Joint ICTP-IAEA Workshop on the Use of Cosmic Ray Neutron Sensor for Soil Moisture Management and Validation of Remote Sensing Soil Moisture Maps

10 May 2021 - 19 May 2021, virtual meeting

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

# Lecture 1
# Use of CRNS for supporting agriculture activities

**Ass.Prof. Gabriele Baroni**

Department of Agricultural and Food Sciences (DISTAL)

Alma Mater Studiorum – University of Bologna

# Outline

- About me
- CRNS for supporting agricultural activities
- Boosting CRNS in agriculture based on new technologies

# Some notes

50 min + 25 min discussion

Looking at participants strong background heterogeneity…nice but challenging for the preparation of the lecture… I hope I made a good compromise

I assume you know everything about how CRNS works based on lectures from T.Franz

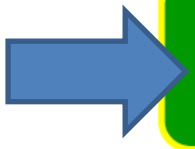
# About me

1. Degree in Environmental sciences and PhD in Agricultural Engineering University of Milan (Italy)

2. Post Doc (~10 years) at University of Potsdam and UFZ – Leipzig (Germany)

3. Since 2019, Associate professor at the Department of Agricultural and Food Sciences (DISTAL)

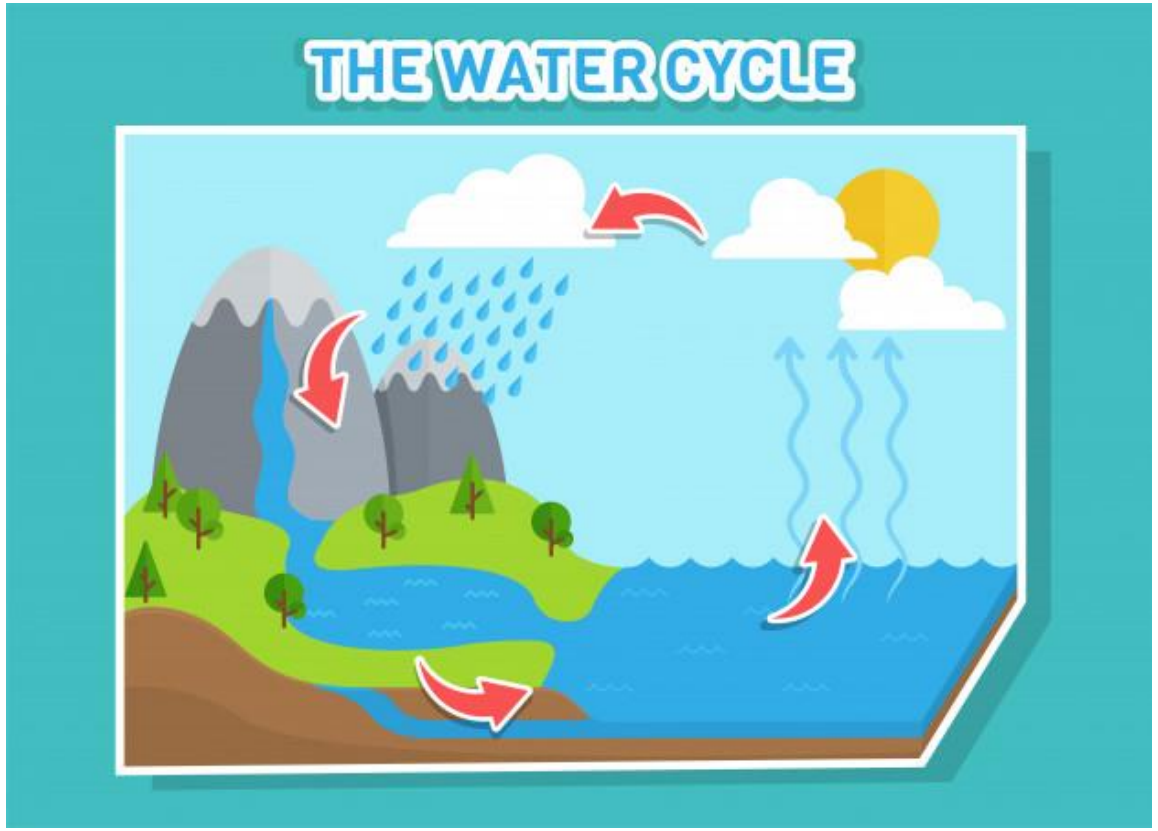
# Divisions at the Department

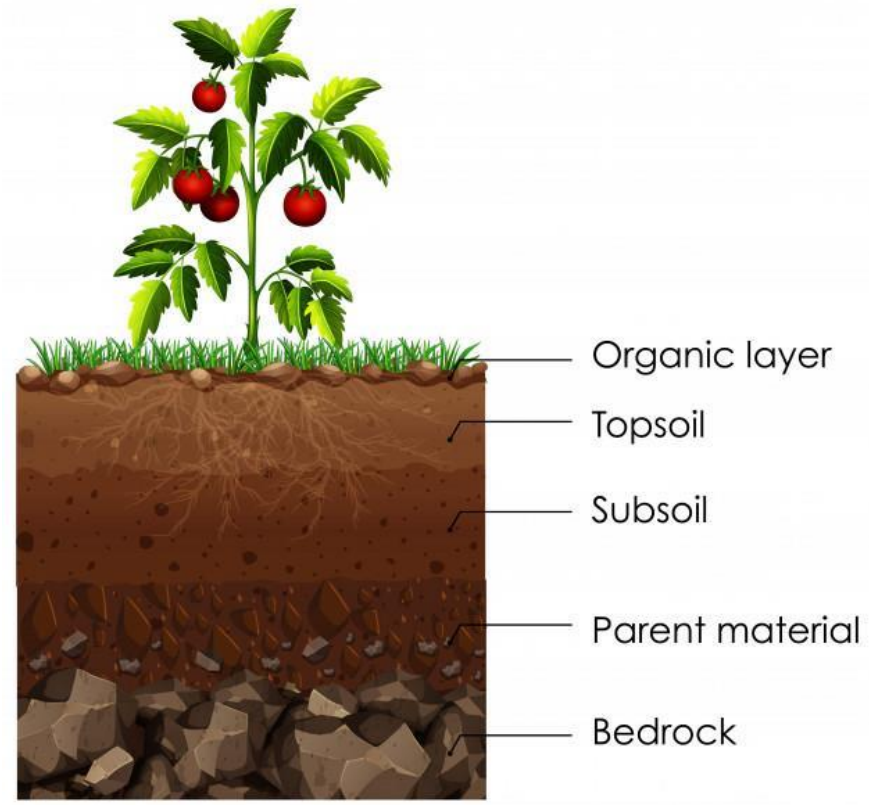


- Agricultural and Food Economics
- Agricultural Chemistry, Pedology and Agricultural Genetics
- Agronomy and Field, Vegetable, Ornamental Crops
- Fruit Tree and Woody Plant Sciences
- Agricultural Engineering
- Plant Pathology and Entomology
- Agro-environmental and Food Microbiology
- Food Science and Technology
- Animal Sciences
- Chemistry, Biochemistry and Botany

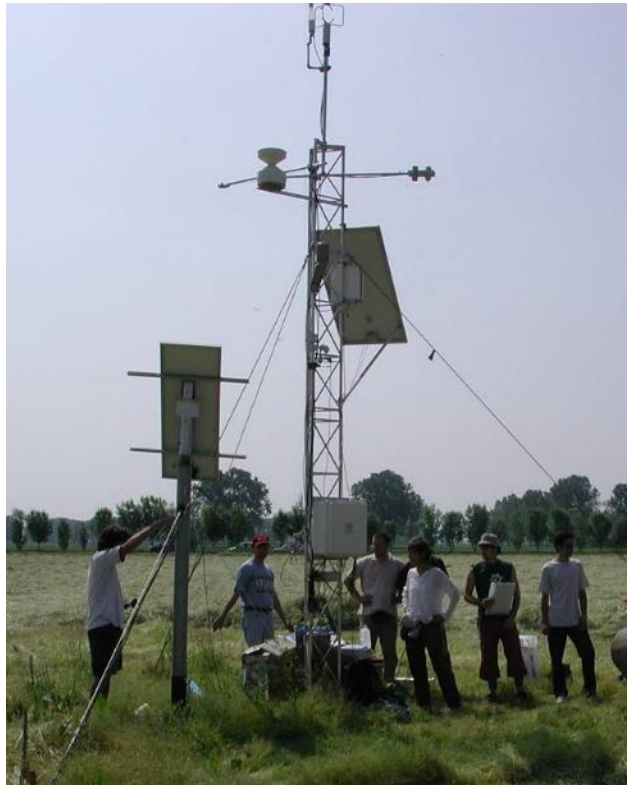
# My research focuses on…

hydrological processes at different spatial and temporal scales and soil-plant systems



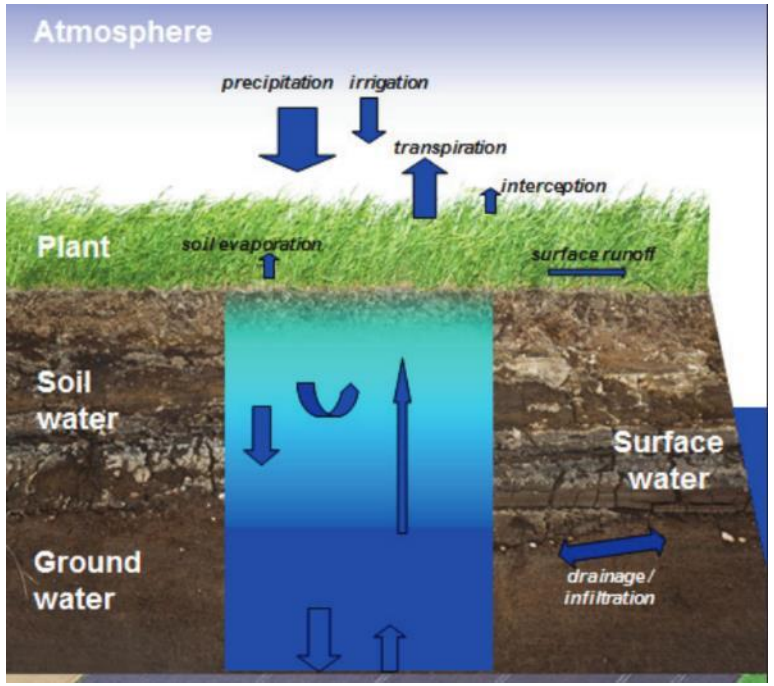
# How? Observations of states and fluxes

