Soil Shear Stability at the Microscale as affected by long-term Potassium Fertilization

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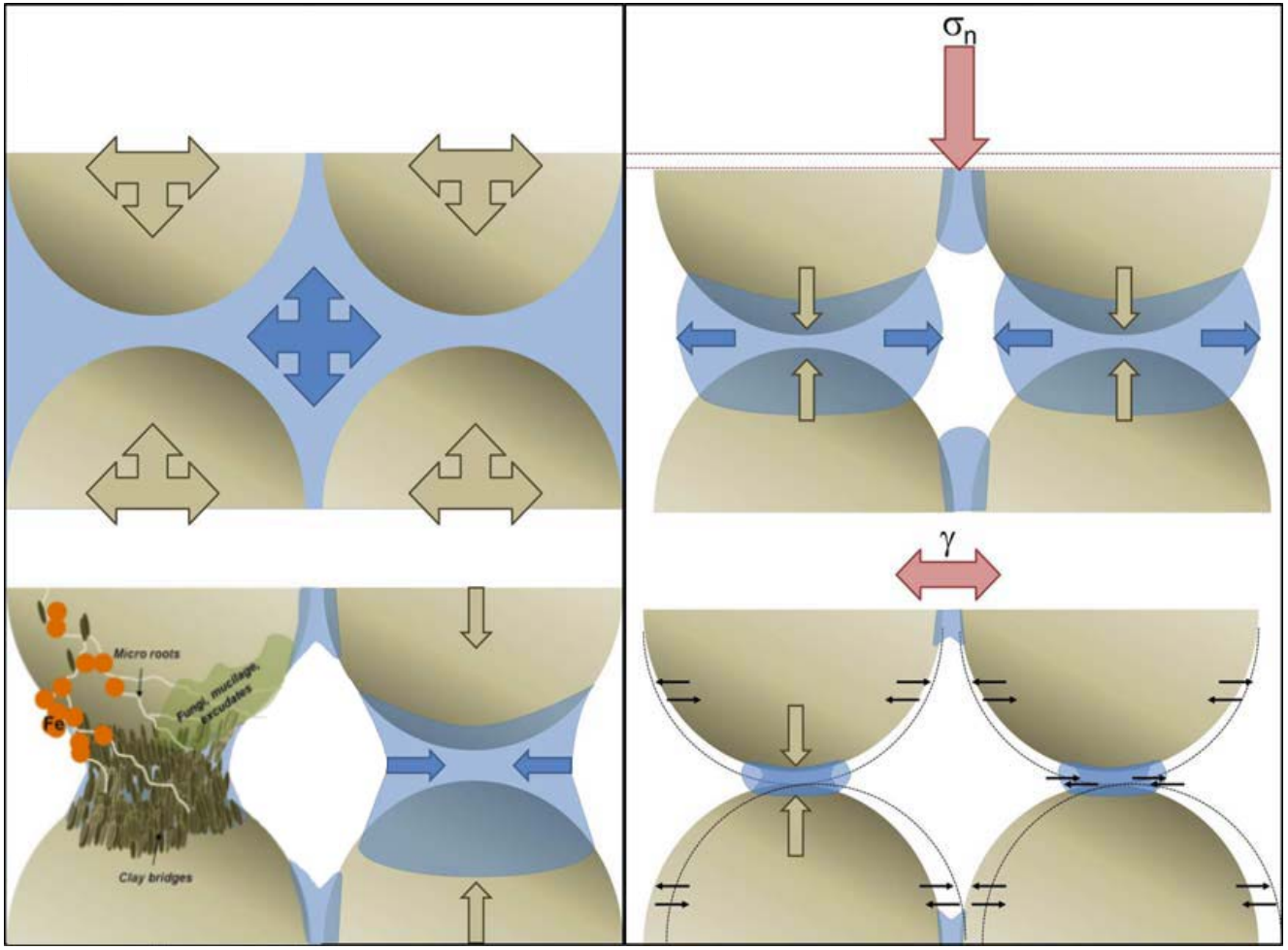
Outline

1. **Motivation**
   - Determinants of soil stability
2. **Materials and Methods**
3. **Results and Discussion**
   - Data from several different measurements that allow for a conclusion on soil stability
4. **Conclusion**

Motivation

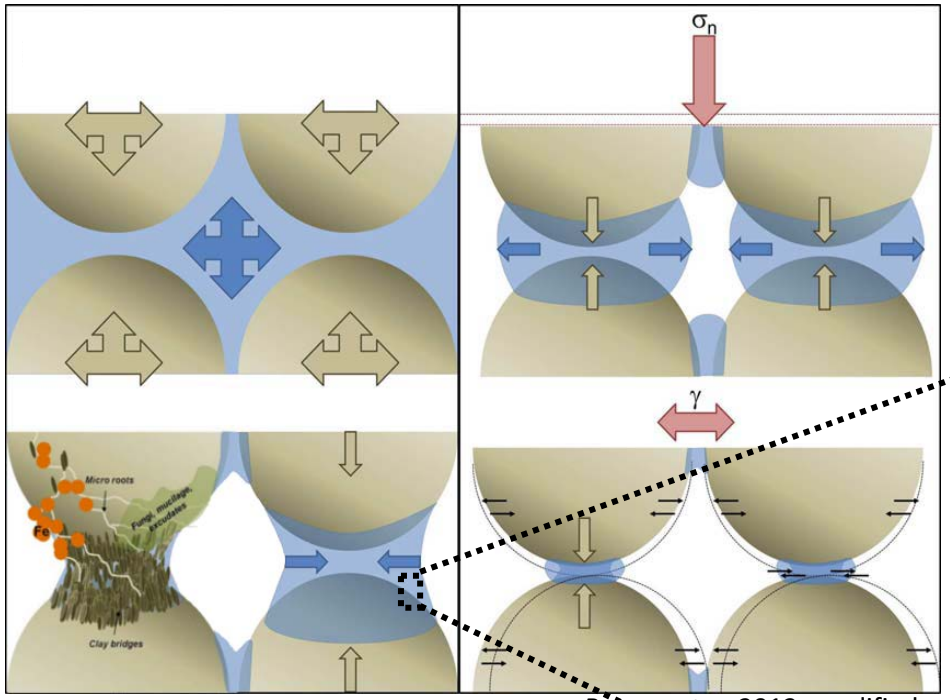
Factors and processes governing soil stability



