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Società Italiana di Agronomia, XLV Convegno Nazionale, Università degli Studi di Sassari, 21 Settembre 2016

The DIAnA project: integrating soil and crop sensing methods to support nitrogen fertilization on wheat and barley

Bregaglio, S., Ortuani, B., Corti, M., Cabassi, G., Cavalli, D., Movedi, E., Gilardelli, C., Degano, L., Confalonieri, R., Facchi, A., Galassi, G., Boschi, L., Casarico, L., Magnani, E., Righi Ricco, C., Ditto, D., Marino Gallina, P.

University of Milan, Department of Agricultural and Environmental Sciences



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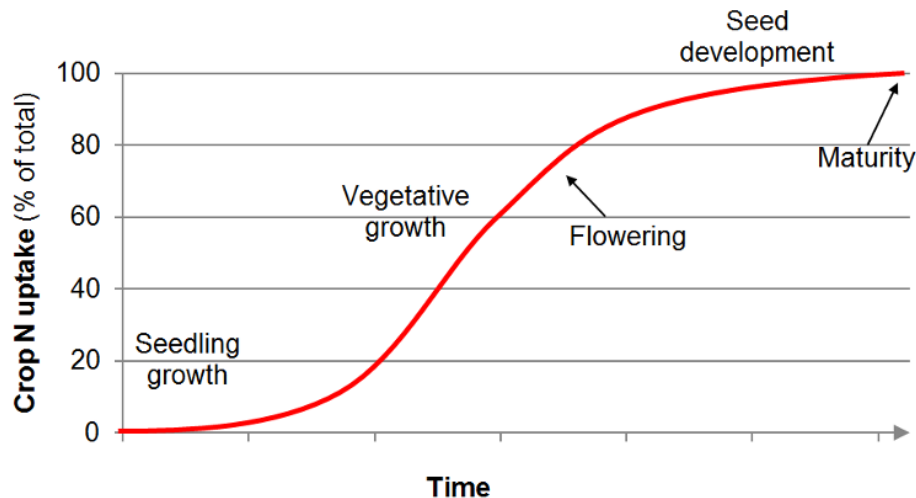
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Introduction

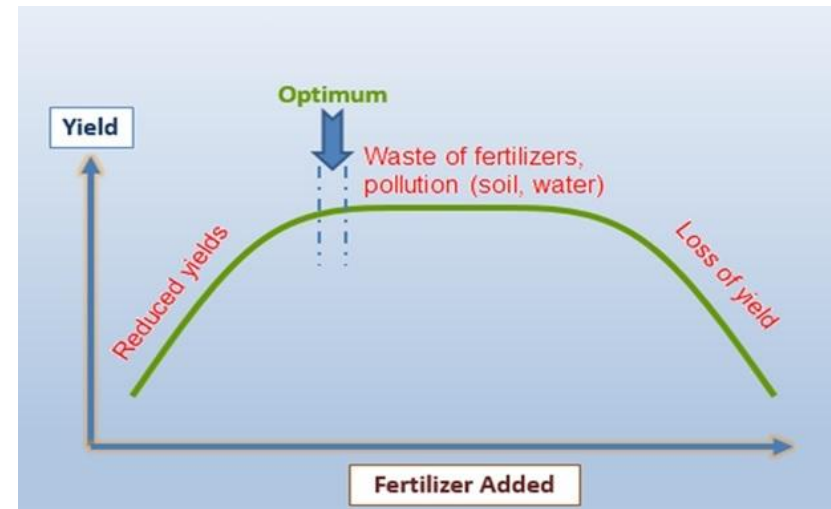
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- In **current high-yielding cropping systems**, the **efficient** application of **nitrogen fertilizers** is essential, as it allows modern cultivars to express their **yield potential** (Sinclair and Rufty, 2012).
- **Optimizing the timing and dose** of nitrogen fertilization is a key challenge for global agriculture (Tilman, 2002), which is in charge of **increasing food production** while **minimizing environmental pollution** due to nitrate leaching, N denitrification and volatilization (Mueller et al., 2012).

N uptake during the crop cycle

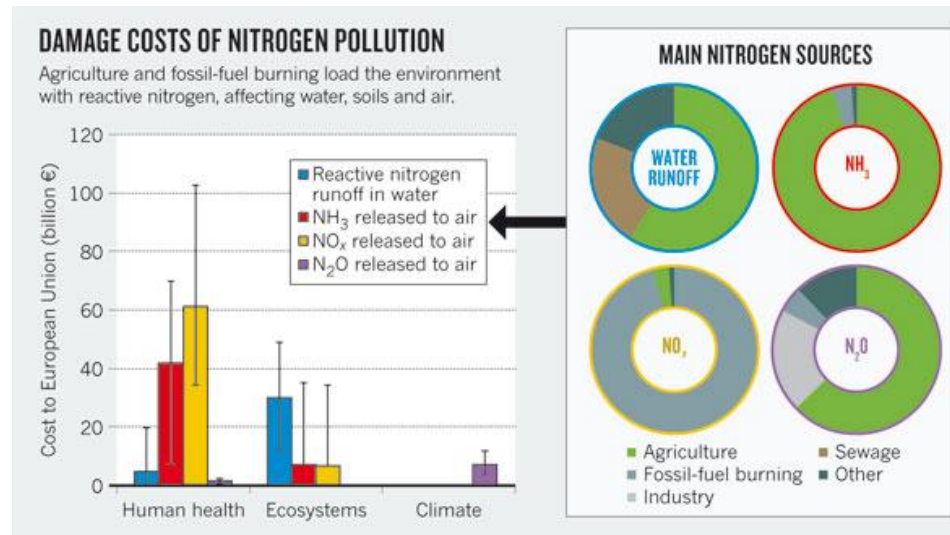
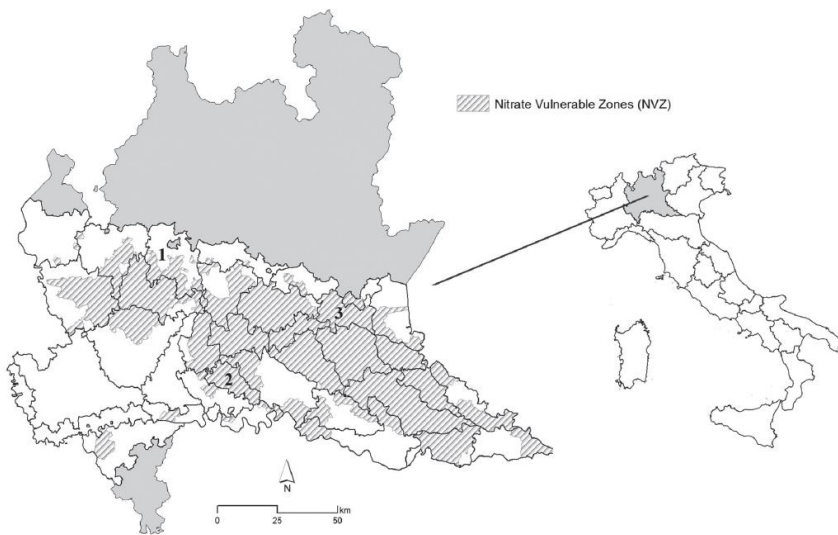


