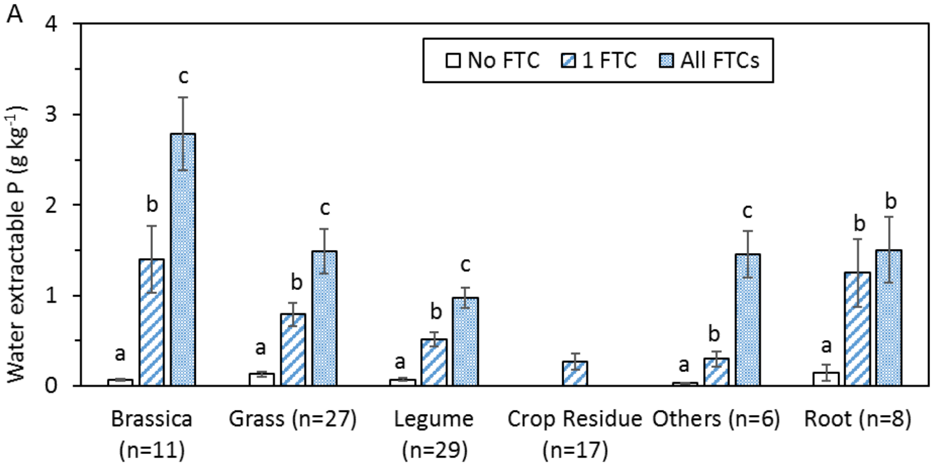
Cold climates (the "D" class): An average temperature above 10 °C in their warmest months and a coldest month average below −3 °C.

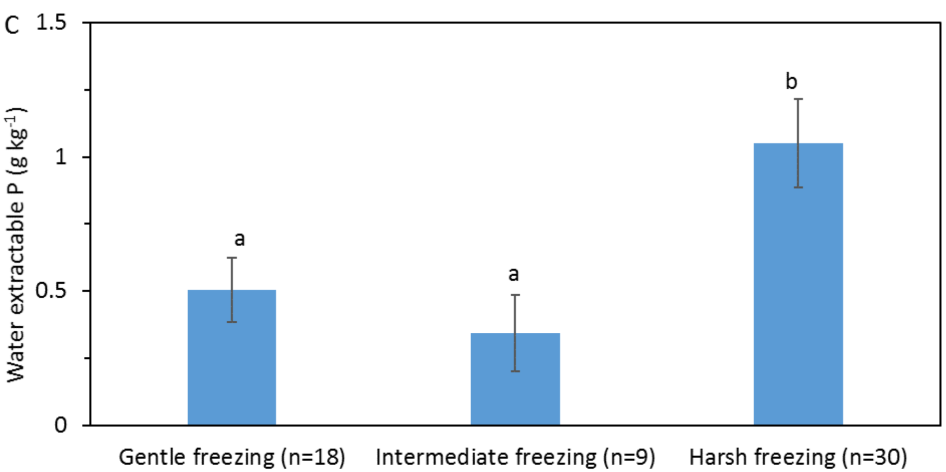
Cover crops and crop residues

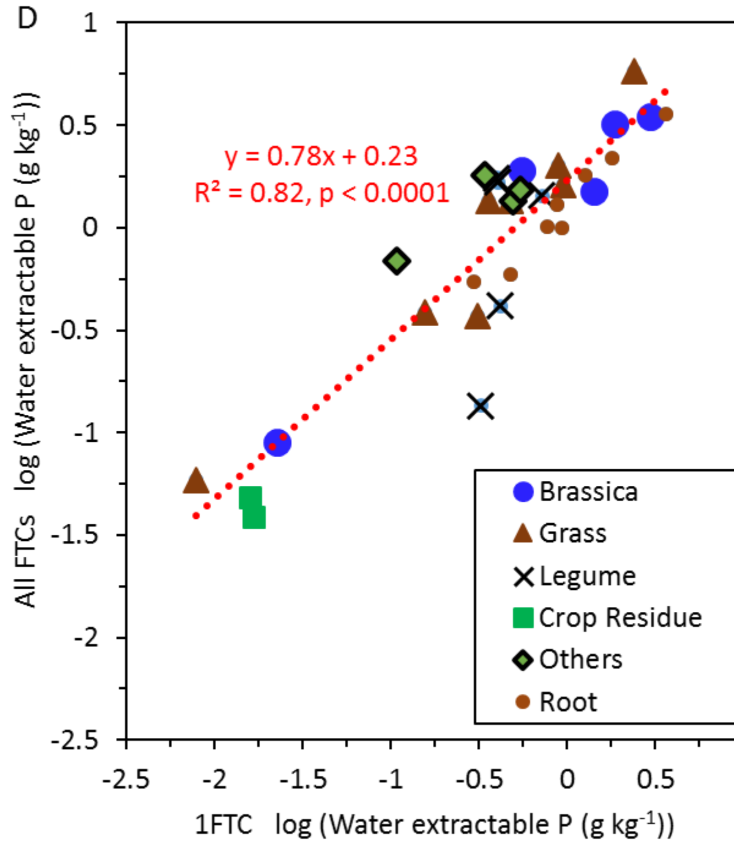
Biomass and total P uptake of cover crops and crop residues in cold climates