Baumgarten 2013, modified

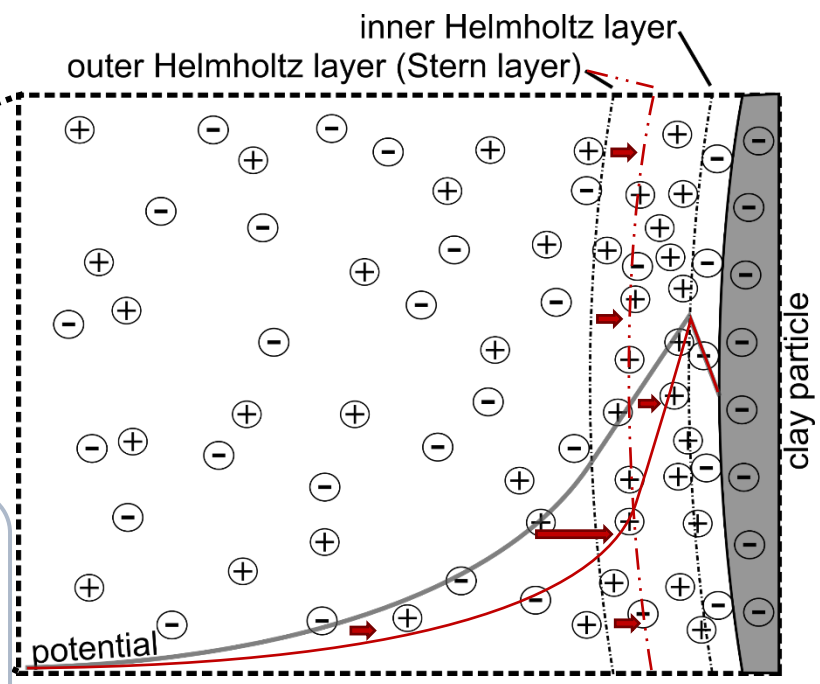
Motivation

Factors and processes governing soil stability



Baumgarten 2013, modified

What happens as a result of fertilization?



Processes that have to be considered:

- Attraction/Repulsion ⟹ Zeta Potential
- Dispersion/Aggregation ⟹ Readily Dispersible Clay
- Soil strength ⟹ Rheometry

Material

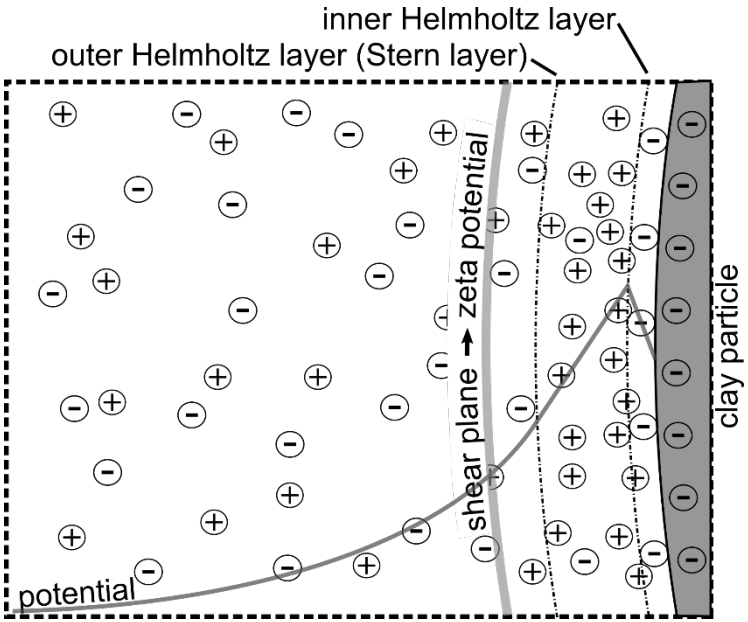
- Topsoil (0-20 cm) samples from two potassium fertilization trials in Germany
- Disturbed and undisturbed soil material
- Standard laboratory analyses according to Blume et al. (2011)

Selected characteristics of the investigated soil material

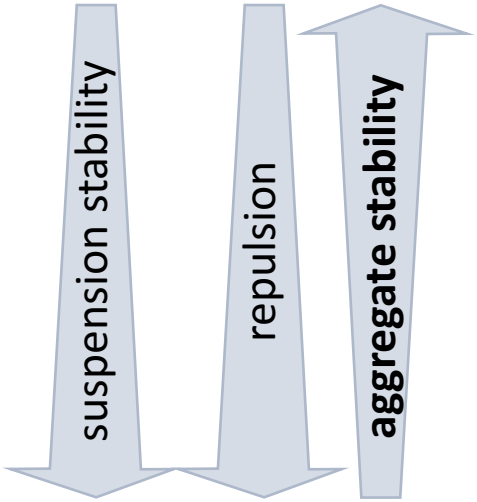
	Fertilization [kg K_2O $ha^{-1}a^{-1}$]	Soil K^+ content* [mg K_2O kg^{-1}]	Texture % Sand	% Silt	% Clay	SOM [% w/w]
Chernozem	0	75	5	72	23	2.6
	50	160	5	72	23	2.6
	100	205	5	71	24	2.6
	150	250	5	72	23	2.6
Podzol	0	45	86	9	5	5.4
	70	50	84	9	7	6.3
	140	90	85	10	5	6.1
	210	145	85	9	6	6.1

* Double lactate soluble K^+

Method 1: Zeta Potential



Classification of suspension stability



ζ [mV]
+5 … > -5
-5 … > -10
-10 … > -20
-20 … > -30
-30 … > -40
-40 … > -50
-50 … > -60
-60 … > -80