Yield response to increased nitrogen dose



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- In Europe, available estimates of the **cost of excessive nitrogen fertilizations** range from **70 to 320 million euro**, representing more than double than the **benefit on farmers' income**.
- **Wheat and barley** are among the main cereal crops, covering nearly **40% of the cropped area**, the former being first in fertilizers application



Sutton, 2011. Nature

- In **Northern Italy**, the two crops extend for **more than 600,000 ha**, and are mainly cultivated in **vulnerable zones for nitrate leaching** (Acutis et al., 2014).

Perego et al., 2013. Italian Journal of Agrometeorology



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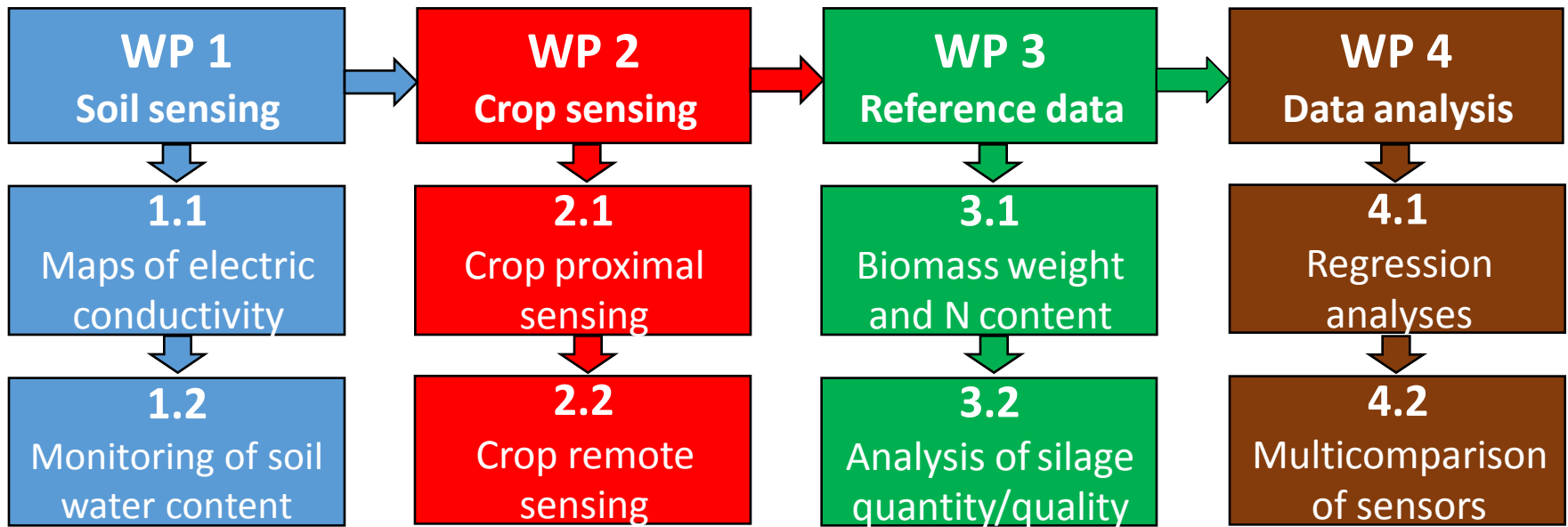
Objective of the project

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- **Improving** the management of **nitrogen fertilizations** in our conditions is then crucial to determine **win-win scenarios between yield and sustainability** of these cereals cropping systems.
- **The DIAnA project** was funded in 2016 by University of Milan with the objective of **setting up an operational framework** to integrate/compare the information collected by **alternative proximal and remote sensing methods** to assess **soil variability** and **to** diagnose the **nitrogen use** and **requirements**.
- The involvement of **domain experts** in different agricultural sciences as **soil mapping and hydrology, agronomy** and **animal nutrition** allowed to use a **multidisciplinary approach** to meet the project objectives.
- The **aboveground biomass**, the **nitrogen content** and then the **nitrogen uptake** were the main crop target variables, which were **monitored during the crop cycle** in order to assess the **nonlinear response** of wheat and barley crops to **nitrogen fertilizations**.

Project organization

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- **WP1** measured the **in-field variability of soil electric conductivity** in a wheat and barley field **to guide the selection of experimental areas**
- **WP2** performed **multiple samplings** to characterize the dynamic pattern of **AGB and N content** via proximal and remote sensing.
- **WP3** produced the **reference data to compare** the performances of the methods, considering also the **qualitative value** for feeding purposes.
- **WP4** is analysing **the relationships** between **reference data** and the **quali-quantitative value** of crop production and compared **the performances** of **proximal and remote sensing methods**.



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Soil proximal sensing

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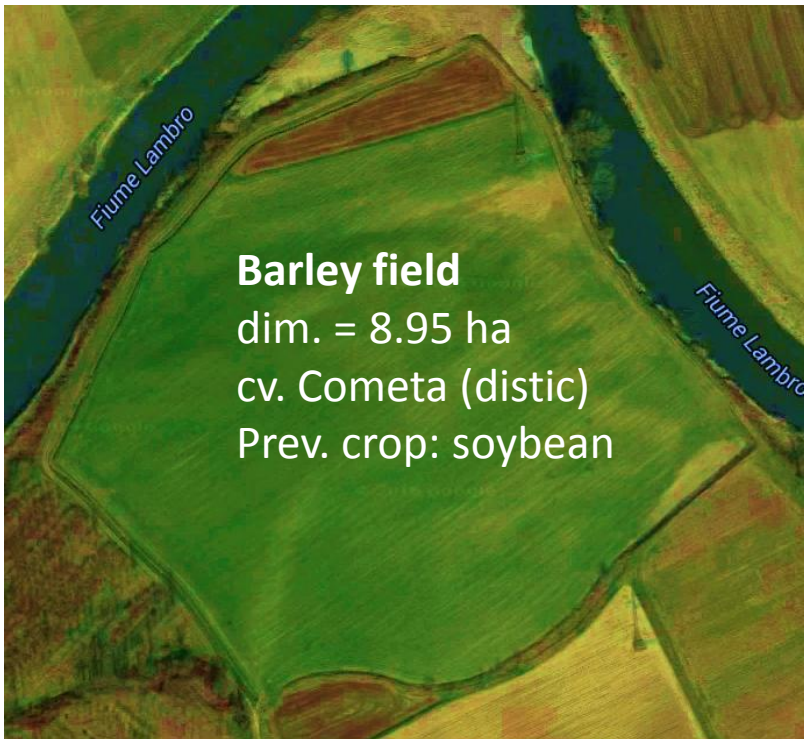
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- A **wheat and a barley** field owned by Fondazione Morando Bolognini were selected to perform our experiment. Soil mapping was carried out on January, 29th



