NFTN conference 2024

OnFarmPlus: large-scale, sensor-intensive multi-plot field trials for testing of biostimulants and precision farming techniques

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Biostimulants and precision farming (PF) claim to improve outputs or mitigate negative side-effects in agricultural crop production due to an **area-specific mode-of-action**:

“Do the right thing at the right spot
(at the right time)”.

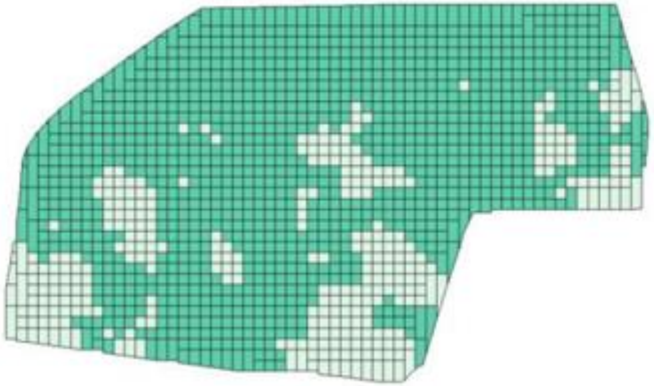
Precision Farming (PF)

- **Area-specific**
  - because soil type, plant nutrient availability, plant water availability, and pest pressure vary across space

- **Time-specific**
  - because – in interplay with climatic conditions – they also vary with time

- Hence, **optimization** of plant productivity is achieved by an area-specific and time-specific agricultural intervention for an improved plant-environment interaction.

Precision agriculture (PA) is a farming management strategy based on *observing*, *measuring* (sensors) and *responding* (technology) to temporal and spatial variability to improve agricultural production and sustainability (Wikipedia, 2023)



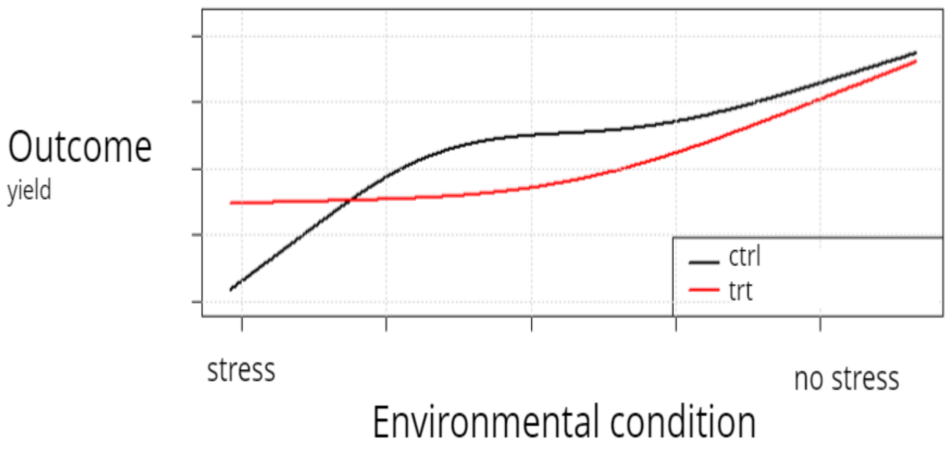
PF & Biostimulant trials

- In PF & biostimulant trials we should seek to estimate the **differential treatment effect** under varying environmental conditions

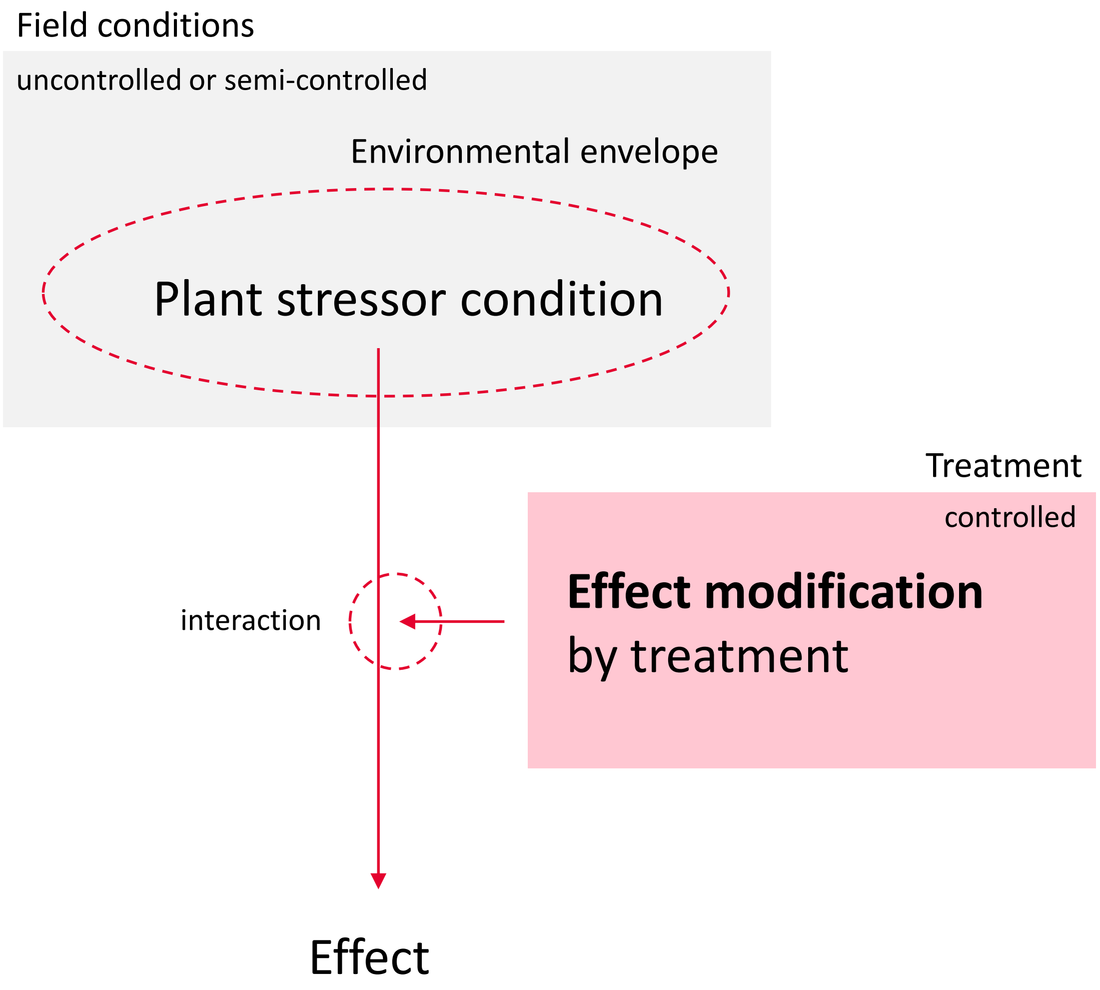
- The varying environmental conditions should include the plant stress condition (**stressor**) that is part of the mode-of-action.

