Nitrate leaching from the rooting zone

- Loss of an important plant nutrient
- Degradation of groundwater quality

Goal: minimize nitrate leaching

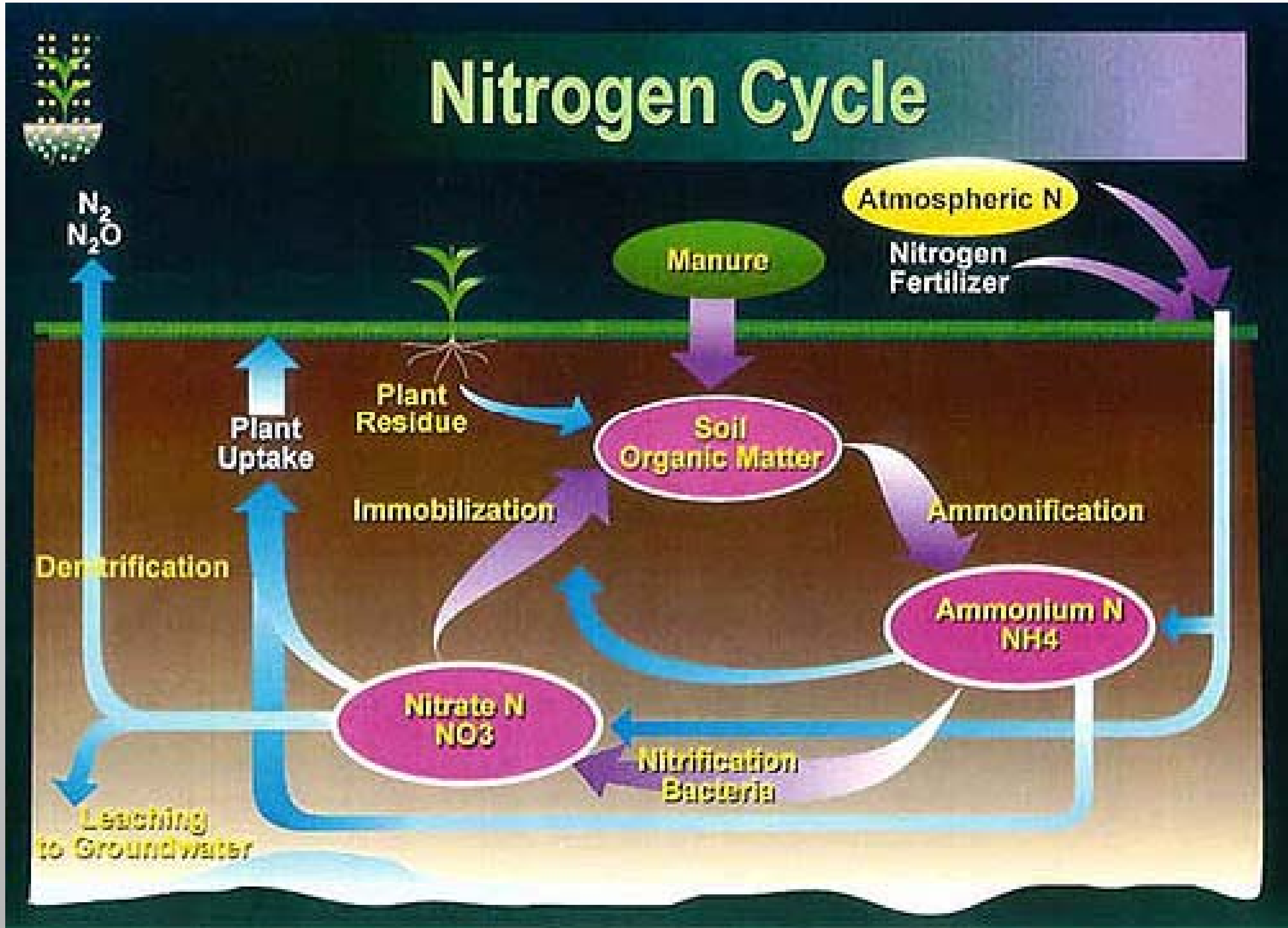
(Possible) Consequences of nitrate leaching into groundwater

- Health aspects :
  If nitrate is reduced to nitrite :
  - sec. toxicity: Methämoglobinämie (blue disease with babies)
  - tert. toxicity : Nitrosaminen and –amiden (carcinogenic)

- Economic aspects
  - Loss of an important plant nutrient → lower farm efficiency
  - Water treatment necessary for drinking water purposes

- Ecological aspects:
  Increased nitrate concentrations in groundwater and surface waters :
  - Threat to natural ecosystems
  - Loss of reactive substances (org. C and reduced sulfur compounds) in the aquifer

Nitrogen cycle



Nitrate leaching into the groundwater:

Determination of nitrate leaching with field experiments

- Determination of causes, relations and magnitude of nitrate leaching ; processes and complex interactions in the field

→ **requirement for targeted measures**

Analysis of nitrate leaching with simulation models

- Determination of the influence of soil, climate, fertilizing and land use on nitrate leaching

→ Applicability of simulation models

Execution of principle and case studies :

- Nitrate leaching danger, sampling date, depth of leaching nomograms

→ **Prognosis with simulation models**

Drinking water act (TrinkwV, 2001)

Nitrate

Guidance value: 25 mg Nitrate/l ≡ **5.6 mg Nitrate-N/l**

Treshold value: 50 mg Nitrate/l ≡ **11.2 mg Nitrate-N/l**

Climate	Amount and distribution of precipitation[1,2] Irrigation (timing, amount of the application) [1,2] Climatic evapotranspiration demand
Soil	Topographic situation (level, sloping) [1] Soil texture and soil texture layering[1,2] Nitrogen in soil organic matter[2] , mineralization[2] Groundwaterlevel[1]
Land use and crops	Type of crop (soil cover, rooting depth, nutrient uptake, water uptake) [1,2] Duration and season of the soil cover [1,2] Number and intensity of soil cultivation
Nutrient input by fertilization	Type of fertilizer (mineral, organic)[2] Amount and splitting of the fertilizer application[2] Time of fertilizer application[2]

[1] Influence on groundwater recharge amount

[2] Influence on concentration in the percolation water

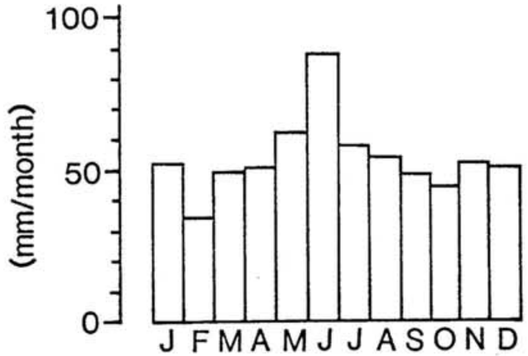
green : site specific

red : land use specific ((manipulable)

Hannover, 1968-1985

Summer wheat

Deep groundwater table



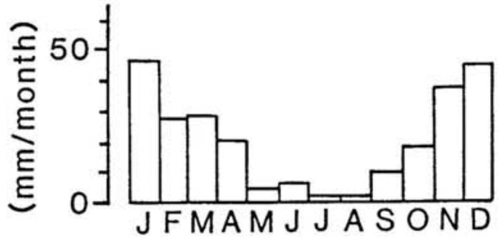
Precipitation

Σ = 640 mm/a

Groundwater recharge

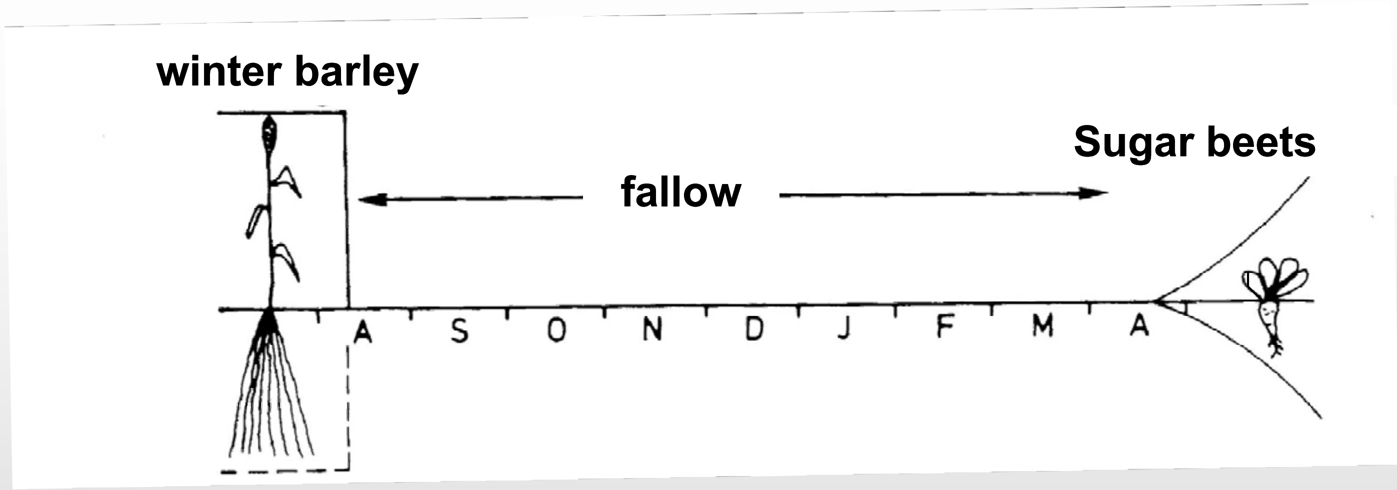
LOESS

Σ = 180 mm/a



SAND

Σ = 256 mm/a

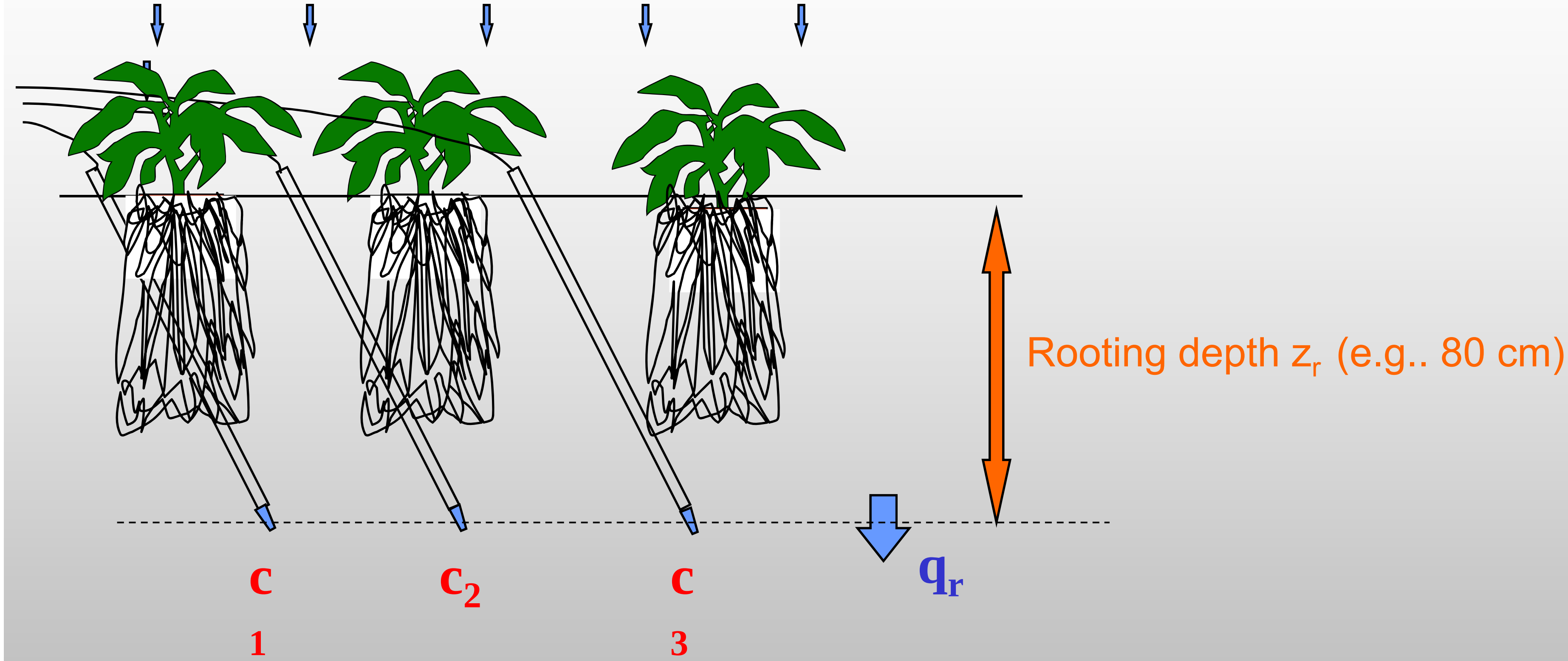


Main leaching period

Nitrate which is in danger of being leached :

- Residual nitrate, i.e. nitrate in the rooting zone after harvest
- Nitrate mineralized from soil organic matter or crop residues
- Nitrate, applied with or mineralized from slurry, organic manure of mineral fertilizer

Measurement of nitrate leaching

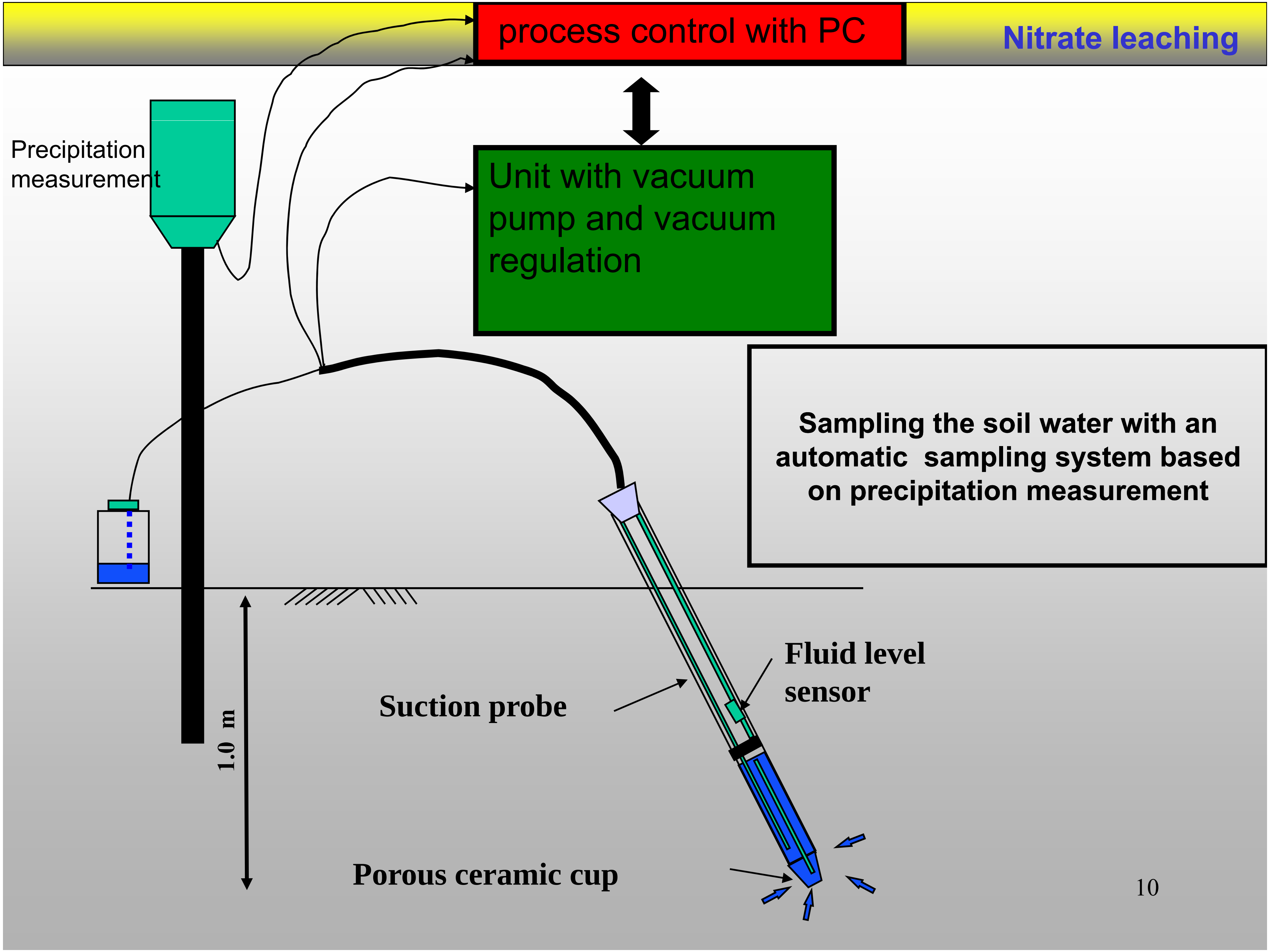


Measurement of mean concentration in the depth z_r :

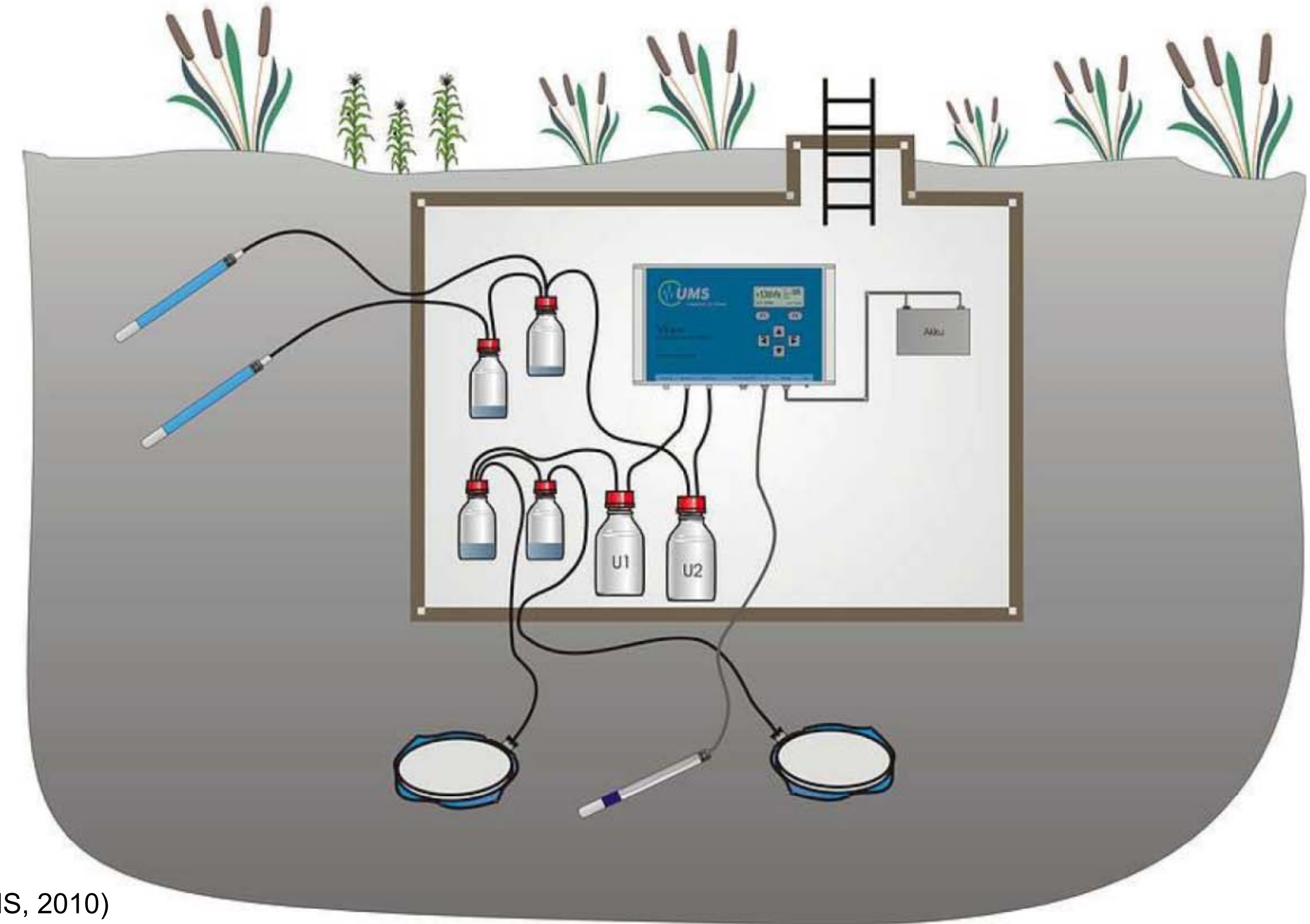
$$c_r = \Sigma(c_1 + ... + c_n)/n$$

Determination of the water flux q_r in depth z_r

Leached amount of nitrate: $Q_{nitrat} = \Sigma(q_r \cdot c_r)$ in kg NO_3-N/ha


process control with PC
Nitrate leaching
Precipitation measurement
Unit with vacuum pump and vacuum regulation
Sampling the soil water with an automatic sampling system based on precipitation measurement
Fluid level sensor
Suction probe
1.0 m
Porous ceramic cup