Soil proximal sensing

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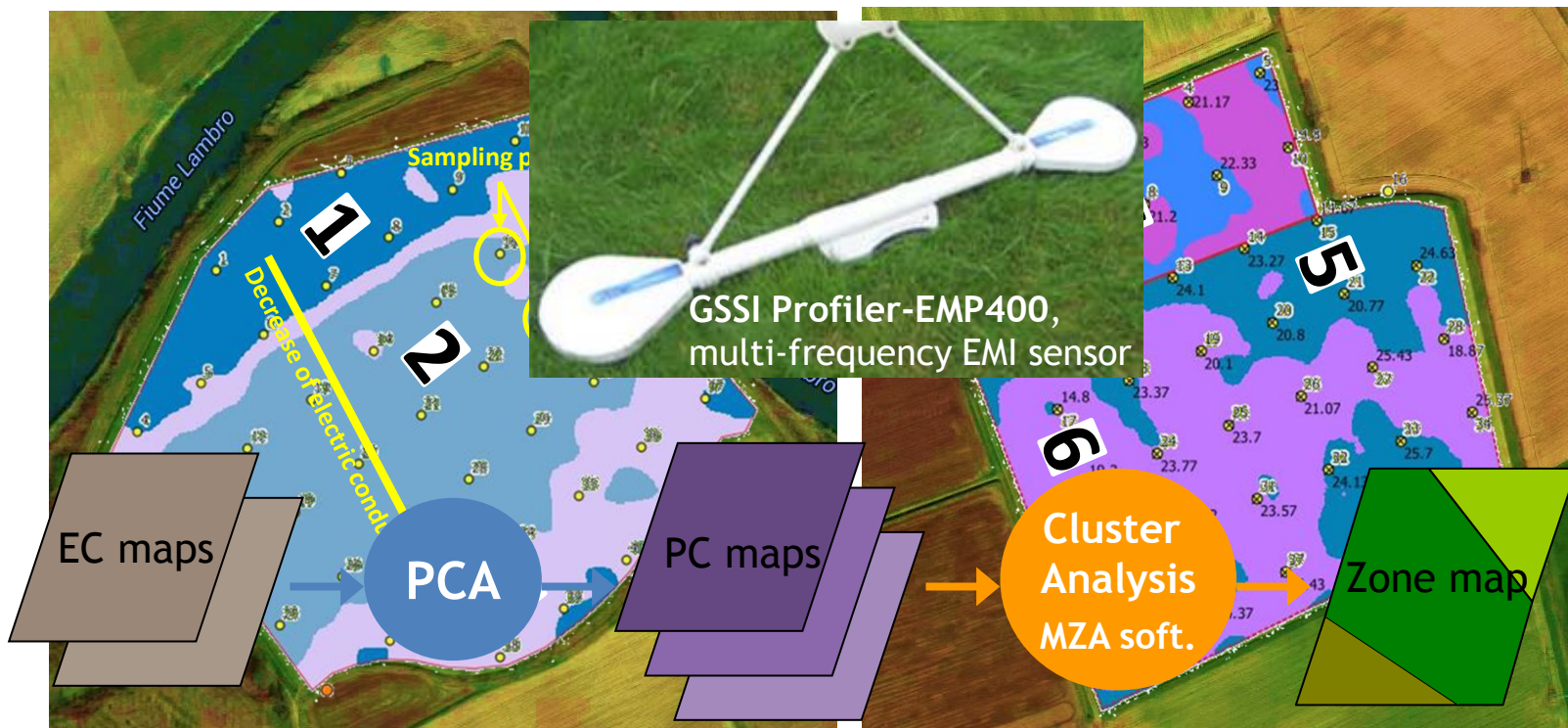
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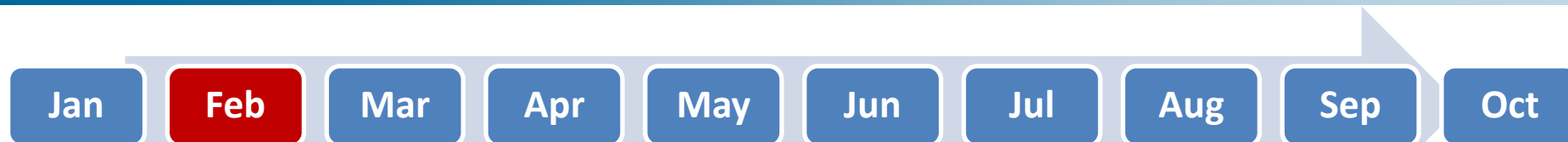
- The two fields were scanned by GSSI Profiler-EMP400, multi-frequency EMI sensor (depth 1-2 and 2-3 m). **PCA** was performed on **EMI results** to select **three homogeneous areas** per field where **experimental plots** were placed.



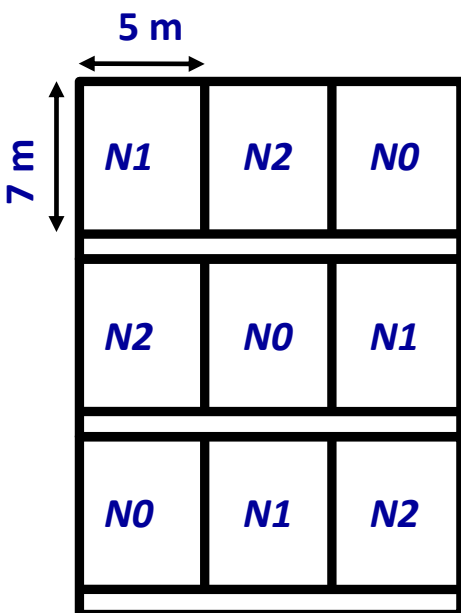


Experiment design

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- In each field, the experiment followed a randomized block design with three replicates (plot size 5m × 7m) .
- The plots received the application of three N levels (N0 = unfertilised, N1, N2, representing 50% and 100% of the farmer fertilization rate, respectively).