Baumgarten 2013, modified

Measure for attractive and repulsive forces between particles

- Calculated from electrophoretic mobility (movement in an electric field)
- 1 ‰ w/w soil suspension (10 mg soil, 10 ml ultrapurified water)
- Ultrasonication to ensure thorough dispersion

Method 2: Readily Dispersible Clay

Soil + purified water = 125 ml

3-5 g field-moist soil

x15

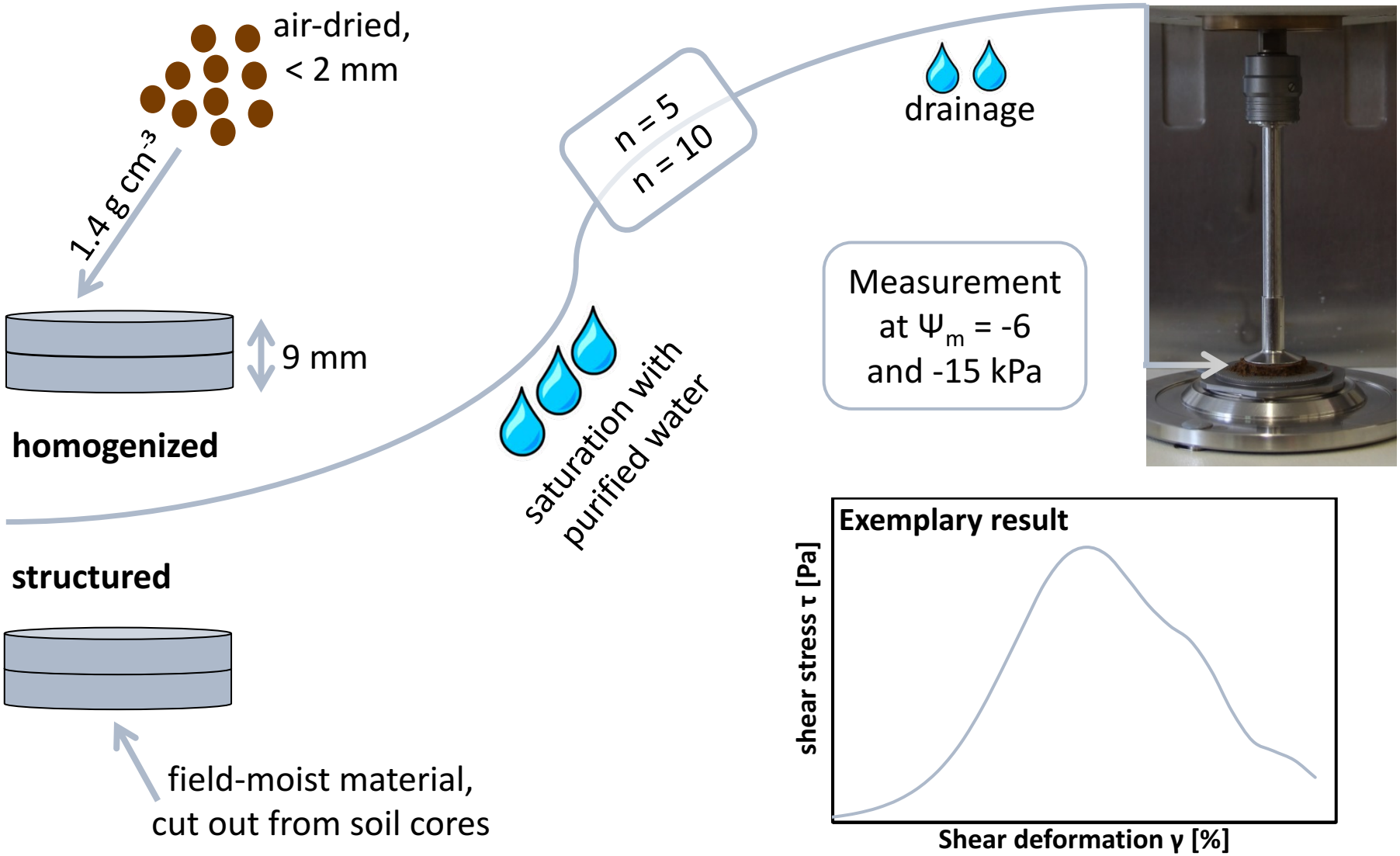
Aliquot
(3 cm depth)
after approx. 2:15 h

Stokes' Law:

$$v = \frac{2r^2(\rho_F - \rho_W)g}{9\eta}$$

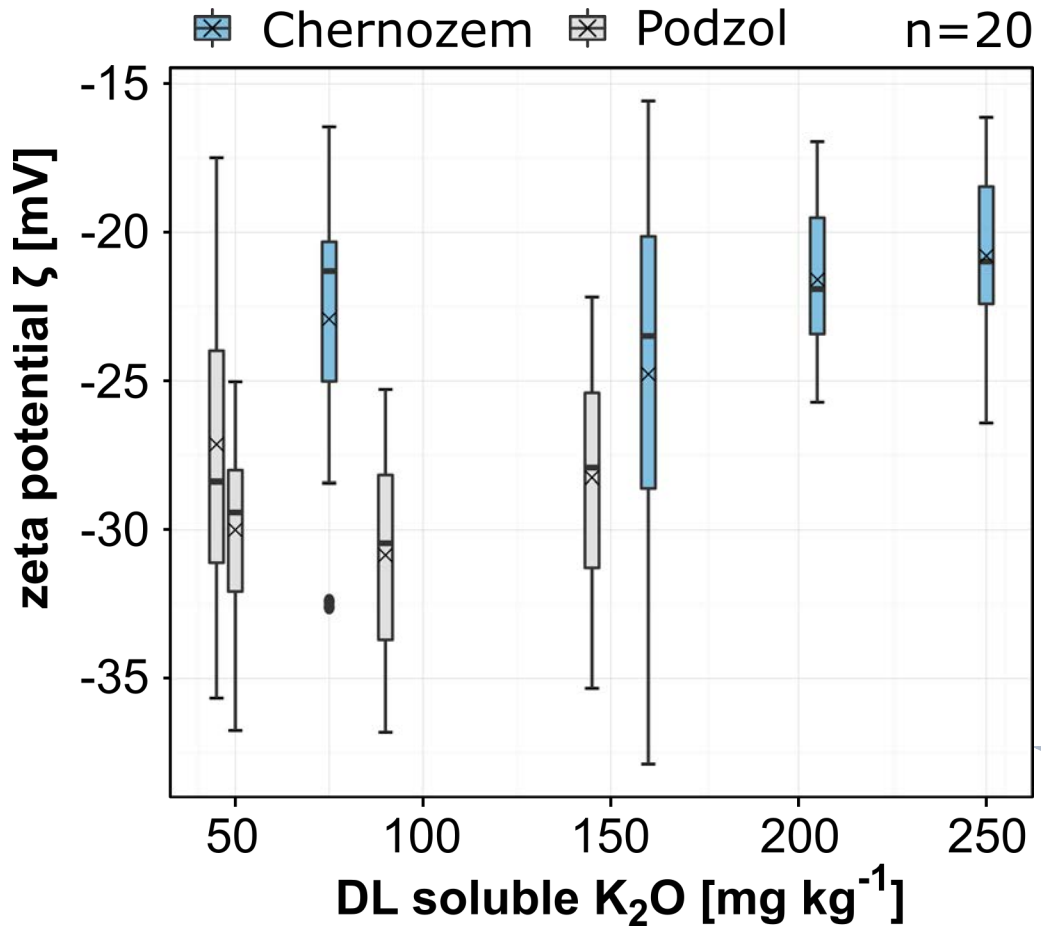
- Turbidity is measured and displayed in Nephelometric Turbidity Units
- Normalized Turbidity is calculated accounting for the dry mass of soil particles in the suspension