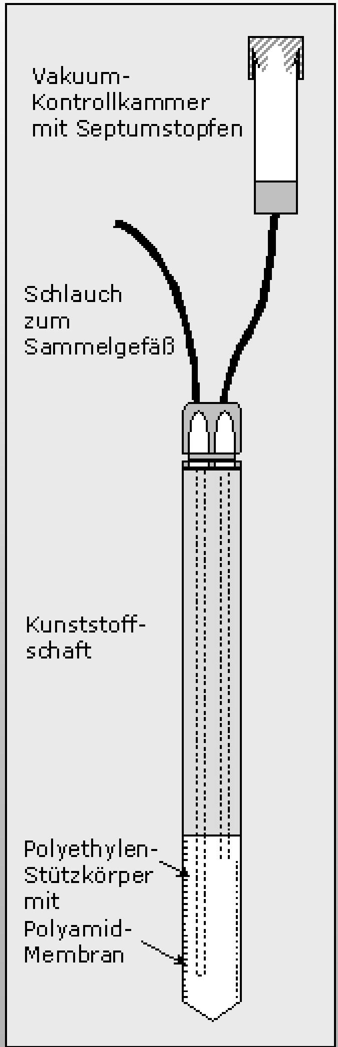
Controlled tension lysimeters



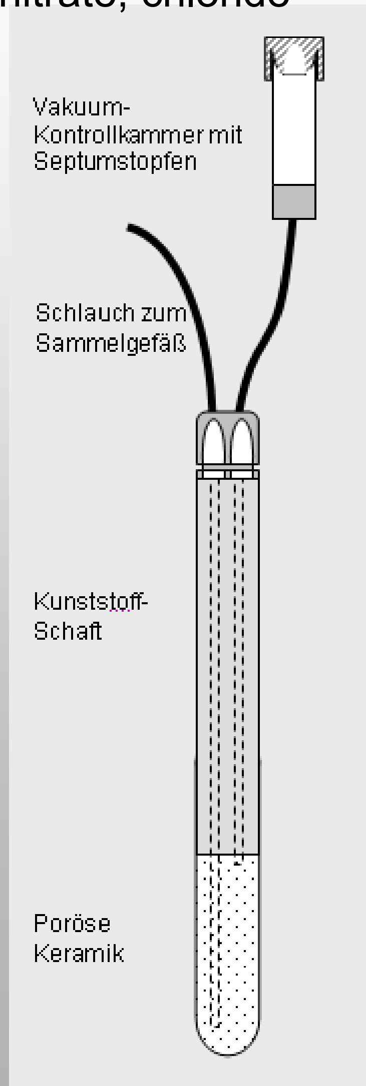
(UMS, 2010)

Suction probes

Suction probe of synthetic material : inorganic trace elements, e.g. Cd, As, Pb

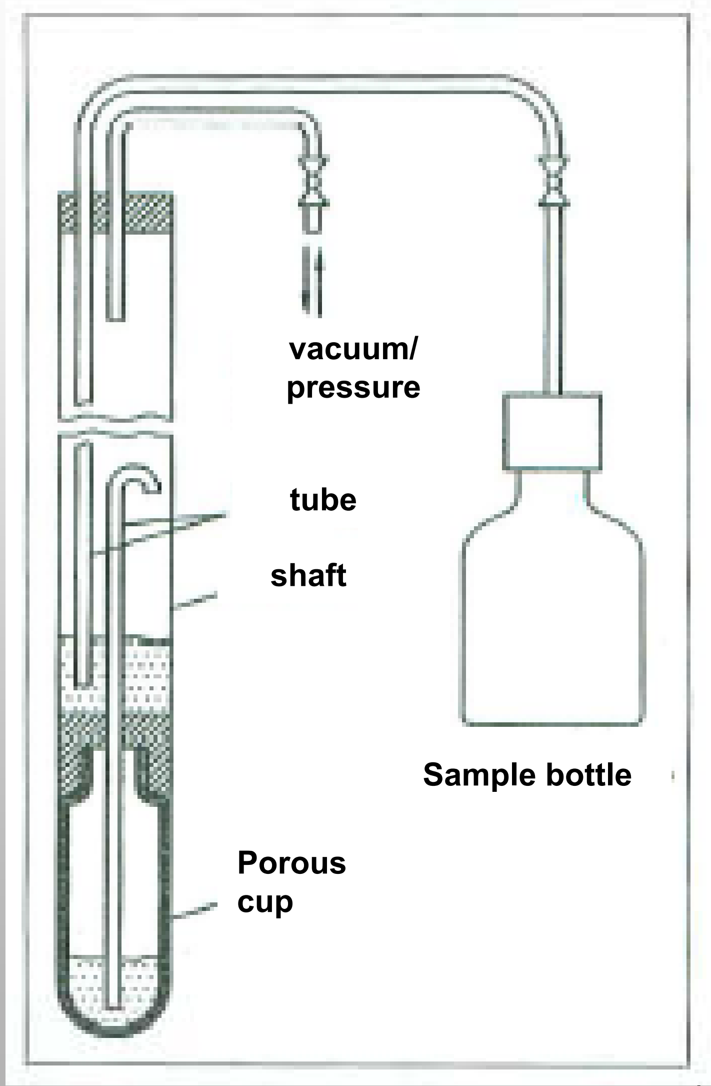


Ceramic suction probe: used for solute which are not absorbed e.g. nitrate, chloride

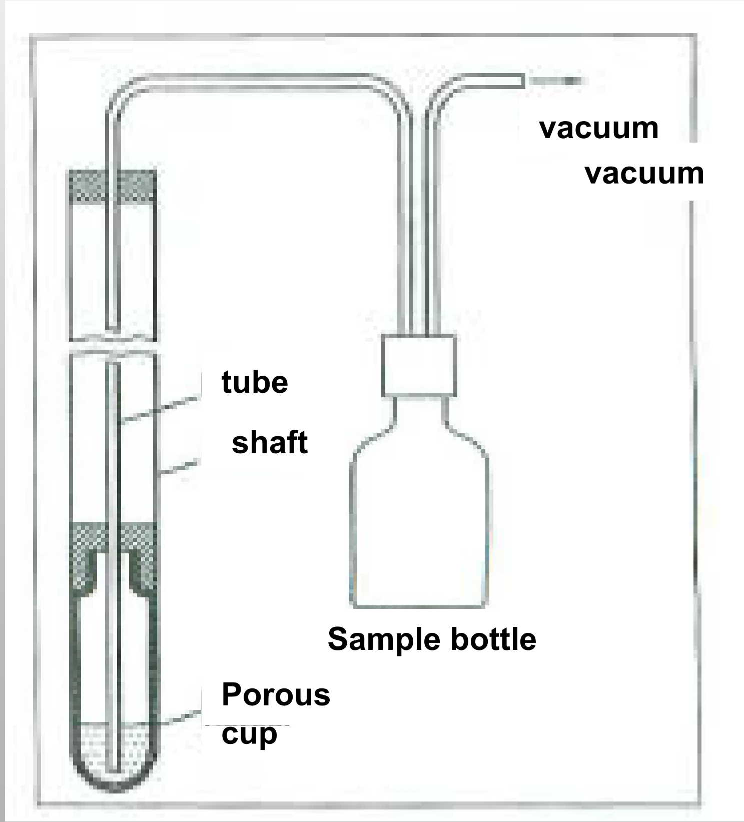


Suction probes and sampling:

two tube / two chamber system



One tube / one chamber system



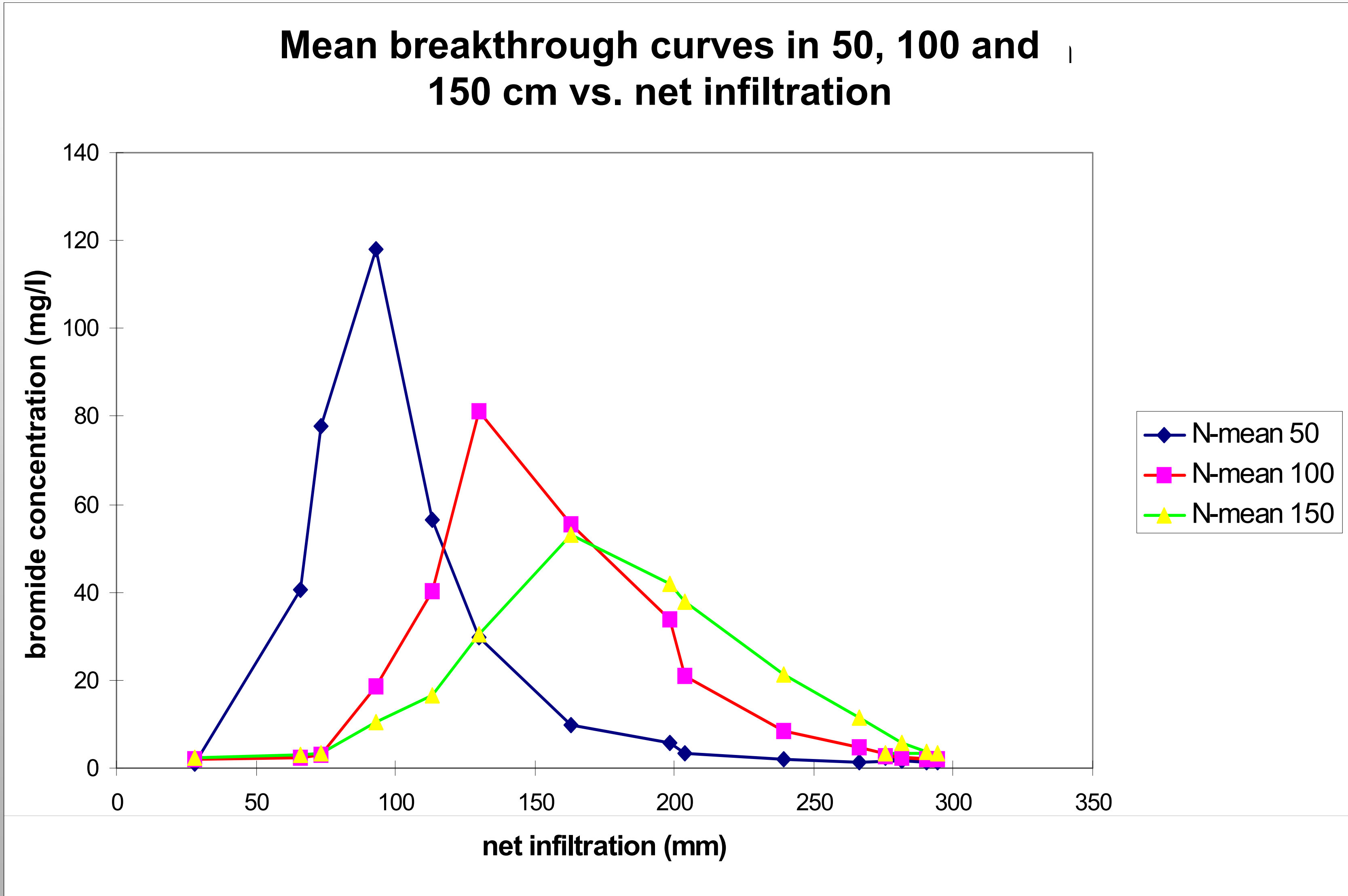
(Kalbe, Berger, 2004

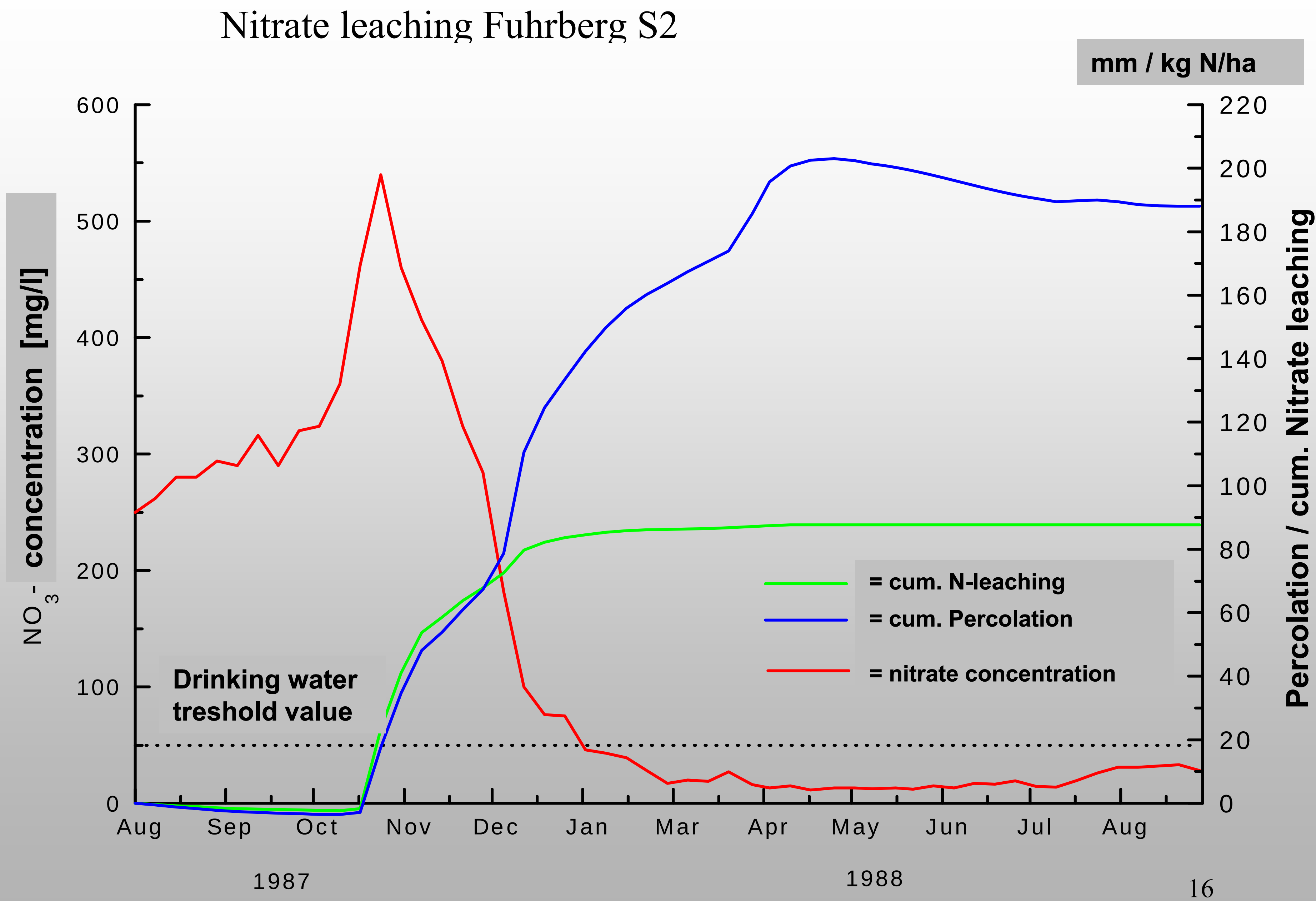
Suction probes

Experimental site Öjendorf: Bromide-tracer experiment

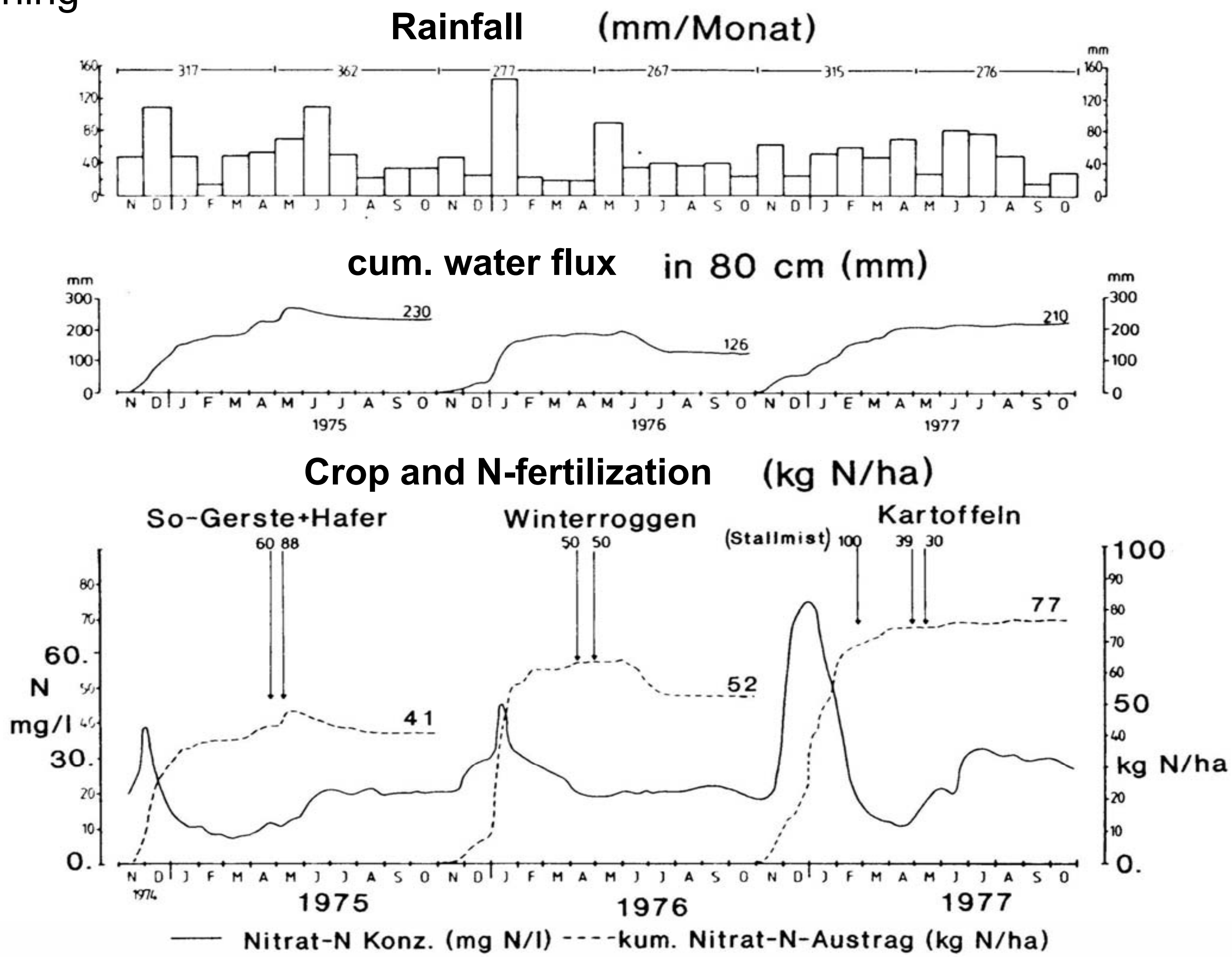
Sandy soil under arable land

Öjendorf: mean breakthrough



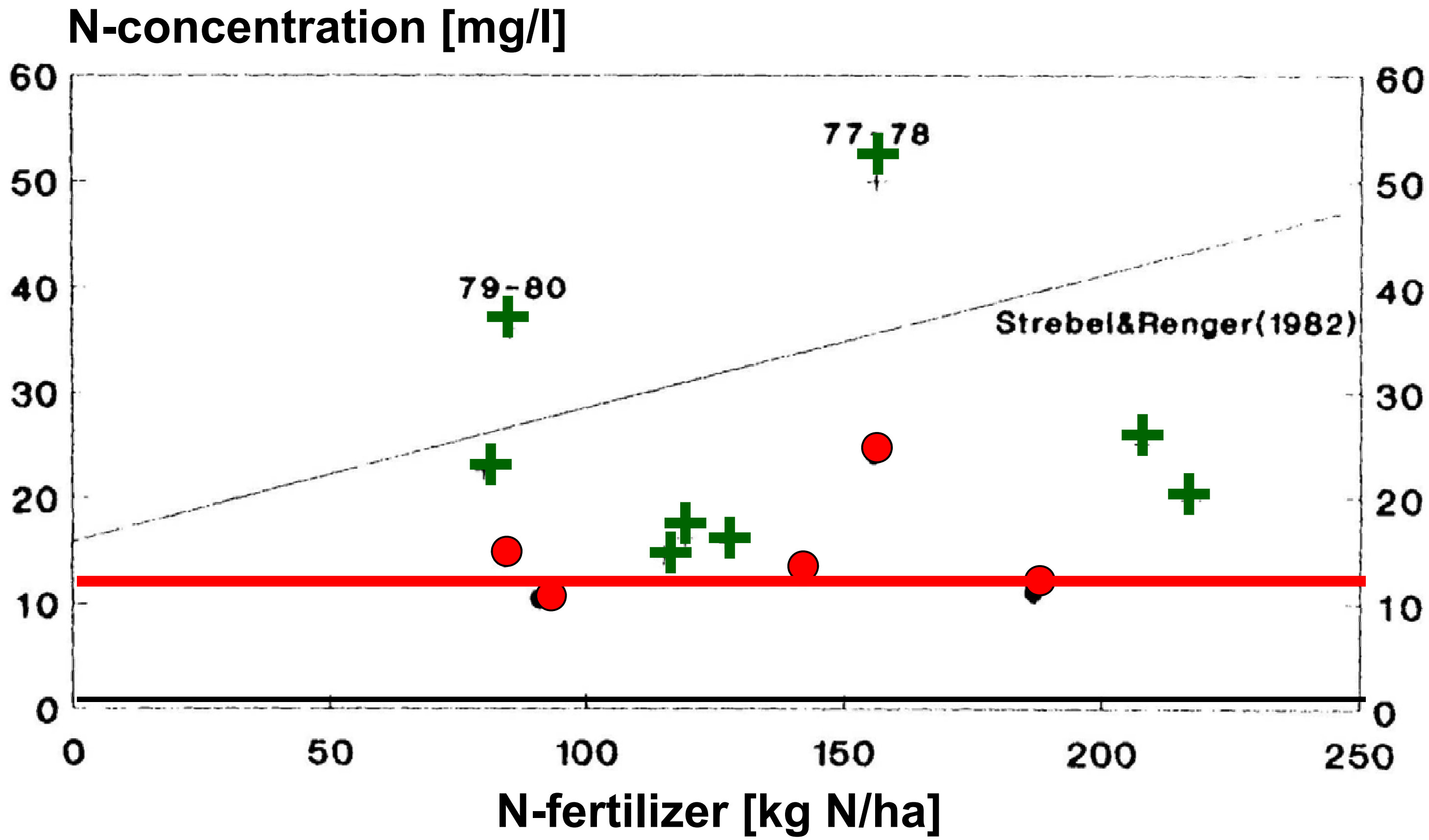

Nitrate leaching Fuhrberg S2
mm / kg N/ha
600
500
400
300
200
100
0
220
200
180
160
140
120
100
80
60
40
20
0
NO3 - concentration [mg/l]
Percolation / cum. Nitrate leaching
= cum. N-leaching
= cum. Percolation
= nitrate concentration
Drinking water treshold value
Aug
Sep
Oct
Nov
Dec
Jan
Mar
Apr
May
Jun
Jul
Aug
1987
1988