BLOCK 3 First top dressing: February, 13th, ammonium nitrate (26.5)

BLOCK 2 Second top dressing: March, 18th, urea (46)

BLOCK 1

N1	kg N ha ⁻¹	
	1 st	2 nd
Barley	26	35
Wheat	26	46

N2	kg N ha ⁻¹	
	1 st	2 nd
Barley	52	69
Wheat	52	92

Proximal sensing

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- Five samplings were performed with **two proximal sensors of the N content** in key phenological stages for nitrogen applications. **Two samplings** were done the day **before** top dressing **fertilizations**; the **last three** at **flowering, watery ripe** and **hard dough stage**.



DUALEX SCIENTIFIC+™

- It measures **the content of chlorophyll and the nitrogen status** as well as the flavonols and the anthocyanins of the leaf.
- It produces an indicator, **NBI**, used as **proxy of crop nitrogen status** basing on primary and secondary metabolism.
- **8 measures** for each plot



PocketN

- It is a **smart app** based on the **acquisition of leaf images** on a background panel with a reflectance close to the one of 18% grey cards used in photography (Confalonieri et al., 2015).
- It provides as output a **unitless index** (the higher the value, the higher nitrogen content).



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Remote sensing

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- **Two flights** with **drones** equipped with **multispectral camera** (RedEdge™ 3, MicaSense) were performed **the same day** of the 2nd and 4th proximal sampling.
- **Seven vegetation indices** were acquired in each experimental unit:
 1. Green Normalized Difference Vegetation Index (gNDVI)
 2. Green Chlorophyll Index (GCI)
 3. Simple Ratio (SR)
 4. Normalized Difference Vegetation Index (NDVI)
 5. Red-Edge Chlorophyll Index (CI_RE)
 6. Normalized Difference Red-Edge (NDRE)
 7. Visible Atmospherically Resistant Index (VARI)
 8. Green Leaf Index (GLI)
- **Destructive samplings** of aboveground biomass (0.5 m²) were also taken in order to obtain **reference data of dry matter and N concentration** (NCHS determination)



Aboveground biomass – barley field

Phenology	Factor	df	F	p-value
Tillering BBCH = 23	Area	2	4.537	0.027
	Nitrogen	2	0.00	1
	Area * Nitrogen	4	0.00	1
Stem elongation BBCH = 30	Area	2	5.448	0.016
	Nitrogen	2	4.194	0.034
	Area * Nitrogen	4	0.680	0.616
Booting BBCH = 43	Area	2	1.039	0.376
	Nitrogen	2	0.849	0.849
	Area * Nitrogen	4	0.810	0.810
Fully ripe BBCH = 99	Area	2	13.267	<0.001
	Nitrogen	2	1.551	0.242
	Area * Nitrogen	4	1.502	0.249

- The effect of the **experimental area was significant** in three samplings out of four.
- **Nitrogen effect** was significant only **at stem elongation phase**, after first top dressing fertilization
- **Interactions** were always **not significant**.

- We had a **very high weed infestation** in this field, so specific results are certainly affected



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Results - ANOVA

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Phenology	Factor	df	F	p-value
Tillering (2-3) BBCH = 22	Area	2	0.300	0.744
	Nitrogen	2	0.00	1
	Area * Nitrogen	4	0.00	1
Tillering (5-6) BBCH = 25	Area	2	3.321	0.062
	Nitrogen	2	9.297	0.002
	Area * Nitrogen	4	1.013	0.430
Stem elongation BBCH = 32	Area	2	37.251	<0.001
	Nitrogen	2	15.788	<0.001
	Area * Nitrogen	4	1.896	0.160
Early milk maturity BBCH = 73	Area	2	117.91	<0.001
	Nitrogen	2	33.64	<0.001
	Area * Nitrogen	4	4.221	0.054
Medium milk maturity BBCH = 75	Area	2	136.31	<0.001
	Nitrogen	2	52.37	<0.001
	Area * Nitrogen	4	4.221	0.016
Fully ripe BBCH = 99	Area	2	292.69	<0.001
	Nitrogen	2	85.159	<0.001
	Area * Nitrogen	4	9.620	<0.001

Aboveground biomass - wheat

- The effect of the **experimental area was significant** starting from stem elongation phase
- **Nitrogen effect** was significant in each sampling performed after top dressing fertilizations.
- **Interactions** were **significant** only during ripening.