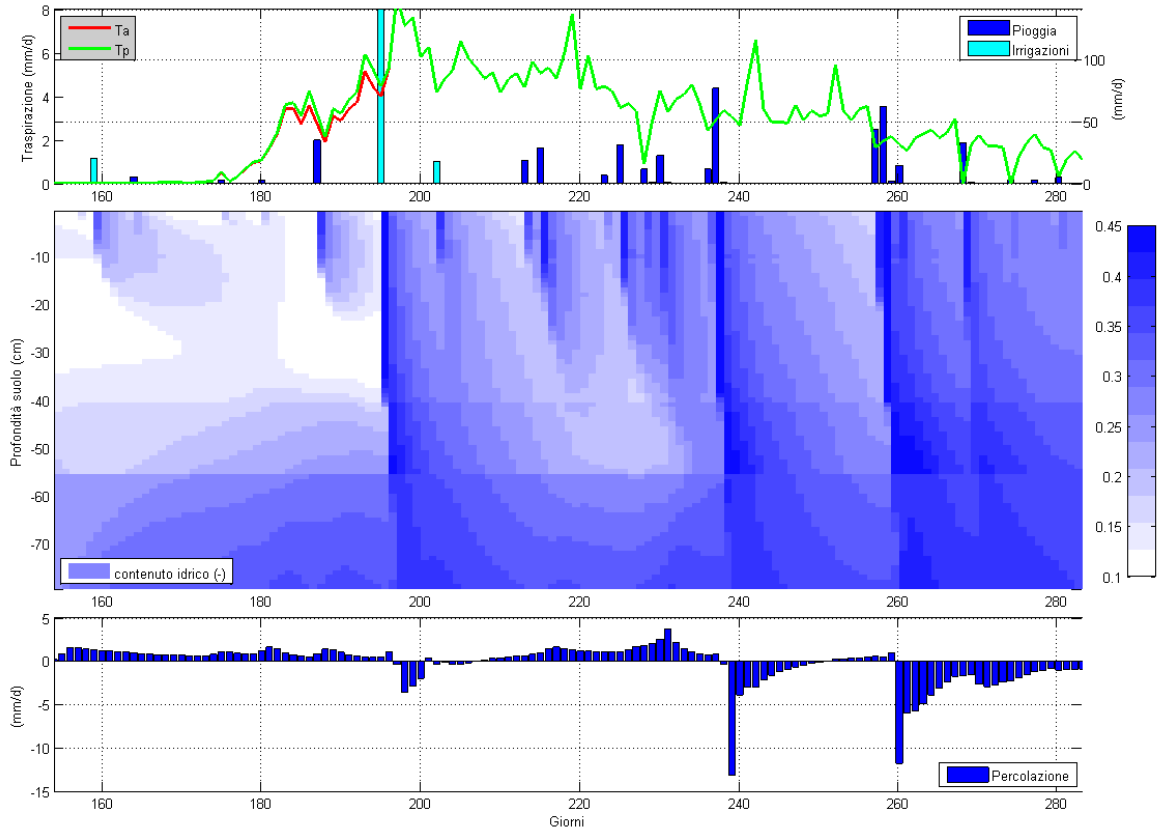


# How? Observations of plant and soil parameters

# How? Modelling water fluxes from field to catchment scale

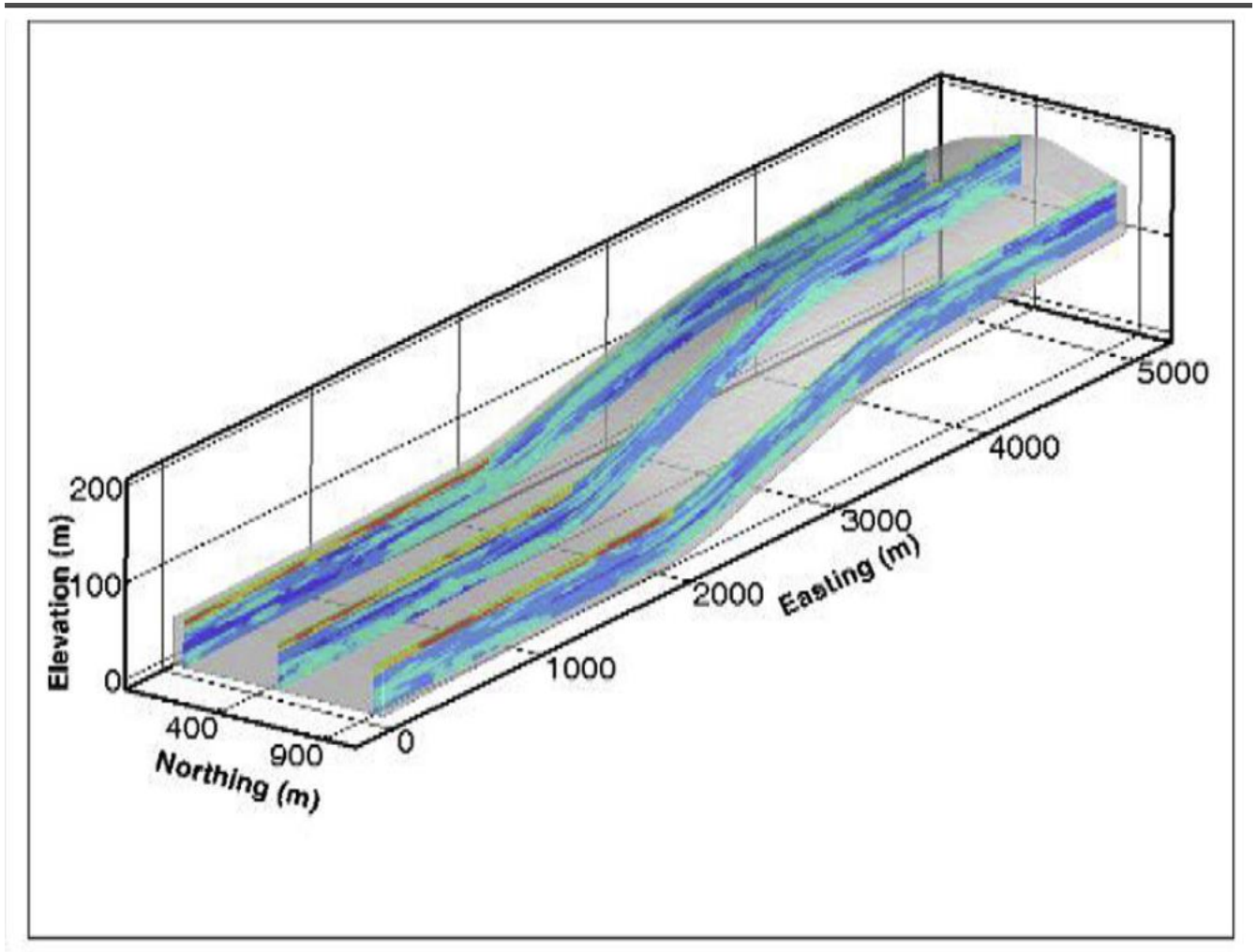
https://www.swap.alterra.nl/



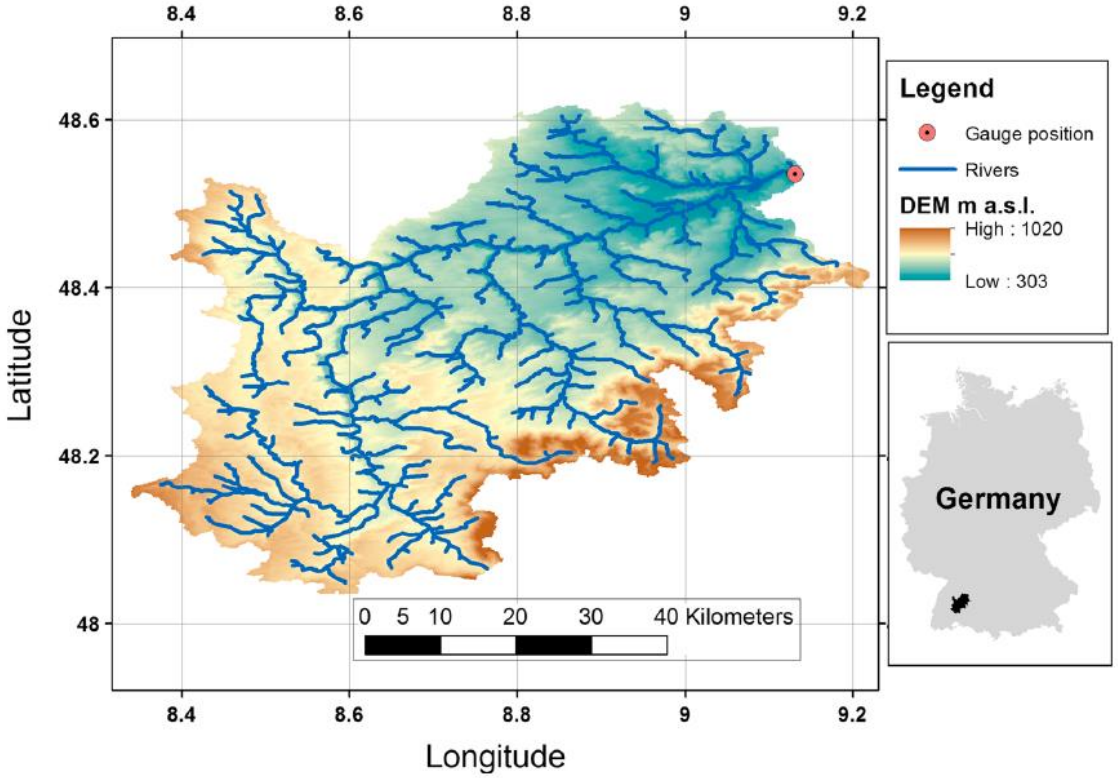

Baroni, G., A. Facchi, C. Gandolfi, B. Ortuani, D. Horeschi, and J. C. van Dam. "Uncertainty in the Determination of Soil Hydraulic Parameters and Its Influence on the Performance of Two Hydrological Models of Different Complexity." *Hydrology and Earth System Sciences* 14, no. 2 (February 2010): 251–70. https://doi.org/10.5194/hess-14-251-2010.

# How? Modelling water fluxes from field to catchment scale

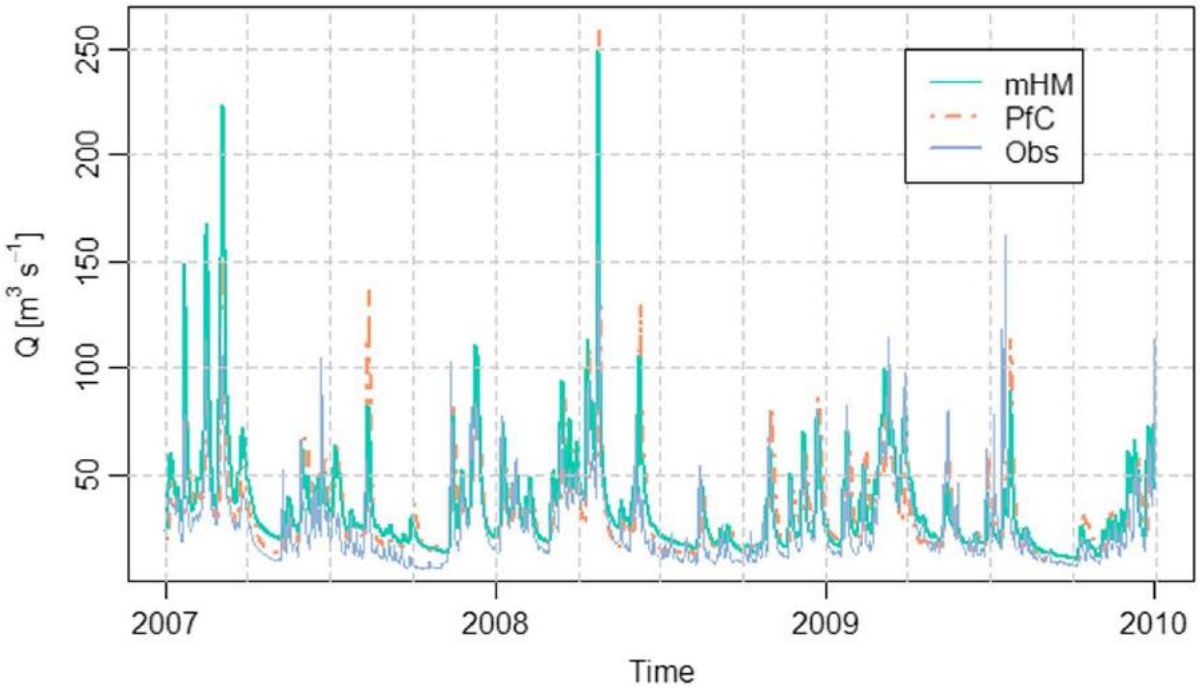



Erdal, Daniel, Gabriele Baroni, Emilio Sánchez-León, and Olaf A. Cirpka. "The Value of Simplified Models for Spin up of Complex Models with an Application to Subsurface Hydrology." *Computers & Geosciences*, January 30, 2019. https://doi.org/10.1016/j.cageo.2019.01.014.

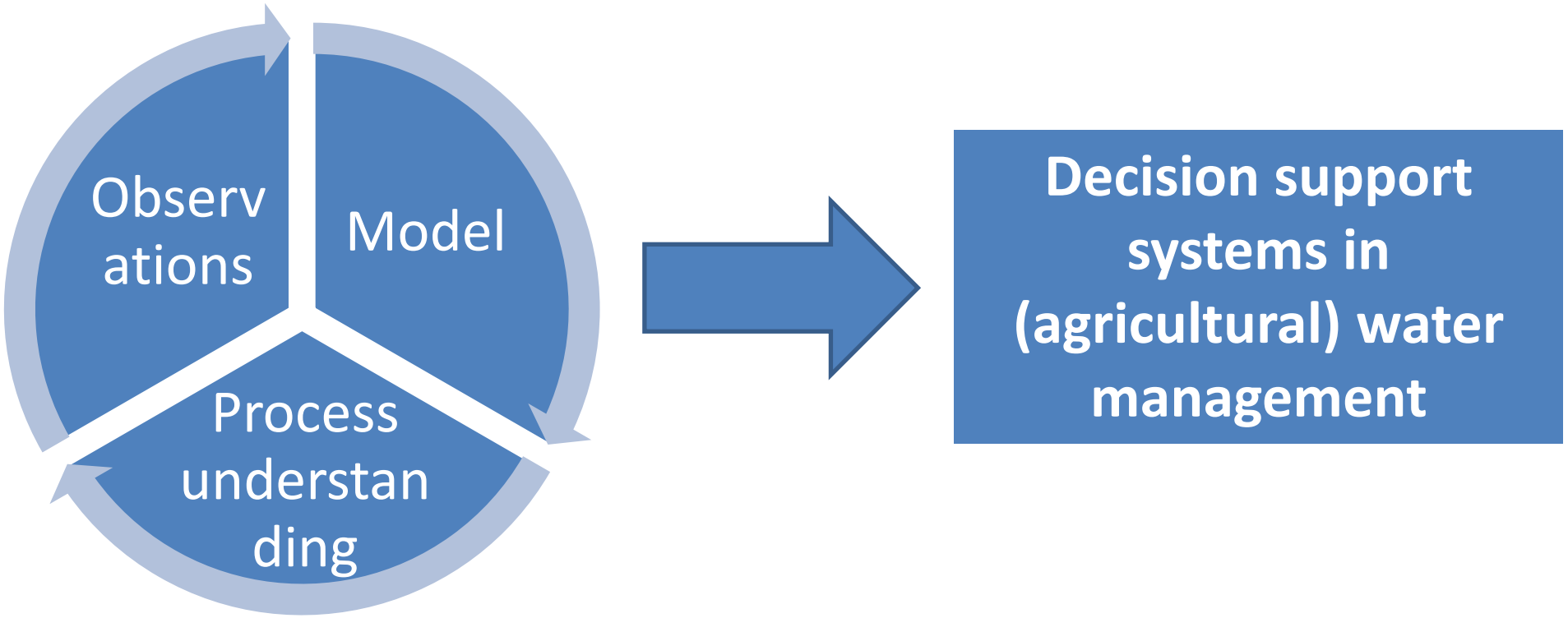
# How? Modelling water fluxes from field to catchment scale