Method 3: Rheometry



Results & Discussion 1: Zeta Potential

Zeta potential as a function of soil K^+ content and texture (Chernozem = silt loam, Podzol = loamy fine sand)



X = arithmetic mean, dots = outliers

repulsion

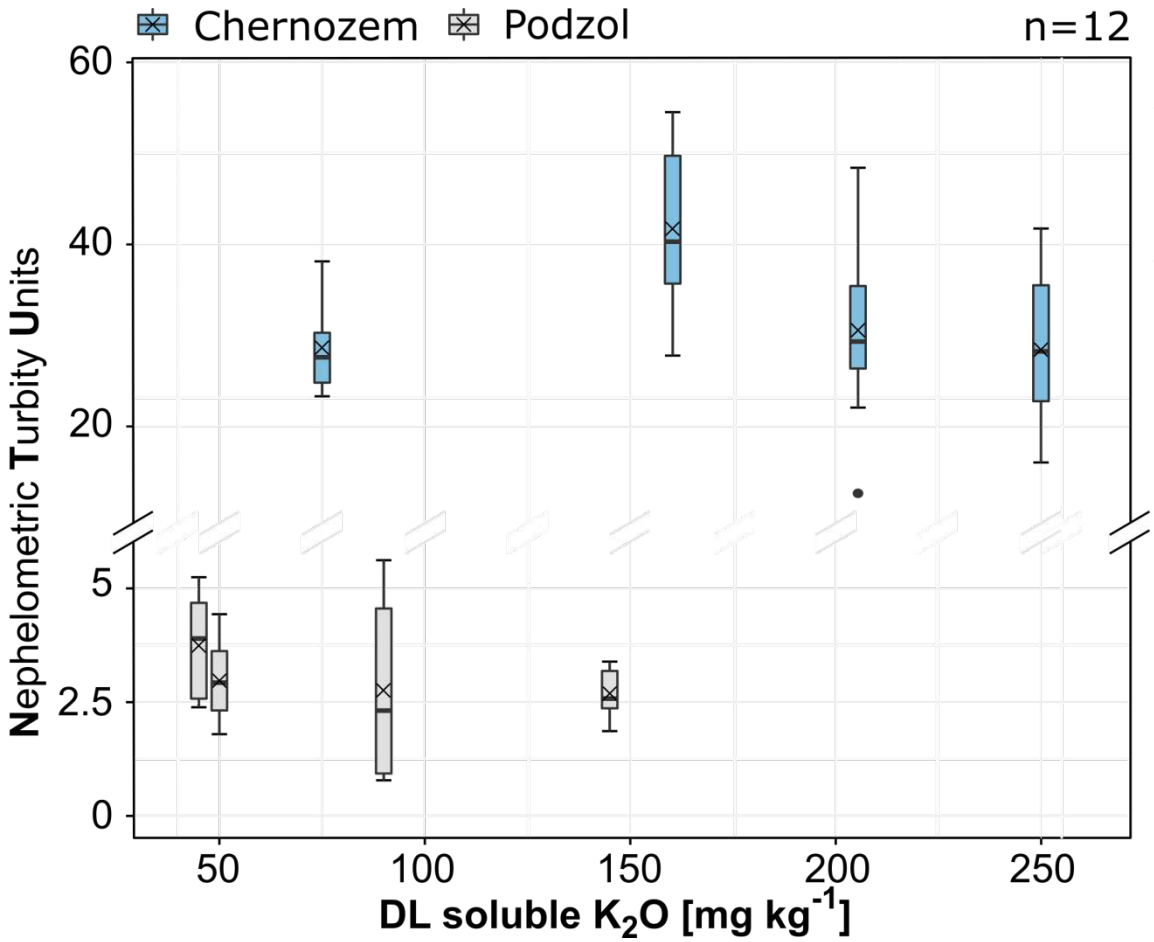
aggregate stability

- **Silt loam:** low fertilization increases repulsion compared to zero fertilization, higher K^+ input reduces repulsion
  ➡ higher aggregate stability
- **Loamy fine sand:** intermediate K^+ input increa pulsion well as

Intermediate potassium fertilization causes the strongest repulsion

Results & Discussion 2: Readily Dispersible Clay

Readily dispersible clay as a function of soil K^+ content and texture (Chernozem = silt loam, Podzol = loamy fine sand)