Water extractable P (WEP) in cover crops and crop residues exposed to freeze-thaw cycles (FTCs)

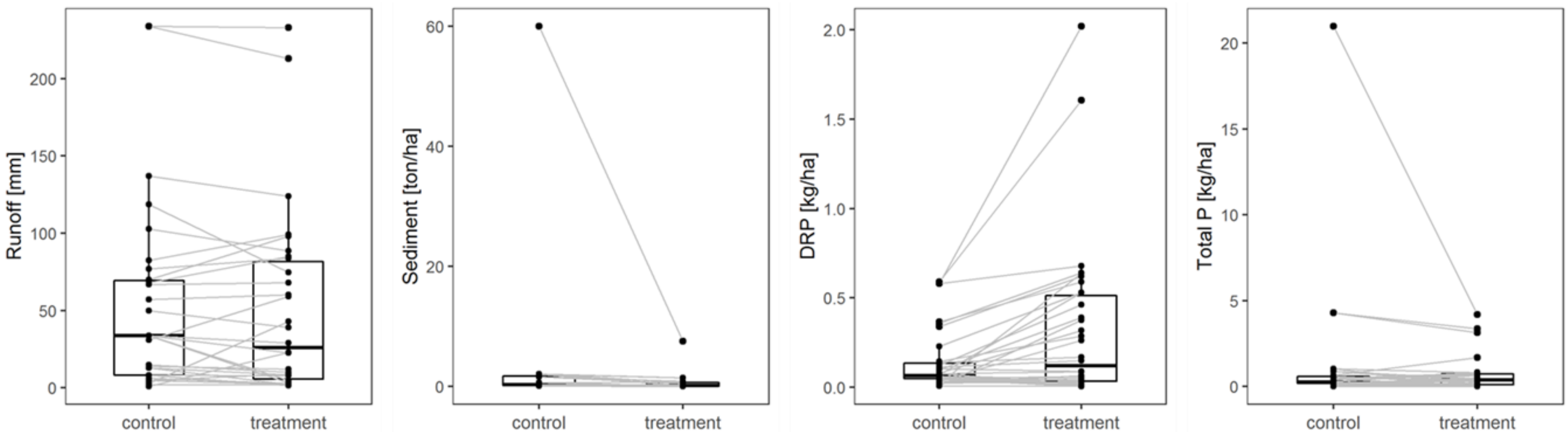




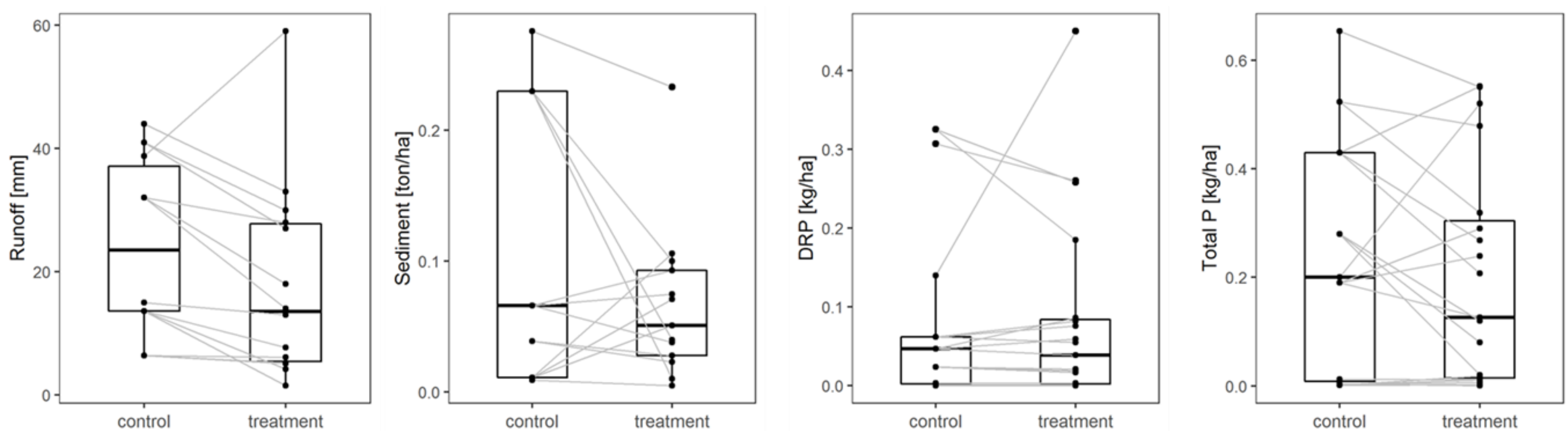


P runoff from cropped soils in cold climates

Crop residues



Cover crops



P runoff from cropped soils in cold climates 1

Study location and references	Comparison subject (cropped soil vs control)	Experiment setup	Total P loss range (kg/ha)	Runoff (%)	Sediment load (%)	Total P load (%)	DRP load (%)	Notes
Crop residue management in no-till systems								
Wisconsin, U.S. (Grande et al. 2005ab)	Corn grain or high-cut silage vs low-cut silage	Simulated rain in spring, field	<0.11	-90 to 85	-94 to 8	-93 to -1	-88 to 177	Denser residue cover decreased total P load in all and DRP load in 9 of 12 years and treatments (manured and unmanured).
Wisconsin, U.S. (Panuska and Karthikeyan 2010)	Corn grain vs corn silage	18 months, field	4 to 21	n.a.	-88	-80	21	Denser residue cover increased total P enrichment in sediments in rainfall-runoff but not in snowmelt-runoff.
Crop residue management associated with tillage methods								
Minnesota, U.S. (Hansen et al. 2000)	Conservation tillage vs conventional tillage	Two snowmelt seasons, field	0.4 to 1.4	46 to 281	88 to 250	200 to 250	143 to 286	Conservation tillage led to more snow accumulation and greater contribution of P loss from crop residues.
Southwest Finland (Puustinen et al. 2005)	Conservation tillage vs conventional tillage	9 years, field	3 to 4	-9 to 0	-70 to -32	-27 to -22	17 to 248	Conservation tillage reduced losses of sediments and particle-bound P but increased DRP losses.