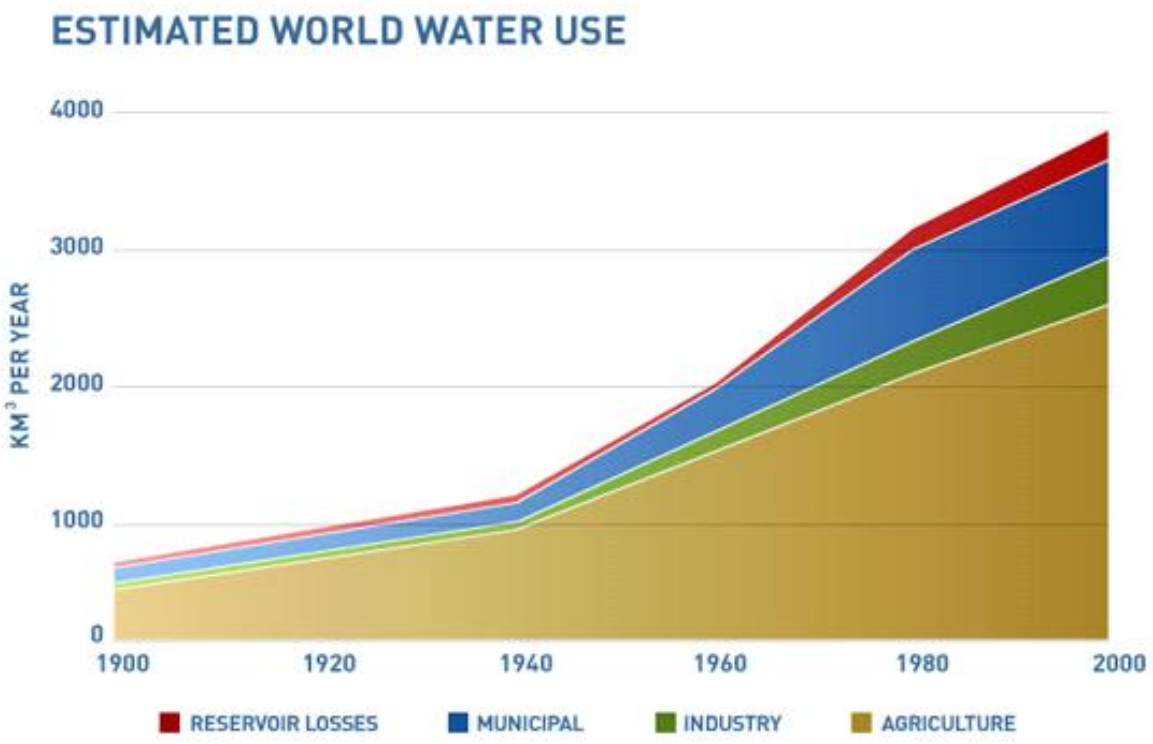

Baroni, Gabriele, Bernd Schalge, Oldrich Rakovec, Rohini Kumar, Lennart Schüler, Luis Samaniego, Clemens Simmer, and Sabine Attinger. "A Comprehensive Distributed Hydrological Modelling Inter-Comparison to Support Processes Representation and Data Collection Strategies." *Water Resources Research*, January 17, 2019. https://doi.org/10.1029/2018WR023941.



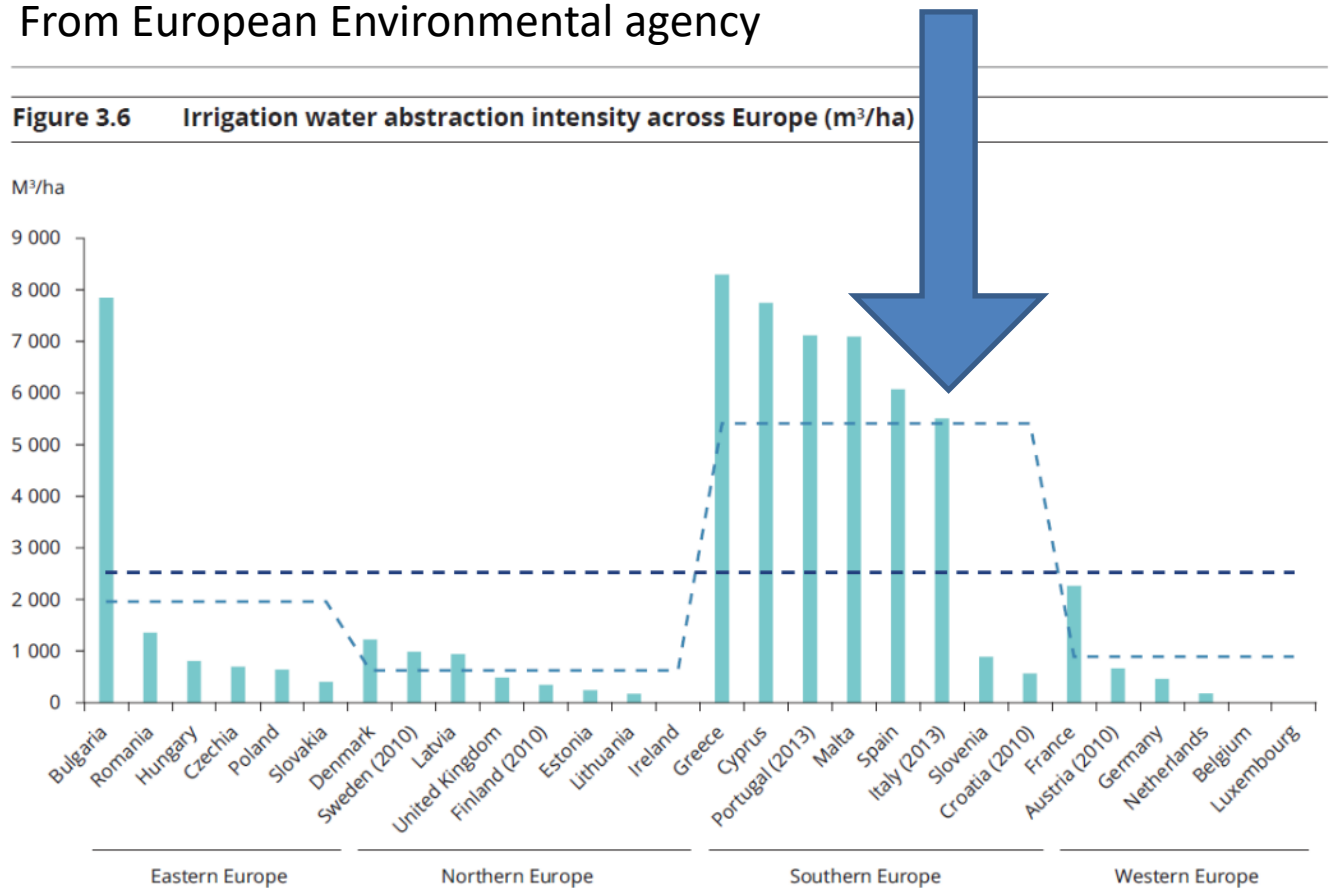
# Scientific support for agricultural water management



# Why water and agriculture?




From European Environmental agency

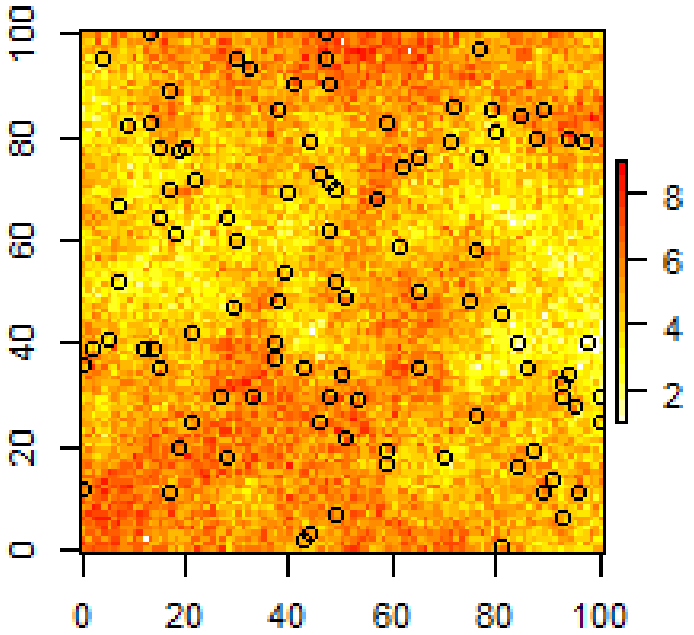


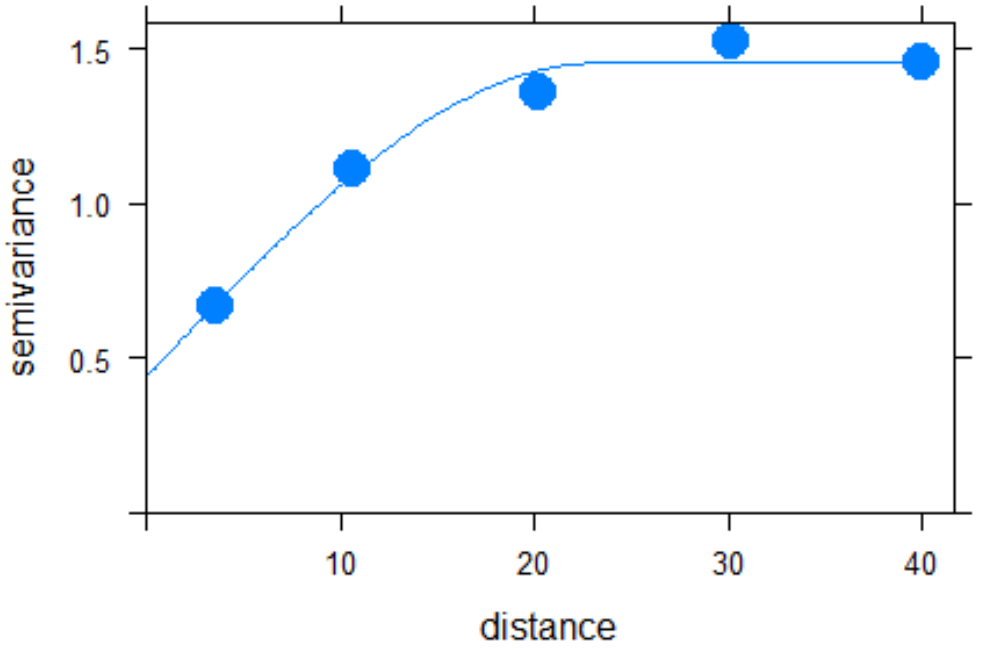

In some regions…we cannot understand the water cycle without knowing agriculture

# Why did I start working on cosmic-ray neutron sensing?

Soil moisture is a key variable for understanding hydrological processes

Ground observations mainly performed with invasive point-scale sensors but strong spatial variability due to soil-plant systems



# Why did I start working on cosmic-ray neutron sensing?

Increased spatial variability due to water management: dis-uniformity of water distributions in each irrigation method

**Flood**

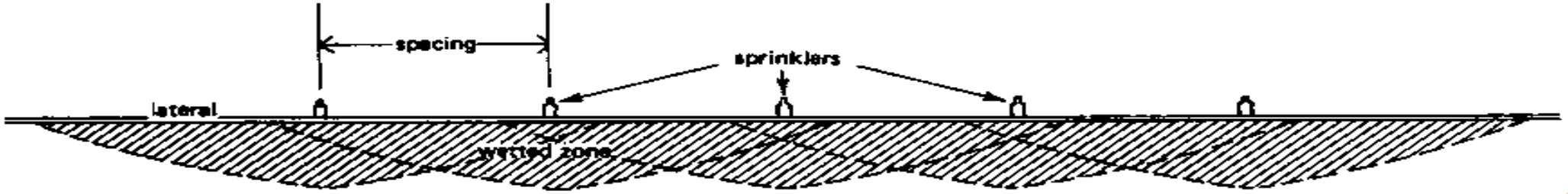
**Sprinkler**

**Drip**

# Why did I start working on cosmic-ray neutron sensing?

Increased spatial variability due to water management: dis-uniformity of water distributions in each irrigation method