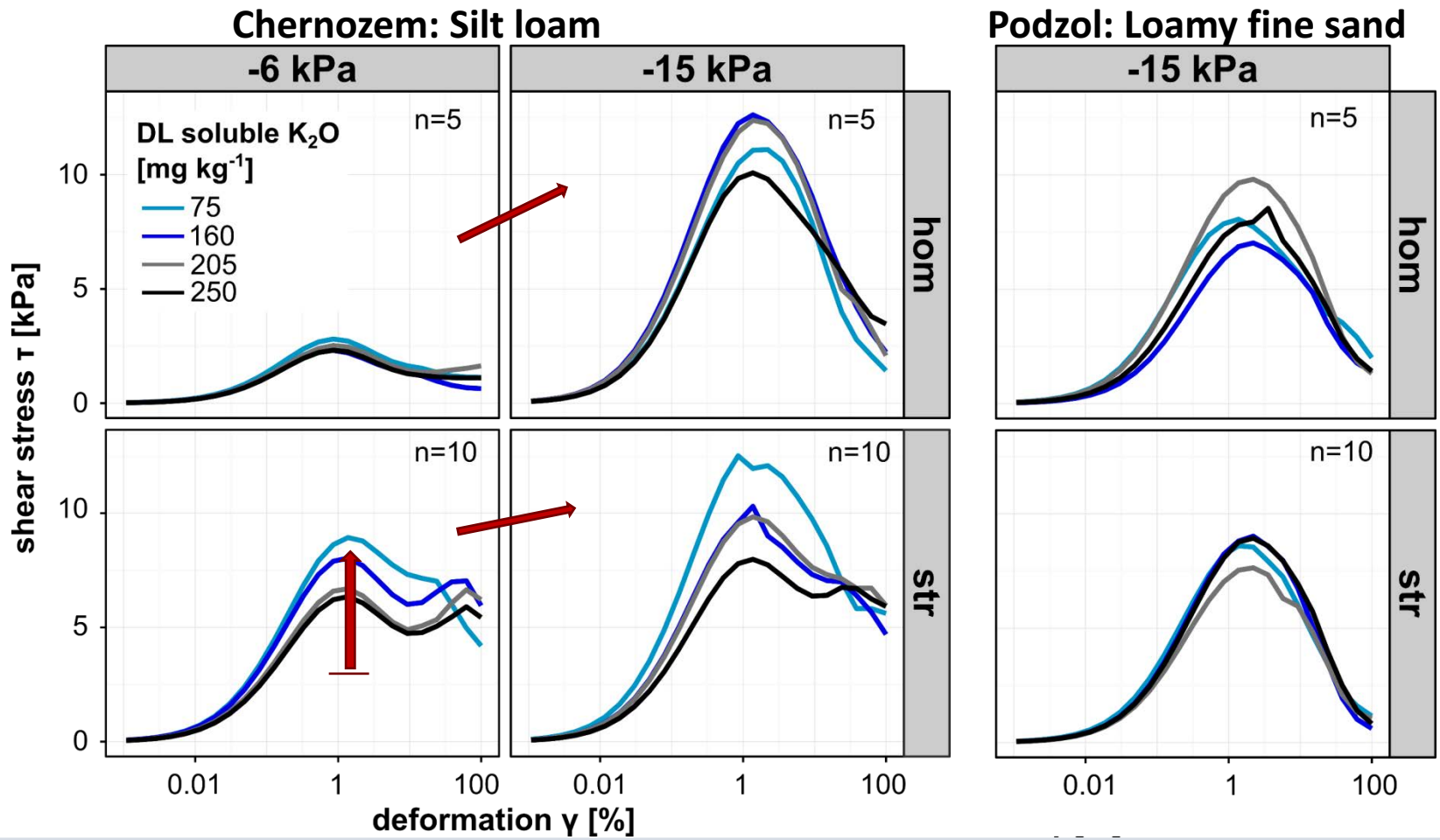


X = arithmetic mean, dots = outliers

- **Silt loam:** RDC in accordance with zeta potential – reduced repulsion
  ⟹ less clay dispersion
- **Loamy fine sand:** RDC diverges from what would be expected due to zeta potential measurements
  - Repulsive forces might be counteracted by hi[illegible] organic [illegible] 6 %), [illegible] break
  - [illegible] use [illegible]nts