Nitrate leaching



$\overline{c}$ = 18 41 37 mg Nitrat-N/l

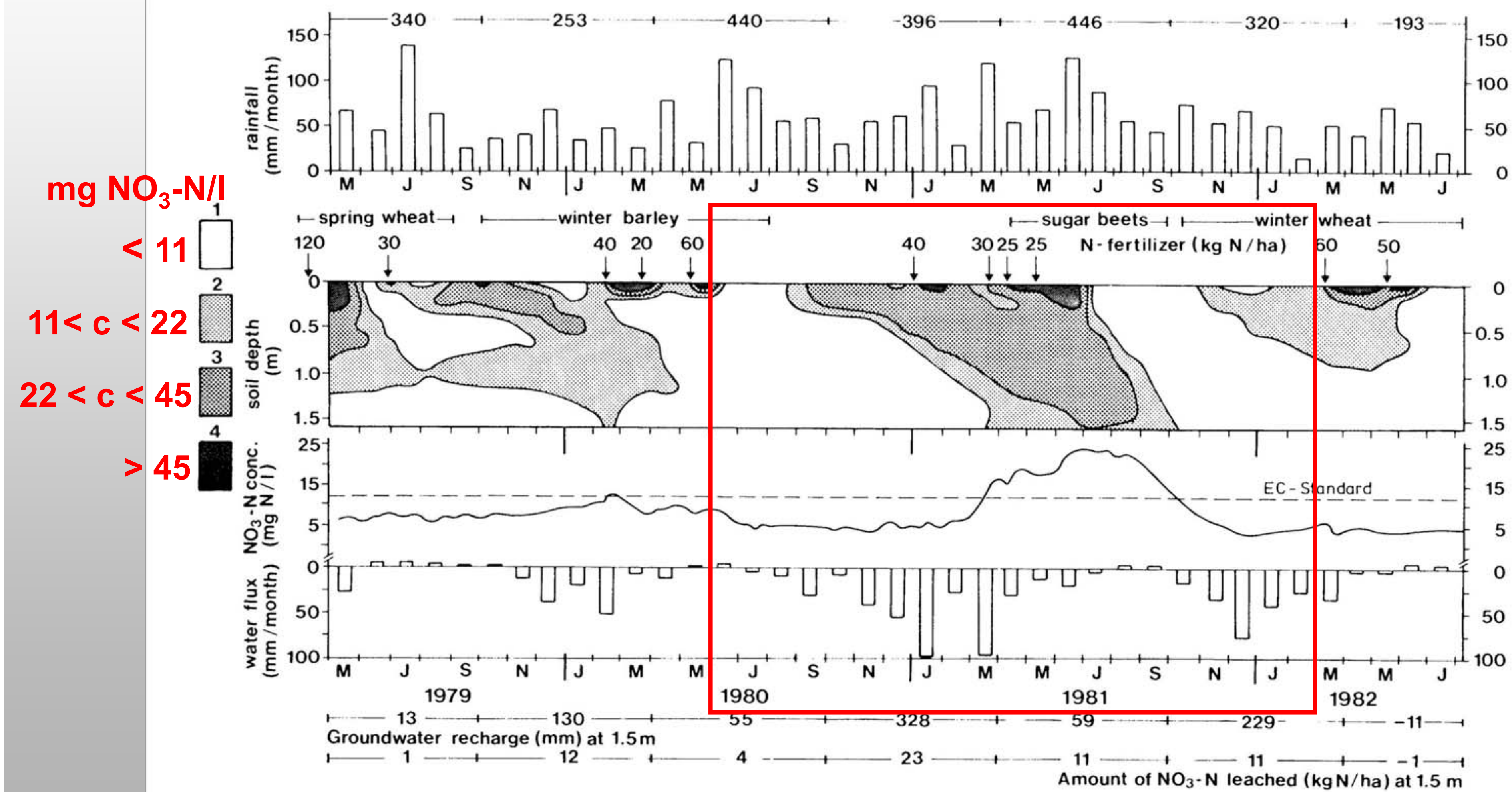
Arable land Fuhrberger Feld 1976-1990



Annual N- fertilizer application and mean nitrate-N-concentration in the annual groundwater recharge

+ = no cover crop **● = with catch crop (after cereals)**

Arable land Ohlendorf loess soil



$\overline{c}$ = 8 mg Nitrat-N/l

Site specific nitrate-N inputs into the groundwater from arable land (mean concentration in the groundwater recharge, Hannover area).

site	**Land use (crop rotation and N-fertilizing)**	**Mean nitrate conc. in the groundwater recharge mg NO_3/l**
Sandy soils	Arable land (cereals, sugar beets/potatoes, ≈ 120 kg N/ha·a)	**100-130**
	Arable land (cereals **with catch crop**, sugar beets/potatoes, ≈ 120 kg N/ha·a)	60-90
	Grassland mowing (250 kg N/ha·a)	**20-40**
	Intens. Grassland (250 kg N/ha·a with 2 LSU/ ha (live stock unit) with ca. 180 grazing days)	60 – 90
	Coniferous forest	2-10
	Decideous forest	20-30
	Black alder	40
Loess soils	Arable land (cereals, sugar beets, ca. 150 kg N/ha·a)	**30-60**

Drinking water max. 50 mg Nitrate/l

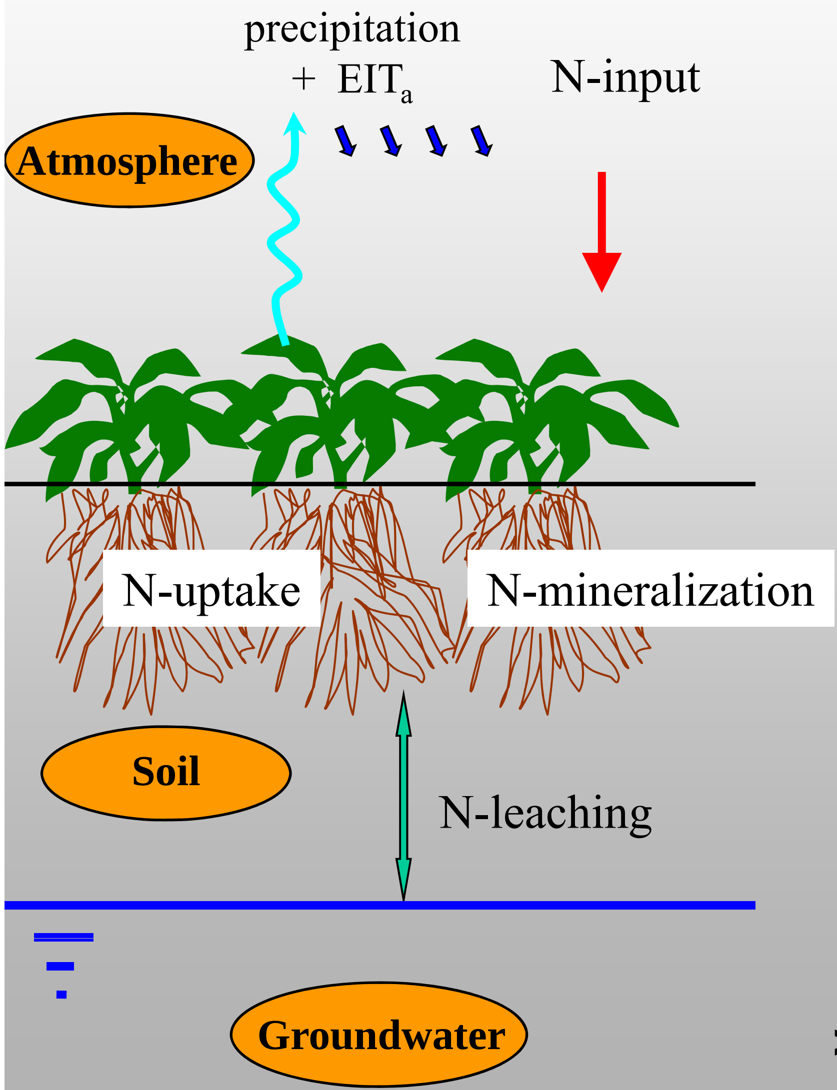
Influence of site properties on nitrate amounts in and nitrate leaching from the rooting zone during the main leaching period

Development and use of deterministic simulation models

Goal:

- Better insight into causes and casual relationships of nitrate leaching
- Conducting case studies with simulation models:
  - Influence of site specific properties
  - Development of sensible warranties, that can also be checked

Numerical simulation model for N-dynamics in soils



- soil water dynamics:

e.g.

- **actual evapotranspiration**
- **water movement**
- **water uptake**

- Nitrogen dynamics in the soil

E.g.

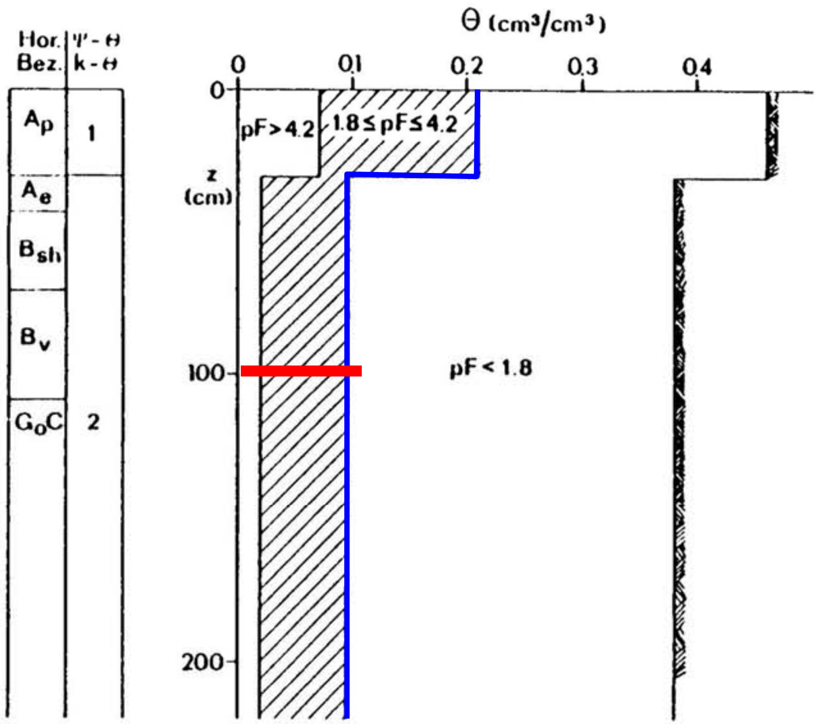
- **nitrate transport**
- **Netto-N-mineralization**
- **N-input (fertilizer, precipitation)**
- **N-uptake by srops**

Calibration and validation of the model

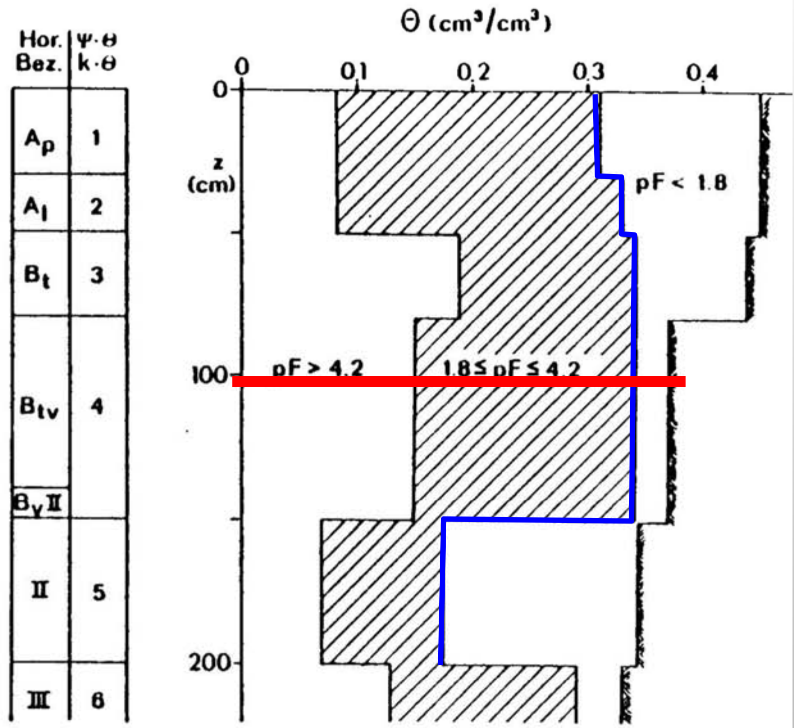
>>>>> Simulation model for case studies <<<<<

Field capacity

$$W(0-z,t_0)=\int_0^z \theta(z,t_0)\,dz$$



Sandy soil (mSfs)