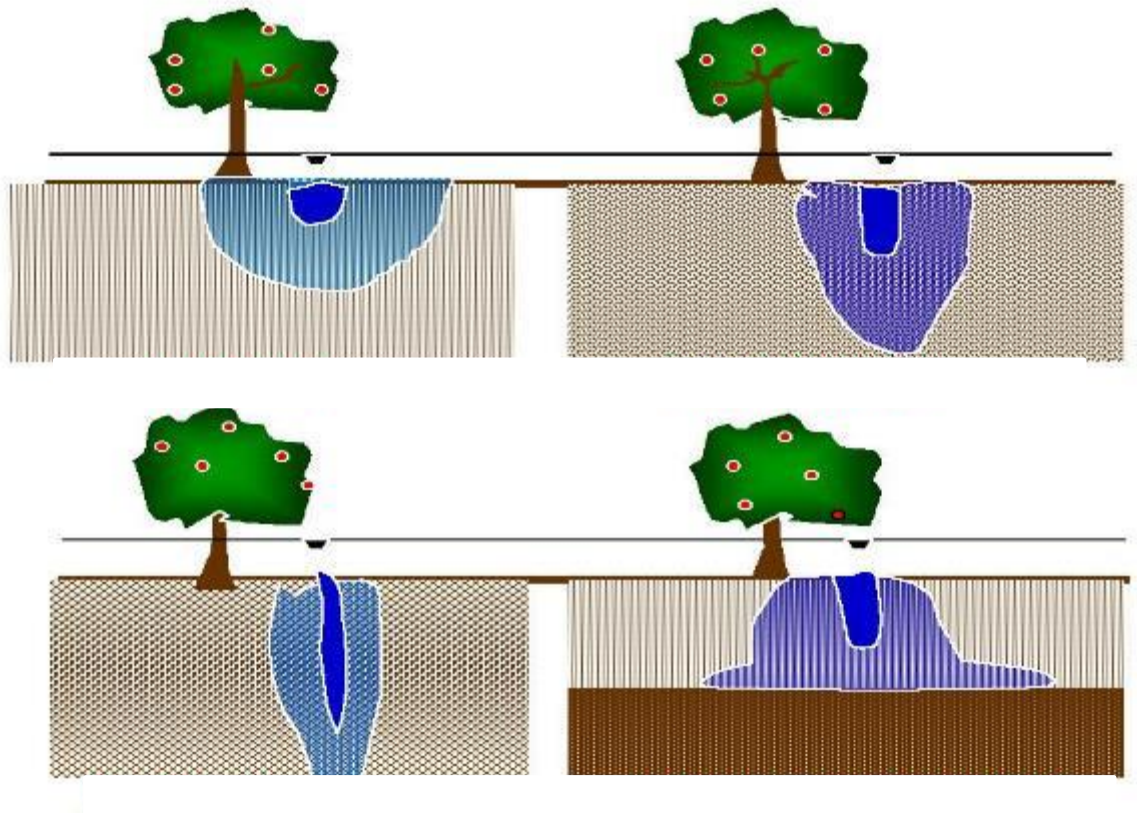
**Sprinkler irrigation systems**



# Why did I start working on cosmic-ray neutron sensing?

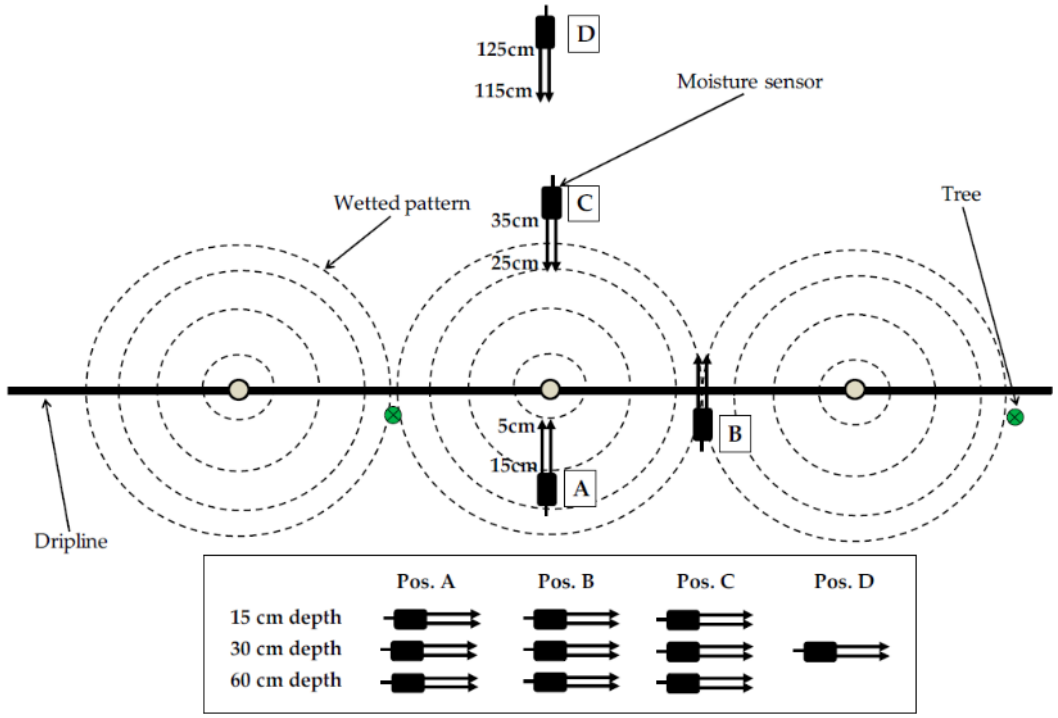
Increased spatial variability due to water management: dis-uniformity of water distributions in each irrigation method

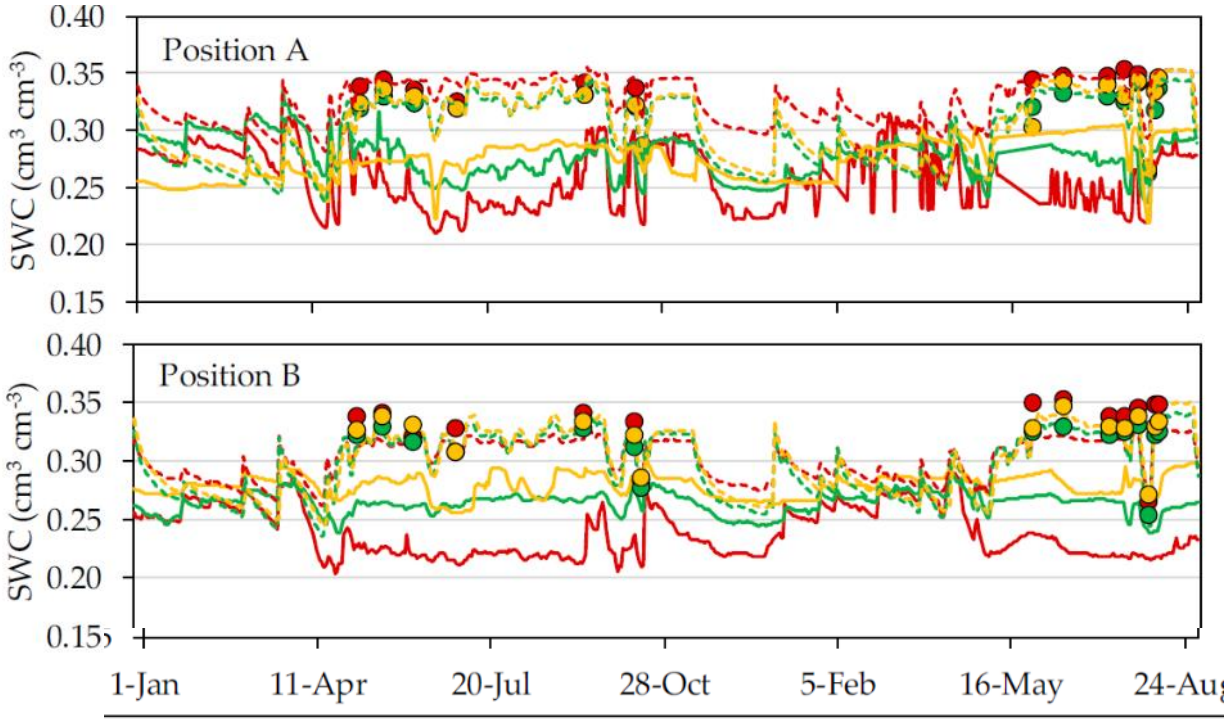
**Drip irrigation**



# An example for drip irrigation

Domínguez-Niño, Jesús María, Jordi Oliver-Manera, Gerard Arbat, Joan Girona, and Jaume Casadesús. "Analysis of the Variability in Soil Moisture Measurements by Capacitance Sensors in a Drip-Irrigated Orchard." *Sensors* 20, no. 18 (January 2020): 5100. https://doi.org/10.3390/s20185100.




large sensor-to-sensor differences, even when installed at equivalent depth and coordinates relative to the drippers

differences cause by the natural variability in size, shape, and centering of the wet area below the drippers, combined with the sharply soil variability

# Why did I start working on cosmic-ray neutron sensing?

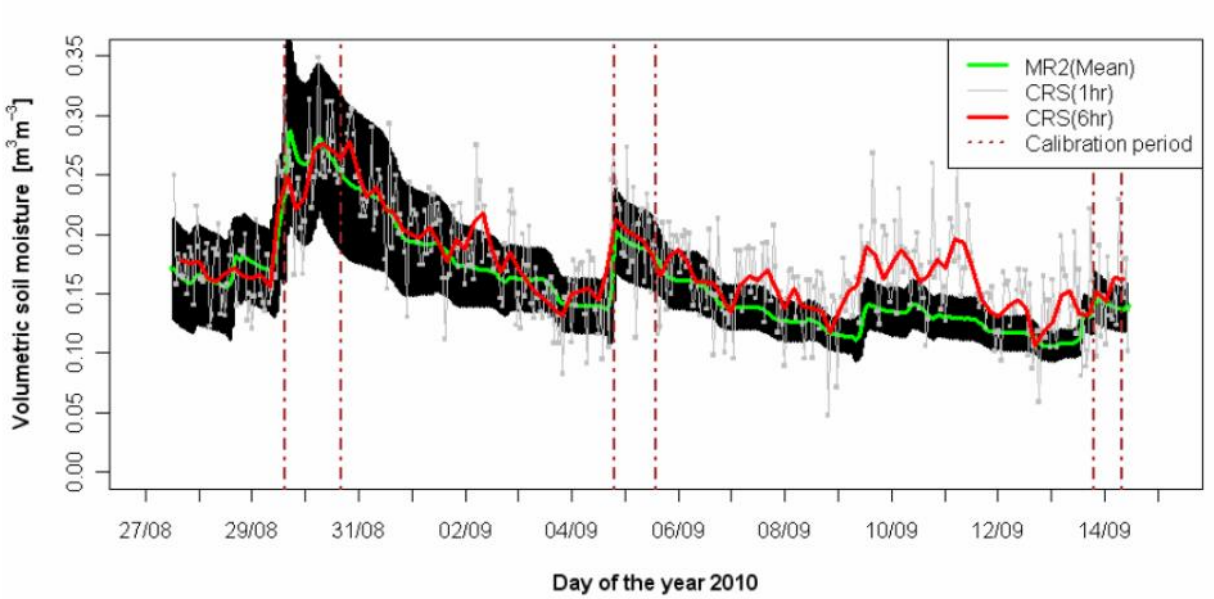
Increased spatial variability due to tillage activities:  soil compaction by tracks

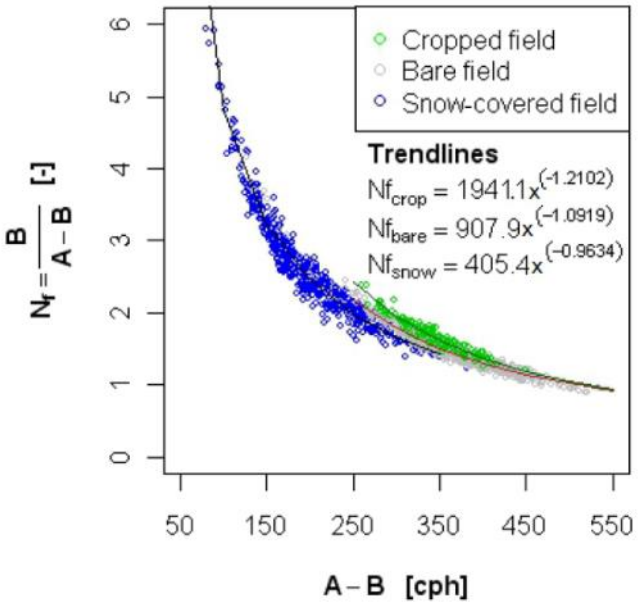

Flooded potato field due to heavy rains in poorly permeable soil due to compaction by heavy mechanization tractors

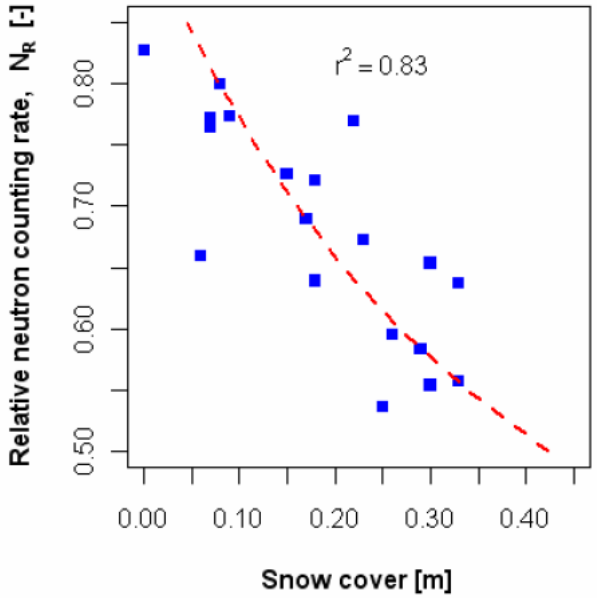
# My experience with cosmic-ray neutron sensing (CRNS)

I moved as post-doc in 2010 at the University of Potsdam (Germany)

First group in Europe working on that with first results about soil moisture, snow and biomass




Rivera Villarreyes, C. A., G. Baroni, and S. E. Oswald. "Integral Quantification of Seasonal Soil Moisture Changes in Farmland by Cosmic-Ray Neutrons." *Hydrology and Earth System Sciences* 15, no. 12 (December 21, 2011): 3843–59. https://doi.org/10.5194/hess-15-3843-2011.