- Differential treatment effects
  = Heterogeneous trt. effects (HTE)
  = Effect modification

- We want to find the function that describes the **conditional average treatment effect** (CATE), when we vary the stressor condition.



PF & Biostimulant trials



Challenges

- Mixture of **exploratory** (environ. envelope) and **confirmatory** (treatment effects) research goals
- Mixture of design-based and observational data: **controlled** (treatment, plant variety), **un-controlled** (climate conditions) and **semi-controlled** (soil conditions) variables.
- Observational data of strongly **correlated, inter-dependent** environmental variables defining the stressor condition
- Effect sizes might be expected to be smaller than conventional alternatives giving rise to **statistical power issues**

How can we achieve all this in a single trial?

Heterogeneous-site trials

- Large scale, sensor-intensive multi-plot field trial
- **Heterogeneous testing area** (field variation)
- Pre-trial collection of remote sensing data (e.g., EM38, NDVI) to guide trial site selection and trial design

Outcomes:

- Close to farmers reality and practice
- **Differential treatment**: CATE estimation and documentation of product performance related to different parameters, e.g. soil texture, topography
- **Precision Farming readiness**: guidelines and/or algorithms for how to use the product under varying conditions

OnFarm^{Plus} field trials

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Pros & Cons

	Classical field trials	Distributed-sites trials	Heterogeneous-site trials (OnFarmPlus)
How	Collection of trials, each conducted at a homogeneous site of largely unknown environmental conditions	Large collection of trials, each conducted at a homogeneous site, but sites chosen to vary in known environmental conditions	One or few trials conducted in heterogeneous trial areas
Differential treatment effect detectable?	No	Yes	Yes
Challenges	Only overall treatment effect but no differential treatment effect detectable	Confounding of site with soil, climate, and trial technicians	To achieve balance in environmental conditions for all treatments
Solutions	Do Distributed-sites trials or OnFarmPlus trials	Careful ***meta-design*** and quantification of confounders (environmental variables)	Careful ***pre-trial* assessments** of heterogeneity of trial area using remote sensing data
Risks	-	Unresolved confounding issue	Single-site vulnerability
Precision Farming readiness	None	Poor	Good

Case: OnFarmPlus Biostimulant trial

AIM

The objective was to conduct a field trial that addresses the **differential treatment effect** of the foliar biostimulants **BlueN®** and **Kinsidro® Grow under varying soil conditions** in an agricultural field. It is hypothesized that the effect of BlueN and Kinsidro® Grow is not uniformly distributed in a field but depends on the availability of **soil N** and **water** to the crop.

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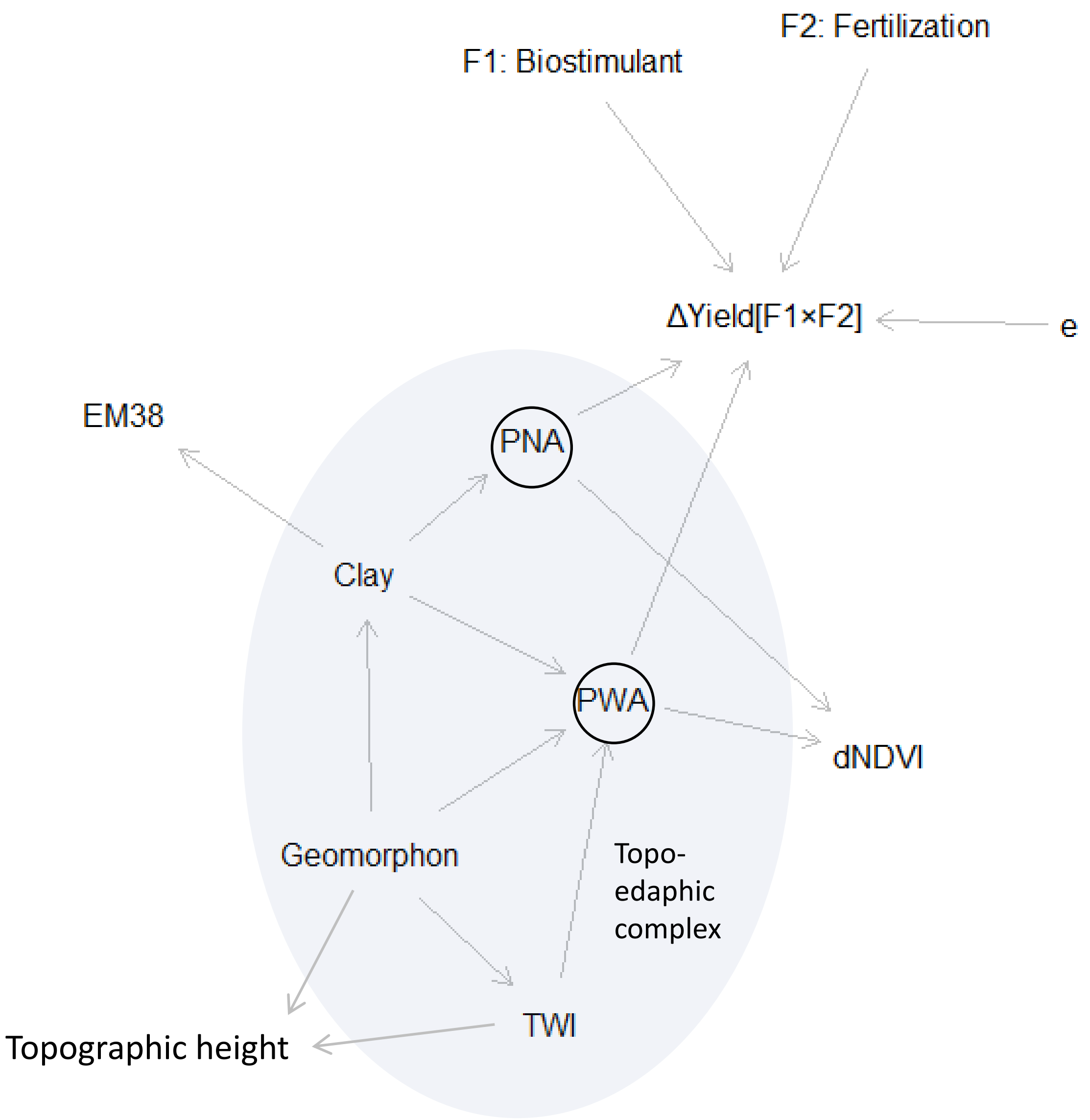