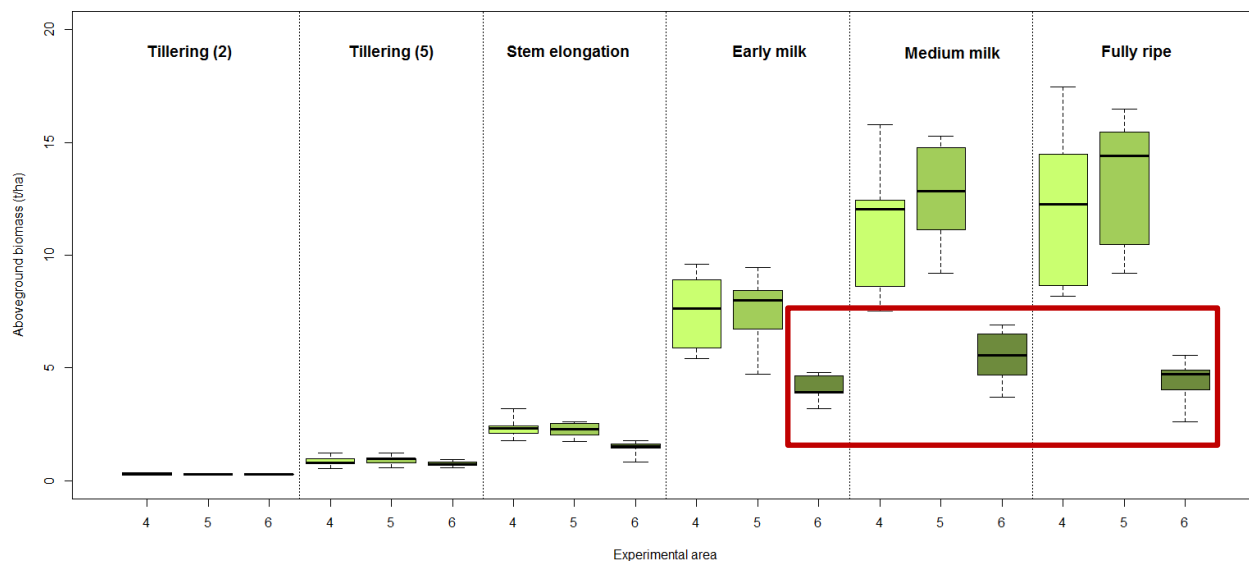
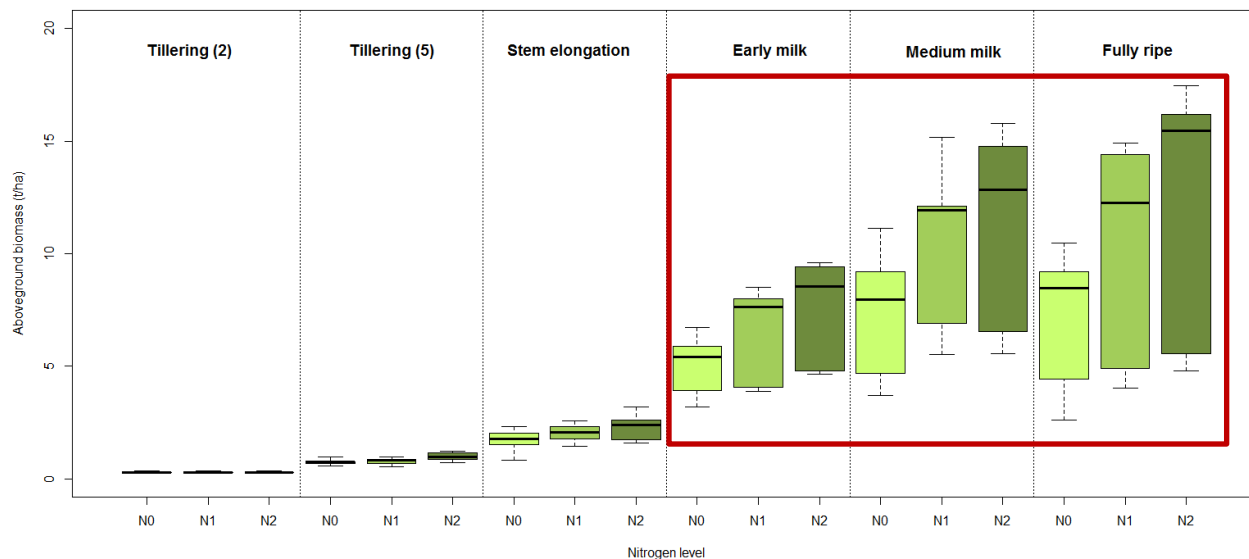


Results - ANOVA

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Aboveground biomass

- Clear gradient in aboveground biomass
 $N_0 < N_1 < N_2$
- **Experimental area 6** showed **stunted growth**, probably due to very high sand content → no N (water stress)
- **Experimental area 5** showed the **highest aboveground biomass**





Preliminary results

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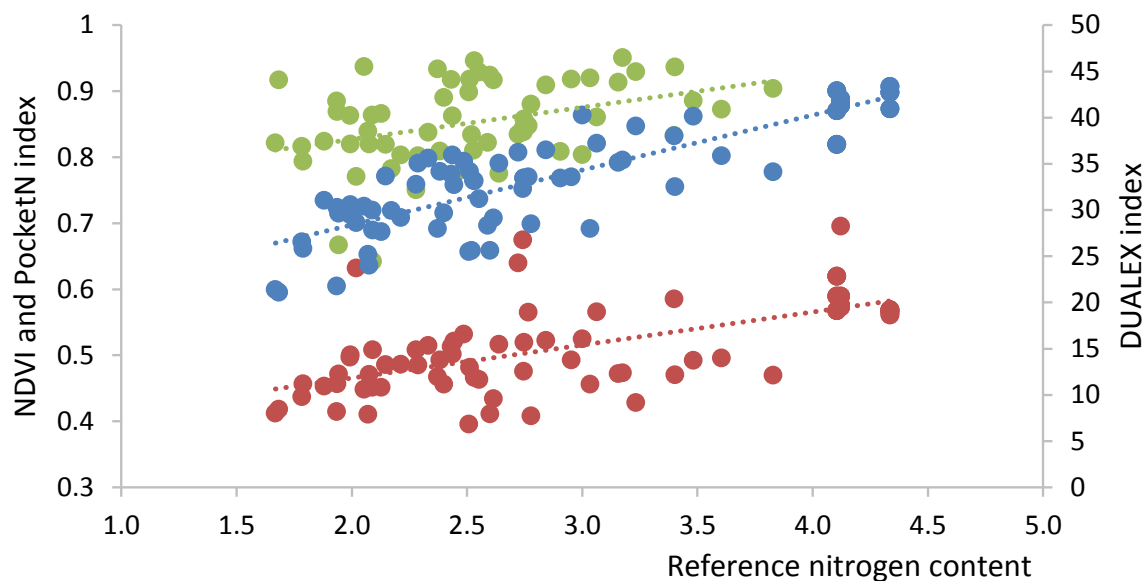
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- A **linear regression analysis** was performed using **reference N content** as dependent variable and the the responses of **proximal and remote sensors** as regressors.
- Only results for barley are shown here.

● PocketN $R^2 = 0.4626$ ● NDVI $R^2 = 0.1438$ ● DUALEX $R^2 = 0.7693$

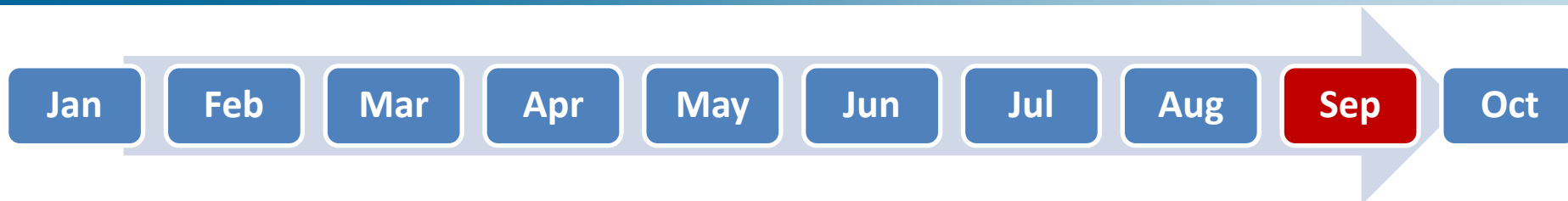


Considering the three experimental areas, **all regressions were significant ($p < 0.01$)**, with DUALEX data showing more correlation with reference N data ($R^2 = 0.769$), followed by PocketN ($R^2 = 0.463$) and NDVI ($R^2 = 0.144$)



Preliminary results

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- After computing **nitrogen concentration** using regression equations, this is the **time dynamic**.