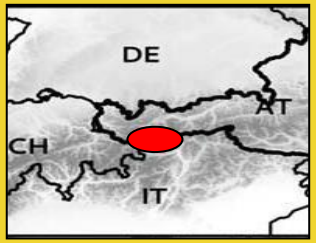
# My experience with cosmic-ray neutron sensing (CRNS)

Tested in several environmental conditions based different collaborations in several countries Germany, Austria, Italy, Brazil, Morocco





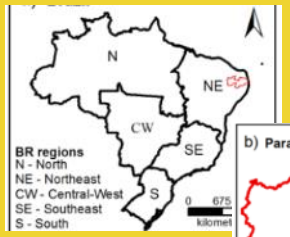
Uni-Potsdam, UFZ, Uni-Hohenheim, Braunschweig (Germany)

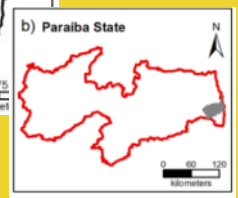




Uni-Innsbruck and AlpS (Austria)



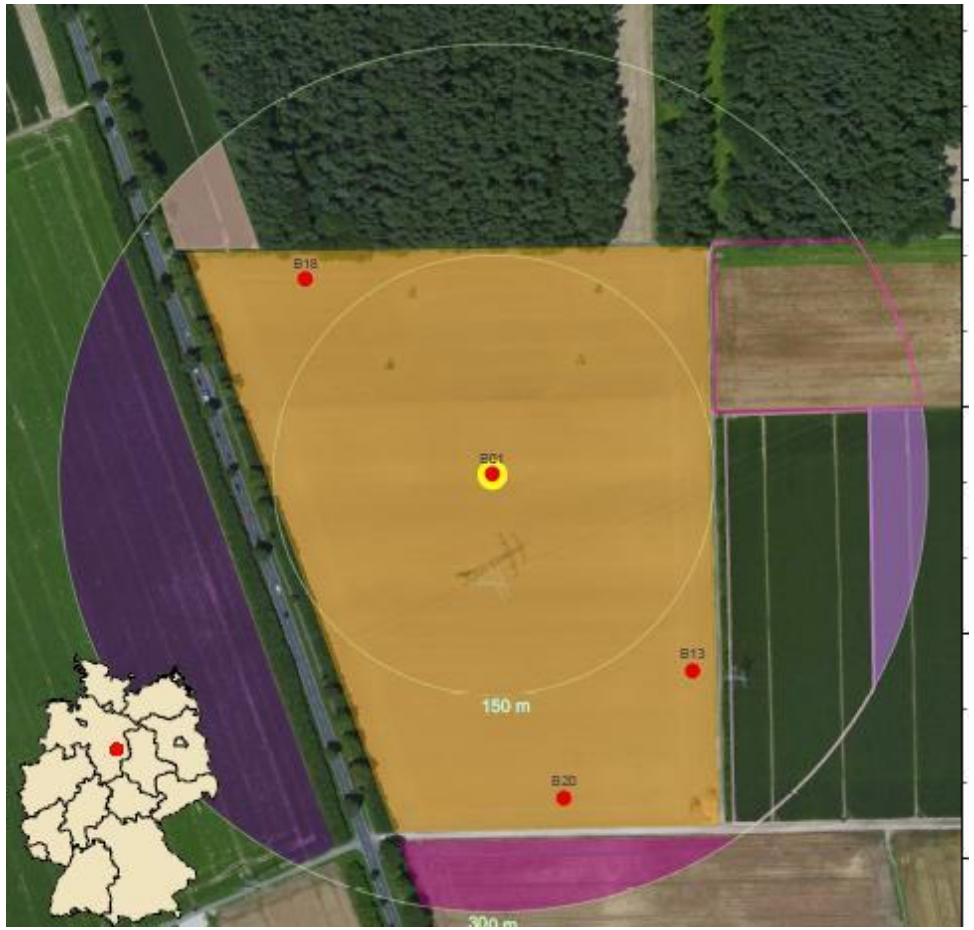
Marrakesh and Rabat (Morocco)



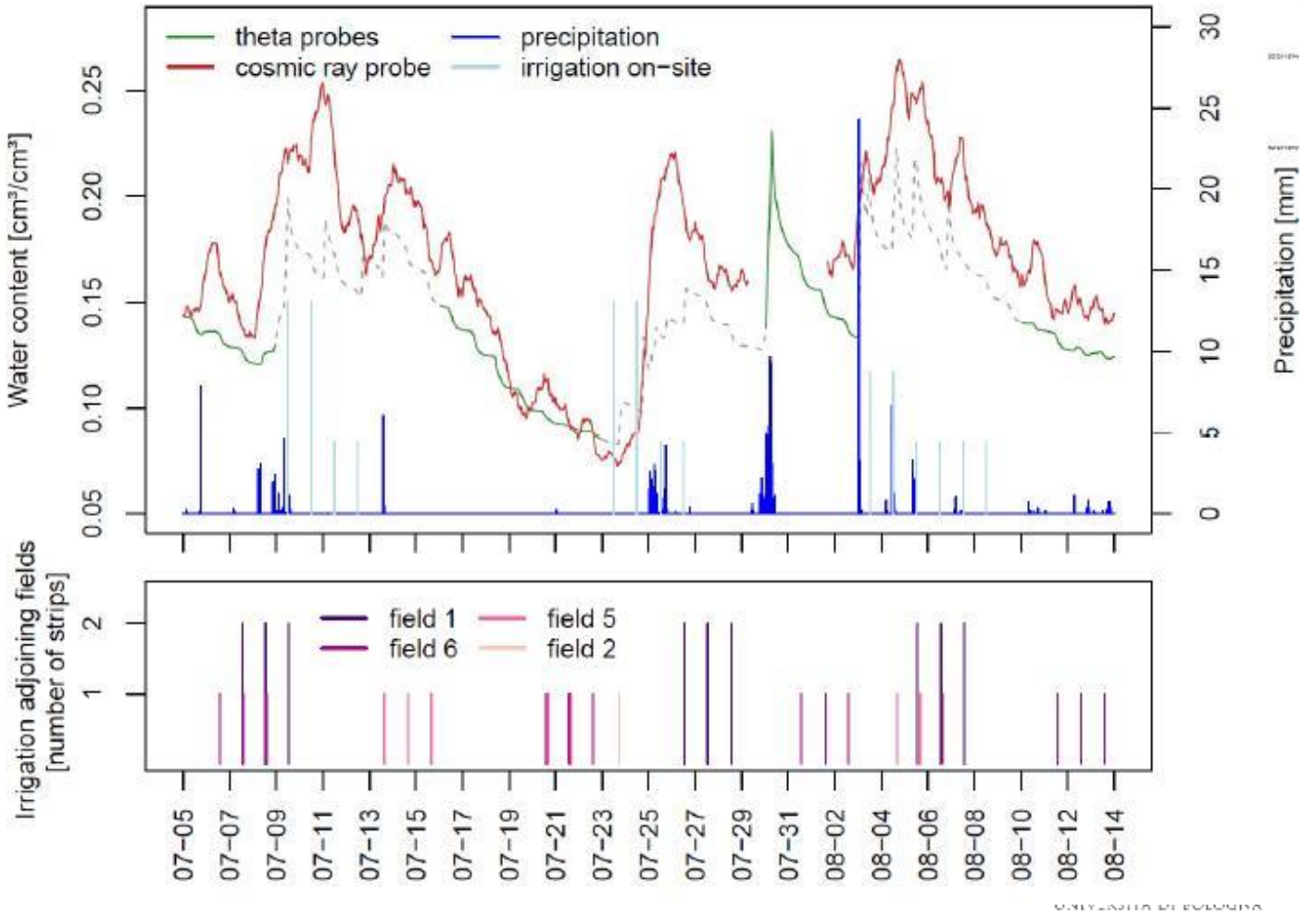




Uni-Paraíba (Brazil)

# CRNS and agriculture




from Schieffile (2013)

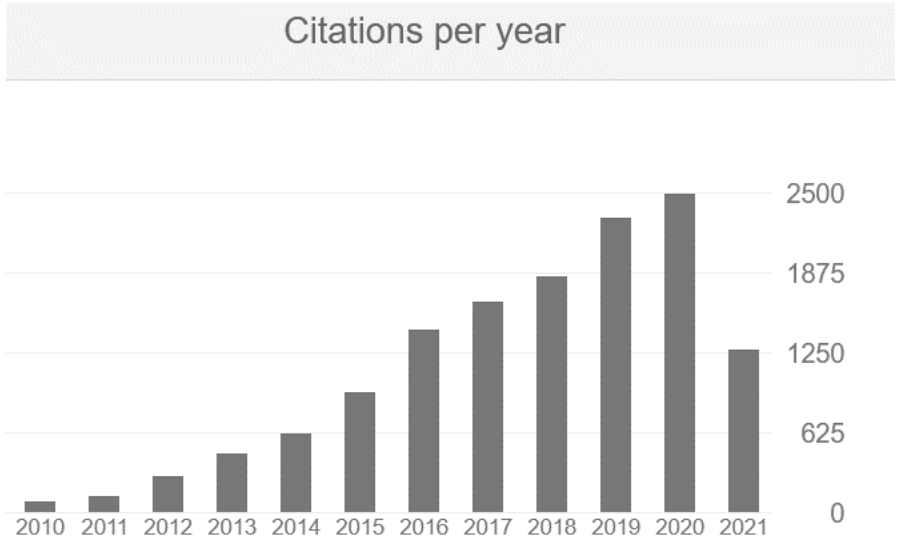


# CRNS… a growing scientific community

Increasing number of groups working with CRNS
Biannual workshop (COSMOS workshop)

**Groups working on CRNS**


Increasing number of publications and citations (from google scholar)



# Where do we stand?

Personally, I would say that CRNS has established as a reliable **soil moisture** and **snow** sensor. **Biomass** estimation needs some further studies.

Many practical products and applications have been foreseen

- Weather
- Drought and irrigation
- Flood and drainage
- Erosion and landslides
- Groundwater recharge and management
- Leaching and groundwater pollutions
- Models and remote sensing calibration and validation
- Data assimilations

# CRNS and agriculture

You should have seen several applications from lectures of T.Franz: e.g., to use CRNS for irrigation scheduling

What else for agriculture? **Soil moisture levels affect**:

- air content, salinity, and the presence of toxic substances
- Regulates soil structure, ductility, and density
- Influences soil temperature and heat capacity
- Prevents soil from weathering
- Determines the readiness of fields to be worked upon
- Excess of water and drainage systems
- Fertilizer and leaching

# Three examples

1. Soil moisture and trafficability

2. Soil moisture, sowing and harvesting

3. Soil moisture, leaching, fertilizer and pesticides

# Soil moisture and trafficability

Soil moisture acts as one of the dominant controls for field trafficability

- Knowing the soil moisture is very important to reduce the impact of field operations on soil compaction
- Reducing compaction will reduce the probability of ponding
- Too wet soil surface leads to stickiness and slipperiness, which may seriously diminish both the mobility of vehicles on wet cohesive soil and the quality of the soil structure by remolding.

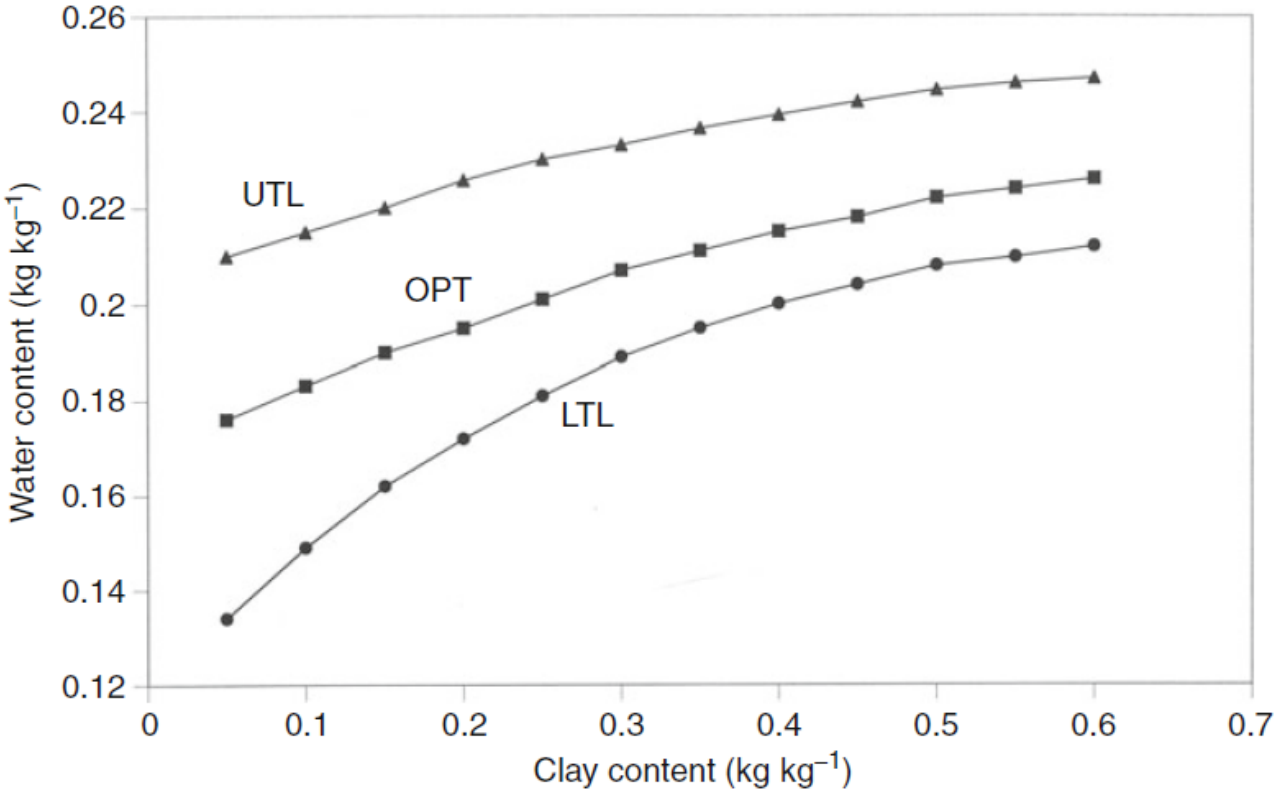
From Regazzi (2020)

# Soil moisture and trafficability

How to estimate trafficability?