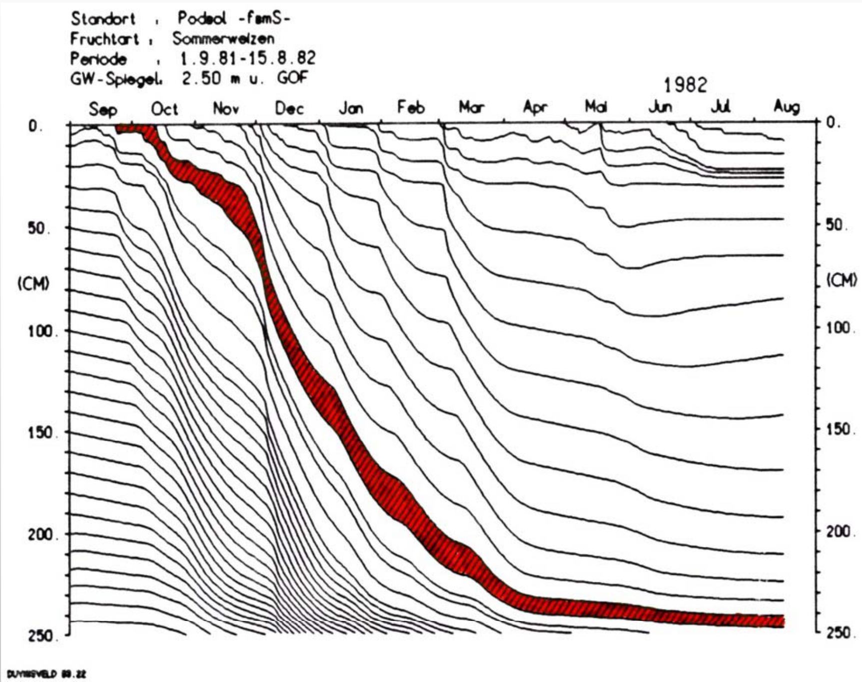


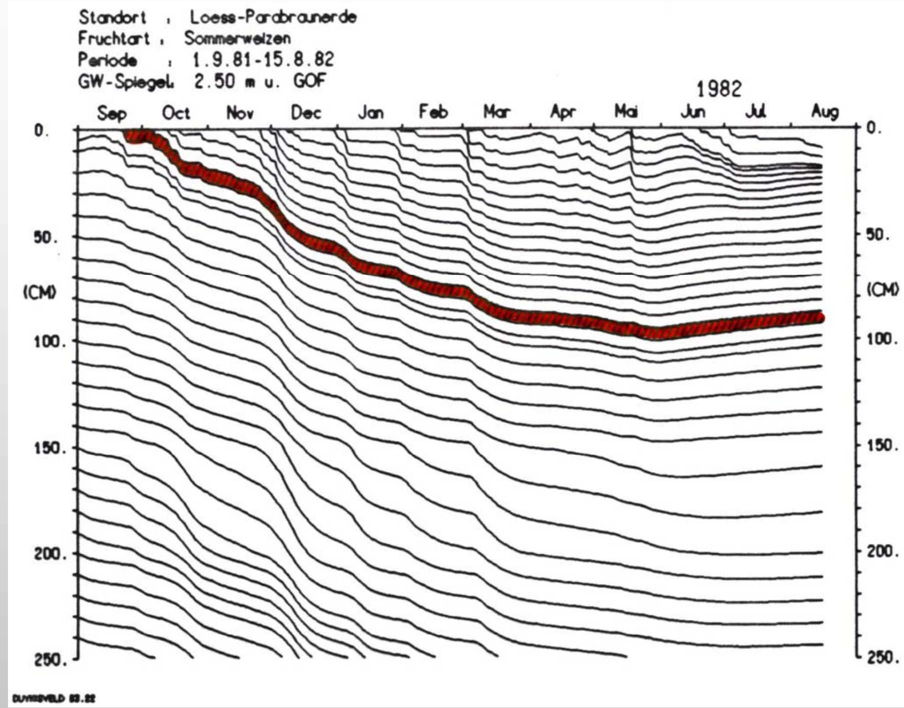
Loess soil

$$W(0-1\,m)=110\,mm$$

$$W(0-1\,m)=310\,mm$$

Time-depth curves of different soil textures

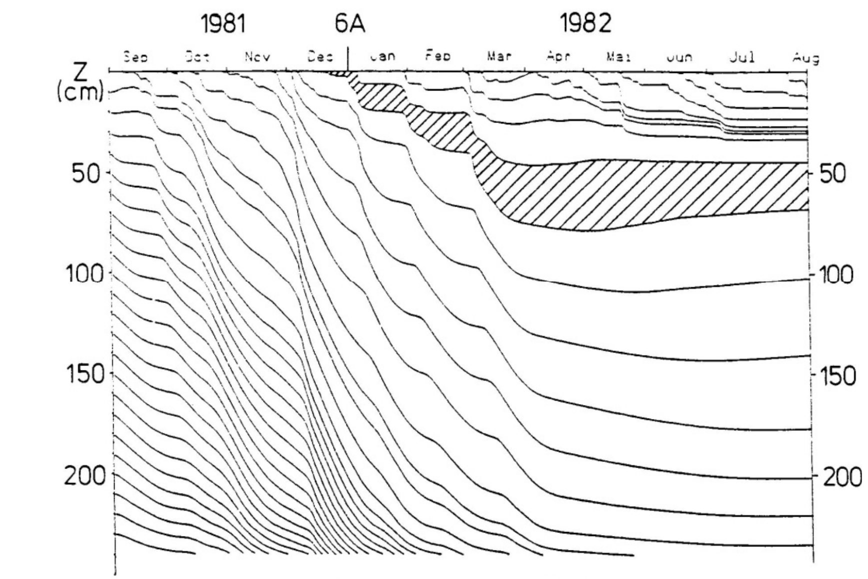


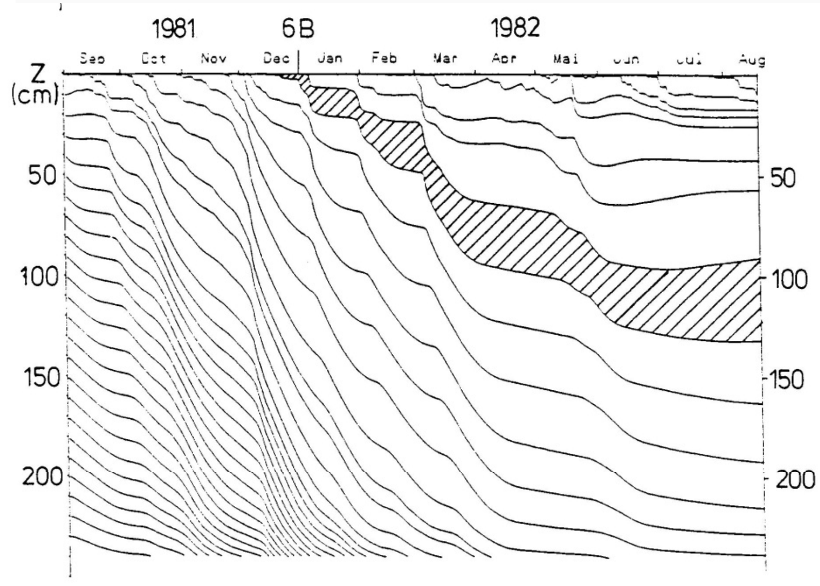


Time-depth curves for a sandy soil

Time-depth curves for a loess soil

Time-depth curves of different crops

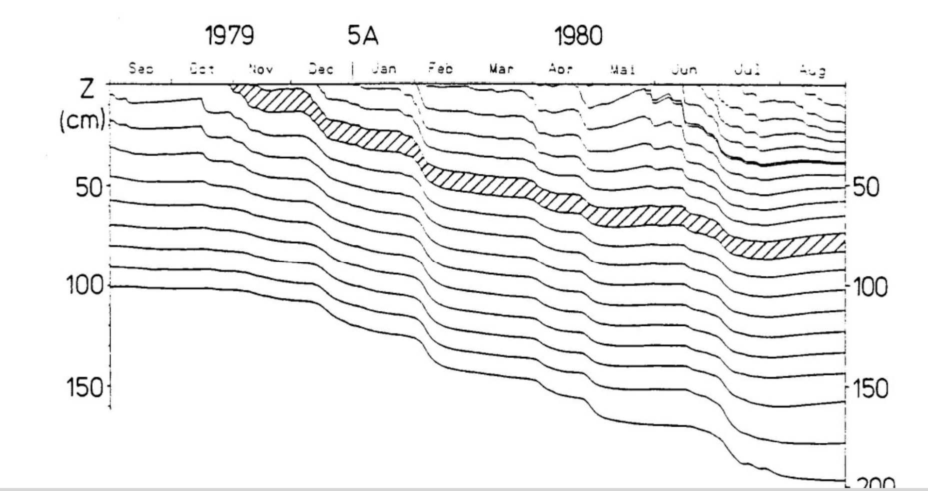


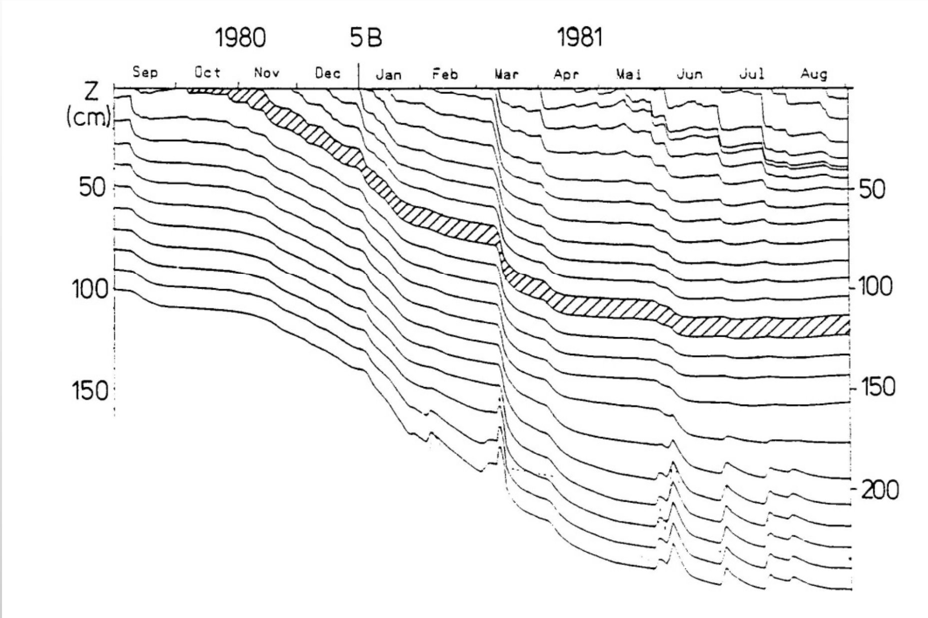


Time-depth curves for winter barley

Time depth curves for sugar beets

Time-depth curves of different precipitation amounts

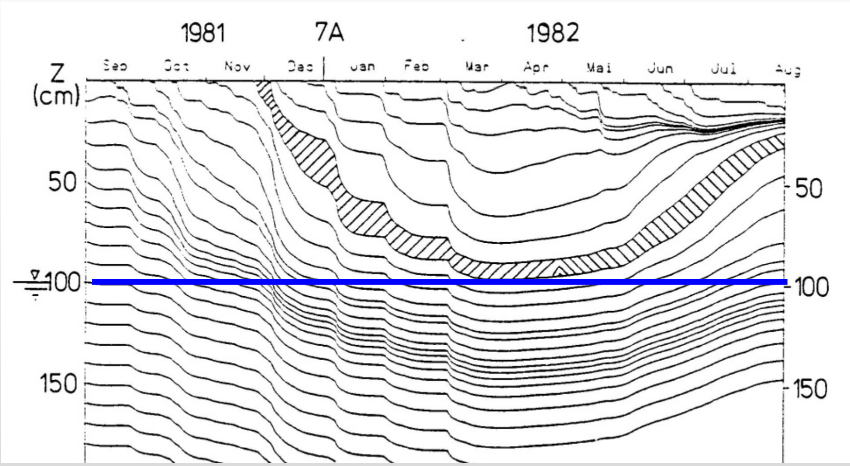


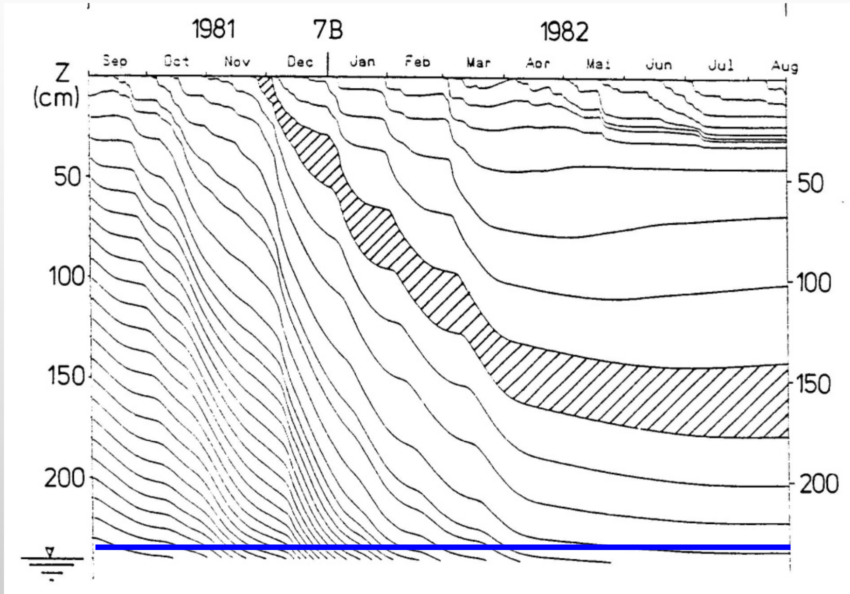


Fall and winter with low precipitation amounts

Fall and winter with higher precipitation amounts

Time-depth curves with different groundwater table depths



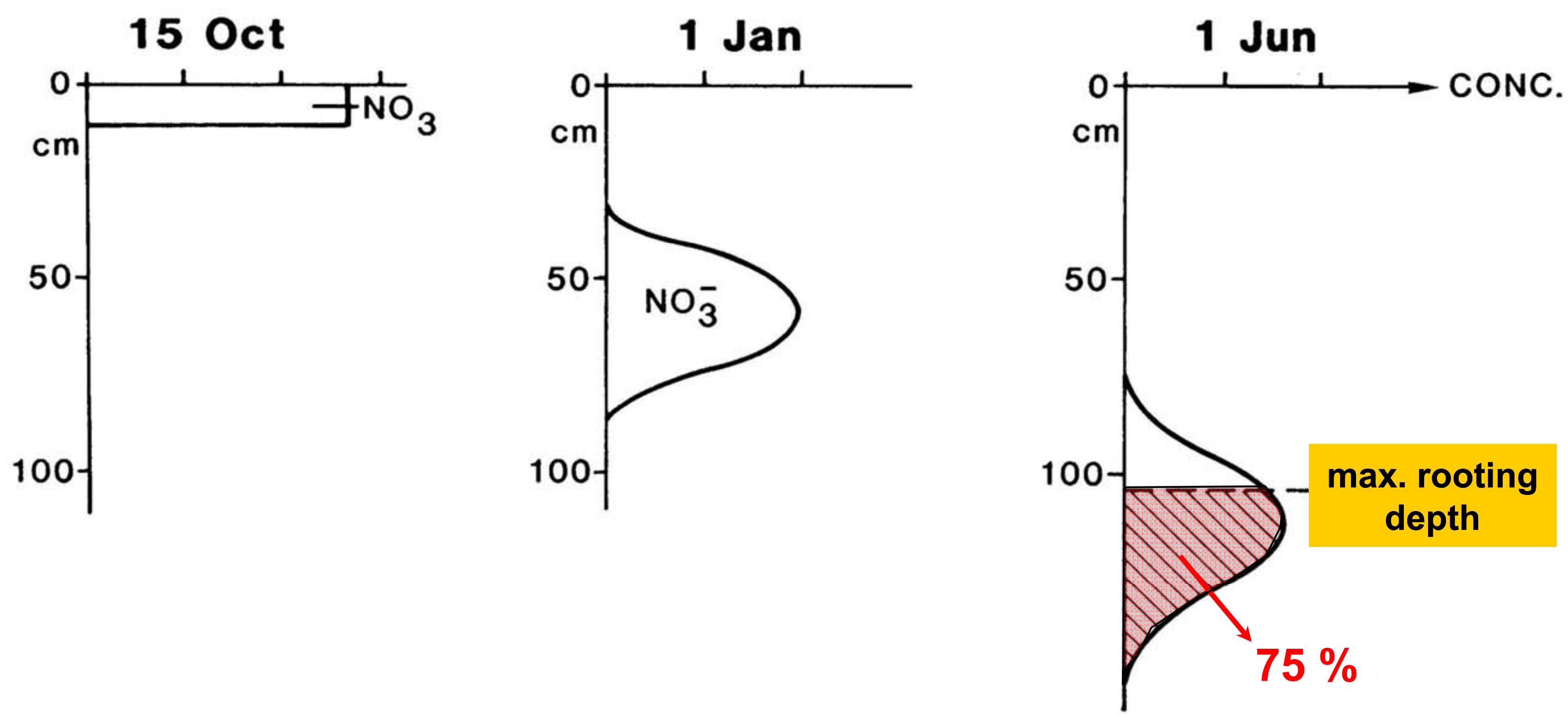


Higher groundwater table

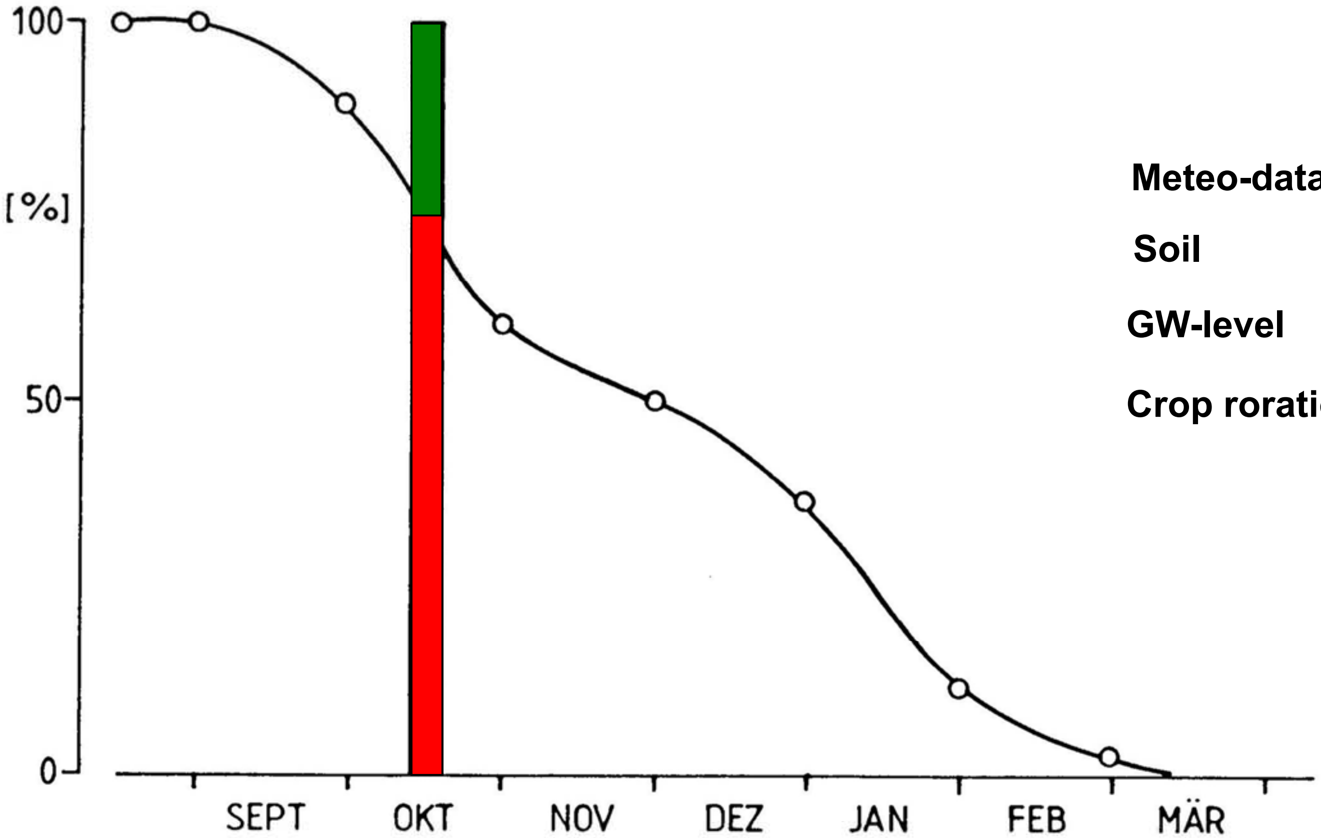
Deeper goundwater tabel

Nitrate leaching risk

Nitrate transport during the main leaching period



Nitrate leaching risk



Meteo-data: 15.8.77 – 30.6.78

Soil : sandy loam

GW-level : deep (> 250 cm)

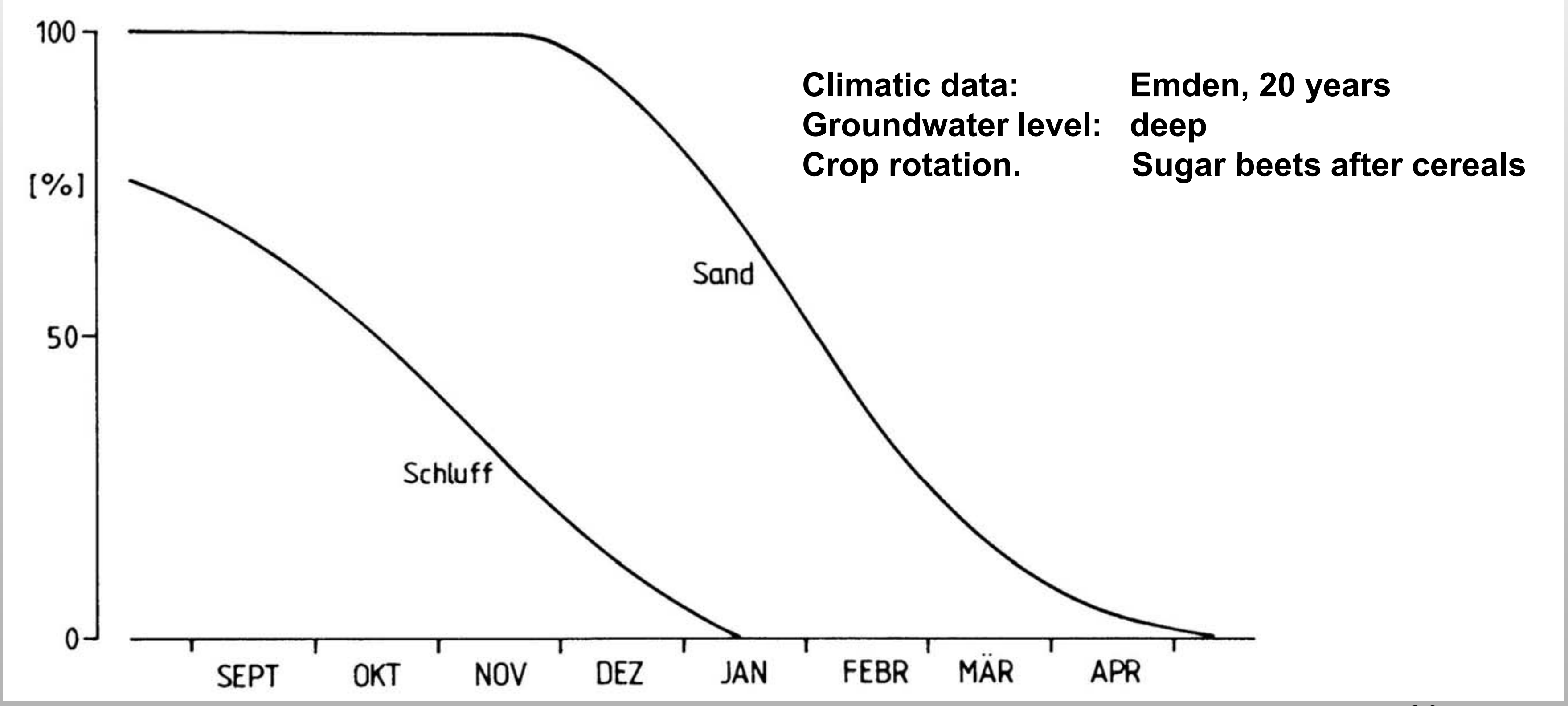
Crop roration : sugar beets after cereals

Red = **in the next vegetation period below the rooting zone of the sugar beet crop**

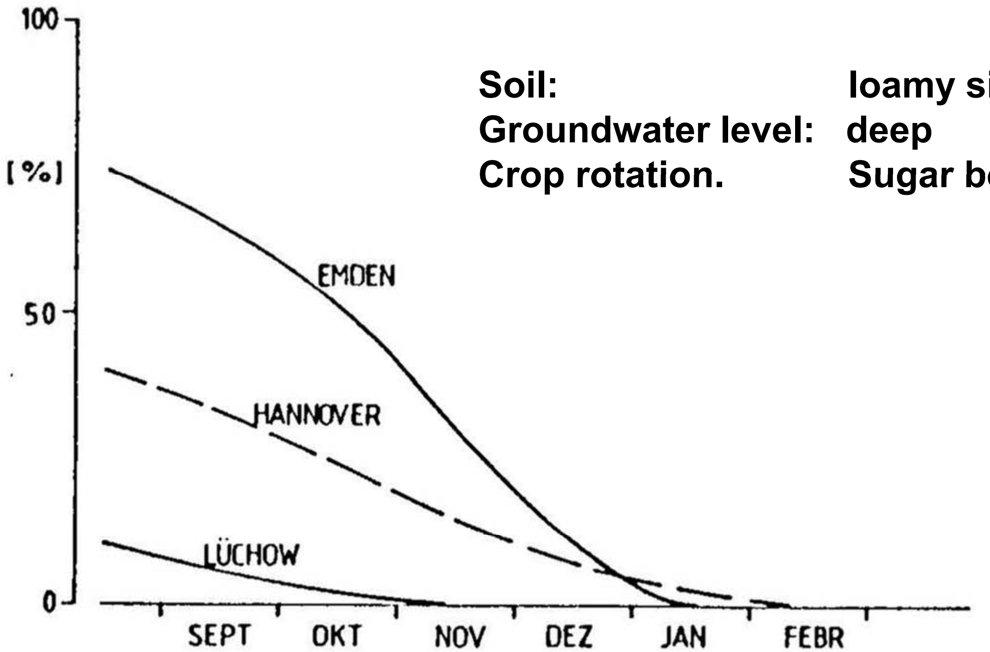
Green = **in the next vegetation period still in the rooting zone of the sugar beet crop**