TWI: topographic wetness index
PNA: plant nutrient availability
PWA: plant water availability

Pre-trial assessments of within-field heterogeneity

Trial locality

Field: 31-1

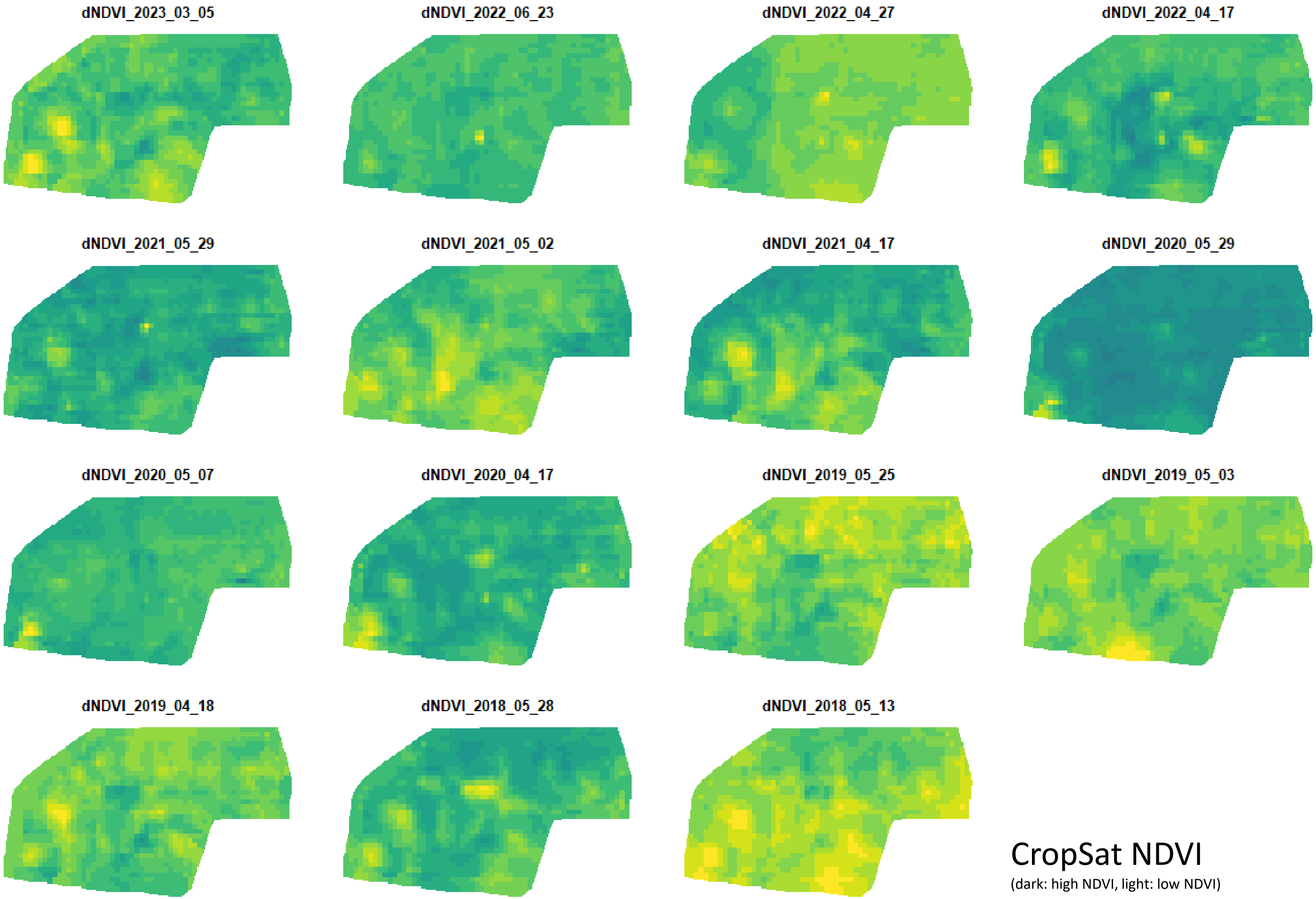
Size: 16.82 ha

JB-nr.: 6, with variable soil according to farmer

Crop in 2023: Winter wheat

Address:

Agro Food Park 12, 8200 Aarhus N



CropSat NDVI

(dark: high NDVI, light: low NDVI)

https://cropsat.com/dk/

Food innovation for the future

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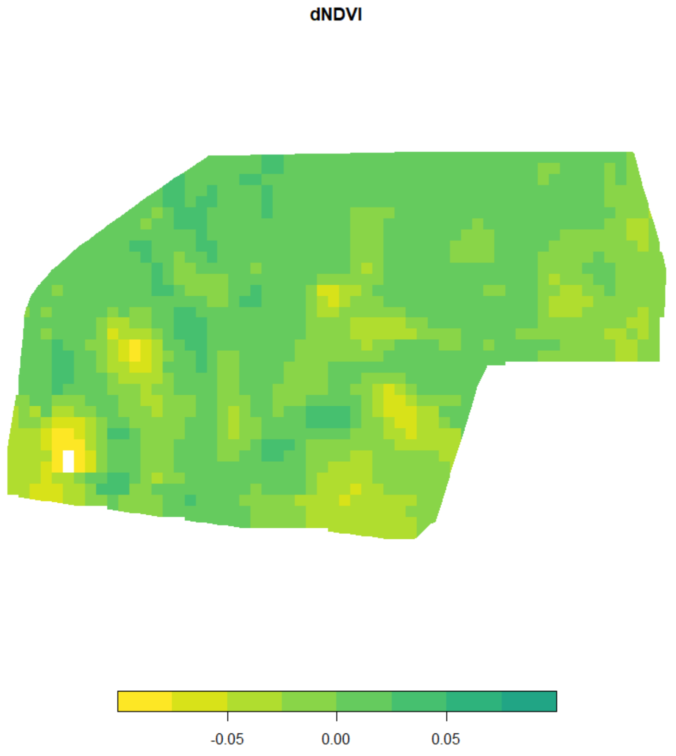
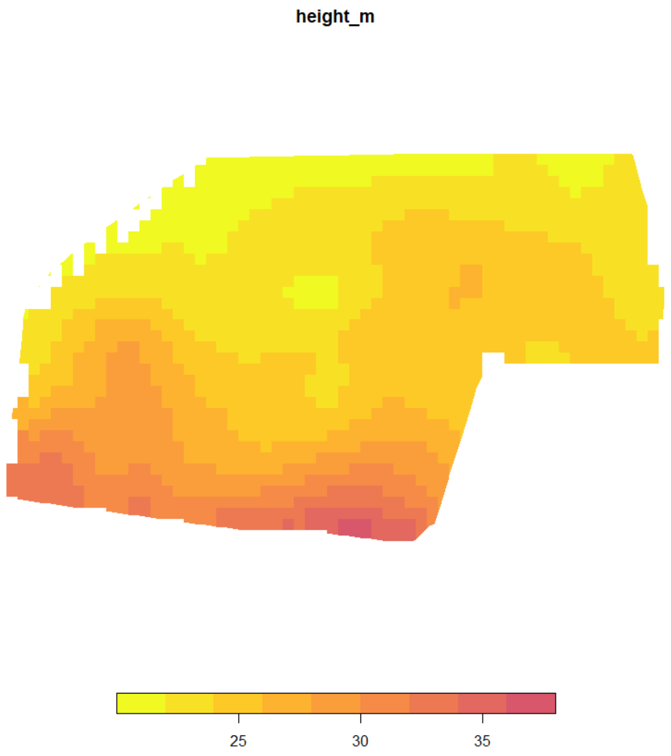