First empirical models have been developed for military purposes: the goal was to understand quickly and easily if a certain place could be crossed by military vehicles

Further studies have tried to quantify the relation between soil properties (tillage limit and soil texture) and soil moisture to find optimal conditions (OPT)



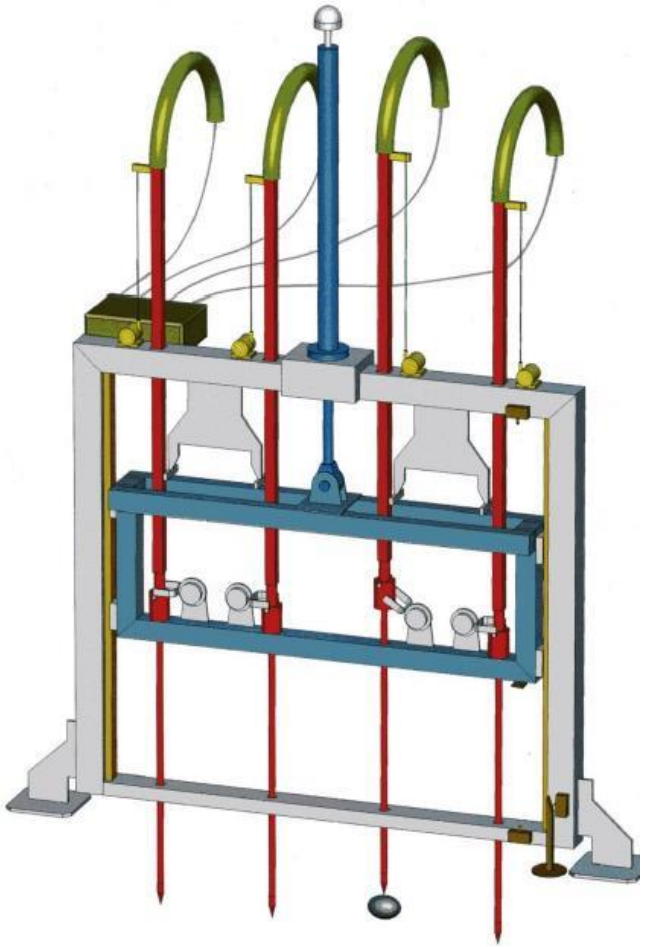

**Trafficability and Workability of Soils, Figure 5** Values of the upper tillage limit UTL, the optimum tillage moisture content OPT (inflection point), and the lower tillage limit LTL as functions of soil clay content (After Dexter and Bird, 2001).

# Penetrometers to quantify soil strength

Common physically based soil measurement methods of the soil strength are shear resistance measured by e.g., penetrometer resistance

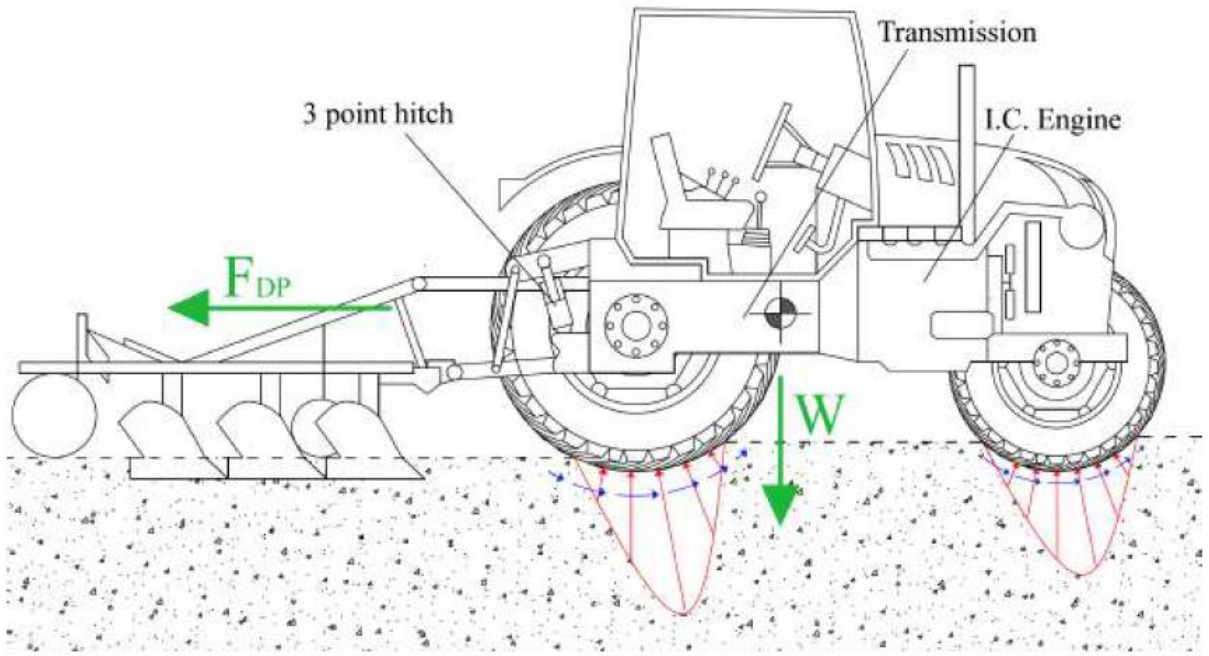
Quadro-penetrometer by ATB


Domsch et al. (2006)



# Optimization of tractors characteristics to minimize effects

From Regazzi (2020)




(a) Forces and stresses during tractor's operational conditions

# But how to measure soil moisture

Direct invasive measurements are not operationally feasible

**E.g., based on remote sensing**

Carranza, Coleen, Harm-jan Benninga, Rogier van der Velde, and Martine van der Ploeg. "Monitoring Agricultural Field Trafficability Using Sentinel-1." *Agricultural Water Management* 224 (September 1, 2019): 105698. https://doi.org/10.1016/j.agwat.2019.105698.

Days favorable for traffic were observed in early spring. This information can aid farmers in the timing of tillage activities or for water managers in deciding to adjust water levels to meet agricultural demands.

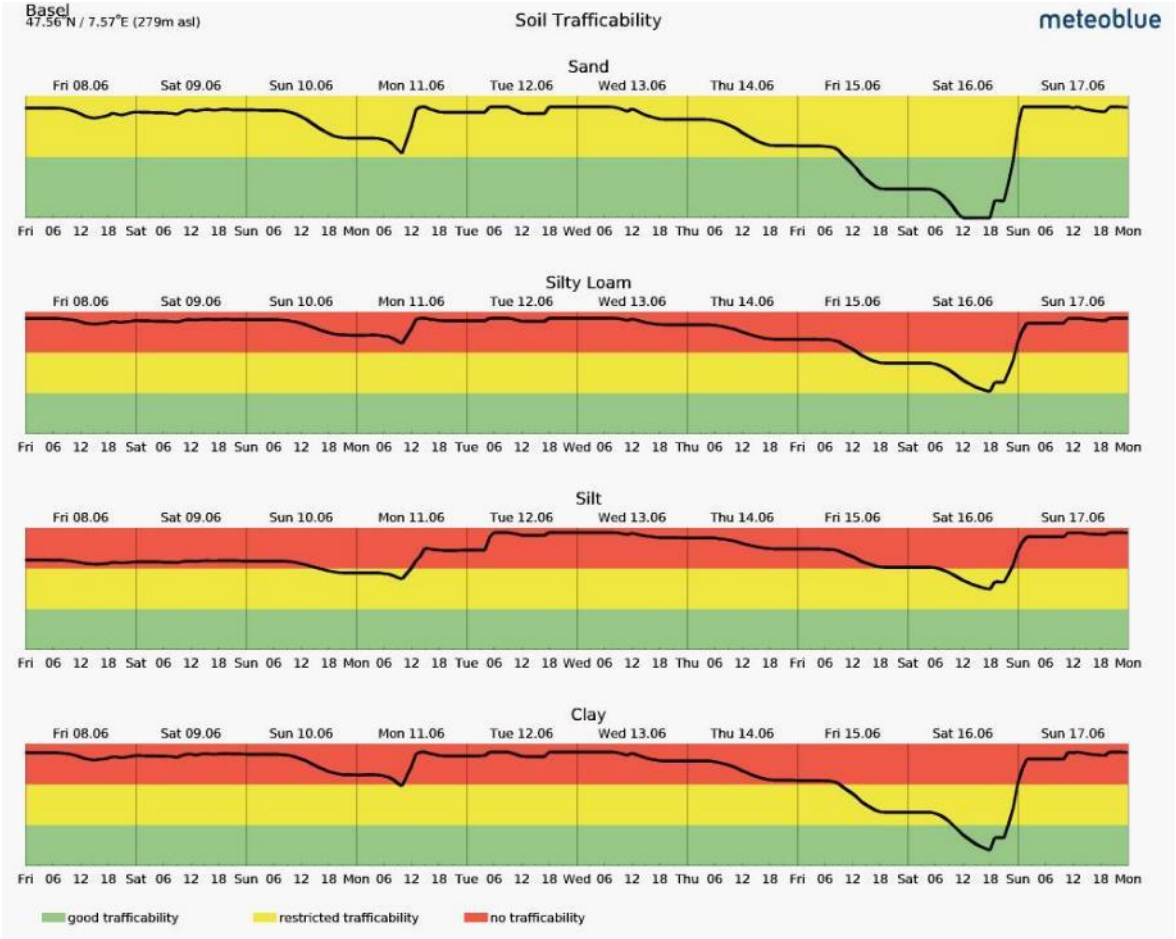
# Modelling e.g., the meteogram Soil Trafficability

It shows the capacity of the soil to support moving vehicles based on the soil type and the development of water content in the topsoil (0-10cm).

Soil Trafficability is represented in a line graph (black) that moves though 3 trafficability conditions, good trafficability (green), restricted trafficability (yellow) and no trafficability (red).

**The calculation uses information of precipitation amount, sunshine hours,** soil-specific water holding capacity and more from the past season, as well as the 7-day forecast.

https://www.meteoblue.com/en/blog/article/show/34885_Soil+Trafficability++



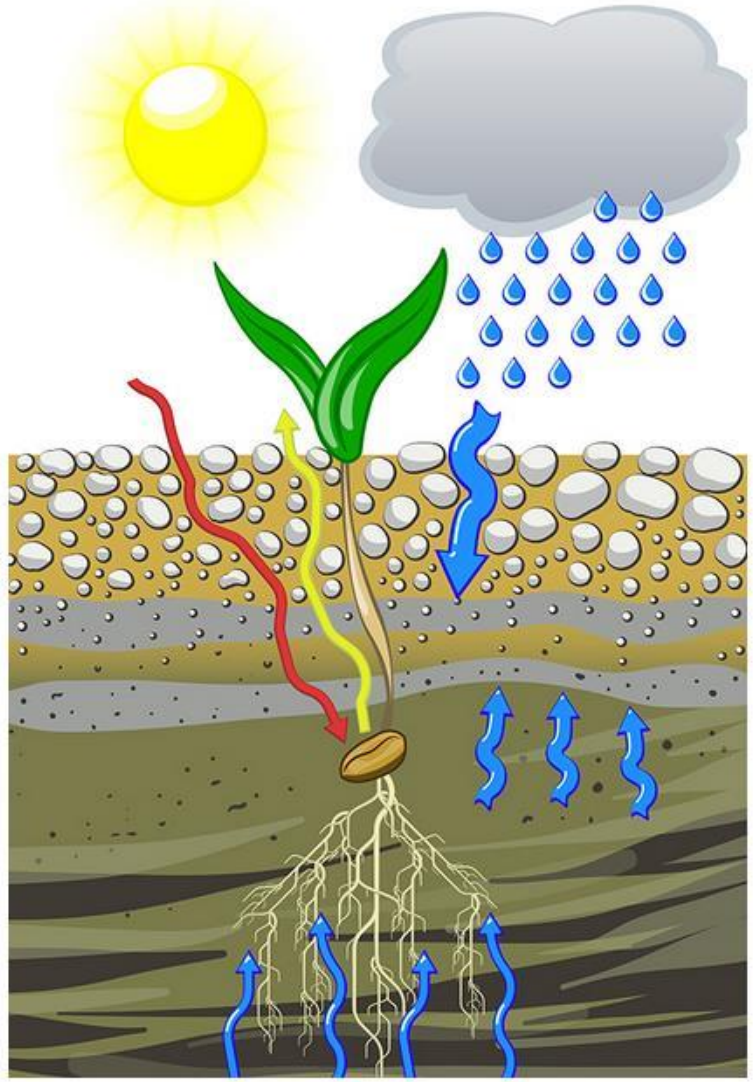
# Soil moisture and sowing

Soil moisture level defines the appropriate time for sowing

Adaptation to seed at different depth depending on soil moisture

Many farmers wait until the topsoil has been moistened to a depth of about 15-20 cm before planting, so that even if there is a subsequent short dry period there is sufficient water within the soil