Nitrate leaching risk

$\overline{N}$ = 781 mm/a



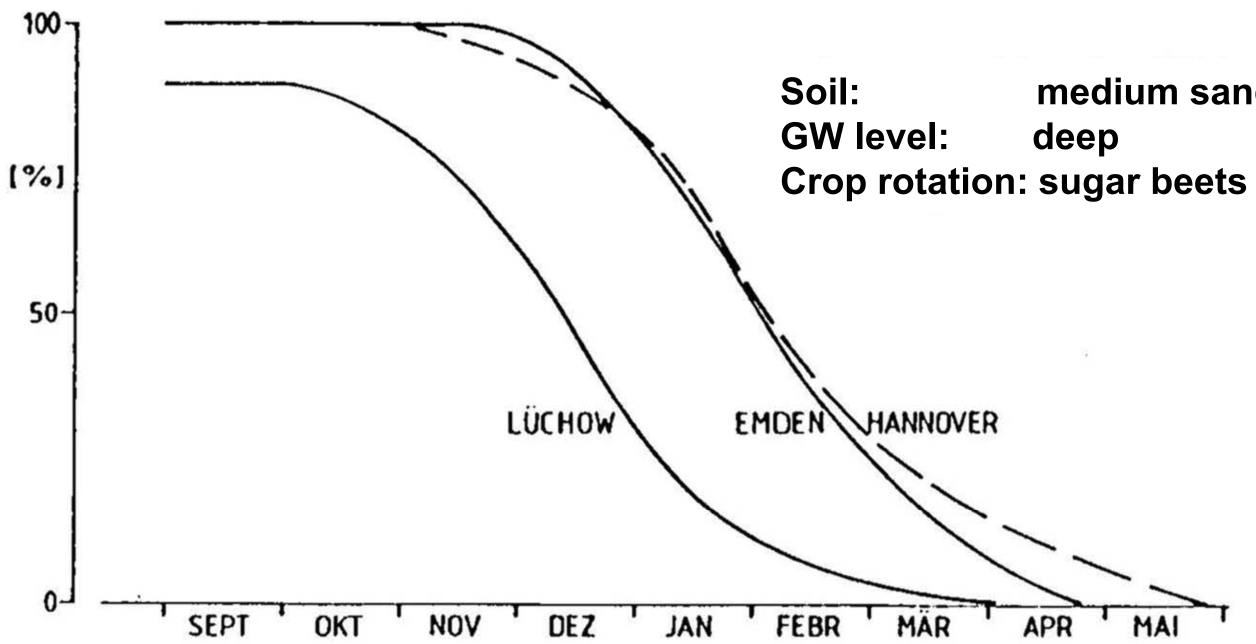
Nitrate leaching risk:



Soil: loamy silt
Groundwater level: deep
Crop rotation. Sugar beets after cereals

Long term mean nitrate leaching risk for 3 different climatic regions in northern Germany on arable land with a loamy silt soil

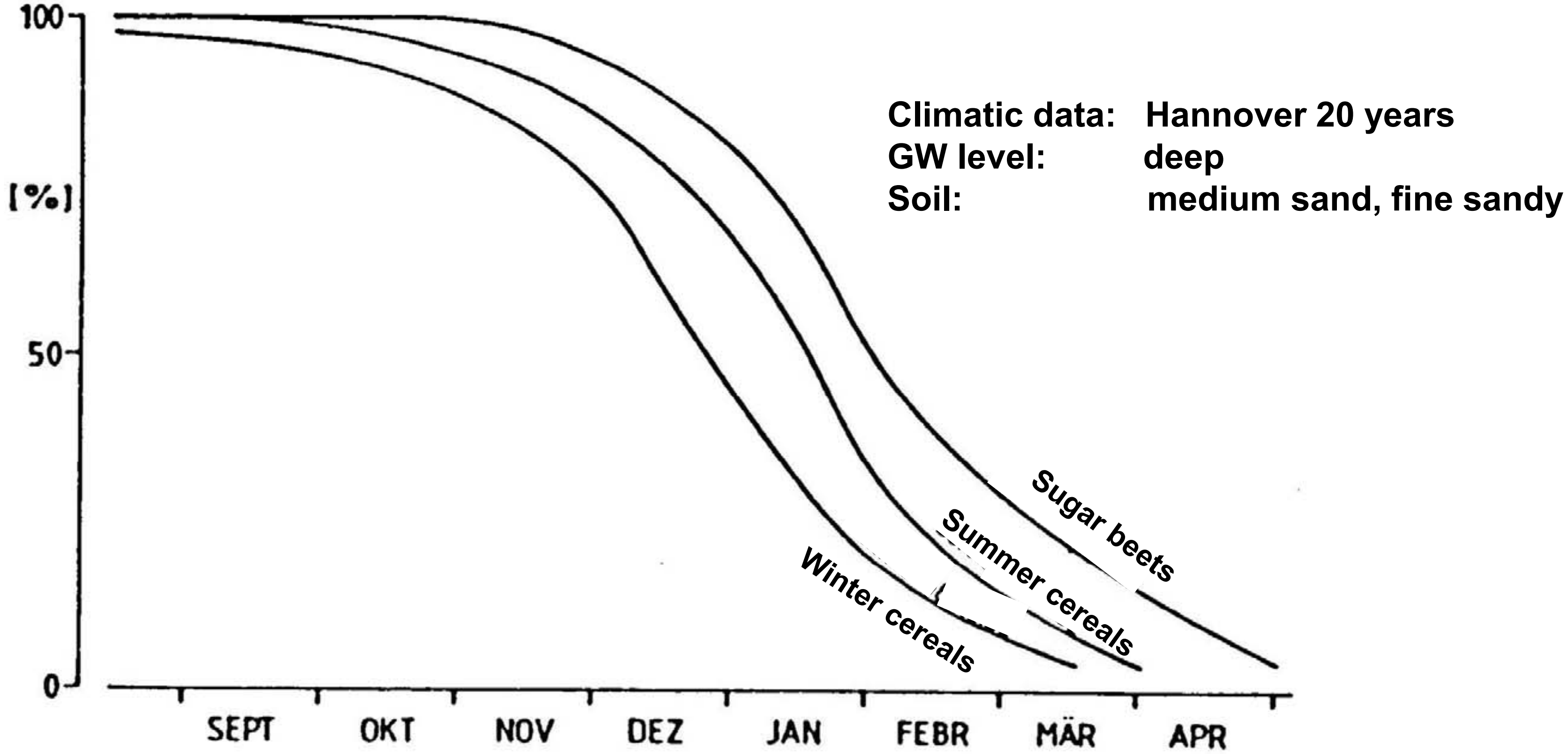
Nitrate leaching risk:



Soil: medium sand, fine sandy
GW level: deep
Crop rotation: sugar beets after cereals

Long term mean nitrate leaching risk for 3 different climatic regions in northern Germany on arable land with a loamy silt soil and a deep groundwater table

Nitrate leaching risk:



Influence of crop rotation on the long term mean nitrate leaching (preceding crop. winter cereals)

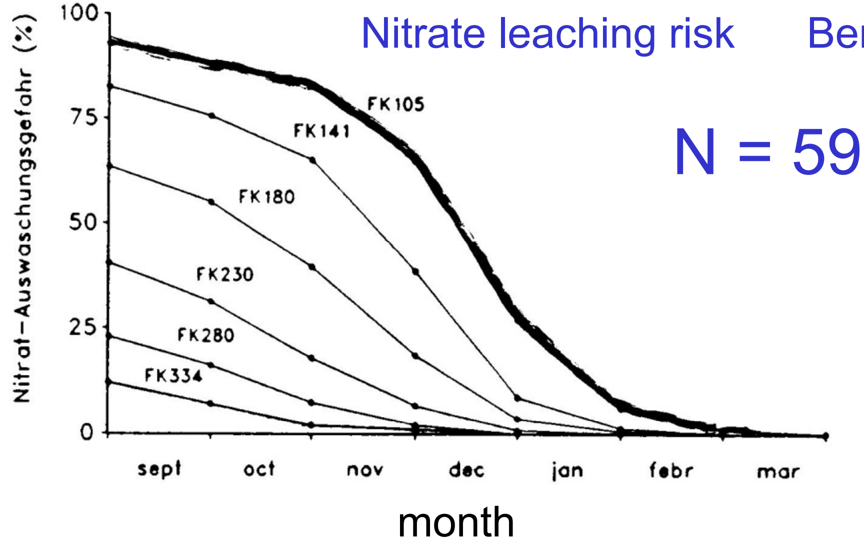
Nitrate leaching risk:

Nitrate leaching risk for different fiied capacities (FK) in the rooting zone

Two different climatic sites

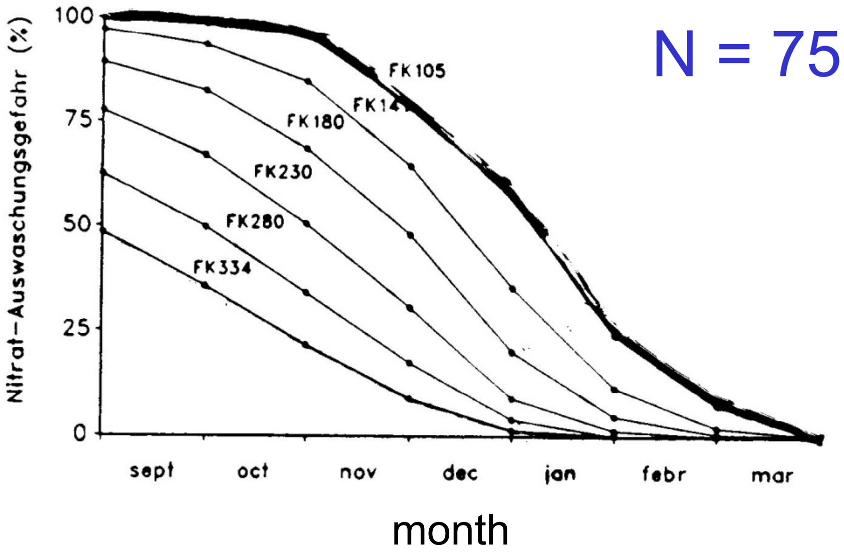
Nitrate leaching risk Berlin 1950-1986:

N = 591 mm/a



Nitrate leaching risk Hamburg 1950-1985:

N = 750 mm/a

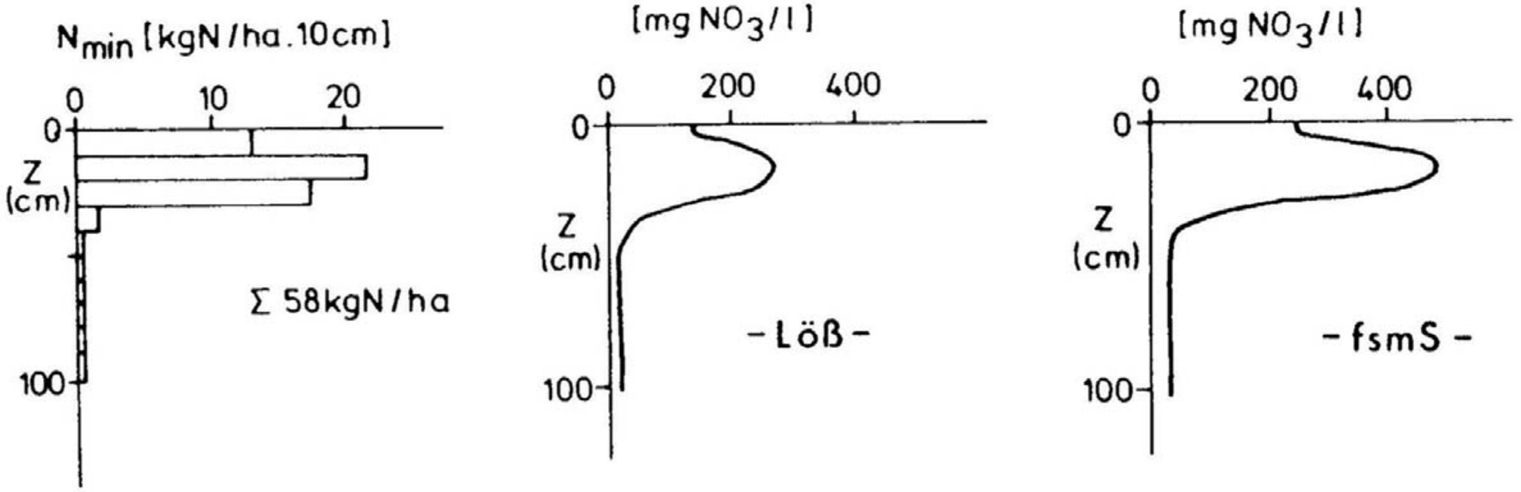


Case study on nitrate stock and nitrate leaching

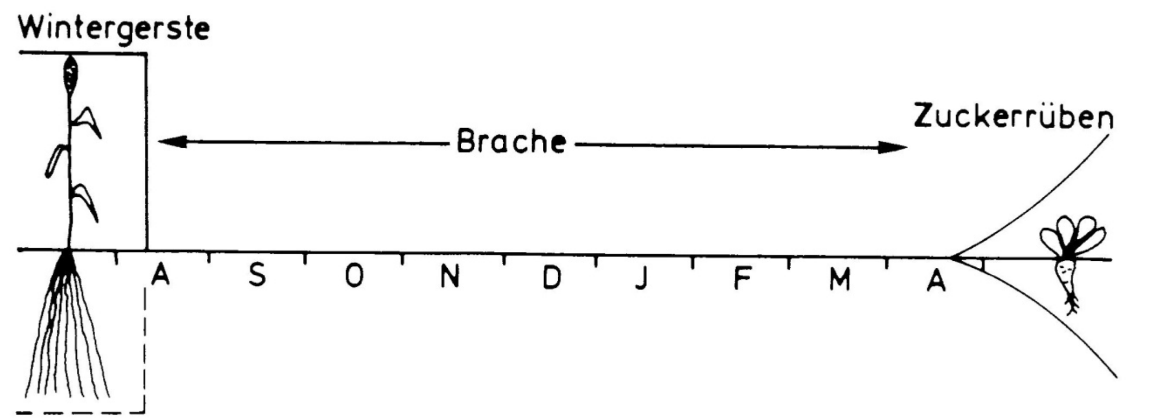
Influence of climate and soil textute

Goal: development of warranties for the agricultural practice , that can also be checked

Nitrate concentration profile on 01.09.

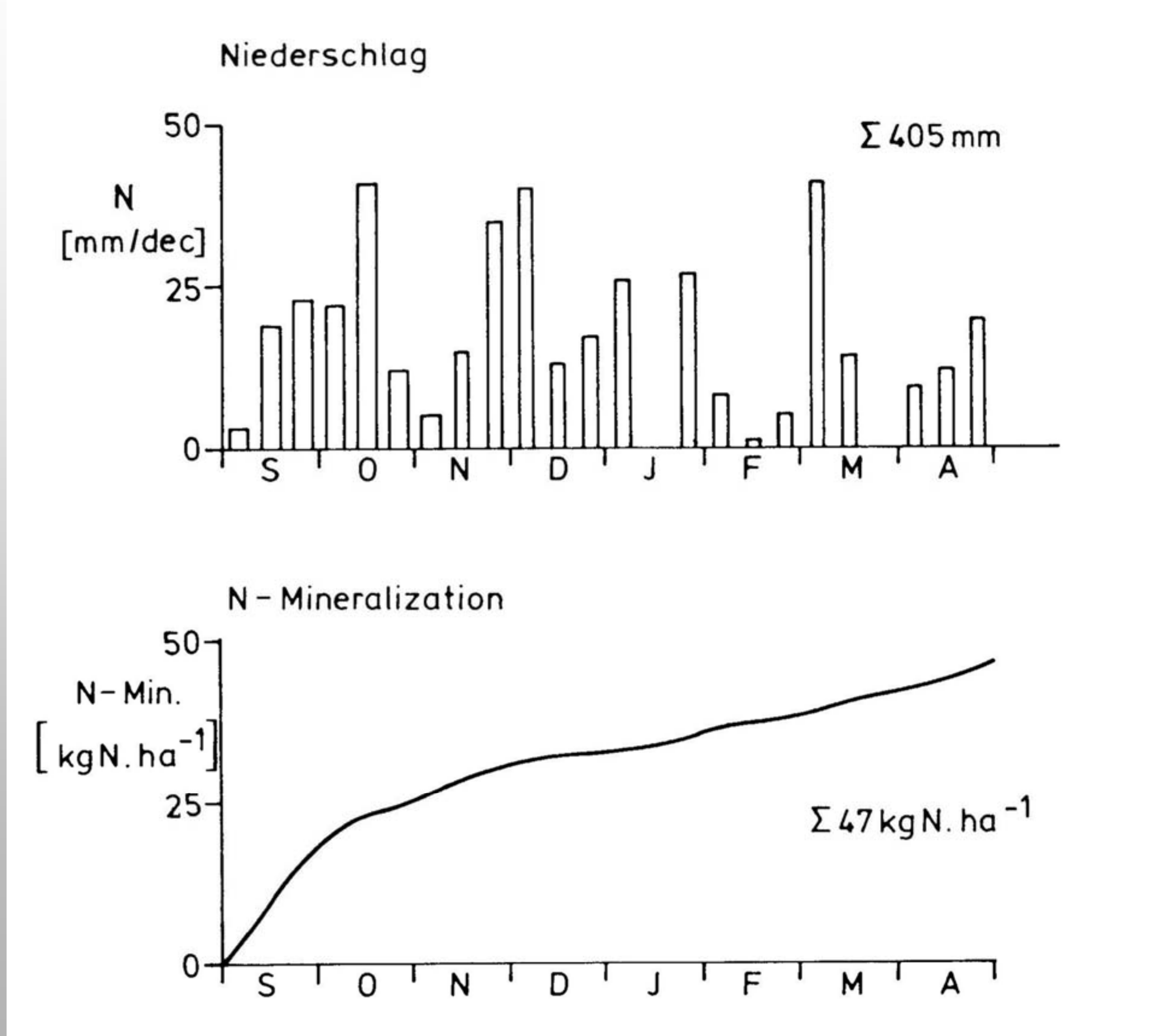


Crop rotation and main leaching period



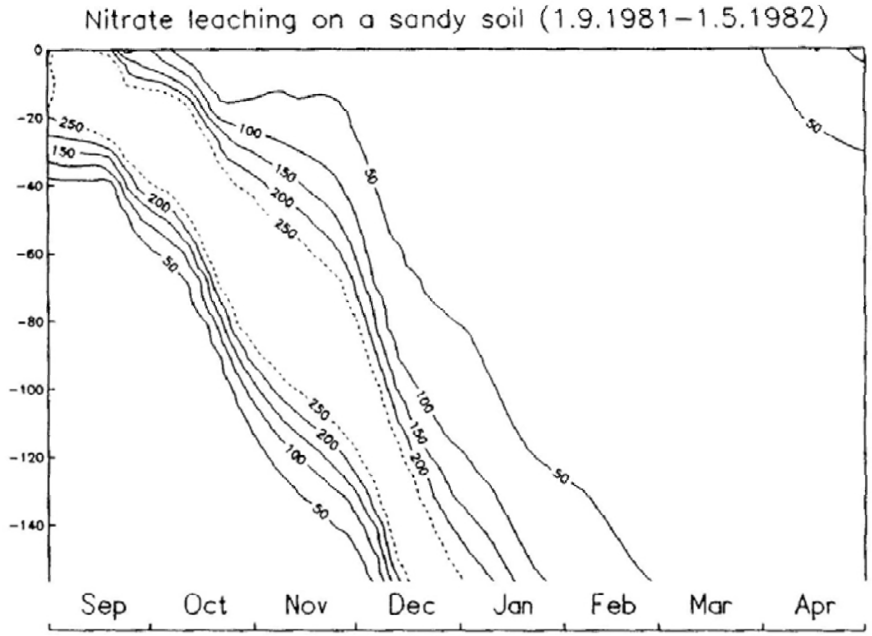
Precipitation distribution

Nitrate production due to mineralization of soil organic matter and plant residues