Manitoba, Canada (Tiessen et al. 2010; Liu et al. 2014)	Conservation tillage vs conventional tillage	16 years, field	<0.1 to 1.7	-37 to 2200	-93 to -46	42 to 3980	62 to 4078	Conservation tillage increased DRP losses due to both direct P loss from crop residues and build-up of P on the soil surface.

P runoff from cropped soils in cold climates 2

Study location and references	Comparison subject (cropped soil vs control)	Experiment setup	Total P loss range (kg/ha)	Runoff (%)	Sediment load (%)	Total P load (%)	DRP load (%)	Notes
Cover crops during non-growing seasons								
Pennsylvania, U.S. (Bechmann et al. 2005)	Annual ryegrass vs bare soil	Simulated FTCs and rain, lab	0.4 to 2	-13	-53	500	200	The cover crop reduced sediment load but increased total P load and DRP load, as compared to bare soil.
Wisconsin, U.S. (Grabber et al. 2013)	Different corn companion crops vs corn residue	Simulated rain in spring, field	<0.1 to 0.3	-89 to -5	-96 to 41	-93 to 53	-29 to 83	Companion crops improved water quality with fall manure applications but not with spring applications.
Ontario, Canada (Cober et al. in press)	Different cover crops vs bare soil	1 season, field	n.a.	n.a.	n.a.	-100 to 2329	-57 to 3043	Total P conc. was increased by hairy vetch but decreased by rye, oilseed radish and oat.
Saskatchewan, Canada (Elliott 2013)	Winter wheat or wheat stubble vs bare soil	Simulated FTCs and snowmelt, lab	0.1 to 0.8	n.a.	n.a.	-39 to 95	20 to 657	Winter wheat contributed more P than wheat stubble to P runoff.
Saskatchewan, Canada (Cade-Menun et al. 2013)	Pasture land vs cropland	1 snowmelt event, field	n.a.	n.a.	n.a.	-30	-50	Significantly higher DRP concentrations in runoff from cropland (related to fertilizer inputs) but lower particulate P than pasture land.