Biomass potential map

dNDVI = mean(NDVI$_{[t]}$ – median(NDVI$_{[t]}$))



https://miljoegis.mim.dk/cbkort?profile=lbst

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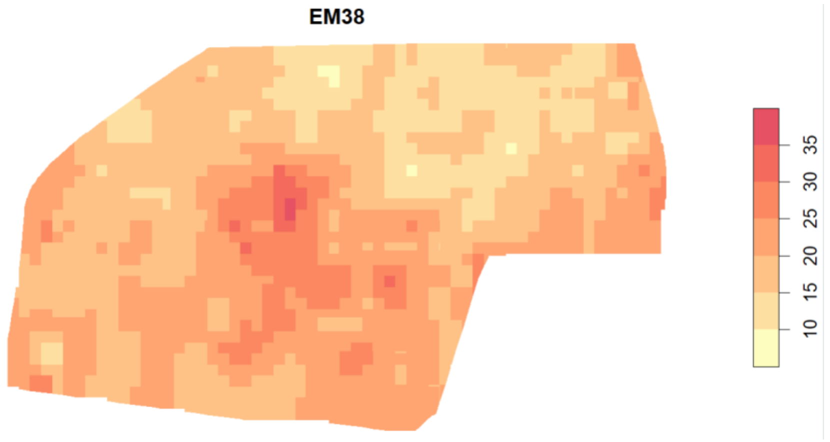
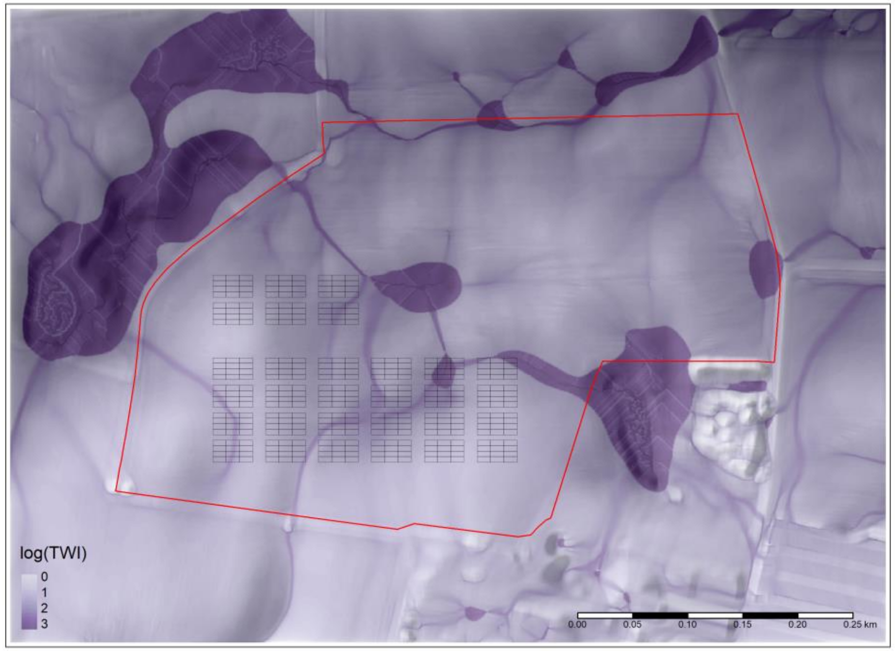
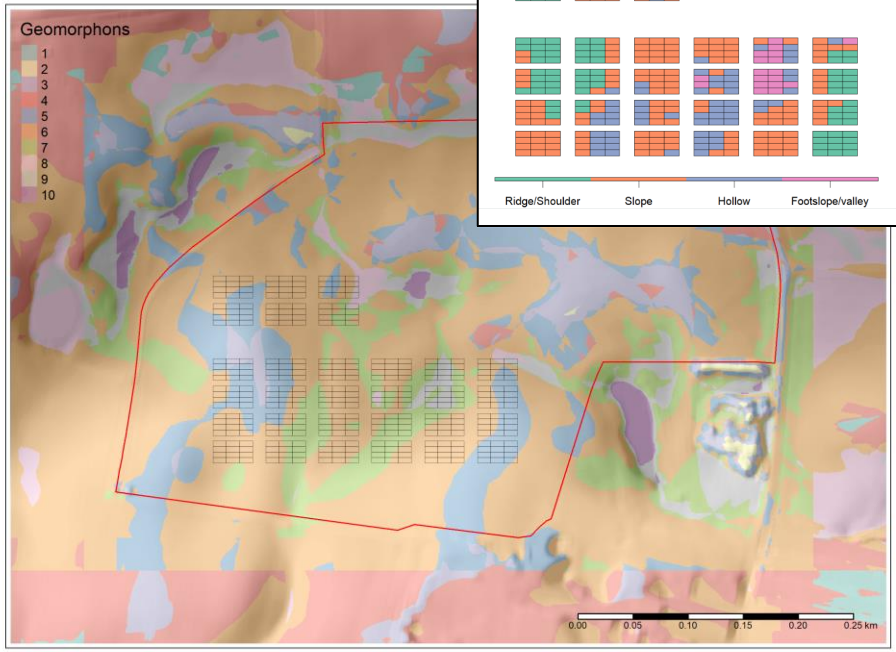
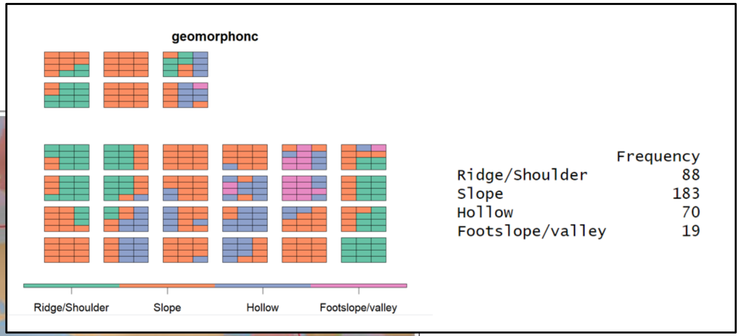








Value	Landform Type
1	Flat
2	Peak (summit)
3	Ridge
4	Shoulder
5	Spur (convex)
6	Slope
7	Hollow (concave)
8	Footslope
9	Valley
10	Pit (depression)

Topographic Wetness Index (TWI)

describing the propensity for a site to be saturated to the surface given its contributing area and local slope characteristics.