"dry plant" when soils are dry prior to the onset of the rains. To avoid premature germination before sufficient rain has fallen, the seeds are usually placed deeper than normal



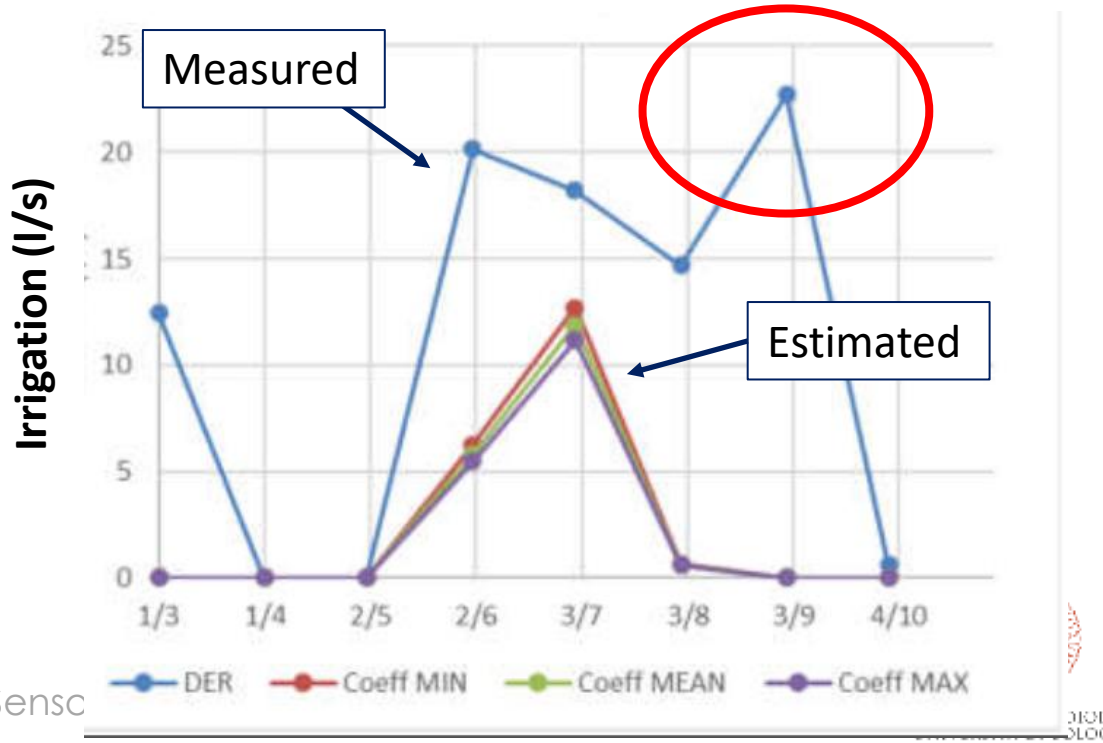
https://www.vaderstad.com/en/know-how/basic-agronomy/seedbeds/seedbed-requirements/

# Soil moisture and harvesting

Soil moisture level defines the appropriate time for sowing, e.g., potatoes

Not too wet as previously discussed for trafficability

But also, not too dry…in Northern Italy a considerable amount of irrigation is practiced before harvesting for preparing the soil. This behavior is not easily quantified for instance by agro-hydrological models that refer to ET for estimation of irrigation water requirements



# Soil moisture, leaching, fertilizer and pesticides

Applying amounts of Nitrogen and Phosphorus fertilizers to soils lacking these nutrients and to pesticides to control biotic stress is a very effective way of increasing crop productivity


A correct timing is important to avoid leaching that:

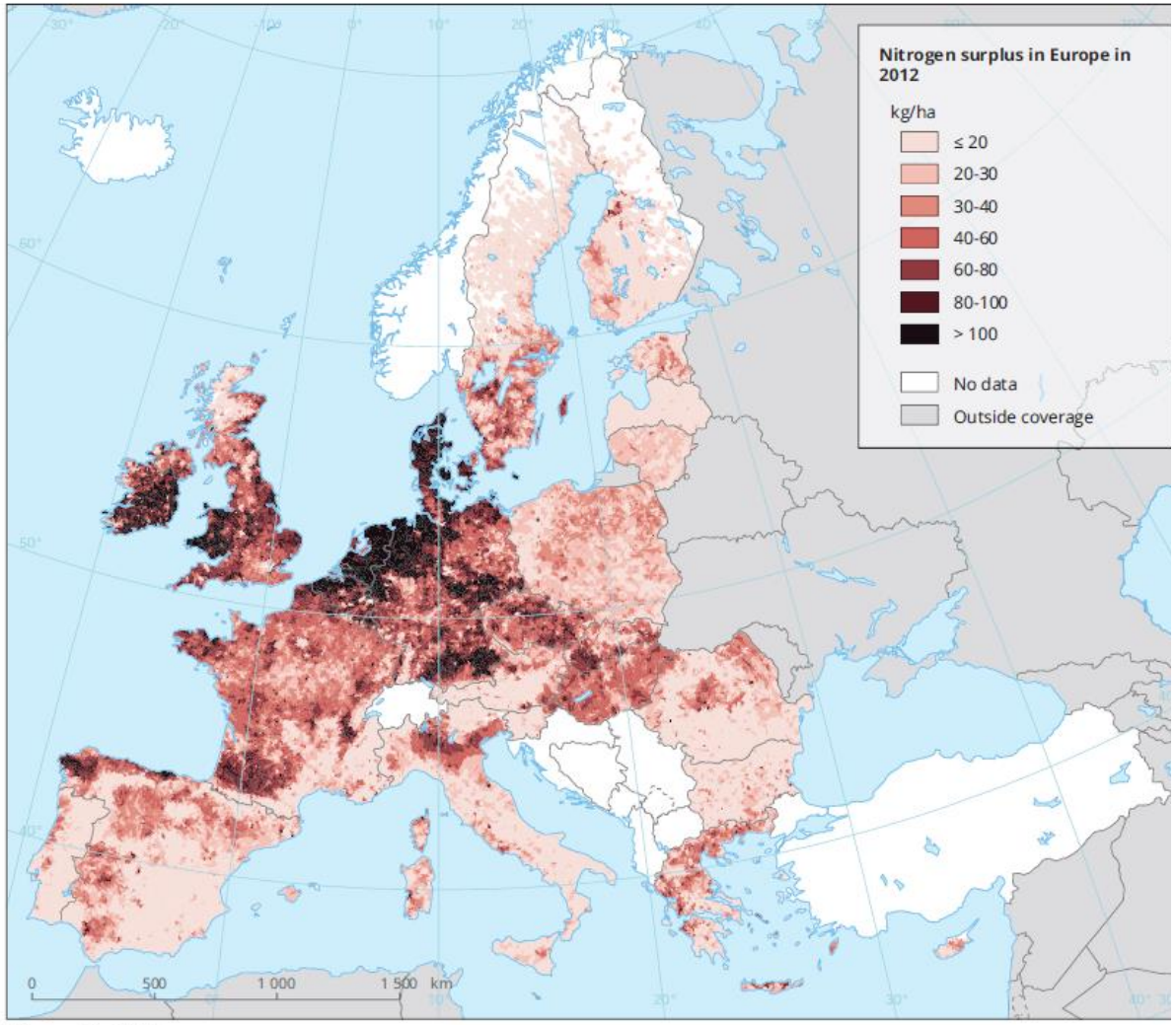
. decrease the effectiveness of the input

. Promote diffuse pollutions to surface water bodies and groundwater

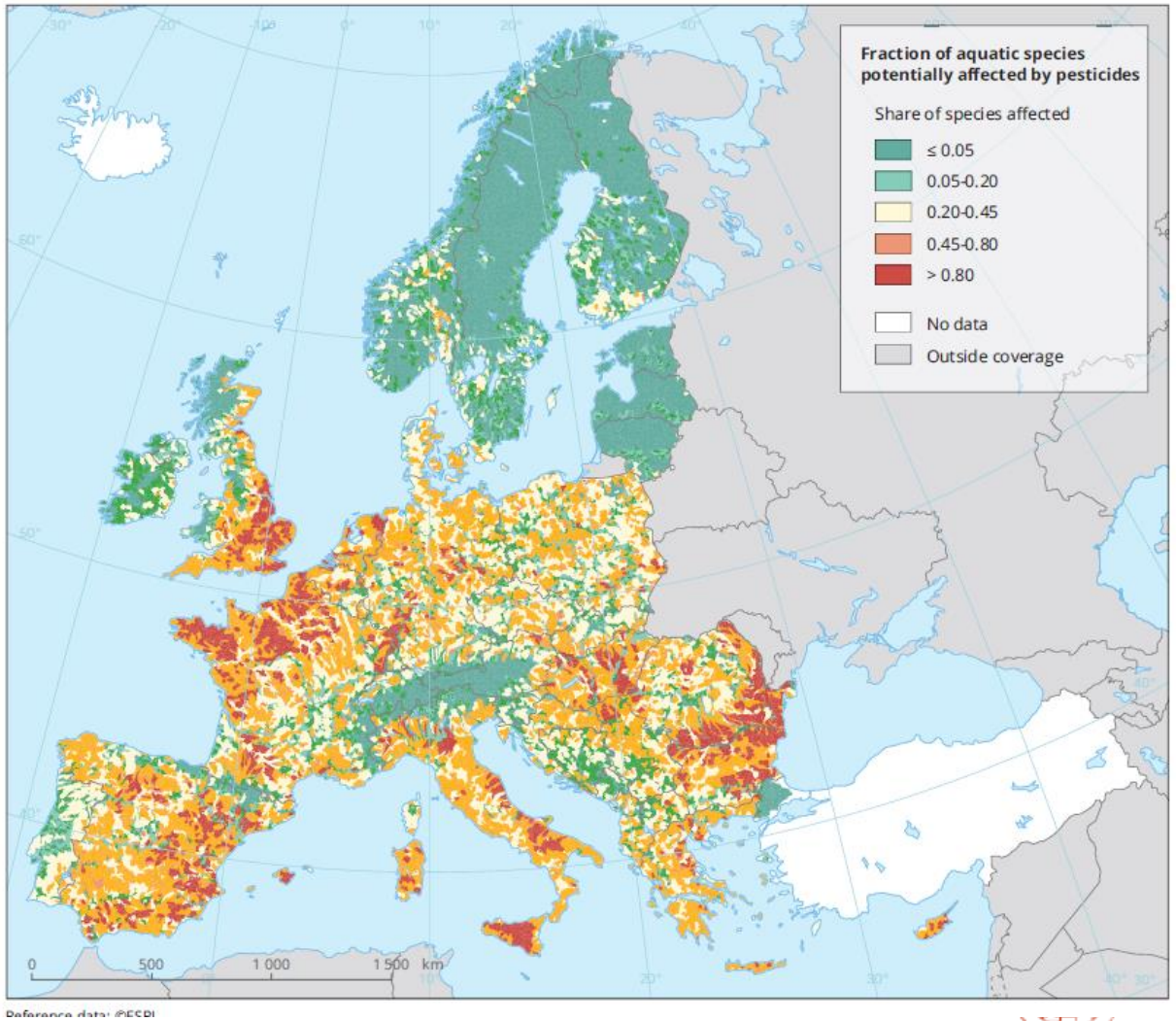
https://czo-archive.criticalzone.org/national/blogs/post/what-is-leaching/

# Soil moisture, leaching, fertilizer and pesticides

**Map 3.1** Nitrogen surplus in Europe in 2012




**Map 3.2** Fraction of aquatic species in Europe potentially affected by pesticides



# Great potential of CRNS for supporting also these activities but…

Trafficability, Sowing, Harvesting, leaching control

So far none of them (as far as I know) has been the focus of current CRNS studies…why?