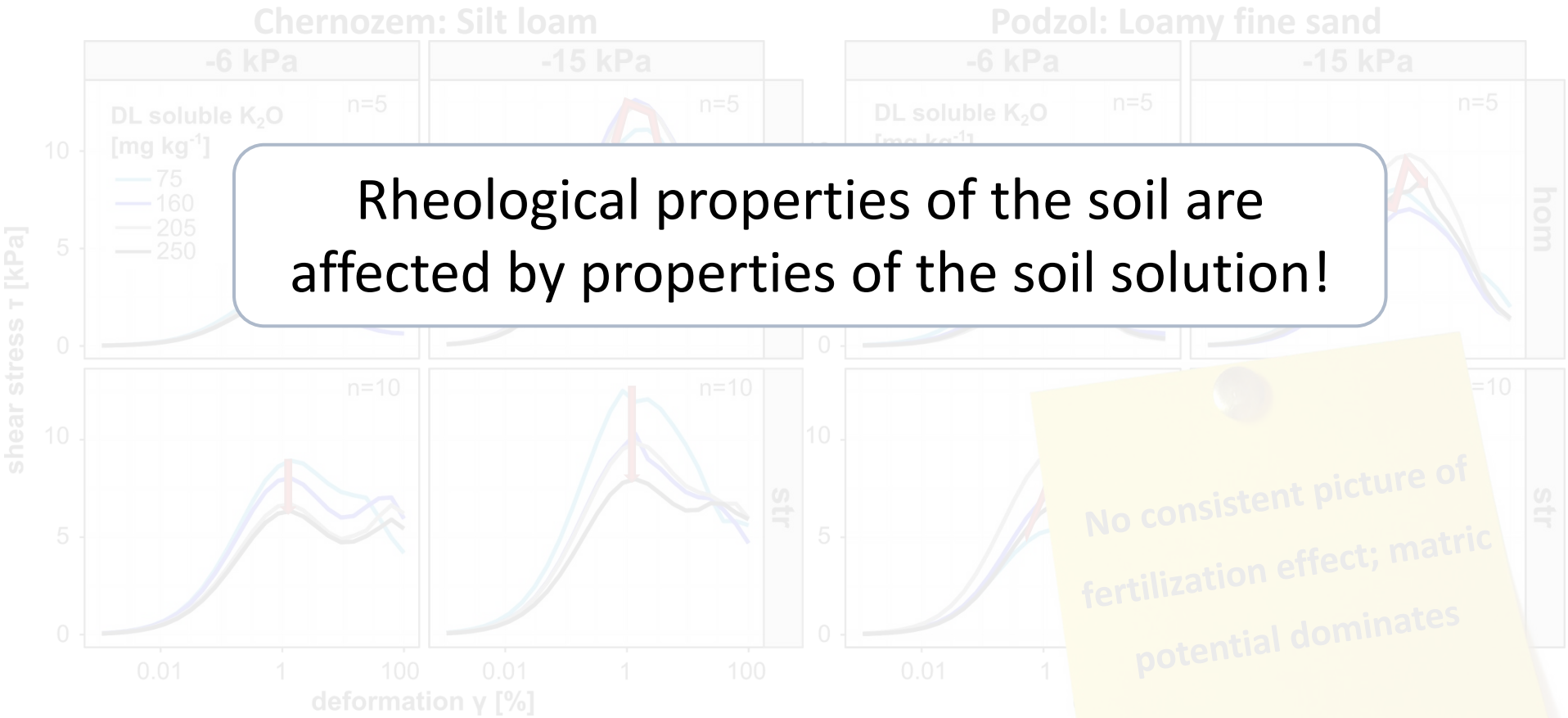
Results & Discussion 3: Rheometry

Shear stress as a function of deformation, soil structure and matric potential for different soil types and fertilization intensities



Results & Discussion 3: Rheometry

Shear stress as a function of deformation, soil structure and matric potential for different soil types and fertilization intensities



Rheological properties of the soil are affected by properties of the soil solution!

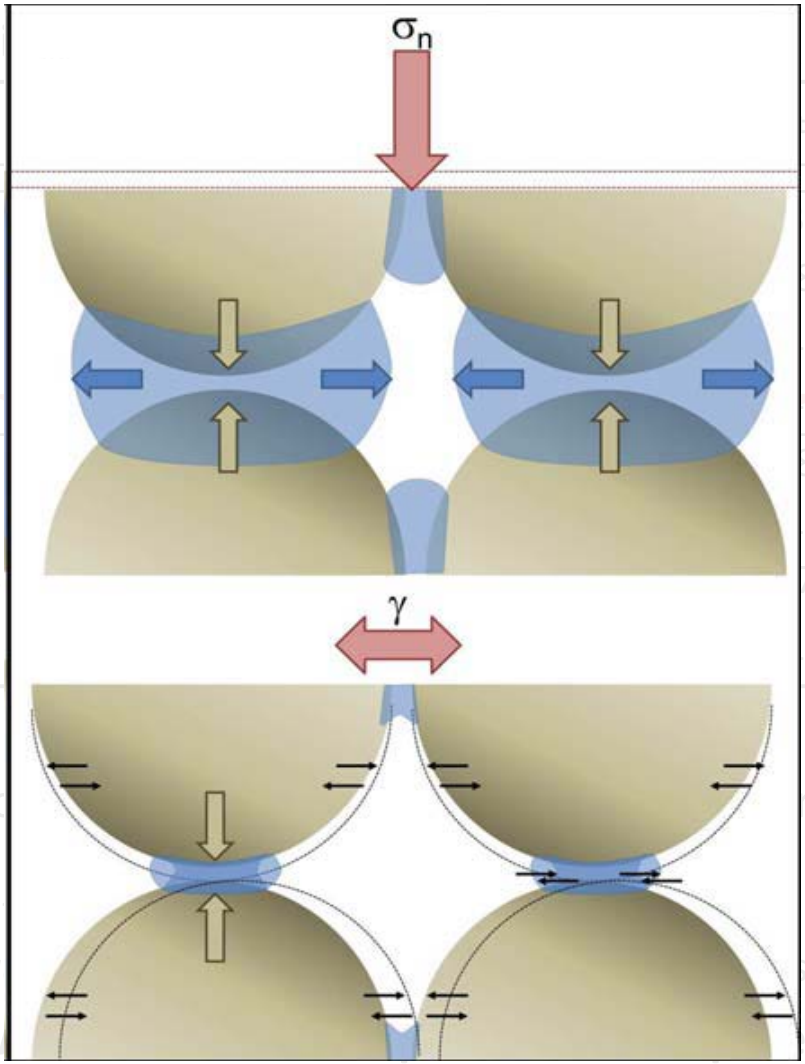
No consistent picture of fertilization effect; matric potential dominates

- less repulsive forces? Reduced dispersion?
- more repulsive

Results & Discussion 4: Soil solution

Basic cation concentrat ≙ soil solution)

	Soil K^+ content [mg K_2O kg^{-1}]			Mg^{2+}_{sat}
Chernozem	75	4	3.4	8.6 ± 1.6
	160	3	3.9	9.7 ± 0.2
	205	6	2.9	12.7 ± 0.9
	250	9	5.6	14.8 ± 0.9
Podzol	45	3	3.6	15.4 ± 0.2
	50	5	4.6	13.3 ± 1.0
	90	4	7.2	20.3 ± 0.8
	145	6	1.5	13.0 ± 0.7