Sampling date 1 - February, 11th

Tillering stage

no fertilization applied

Sampling date 2 - March, 17th

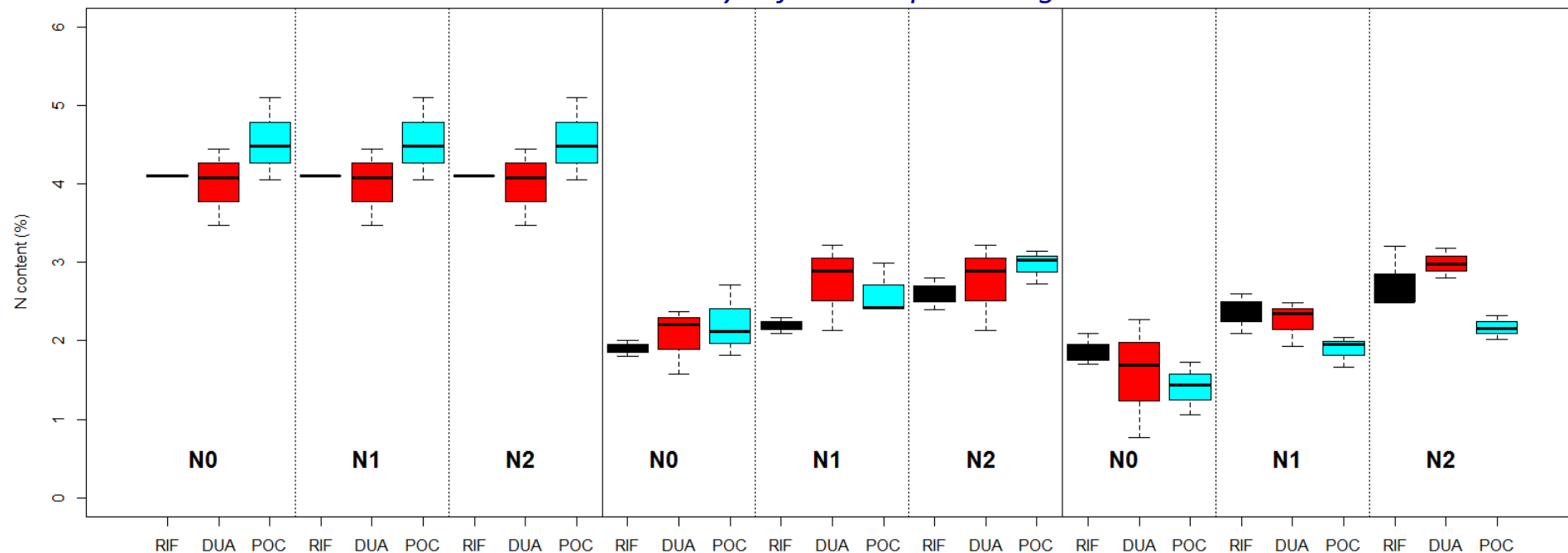
Stem elongation

15 days after 1st top dressing

Sampling date 3 - April, 5th

Booting

15 days after 2nd top dressing





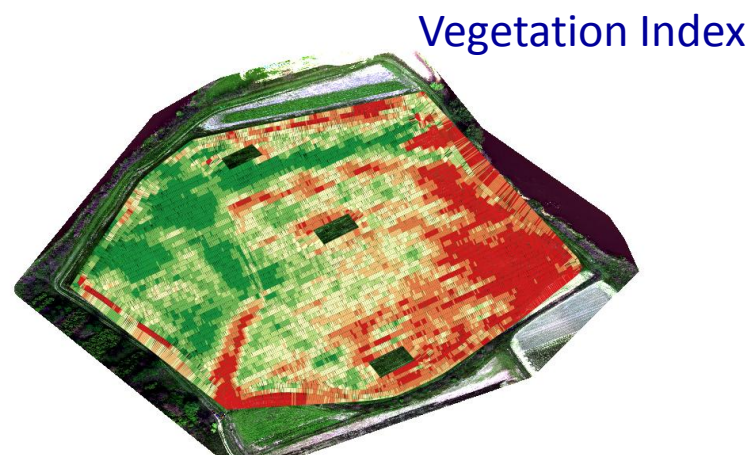
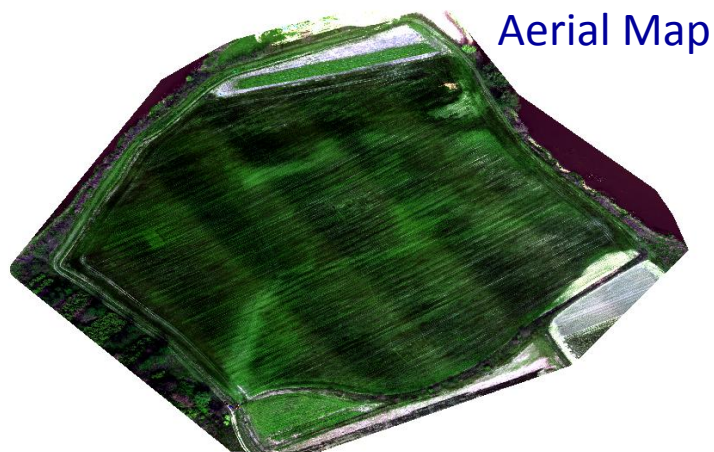
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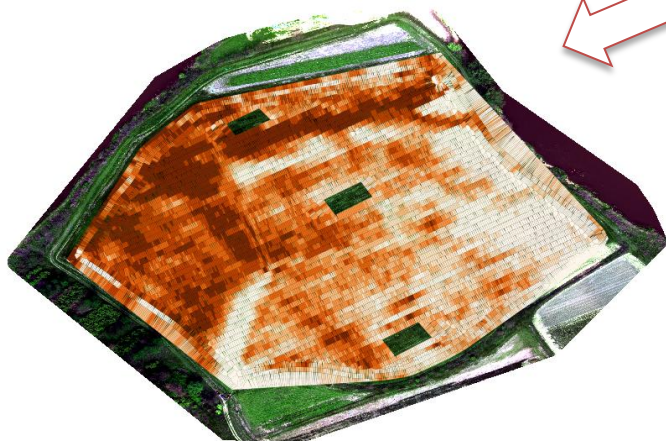
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Preliminary results