- Over the last 15 years, the use of CRNS still limited to **research groups**
- Apart from the inherent period of acceptance of new technologies for practical applications, probably **two additional main issues**:

1. Relative more complex signal (footprint and penetration depth) and data processing: this topic discussed and presented by T.Franz and R.Rosolem

2. Technology…

# Boosting CRNS agricultural applications with new technologies

So far CRNS sensors based on shielded proportional gas tube for measuring epithermal neutrons

These proportional gas tubes used also for other applications, and if we look at literature, we find that already 10 years ago there was the call to new sensors

Self-assembled CRNS based on Canberra proportional gas tube (2010)

Nuclear Instruments and Methods in Physics Research A 696 (2012) 110–120

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima




Testing on novel neutron detectors as alternative to $^{3}$He for security applications

Paolo Peerani [a,*], Alice Tomanin [a,b], Sara Pozzi [c], Jennifer Dolan [c], Eric Miller [c], Marek Flaska [c], Marco Battaglieri [d], Raffaella De Vita [d], Luisa Ficini [d,e], Giacomo Ottonello [d], Giovanni Ricco [d,e], Geraint Dermody [f], Calvin Giles [f]

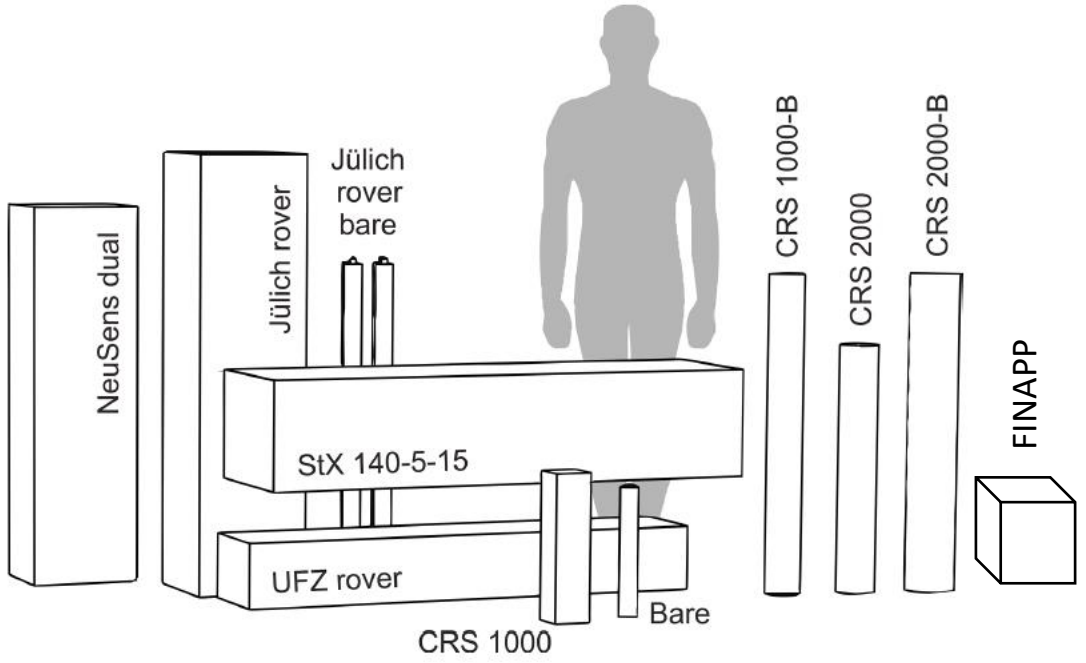
# Boosting CRNS agricultural applications with new technologies

Since some years, we are approaching now also new detectors for CRNS applications.

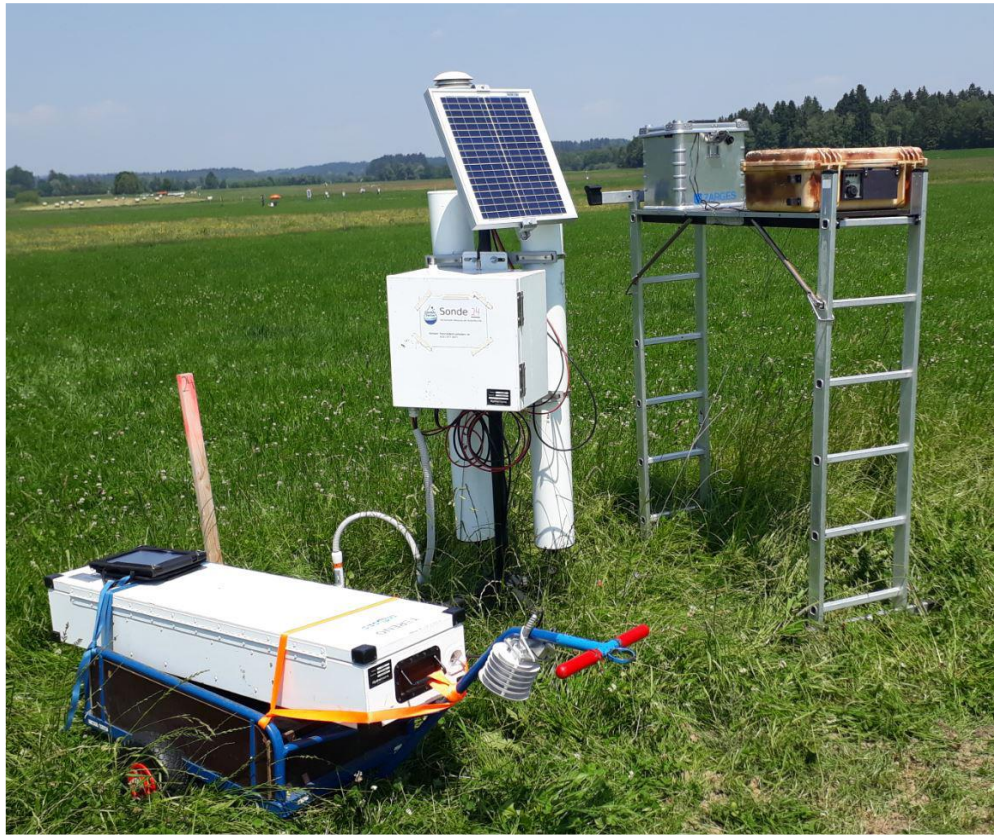
So far four main companies (as far as I know) and many models…more options and opportunities

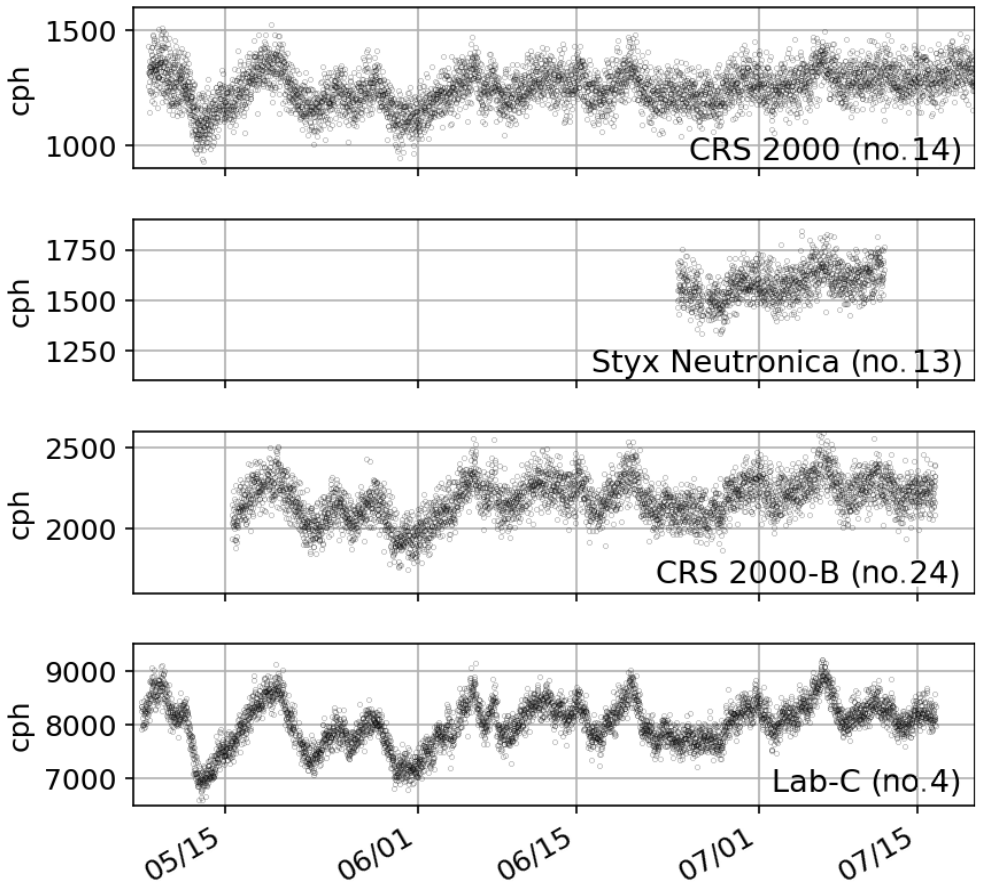
Initiative to compare different sensors, sensitivity and practical advantages (costs, weights and dimensions)

Modified from Fersch, Benjamin, Till Francke, Maik Heistermann, Martin Schrön, Veronika Döpper, Jannis Jakobi, Gabriele Baroni, et al. "A Dense Network of Cosmic-Ray Neutron Sensors for Soil Moisture Observation in a Highly Instrumented Pre-Alpine Headwater Catchment in Germany." *Earth System Science Data* 12, no. 3 (September 23, 2020): 2289–2309. https://doi.org/10.5194/essd-12-2289-2020.



# Boosting CRNS agricultural applications with new technologies

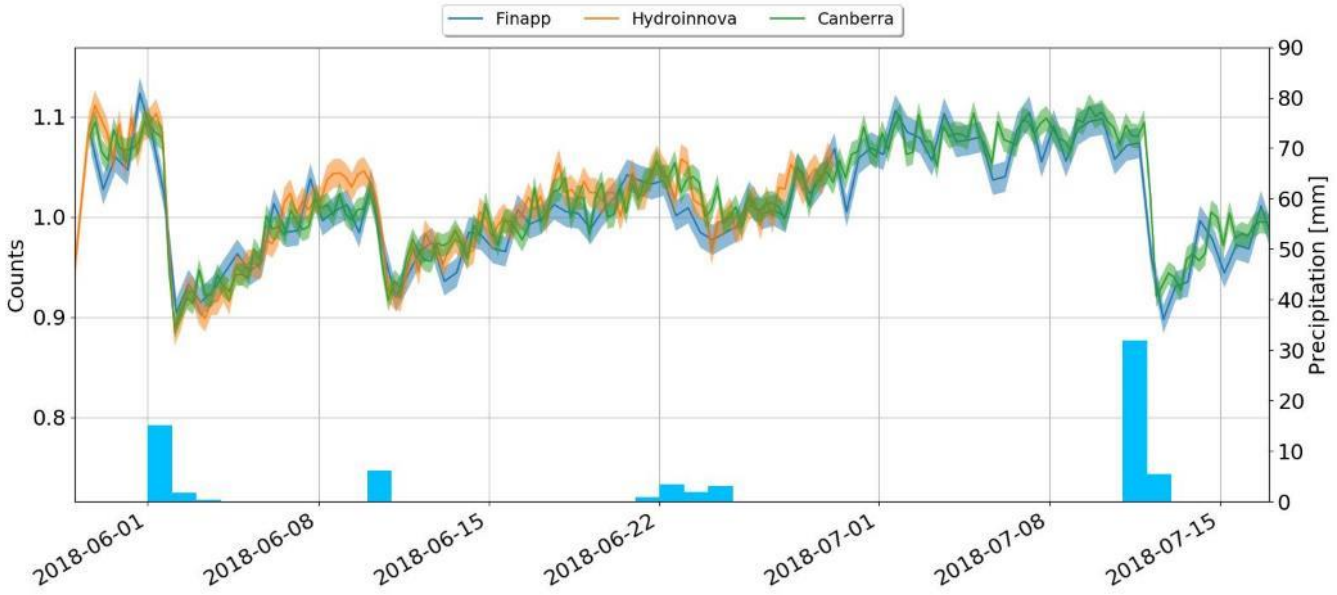





Fersch, Benjamin, Till Francke, Maik Heistermann, Martin Schrön, Veronika Döpper, Jannis Jakobi, Gabriele Baroni, et al. "A Dense Network of Cosmic-Ray Neutron Sensors for Soil Moisture Observation in a Highly Instrumented Pre-Alpine Headwater Catchment in Germany." *Earth System Science Data* 12, no. 3 (September 23, 2020): 2289–2309. https://doi.org/10.5194/essd-12-2289-2020.

# My specific activities

- I'm currently testing a new sensor developed by a group in Padova (Italy) in different environmental conditions
- First results have been published (Stevanato et al., 2019). The new detector showed to be a competitive alternative to proportional gas tubes with the advantages of measuring also other particles (muon and gamma)





Stevanato, Luca, Gabriele Baroni, Yafit Cohen, Fontana Cristiano Lino, Simone Gatto, Marcello Lunardon, Francesco Marinello, Sandra Moretto, and Luca Morselli. "A Novel Cosmic-Ray Neutron Sensor for Soil Moisture Estimation over Large Areas." *Agriculture* 9, no. 9 (September 2019): 202. https://doi.org/10.3390/agriculture9090202.

# My specific activities

Potsdam University (Germany)

Current studies aiming on:

- Further comparison of different detectors in collaboration with IAEA (Vienna, Austria) and University of Potsdam (Germany)
- Integrating of CRNS into agro-metereology station for drought monitoring
- Improving the use of CRNS for irrigation scheduling and agricultural activities

# Conclusions

Soil moisture estimation based on CRNS has many potentialities

- for supporting agriculture activates
- for developing agricultural best management practices

So far most of them have not been explored due to some extend on:

- Time lag of accepting new technology
- Relative complexity in comparison to point-scale soil moisture sensors
- Manufactures (proportional gas tubes)

Several initiatives are boosting the applications of CRNS. Among them, this nice workshop promoted by the International Centre for Theoretical Physics and IAEA

**I hope I made with this presentation my first contribution for further advances**

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

**Ass.Prof. Gabriele Baroni**

Department of Agricultural and Food Sciences (DISTAL)

g.baroni@unibo.it