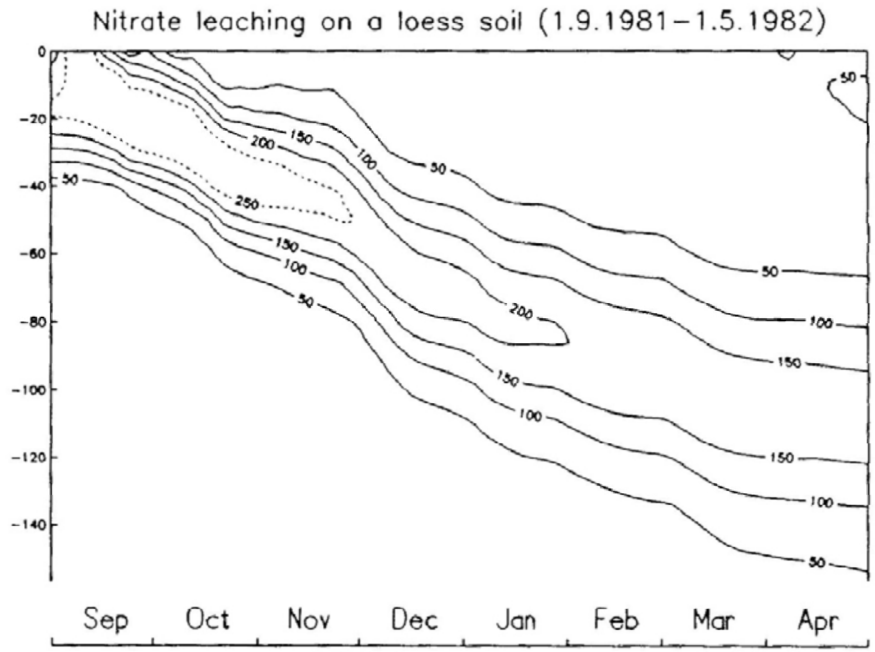
...ching

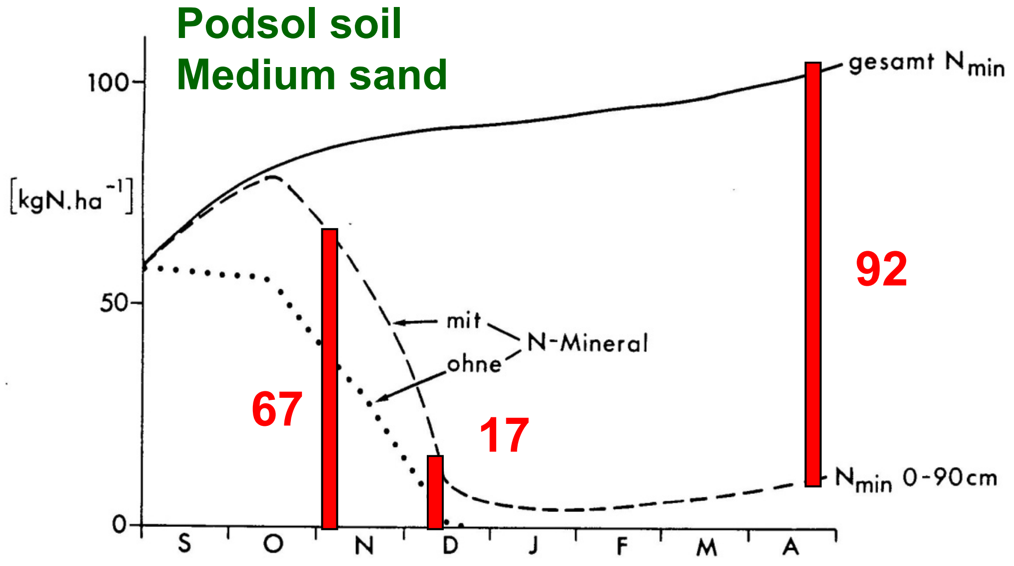
Sandy soil



Nitrate leaching during the main leaching period

Loess soil



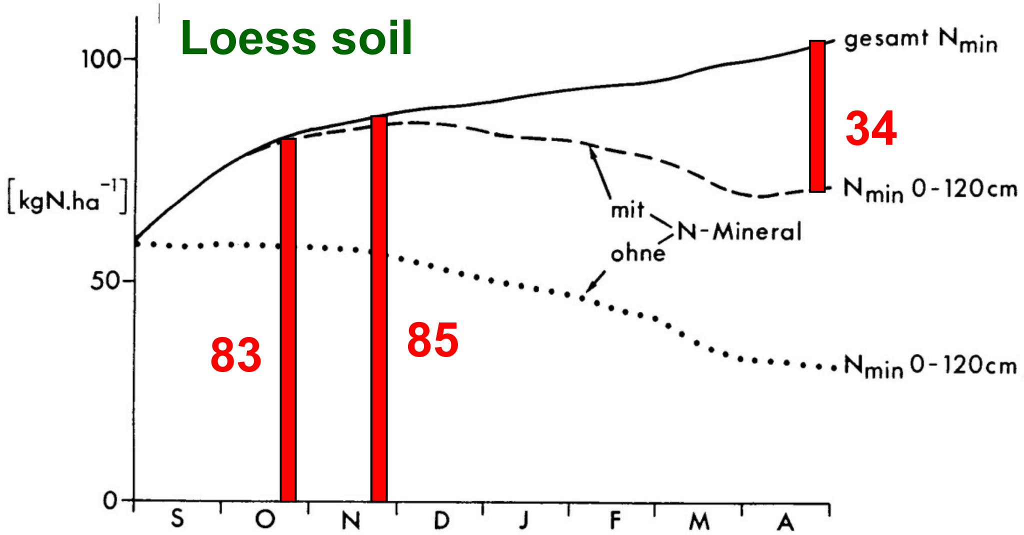


Sandy soil: rooting depth 0-90 cm

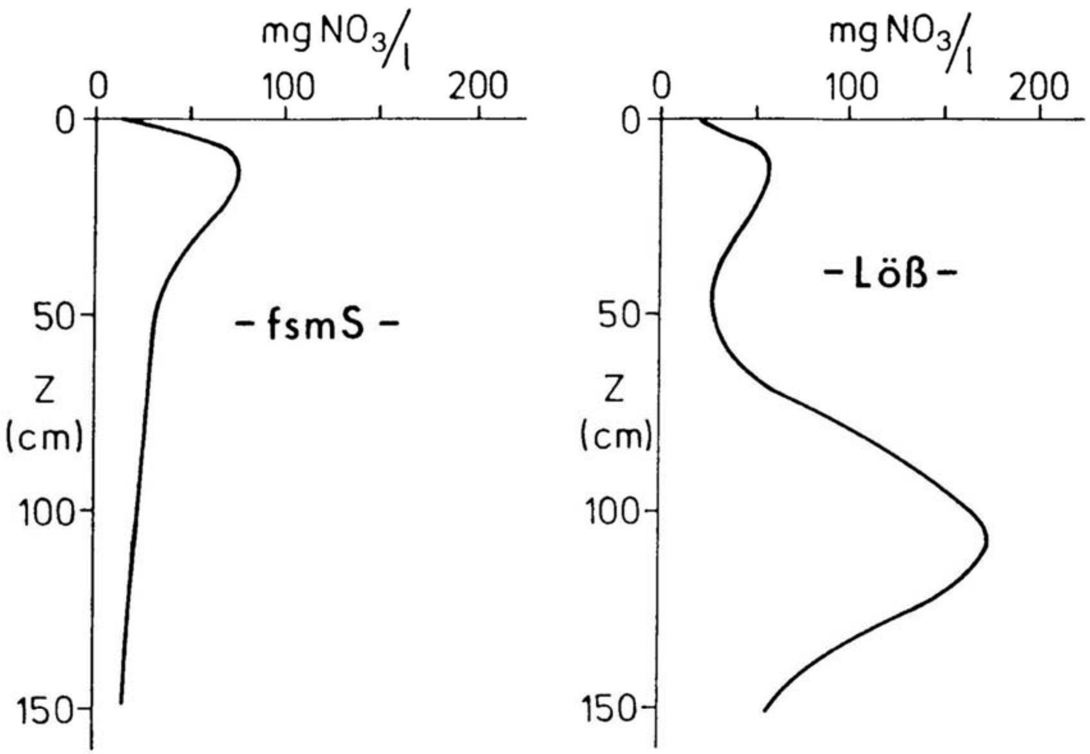
$\bar{c}$ = 31 mg NO_3-N/l

Loess soil: rooting depth 0-120 cm

$\bar{c}$ = 11 mg NO_3-N/l



Nitrate concentration profile on 01.05.

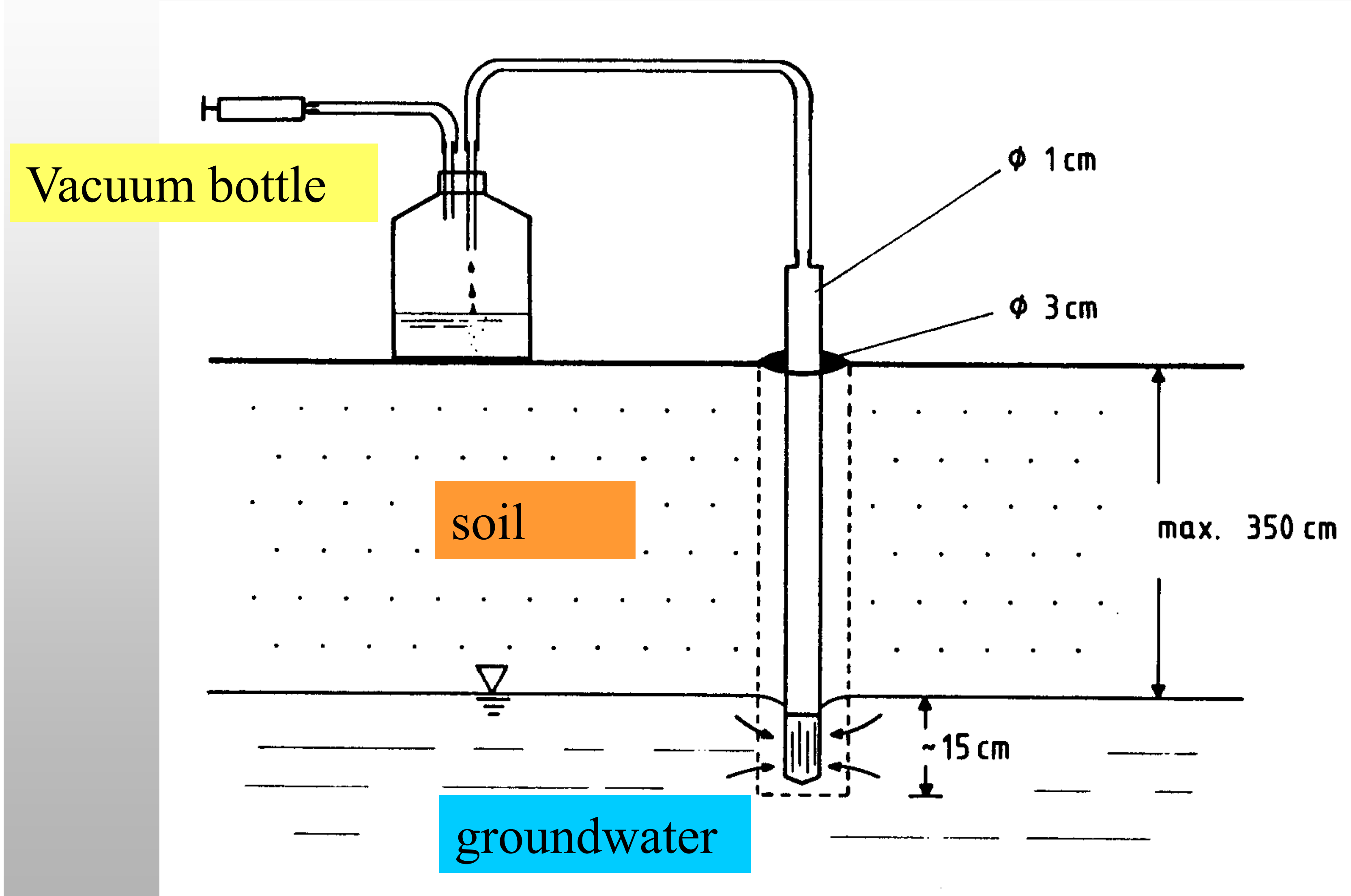


Nitrate amount in the rooting zone:

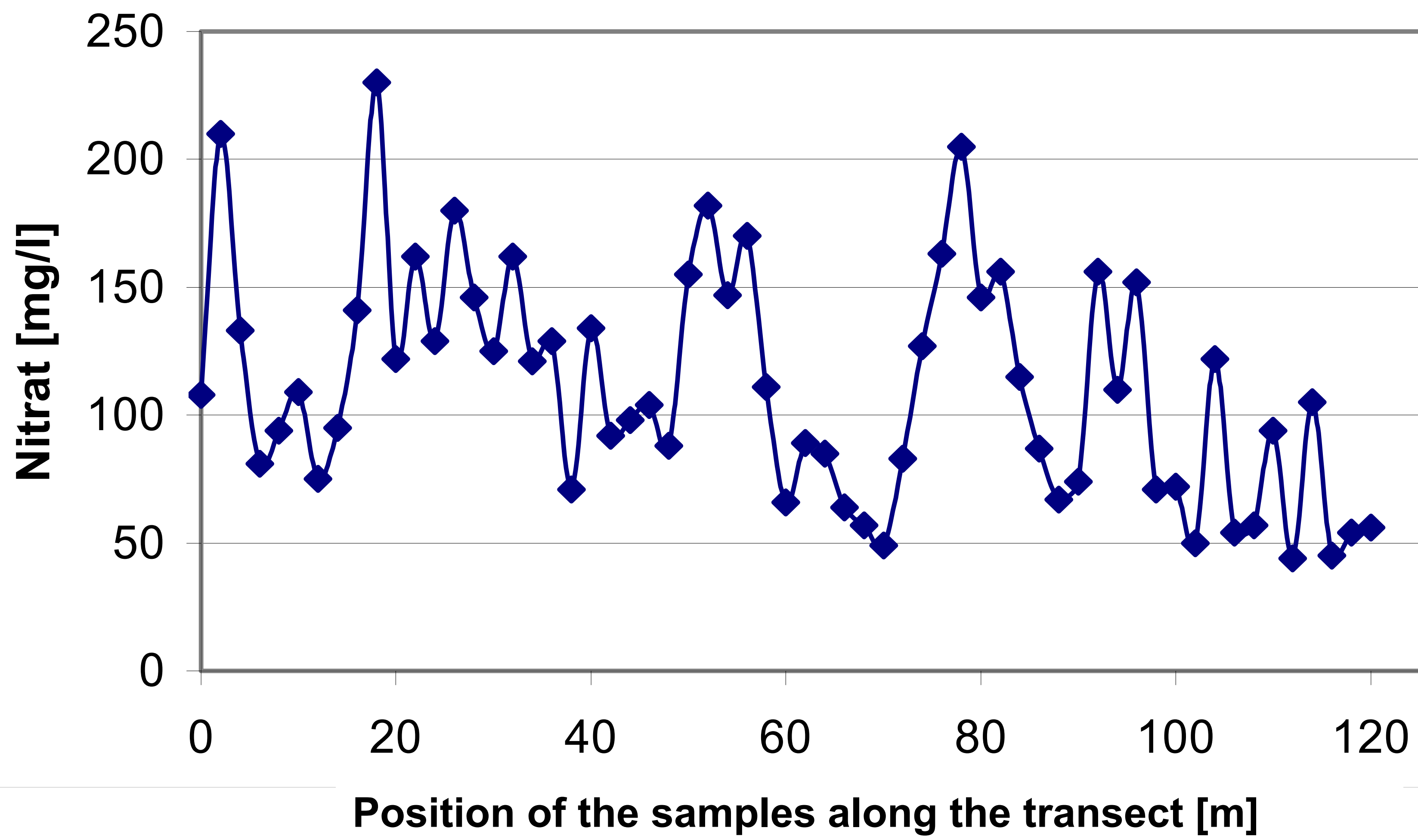
0 - 30 cm :	9
30 - 60 cm :	2
60 - 90 cm :	2
	13 kgN/ha

0 - 30 cm :	10
30 - 60 cm :	7
60 - 90 cm :	17
90 -120 cm :	38
	72 kgN/ha

Sampling the uppermost groundwater

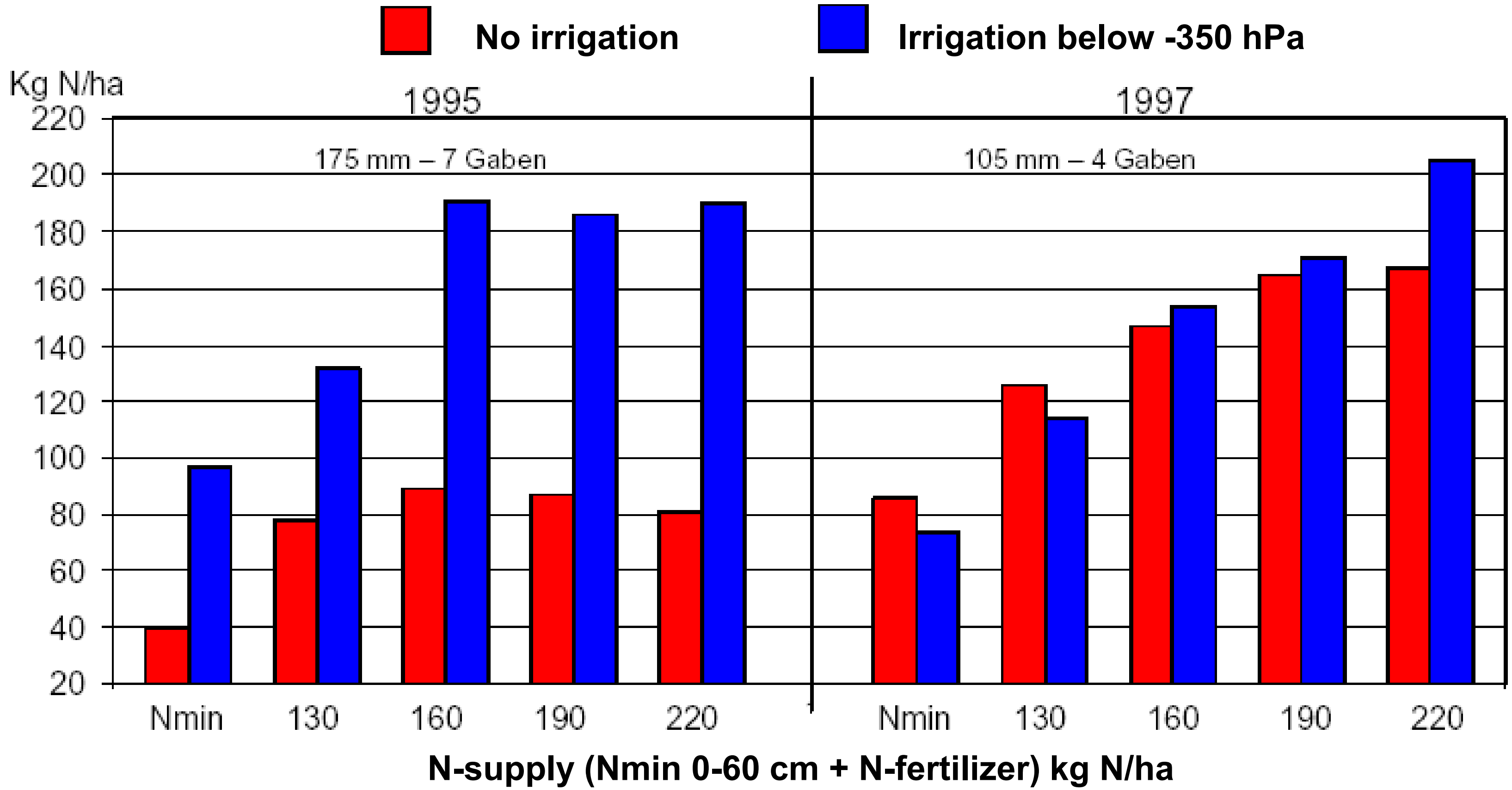


Nitrate concentration (mg/l) along a sampling transect on arable land



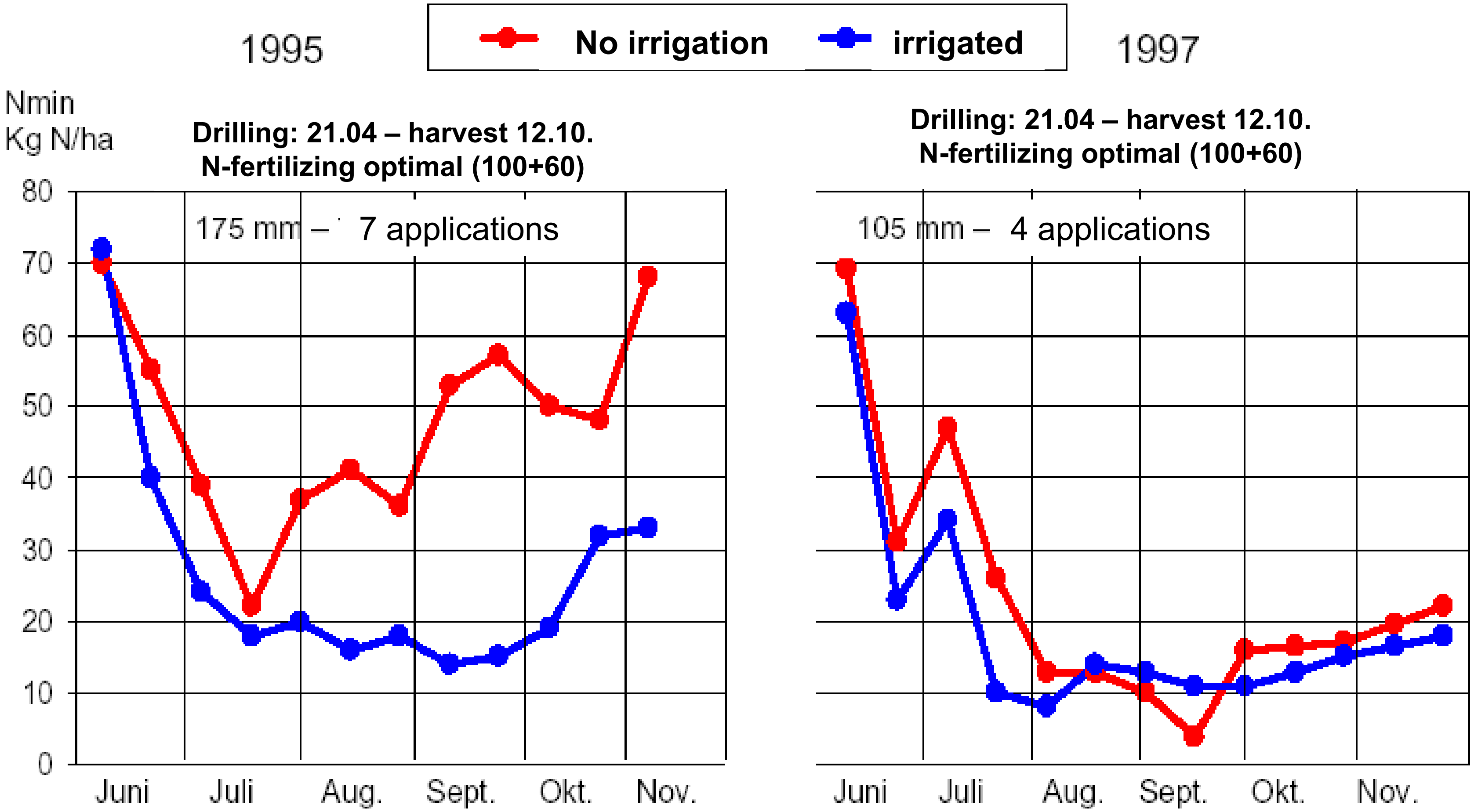
Landwirtschaftskammer Niedersachsen

N-removal with potatoes tubers with different N-supply and different irrigation amounts