Geomorphons - landform classification

line-of-sight analysis for the eight topographic profiles in the cardinal directions surrounding each grid cell.

Trial design

Trial design: 2-factorial strip trial in a generalized strip-block design with *5 replicate blocks* and *2 strips of 3 geo-referenced pseudoreplicates* per factor 1 × factor 2 combination within each replicate block.

Factor 1:

1: untreated
2: BlueN
3: Kinsidro Grow
4: combined BlueN-Kinsidro

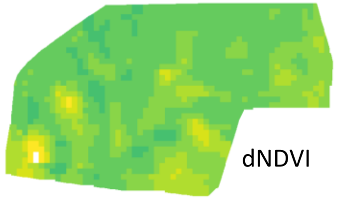
Factor 2:

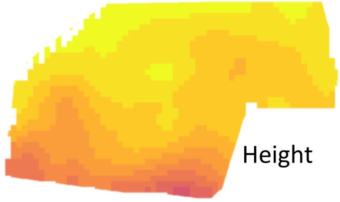
A: standard N fertilization level (Farmer's ”norm”)
B: standard minus 30 kgN/ha
C: standard minus 50 kgN/ha

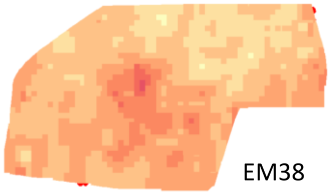
Randomization: Randomization was carried out within each replicate block for factor 1 and 2 such that:

- factor 2 treatment blocks were placed perpendicular to the tractor tracks
- factor 1 treatment strips, following the tractor track direction across factor 2 levels, were in duplicates one at each side of the tractor track centered within each replicate block, thus yielding two strips of three pseudo-replicate plots within each replicate block crossing the factor 2 blocks

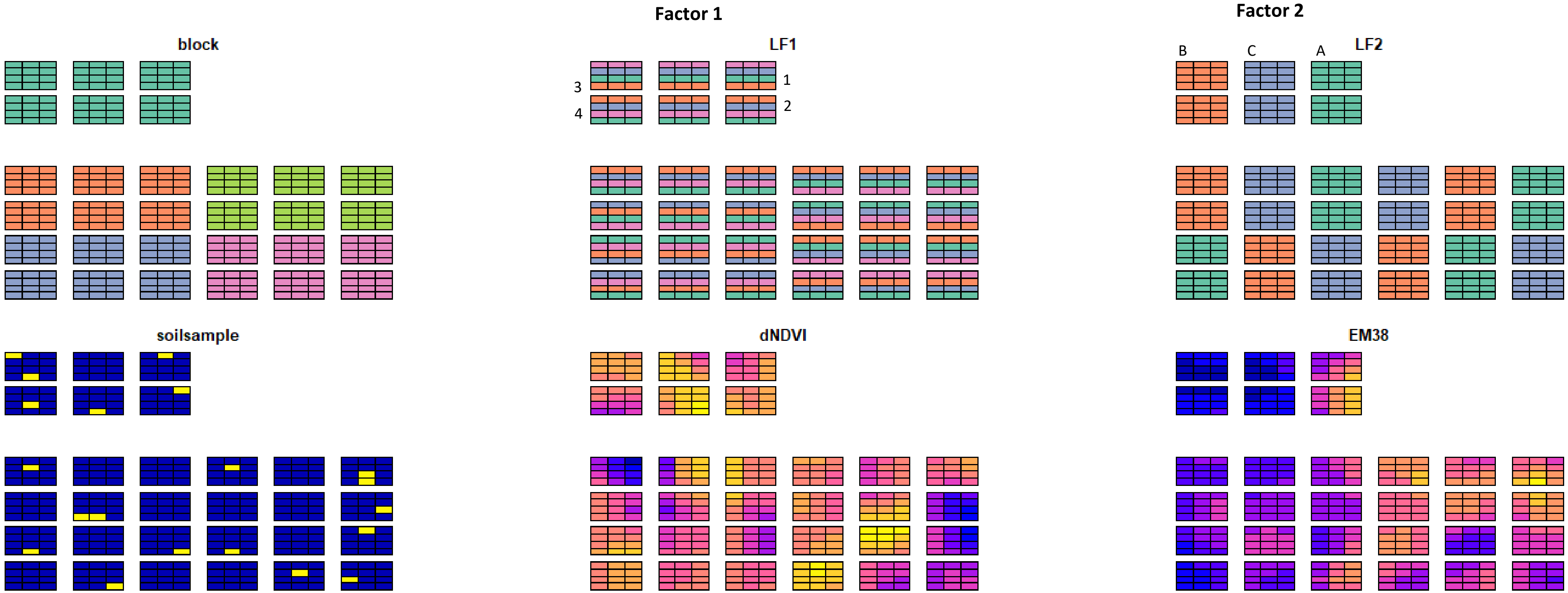
and subject to the constraint that the achieved distribution in EM38, dNDVI, and topographic height was insignificantly different among treatment 1 and 2 combinations as evaluated by the Kolmogorov–Smirnov statistic.