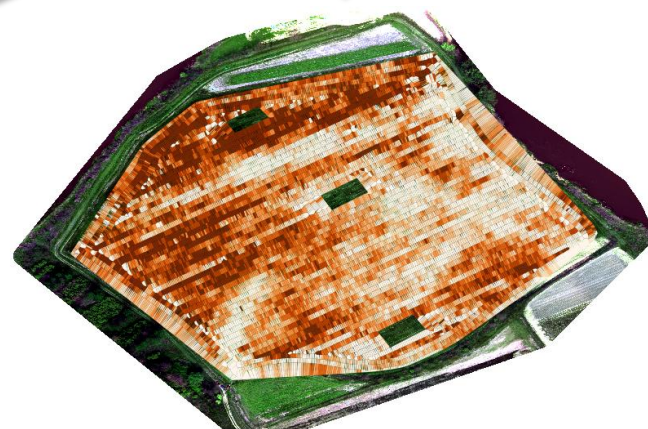
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*Empirical
correlation*



Estimated Yield Map



Actual Yield Map



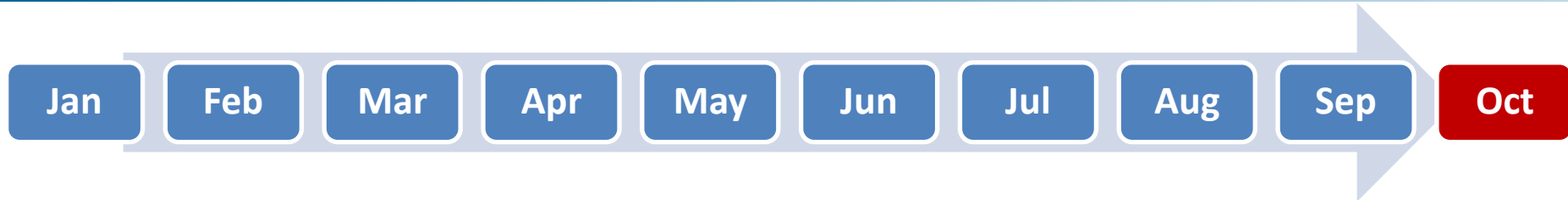
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Conclusions

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- This is an **ongoing work** (the project ends in December). We have still to
 - ✓ **analyse nitrogen content** in the last sampling,
 - ✓ Perform **bromatological analysis** on **winter wheat** collected at milk maturity
 - ✓ **Statistical analysis must be improved**, as well as the **calibration of proximal sensors**
 - ✓ We have to estimate **crop nitrogen uptake** based on aboveground biomass and nitrogen concentration, and to **correlate** it with the **responses** of **remote and proximal** sensors.
- **These results are preliminary**, and indicate that the datasets collected during the project are valuable and can be functional to fulfill the project objective.
- A MS Access **database** is being developed, to make **available** these data **for the community**.



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Thank you for your attention





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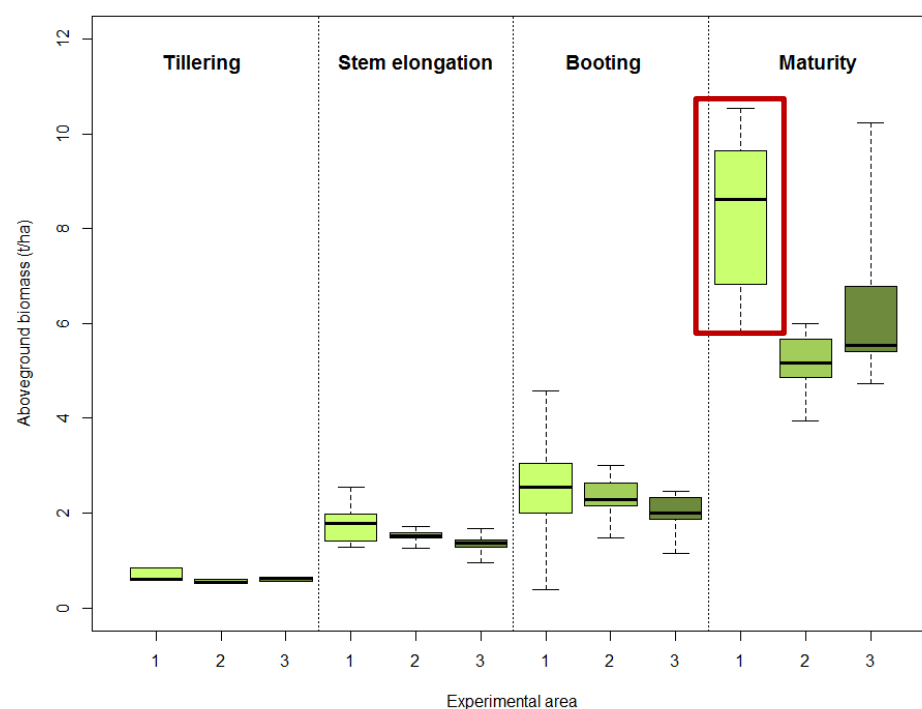
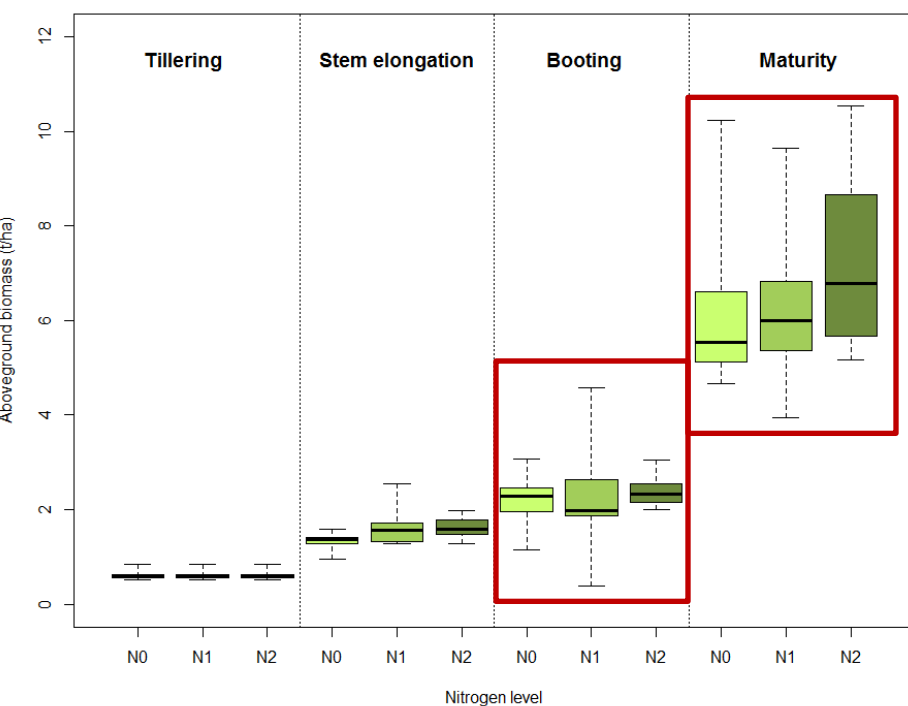
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References