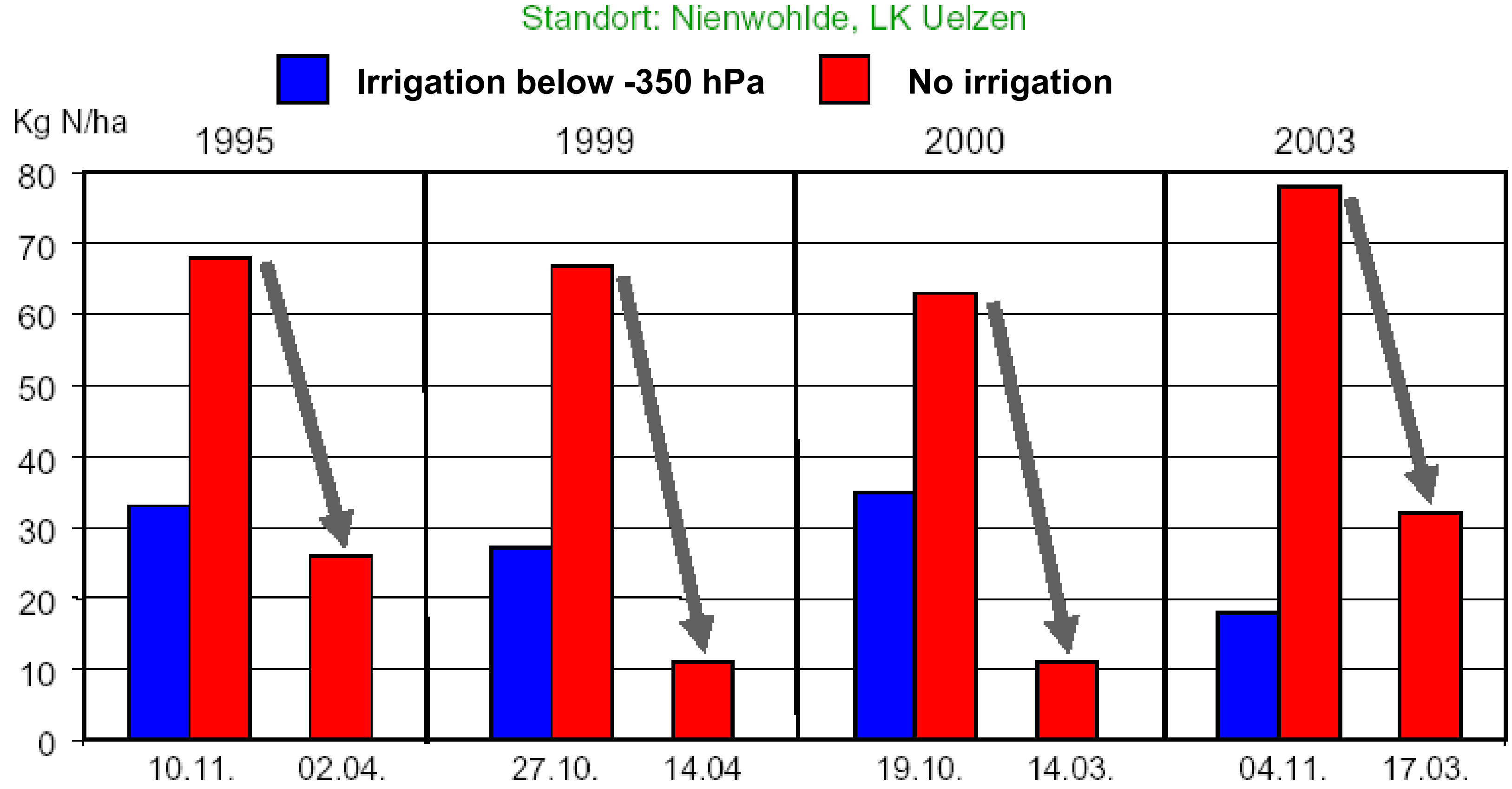
Landwirtschaftskammer Niedersachsen

Nmin-values under potatoes kg N/ha



Landwirtschaftskammer Niedersachsen

Nmin-values after potatoes at the beginning of the groundwater recharge period

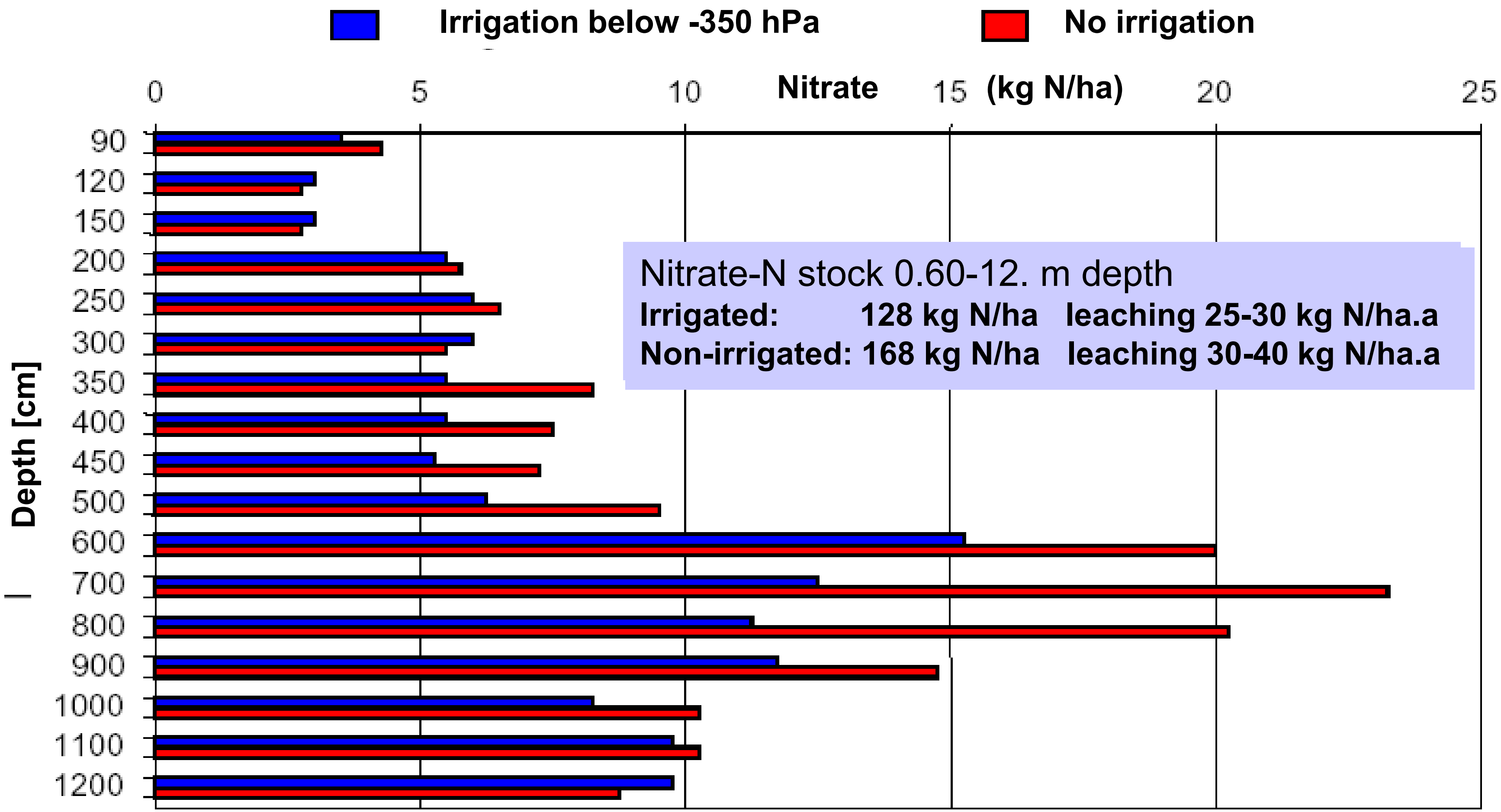


Nitrate leaching

Landwirtschaftskammer Niedersachsen

N-amounts vs. depth in soil profiles after a 10-year supplemental irrigation experiment

Mean value from 8 profiles up to 12 m depth



Reduction of nitrate leaching:

- Fertilizing after the N_{min}-Method: Minimizing the N_{min}-stock at harvest
- Dividing the fertilizer application: shallow rooting crops and sandy soils
- Catch crops: uptake of the residual-N_{min} and mineralised Nitrate (no legumes)
- Animal manure: slurry and stall manure: application as with mineral fertilizer
- Carefull irrigation planing: improved N-uptake
- Further measures: undersown crops, N-fertilizing with simulation models, better crop rotations, precision agriculture

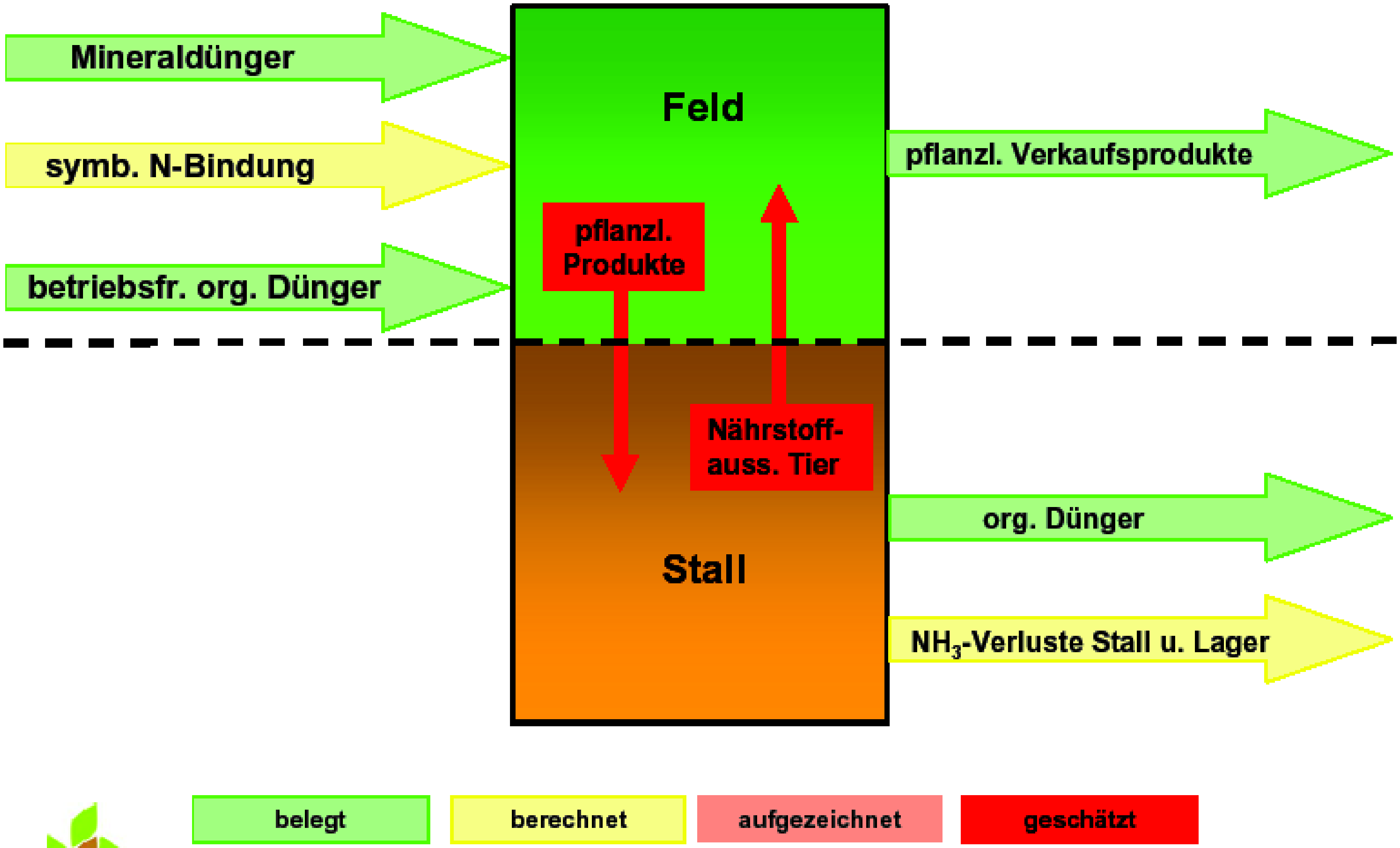
-

Feldberegnung in der Landwirtschaft:

Feldberegnung ist grundwasserschonend, wenn mit dem geförderten Wasser sparsam umgegangen wird und wenn die gedüngten Nährstoffe durch gezielt und gleichmäßig verabreichte Wassergaben weitestgehend in Ertrag umgesetzt werden.

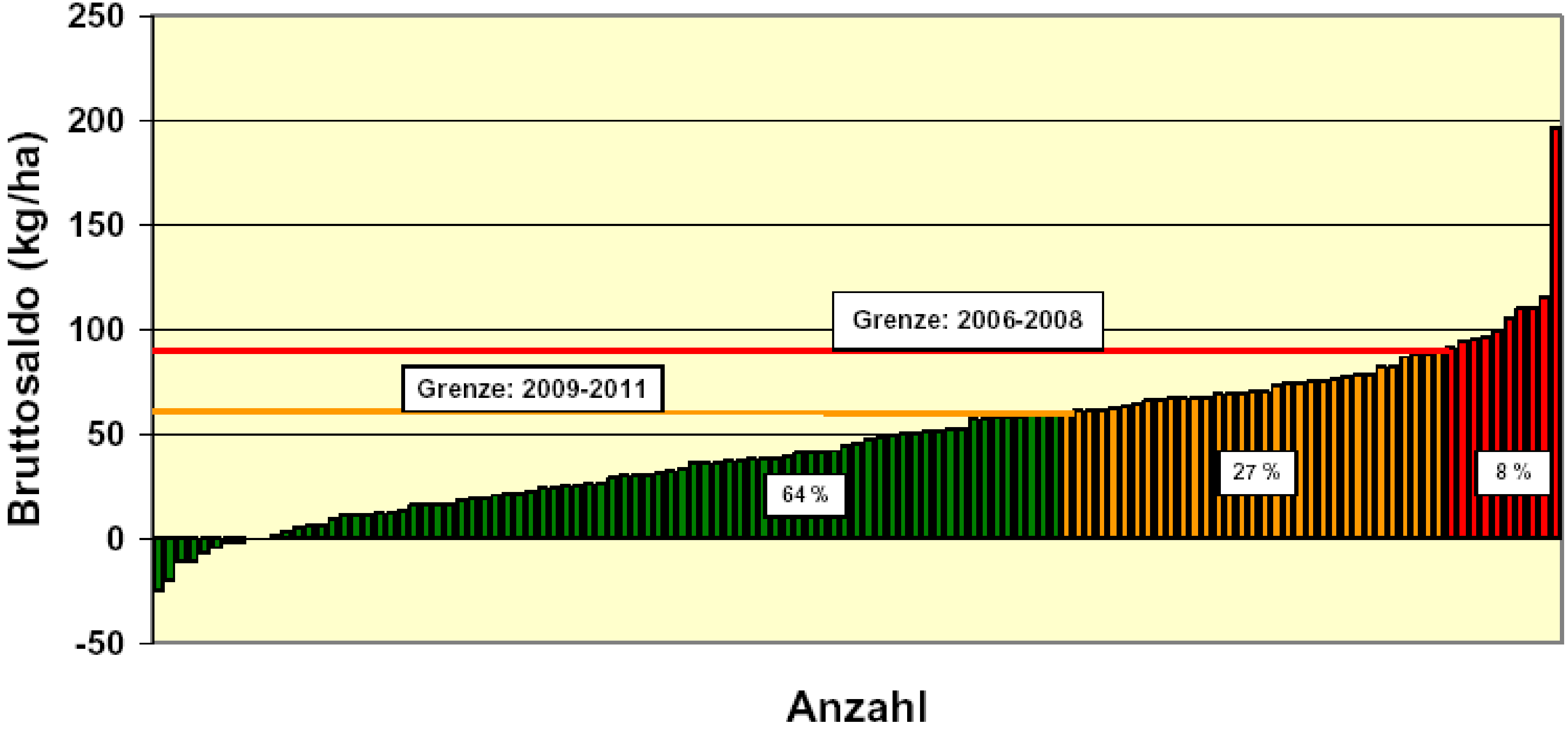
Feldberegnung dient dem Grundwasserschutz durch sichere Erträge, hohe Nährstoffentzüge und damit geringere Restnitratgehalte im Boden nach der Ernte. Dadurch wird die mögliche spätere Verlagerungsgefahr mit der im Herbst einsetzenden Sickerung deutlich vermindert.

Nährstoffsaldo auf Betriebsebene (Feld-Stall-Ansatz)



N-Saldo viehloser Betriebe - Deutschland

(HT-Ansatz, n=89)



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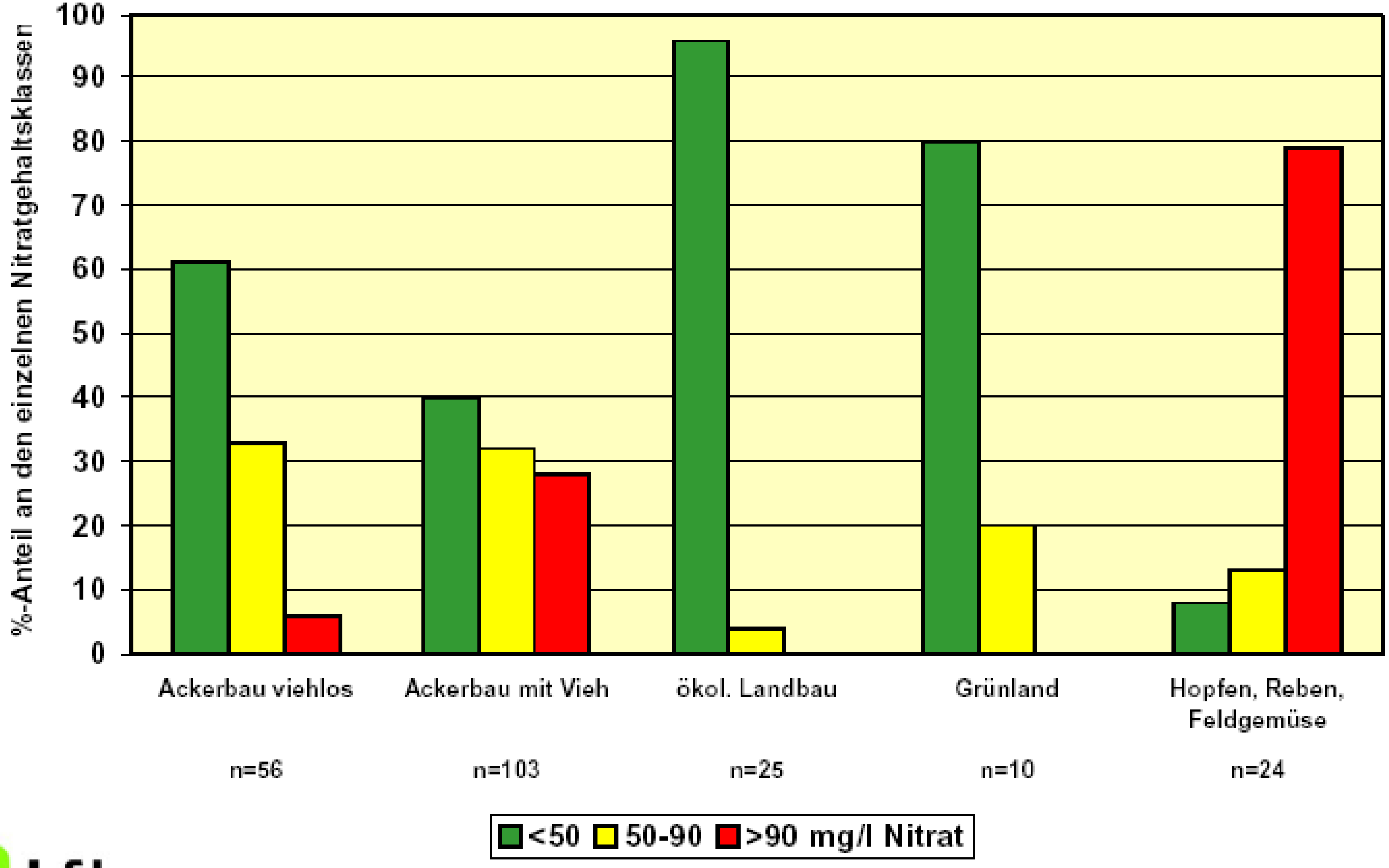
Mittlere Nitratkonzentration im Sickerwasser in Abhängigkeit vom N-Saldo