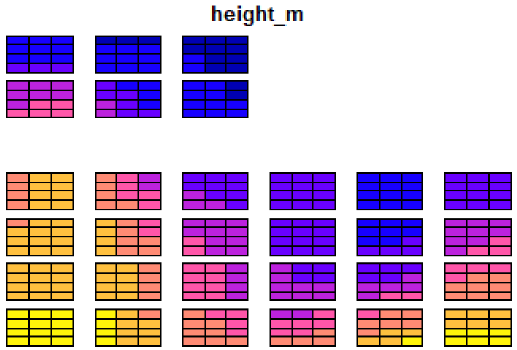

dNDVI


Height


EM38


block
1
2
3
4
5
LF
LF2
LF1
ministrip
ministripblock
miniblock
block
Zoom full
100 m
Leaflet | Tiles © Esri — Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, UPR-EGP, and the GIS User Community





Factor 1:

- 1: untreated
- 2: BlueN
- 3: Kinsidro Grow
- 4: combined BlueN-Kinsidro

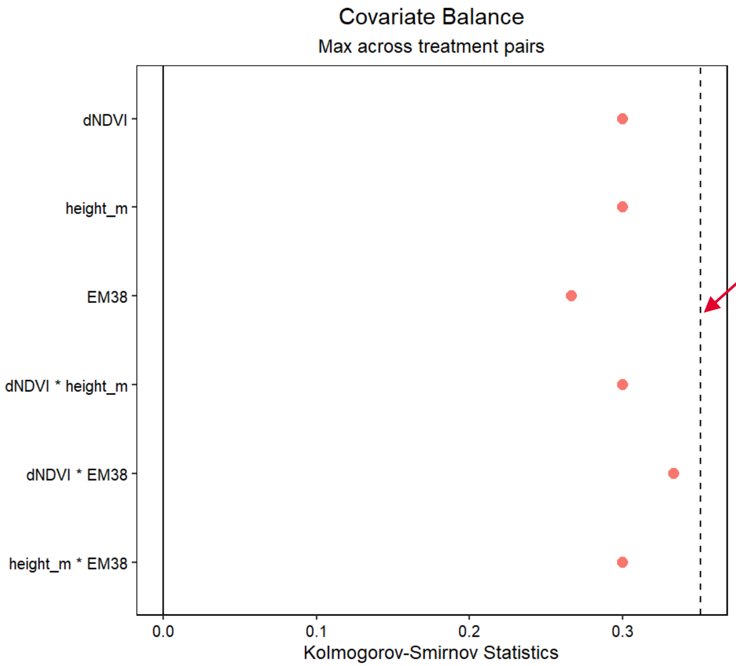
Factor 2:

- A: standard N fertilization level (Farmer's ”norm”)
- B: standard minus 30 kgN/ha
- C: standard minus 50 kgN/ha

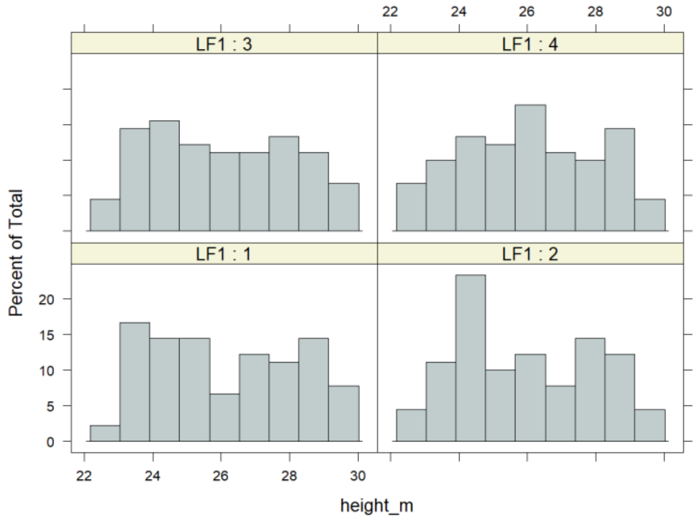
Realized trial area: 4.15 ha
N = 360 plots

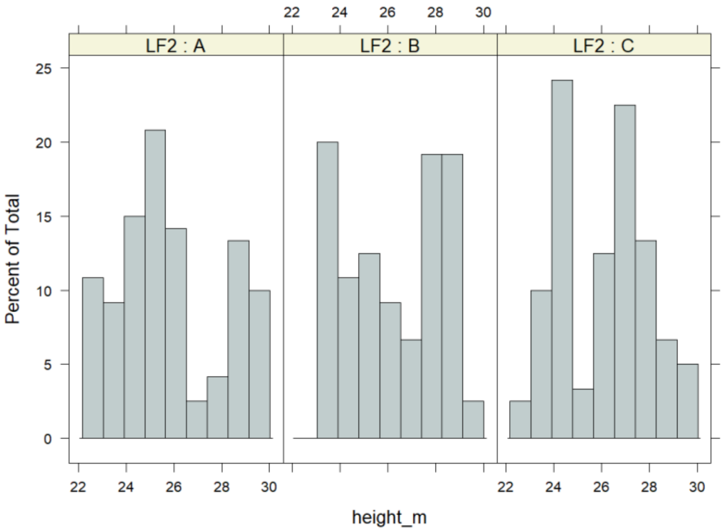
Balance

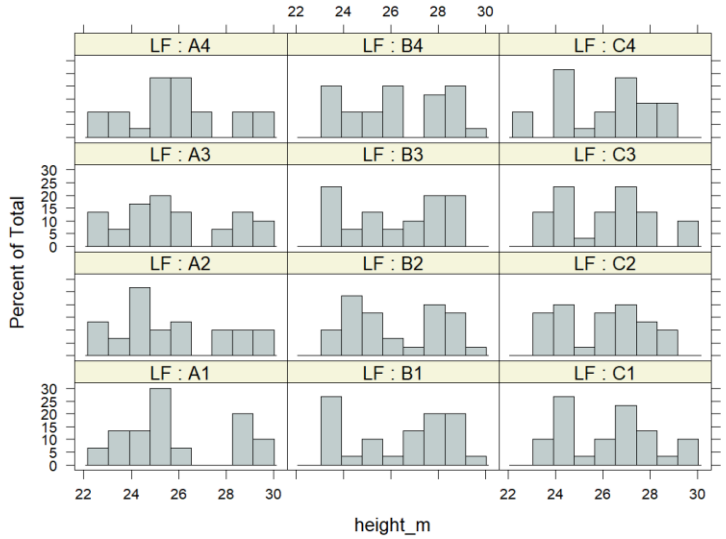
Treatments must be balanced w.r.t. the background environmental conditions of interest (stressors)