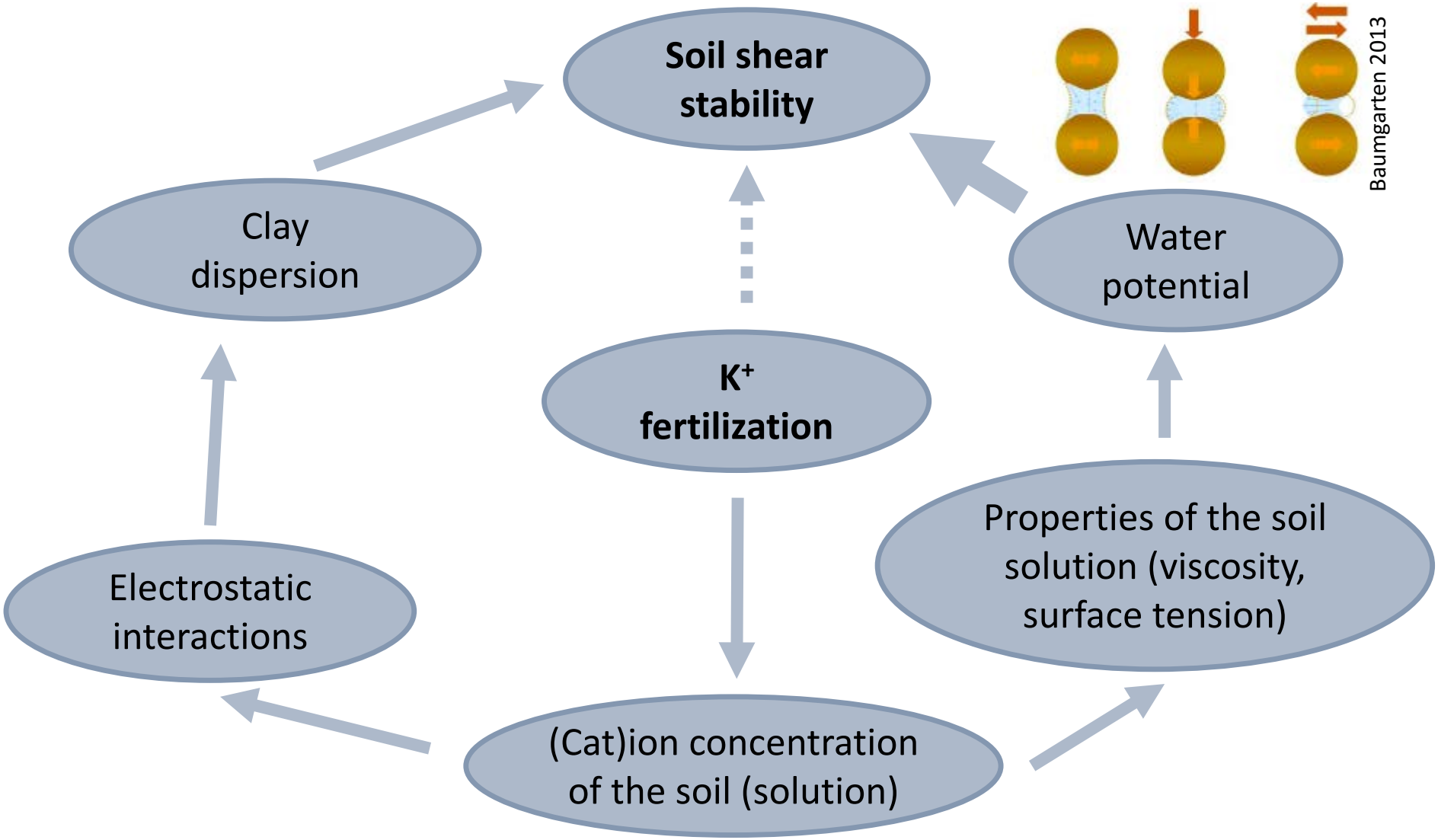


Baumgarten 2013, modified

- Increased ion co rface tension of aqueous salt so
  - Reduced wa
  - Enhanced w ion (Becher 2001)

higher w dials (drainage levels)

Conclusion


Soil shear stability
Clay dispersion
Water potential
Baumgarten 2013
K^+ fertilization
Properties of the soil solution (viscosity, surface tension)
Electrostatic interactions
(Cat)ion concentration of the soil (solution)

Thank you for your attention!

Literature

Baumgarten, W 2013, *Soil microstructural stability as influenced by physicochemical parameters and its environmental relevance on multiple scales*, habilitation thesis, Kiel University.

Becher, HH 2001, 'Soil physical properties of subsoils contaminated with light nonaqueous phase liquids (lNAPLs)', *Journal of Plant Nutrition and Soil Science*, vol. 164, no. 5, pp. 579-584.

Blume, HP, Stahr, K & Leinweber, P 2011: *Bodenkundliches Praktikum - Eine Einführung in pedologisches Arbeiten für Ökologen, insbesondere Land- und Forstwirte, und für Geowissenschaftler,* Spektrum Akademischer Verlag, Heidelberg. ISBN: 978-3-8274-1553-0

Holthusen, D, Haas, C, Peth, S & Horn, R 2012, 'Are standard values the best choice? A critical statement on rheological soil fluid properties viscosity and surface tension', *Soil and Tillage Research*, vol. 125, pp. 61-71.

Mezger, TG 2012, *Das Rheologie Handbuch*. Vincentz Network GmbH & Co. KG, Hannover.