N-Saldo (kg/ha)	n	Mittelwert (mg/l)	Medianwert (mg/l)
> 20	58	46	38
20-45	55	54	44
46-70	52	55	46
> 70	58	73	58

Verteilung von 218 Schlägen auf Landnutzungsklassen und Nitratkonzentration in der Sickerwasserzone

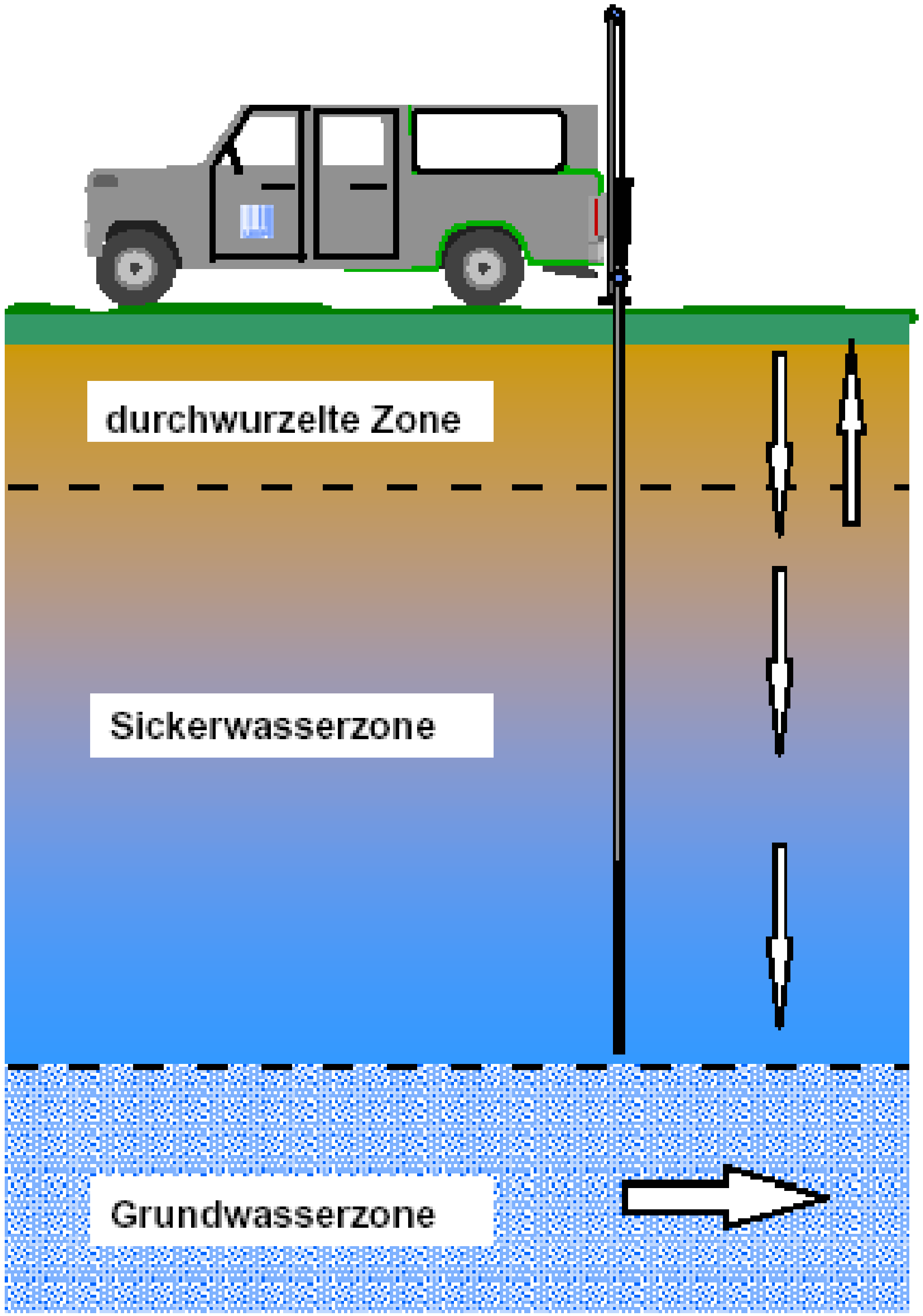


Mittlere Nitratkonzentration, Minimum- und Maximumwerte im Sickerwasser (mg/l) in Abhängigkeit von der Nutzungsform

Nutzungsform		n	Nitrat (mg/l)		
			Mittelwert	Minimum	Maximum
Acker	**üblicher Landbau**				
	ohne Vieh (< 0,2 GV/ha)	56	48	5	132
	mit Vieh (∅ 1,7 GV/ha)	103	75	8	376
	ökologischer Landbau (∅ 0,8 GV/ha*)				
	Umstellung vor mehr als 6 J .	16	29	8	46
	Umstellung vor weniger als 6 J.	9	34	16	50
Grünland		10	25	2	65
Hopfen, Feldgemüse, Reben		24	157	3	420

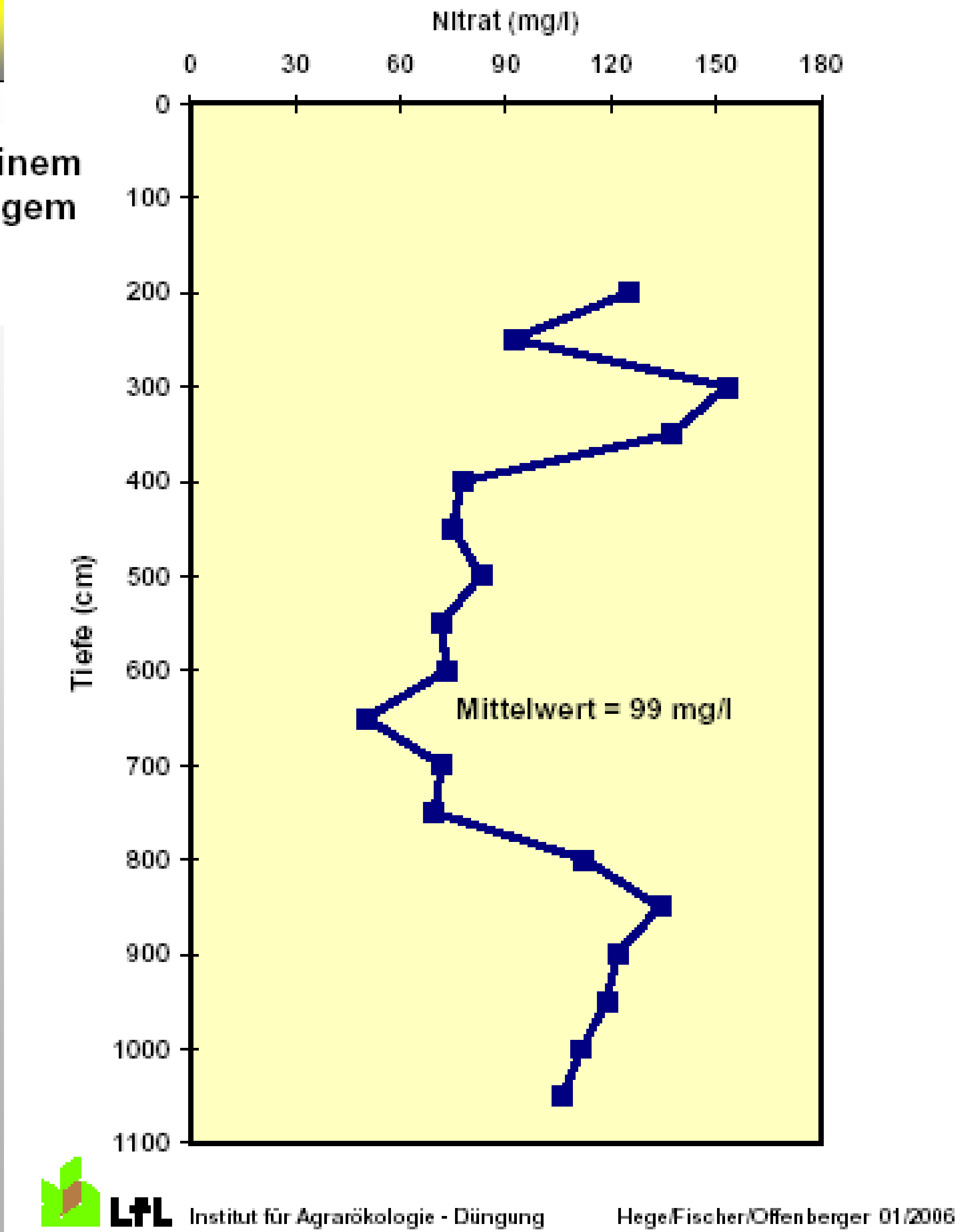
* inkl. viehloser Betriebe

Schemaskizze:
Durchführung der Tiefenbohrung mit einem Rammbohrgerät

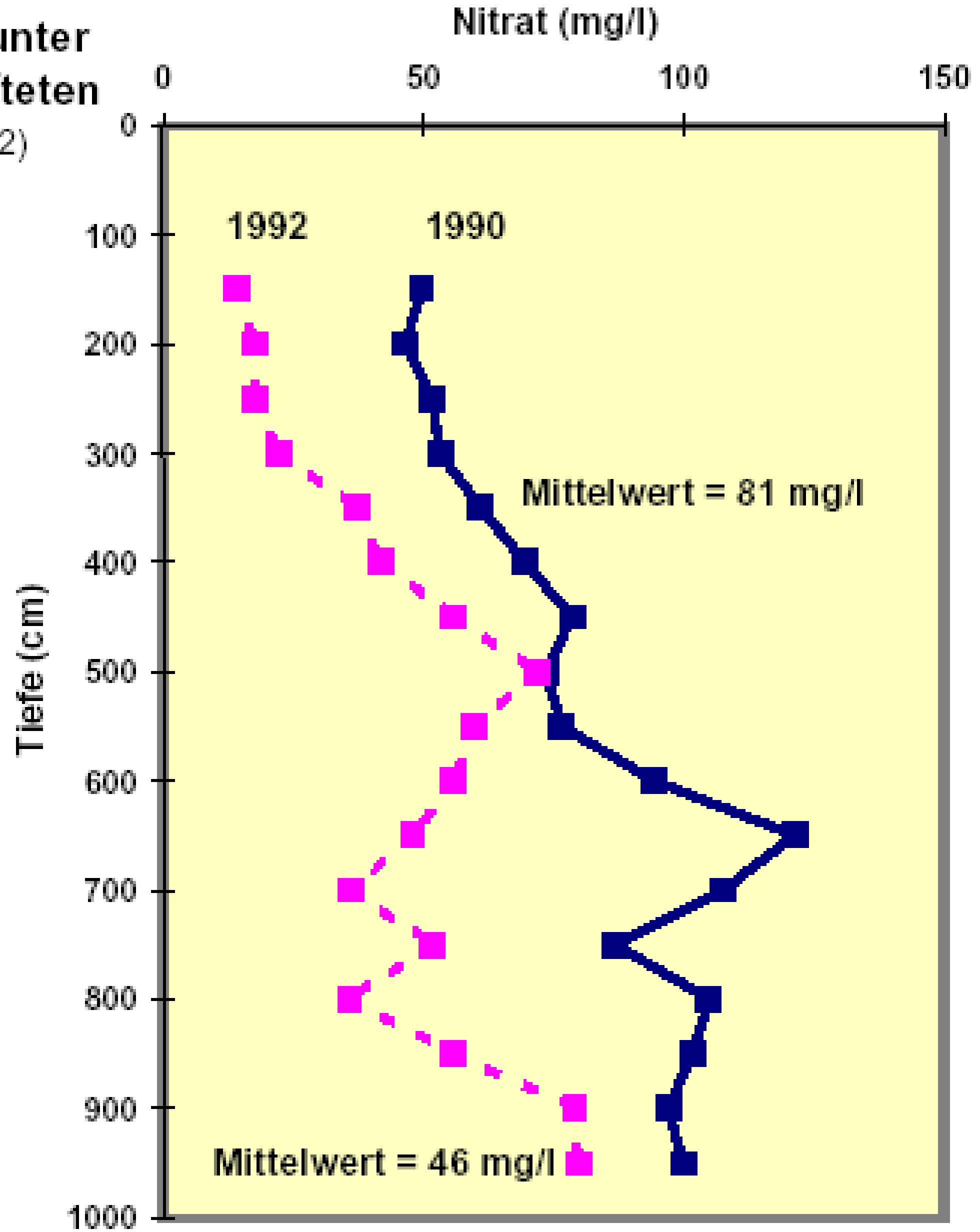


Nitratgehalte einer Ackerfläche mit einem N-Saldo von 83 kg/ha.a und ungünstigem Wirtschaftsdüngermanagement

(konventioneller Betrieb)



Nitratgehalte im Bodenwasser (mg/l) unter einer seit 1987 ökologisch bewirtschafteten Ackerfläche (Probennahme 1990 und 1992)



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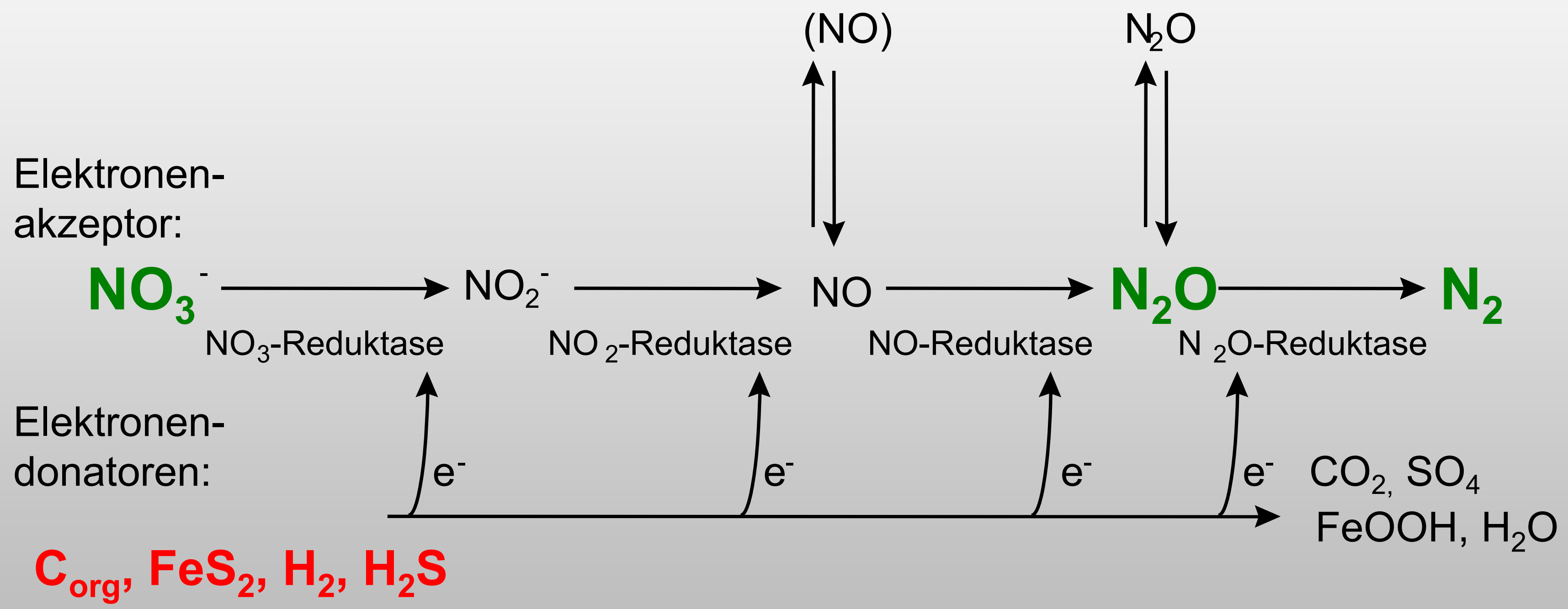
Hege/Fischer/Offenberger 01/2006

Schematische Darstellung der Denitrifikation mit beteiligten Enzymen, Substraten und Produkten

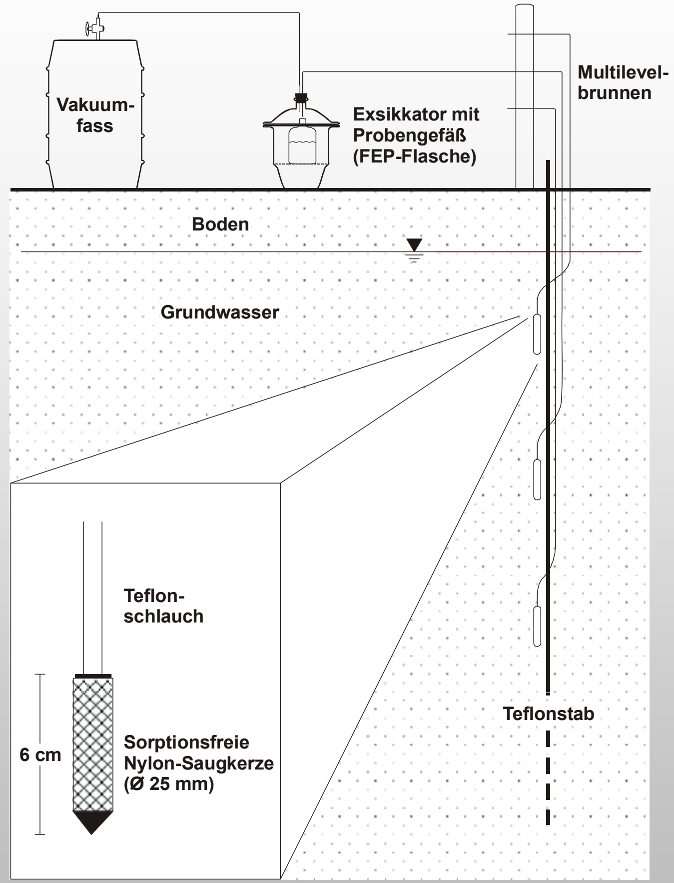


Bewertung der Denitrifikationsleistung der Wurzelzone von Böden

(nach GÄTH et al. 1997, modifiziert von HÖPER 2001)

Kennzeichnung der Denitrifikationsstufe		Denitrifi-kationsrate	Grund-/Stauwasser-einfluss in Wurzelzone (Randbedingung)	Geologische Ausgangssubstrate	Bodentypen (Beispiele)
Kurzzeichen	**Bezeichnung**	**kg/N/ha/a**			
1	sehr gering	<10	ganzjährig keine Wassersättigung	flachgründig verwitterte Festgesteine und tiefgründig verwitterte sandige Festgesteine sandige Lockergesteine	Syrosem, Ranker, Regosol, Rendzina Braunerde, Bänderparabraunerde, Podsol
2	gering	10 - 30	ganzjährig keine Wassersättigung	schluffige bis tonige Lockergesteine tiefgründig zu Schluff und Ton verwitterte Festgesteine humusreiche sandige Lockergesteine	Pararendzina[1] Parabraunerde[1] (Trocken-)Schwarzerde Auenböden[4] Terra fusca[1], Terra rossa[1] Kolluvium[1] Plaggenesch, Sandmischkultur
3	mittel	30 - 50	grundwasserfern, aber 3 bis 6 Monate Stauwassereinfluss	schluffige bis tonige Lockergesteine und tiefgründig verwitterte schluffige bis tonige Festgesteine	Pelosol Pseudogley
4	hoch	50 - >150	6 bis 9 Monate Grund- und Stauwassereinfluss Grundwasser unterhalb Torfkörper	fluviale, limnogene und marine Lockergesteine Hoch- und Niedermoortorfe	Gleye, Stagnogley Auenböden[5] Marschen Niedermoor, Hochmoor
5	sehr hoch	>>150	Grundwasser im Torfkörper ganzjährig Grundwassereinfluss	Anmoore, Moore und organische Mudden[2] z. T. humusreiche, fluviale, limnogene und marine Lockergesteine	Niedermoor, Anmoorgley Gley-Tschernosem Gley-Auenböden
			lang anhaltende Wassersättigung	Gesteine mit hohem Anteil an fossilem C und reduzierten S-Verbindungen	verschiedene Böden[3] Pelosole

1) bei mittleren bis starken Pseudogleymerkmalen Zuordnung in Stufe 3
2) bei ganzjähriger Trockenlegung Zuordnung in Stufe 2 oder 3
3) z. B. Lias, Untere Kreide und braunkohle- bzw. pyrithaltige Geschiebelehme
4) Grundwasser im Kies
5) Grundwasser im Auenboden



Prinzip eines Multilevelbrunnens: spezielle Anordnung für die Beprobung des Grundwassers zur Bestimmung von anorganischen Spurenstoffen (Duijnisveld et al. , 2008)