- Acutis, M. et al., 2014. ValorE: An integrated and GIS-based decision support system for livestock manure management in the Lombardy region (northern Italy). *Land Use Policy* 41:149-162.
- Confalonieri, R., Paleari, L., Movedi, E., Pagani, V., Orlando, F., Foi, M., Barbieri, M., Pesenti, M., Cairati, O., La Sala, M.S., Besana, R., Minoli, S., Bellocchio, E., Croci, S., Mocchi, S., Lampugnani, F., Lubatti, A., Quarteroni, A., De Min, D., Signorelli, A., Ferri, A., Ruggeri, G., Locatelli, S., Bertoglio, M., Dominoni, P., Bocchi, S., Sacchi, G.A., Acutis, M., 2015. Improving in vivo plant nitrogen content estimates from digital images: trueness and precision of a new approach as compared to other methods and commercial devices. *Biosystems Engineering*, 135, 21-30.
- Mueller N. et al., 2012. Closing yield gaps through nutrient and water management. *Nature* 490:254-7.
- Perego, A., Giussani, A., Fumagalli, M., Sanna, M., Chiodini, M., Carozzi, M., Alfieri, L., Brenna, S., Acutis, M., 2013. Crop rotation, fertilizer types and application timing affecting nitrogen leaching in nitrate vulnerable zones in Po Valley. *Italian Journal of Agrometeorology* 2, 39-50.
- Sinclair, T.R., Rufty, T.W., 2012. Nitrogen and water resources commonly limit crop yield increases, not necessarily plant genetics. *Glob. Food Sec.* 1:94-98.
- Sutton, M.A. et al., 2011. Too much of a good thing. *Nature* 472:159-161
- Tilman G. et al. 2002. Agricultural sustainability and intensive production practices. *Nature*, 418:671-7.

- **Large variability** in the **nitrogen effect**, with **no clear increase** in **aboveground biomass** with higher N doses.
- **Experimental area 1** was **more productive** in terms of biomass.
- **Experimental areas 2 and 3** showed **similar growth** of barley crop.





Preliminary results

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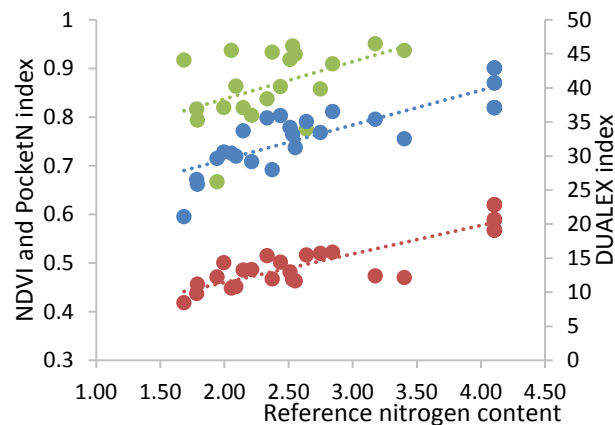
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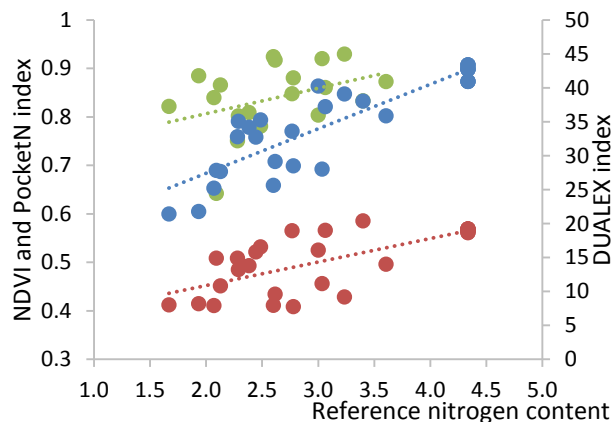
Area 1

● PocketN ● NDVI ● DUALEX
 $R^2 = 0.799$ $R^2 = 0.224$ $R^2 = 0.741$



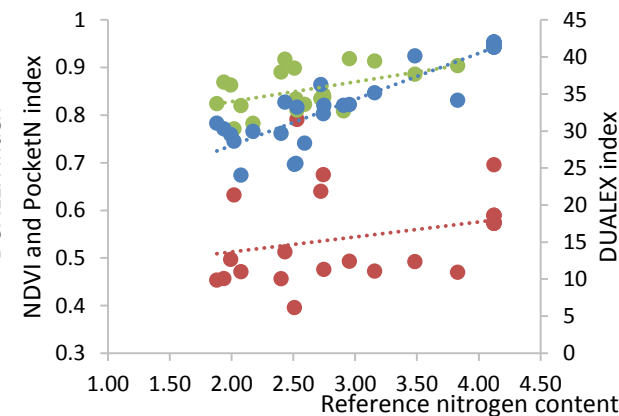
Area 2

● PocketN ● NDVI ● DUALEX
 $R^2 = 0.526$ $R^2 = 0.149$ $R^2 = 0.777$



Area 3

● PocketN ● NDVI ● DUALEX
 $R^2 = 0.095$ $R^2 = 0.223$ $R^2 = 0.811$



- **DUALEX** resulted the **most accurate sensor** in reproducing the variability of N concentration, with **similar performances** in the three areas (R^2 ranging from 0.77 to 0.82).
- **NDVI** kept a **low and stable** degree of accuracy (R^2 ranging from 0.15 to 0.22).
- Poor results of **PocketN** only in Area 3, due to **errors in image acquisition**.