Appendix

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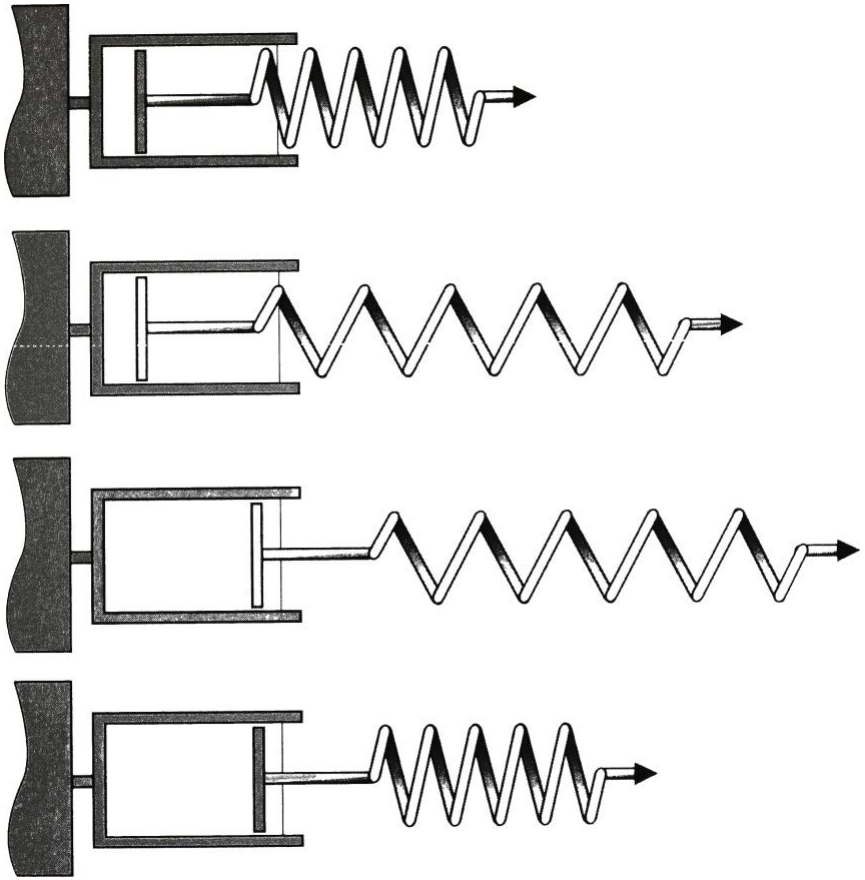
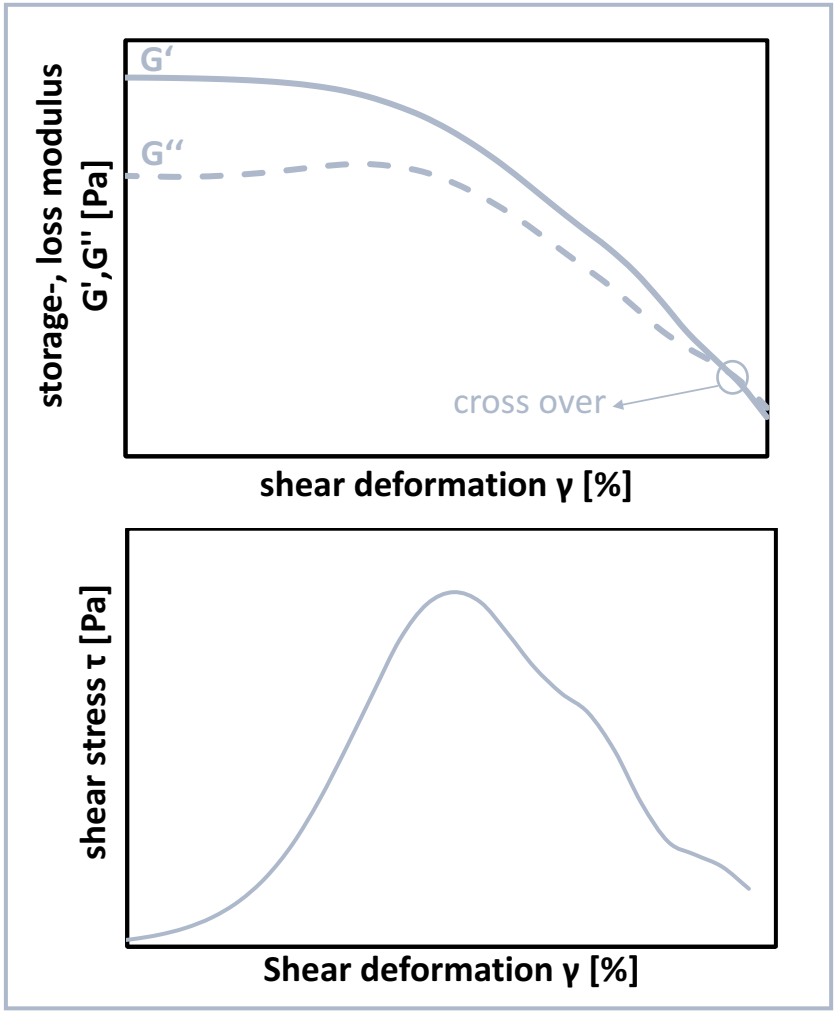
Appendix

Soil – a viscoelastic substance



Viscoelastic deformation behaviour
(Mezger 2012, modified)



Exemplary result of an Amplitude Sweep Test

Appendix

Water content of the samples used for rheometry at their respective drainage levels

	Soil K^+ content [mg kg^{-1}]	hom		str	
		-6 kPa	-15 kPa	-6 kPa	-15 kPa
		Water content [% w / w]			
Chernozem	75	32.2 ± 1.1	22.1 ± 0.3	24.7 ± 1.9	23.6 ± 0.8
	160	32.6 ± 1.9	24.2 ± 0.2	25.6 ± 1.2	24.2 ± 1.3
	205	33.0 ± 0.4	23.3 ± 0.2	25.6 ± 1.5	24.4 ± 0.7
	250	34.2 ± 0.5	25.5 ± 0.3	26.4 ± 1.5	24.9 ± 0.6
Podzol	45	23.5 ± 0.5	11.8 ± 0.2	19.0 ± 2.0	14.8 ± 1.4
	50	29.2 ± 0.5	15.7 ± 0.4	20.8 ± 2.2	15.7 ± 2.2
	90	27.3 ± 0.2	14.5 ± 0.3	18.5 ± 3.1	16.0 ± 1.7
	145	28.1 ± 0.3	15.6 ± 0.2	17.9 ± 1.0	15.6 ± 1.6

Appendix

60er Kali® gran.

EG-DÜNGEMITTEL
Kaliumchlorid 60
60 % K_2O, wasserlösliches Kaliumoxid

Version 4.0

Chemische Zusammensetzung:	typisch	w
• Kaliumchlorid (KCl)	95,4	%
• Nebenbestandteile (NaCl, $MgCl_2$, $MgSO_4$, K_2SO_4, $CaSO_4$)	4,4	%
• Anhaftende Feuchte	0,2	%