Critical value
α = 0.05

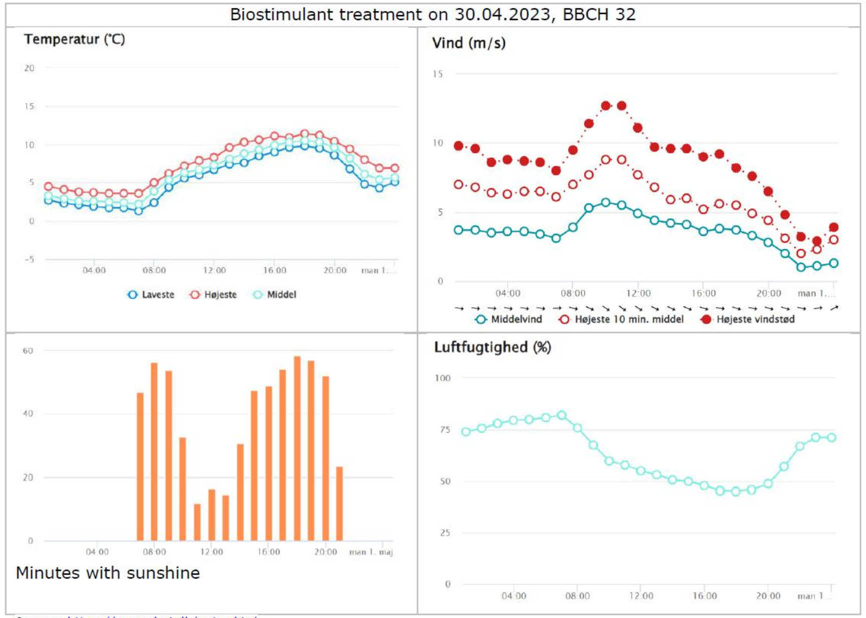






Trial excecution

Information/Activity	
Trial location	UTM, zone 32, E 571215 N 6229423
Soil type(s)	Clayey sand, Sandy clay, Clay; JB-nr: {4, 5, 6, 7, 10}
N fertilization	03.04.2023: 80 kgN/ha 17.04.2023: according to factor 2 +100, +70, and +50 kgN/ha
Drone flight 1	25.04.2023 BBCH growth stage 30, link to image
Biostimulant treatment	30.04.2023, BBCH growth stage 32; mean daily temperature (°C) [Min., Max.] = 6.3 [1.2, 11.4], see appendix for more information on weather conditions on treatment day.
Drone flight 2	05.04.2023, BBCH growth stage 37, link to image
Drone flight 3	15.05.2023, BBCH growth stage 43, link to image
Drought period	Between 27.05.2023 and 01.07.2023, Drought Index DI > 8.0, see DMI.
Drone flight 4, pre-harvest	11.08.2023, BBCH growth stage 90, link to image, No lodging detected in any of the trial plots.
Harvest date	21.08.2023, BBCH growth stage 90
Yield level (86% DM), 2023	Mean yield [IQR] = 92.8 hkg/ha [83.2, 102.6]



Source: https://www.dmi.dk/vejrarkiv/

Fig. A1: Weather data for the day of biostimulant application in the current trial.

Results

Table 2: Model fit evaluation

	dNDVI	**Yield (hkg/ha)**	**Protein yield (kg/ha)**	**Growth** $\Delta NDRE_{30-37}$	**Growth** $\Delta NDRE_{30-43}$
Observed variation					
Median	0.002	92.5	667.3	0.16	0.20
Min.	-0.061	55.5	434.6	0.10	0.13
Max.	0.036	134.0	1059.2	0.22	0.26
Spatial range	26 m	25 m	24 m	27 m	29 m
Model control					
Moran's *I* test p-value	0.39	0.85	0.99	0.81	0.11
Model fit					
RMSE	0.004	6.9 hkg/ha	53.4 kgN/ha	0.02	0.01
in % of median	-	7.4%	8.0%	9.4%	6.9%
R^2	**0.956**	**0.778**	**0.788**	**0.535**	**0.630**
Spatial comp. η^2	0.397	0.486	0.364	0.338	0.372
Fixed part η^2	0.556	0.271	0.389	0.194	0.263
Fixed model terms (p-value)	TWIrank × Geomorphon ($p < 0.001$) Clay% × Geomorphon ($p < 0.001$)	GP × Trt × Nlevel ($p < 0.001$)	GP × Trt × Nlevel ($p = 0.001$)	GP × Trt ($p < 0.001$) GP × Nlevel ($p < 0.001$)	GP × Trt ($p < 0.001$) GP × Nlevel ($p < 0.001$)

Precision Farming potential:
The current trial demonstrates the potential for VR application of BlueN and Kinsidro Growth to optimize yield, protein yield, and crop growth.

The spatial autoregressive filtering model

$$f(x) = Yield = \beta_0 + \boldsymbol{E_{SAR}\gamma} + \beta_1 Ntrt + \beta_2 Trt + \beta_3 GP + \beta_4 Ntrt \times Trt + \ldots + \beta_k GP \times Ntrt \times Trt + e$$