P runoff from cropped soils in cold climates 3

Study location and references	Comparison subject (cropped soil vs control)	Experiment setup	Total P loss range (kg/ha)	Runoff (%)	Sediment load (%)	Total P load (%)	DRP load (%)	Notes
Cropping systems (year-round monitoring)								
Oregon (Douglas et al. 1998)	Wheat-pea rotation vs fallow	5 years, field	4 to 50	-92 to -58	-99 to -88	-90 to -44	-67 to -50	Erosive fields with large sediment and P losses.
Wisconsin (Roberson et al. 2007)	Alfalfa full growth vs cut	1 year, field	0.3 to 0.7	-34 to -25	-41 to -16	-39 to -8	-43 to -15	Alfalfa full growth had a strong tendency to decrease P losses, but the effect was not significant.
Sweden (Ulén 1997)	Winter wheat or perennial ryegrass vs bare soil	3 years, field	<0.02	n.a.	n.a.	-79 to 1147	-25 to 50	Cover crops significantly elevated DRP concentrations in runoff but they did not cause a concern because of very low annual P loads.
Norway (Uhlen 1989)	Cover crop vs crop stubble	8 years, field	n.a.	n.a.	n.a.	16 to 1693	100 to 1473	Cover crops increased DPR and total P concentrations.
Manitoba, Canada (Liu et al. 2014)	Perennial forage vs annual crop	8 snowmelt seasons, field	0.2 to 0.5	52	-44	160	221	Conversion from annual crops to perennial forages increased dissolved P and total P loads in snowmelt runoff.
Saskatchewan (Schneider et al. submitted)	Green manure vs fallow	10 years, field	0.01 to 0.1	-19	-44	n.a	33 to 71	Green manure significantly increased dissolved P concentrations but increase in loading was not significant.

P loss across scales in cold climates

Study location and method	Winter soil cover	Plant WEP or total P release from plant materials (kg/ha)	Soil WEP or P release from soil materials (kg/ha)	Total P runoff from cropped soils (kg/ha)	P retention coefficient in runoff
Ontario, Canada, field monitoring over 1 year (Lozier et al., 2017)	Winter wheat residue; oat; red clover	0.03-7.7 (mean: 2.37)	5.8-21.1 (mean: 13.5)	0.01-0.18 (mean: 0.09)	0.96
Saskatchewan, Canada; simulated snowmelt in lab (Elliott, 2013)	Winter wheat; wheat stubble	0.09-1.61 (mean: 0.85)	0.23-0.41 (mean: 0.32)	0.14-0.80 (mean: 0.47)	0.45
Manitoba, Canada; field monitoring for several years (Liu et al., 2014b)	Canola stubble; barley stubble; wheat stubble	0.2-5.8 (mean: 3.0)	n.a.	0.01-0.83 (mean: 0.42)	0.86
Manitoba, Canada; field monitoring over 2 years (Wilson, unpublished data)	Stubble of wheat, alfalfa, canola, oat, hemp, soybean, all with weeds and chaff	0.42-3.17 (mean: 1.65)	n.a.	<0.01-0.7 (mean: 0.24)	0.85

Conclusions

- Cover crops and crop residues constitute a sizable P pool in non-growing seasons, and much of the P in the plant materials is water extractable after repeated FTCs.
  - WEP conc. (g/kg) are affected by crop species, hardiness, and freezing regimes e.g. temperature and FTC number.
  - WEP amounts (kg/ha) are also affected by the factors influencing crop biomass, e.g. climate, soil and management.
- The mobility of plant WEP, and controls on P runoff in field conditions are still poorly understood. Soil P losses are dynamic and complicated by interactions between soil, plant, and hydrological processes.
- The inconsistent patterns of P runoff are likely a result of the varying importance of the plant P pool relative to the soil and fertilizer or manure P pools, highlighting the need to consider site-specific factors in choice of a winter crop cover. Clearly, **soils** can retain a large amount of P that is released from plant materials.

Future research needs

- ❖ Quantify contributions of the P in winter crop covers to P runoff for different geo-physical conditions;
- ❖ Identify reliable plant and soil P analytes to predict P runoff;
- ❖ Improve cover crop establishment and cold hardiness;
- ❖ Understand the interactions between plant (particularly roots), soil, management and climates on P loss;
- ❖ Evaluate agronomic and environmental trade-offs; and
- ❖ Predict the influences of future climate scenarios on the impacts of winter soil cover on water quality.

Thank You for Your Attention!

Liu et al. Impacts of cover crops and crop residues on phosphorus losses in cold climates: a review, plan to submit to Journal of Environmental Quality, jian.liu@usask.ca