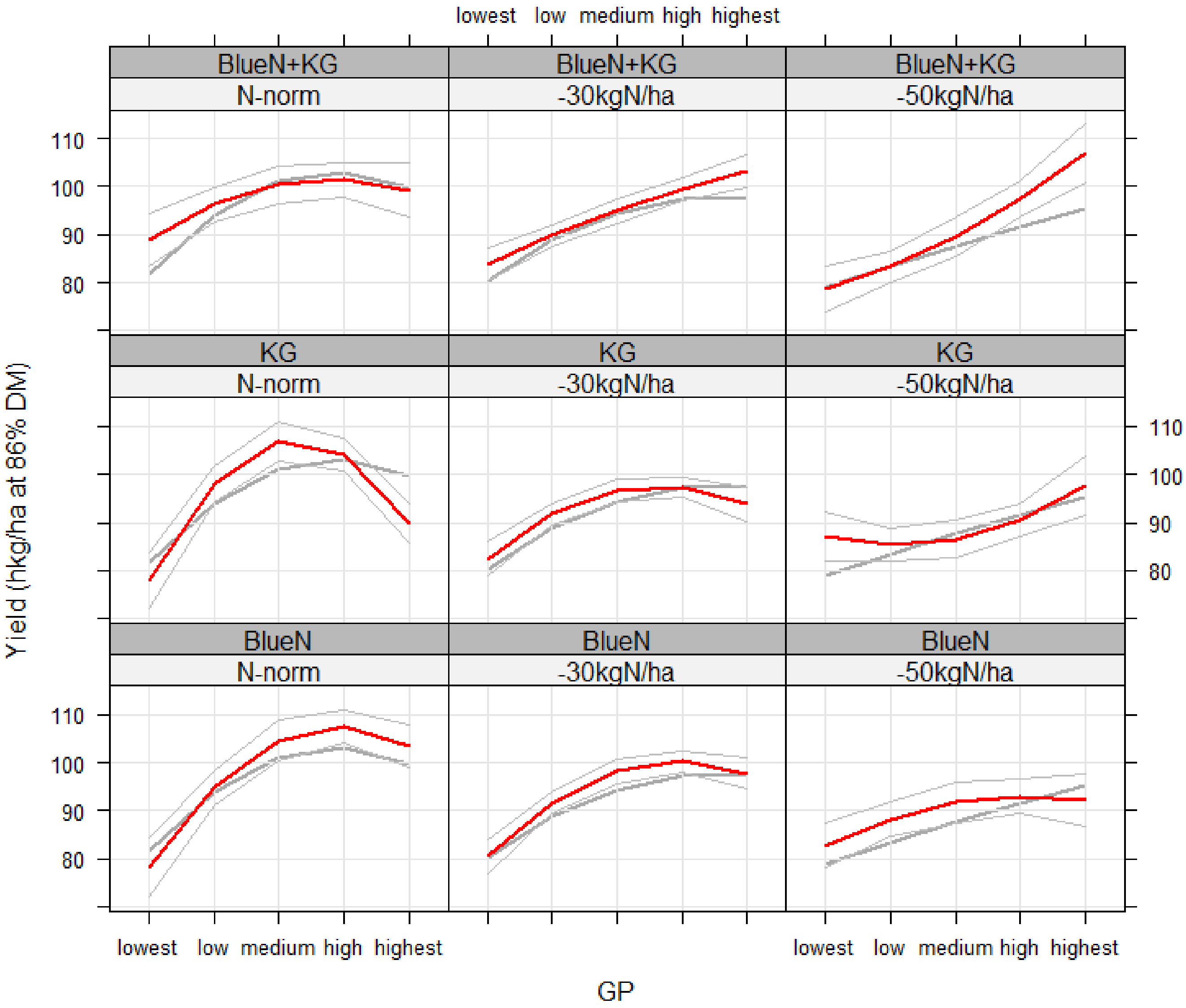
$$e \sim N(0, \sigma^2)$$

$\boldsymbol{E_{SAR}}$:= Matrix of eigenvectors of projected spatial distance matrix

Tiefelsdorf & Griffith 2007. Environment and Planning A 2007, volume 39, pages 1193 ^ 1221

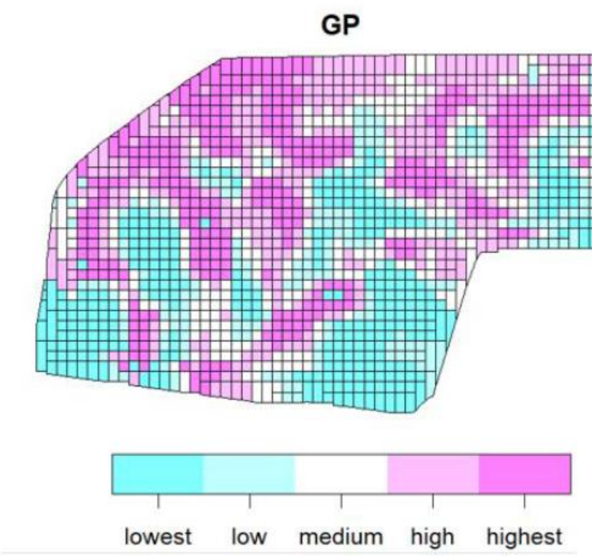
$R^2 = 0.78$
RMSEP = 6.9 hkg/ha

The differential Biostimulant-treatment – by – N-treatment – by – Growth Potential (GP) effect



satellite-based growth potential (dNDVI)

Food innovation for the future



Scenario calculation

Area	15.6 ha
BlueN	300 DKK/ha
Wheat	150 DKK/hkg
N-fertilizer	11 DKK/kgN
Savings, -30 kgN/ha reduction	330 DKK/ha
% area applied when expected yield increase > 0.25 hkg/ha	77%

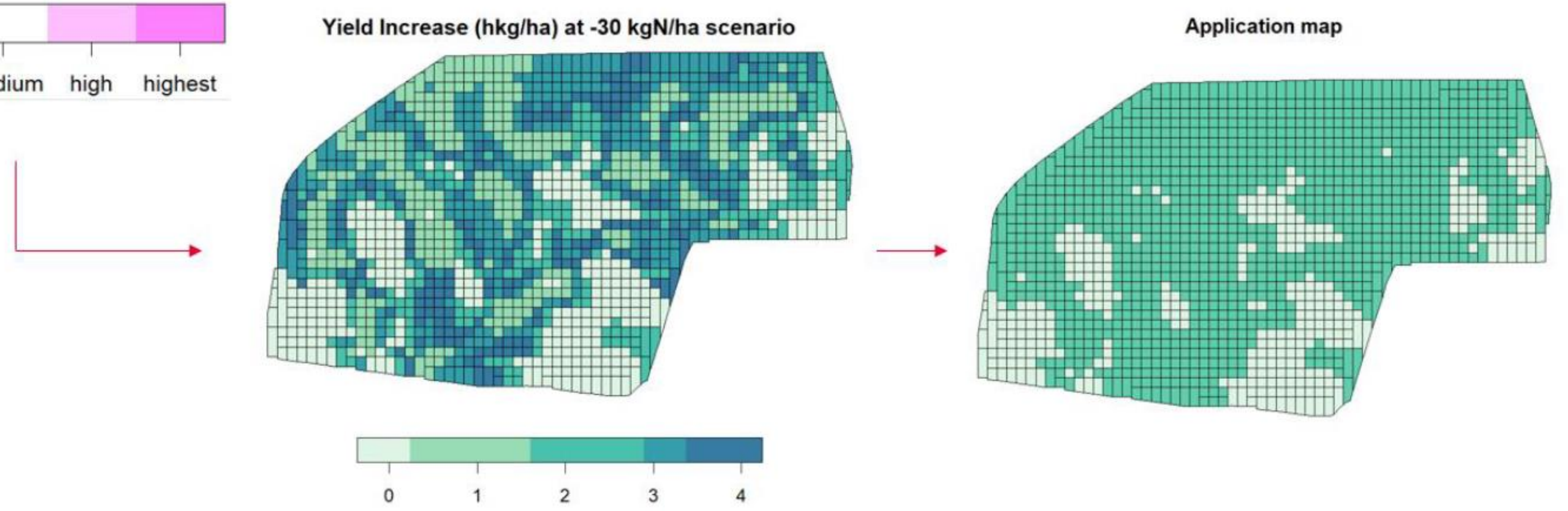


Fig. A3: Example of application map generation based on a GP map calculated from historical sentinel 2 satellite data under a -30 kgN/ha N-reduction scenario.

Conclusions & Perspectives

Conclusions

- OnFarm^{Plus} trials rely on **large-scale heterogeneity** in the field. Although this makes the trial expensive, more complex problems and/or techniques can be addressed that seek to meet the needs of modern agriculture (e.g., biostimulants, precision farming, PF).

- The OnFarm^{Plus} trial concept relies heavily on **pre-trial sensor-data assessment** in order to obtain treatment comparisons that are **balanced** w.r.t. the background environmental conditions of interest (stressors).

- In this, the OnFarm^{Plus} trial concept can efficiently be used address the **differential treatment effects** of biostimulants and PF techniques, and, hence, the **precision-farming-readiness**.

- OnFarm^{Plus} trials should be replicated (sites and years) to prevent single-site vulnerability to biased conclusions.

Thank you

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