Using spectral reflectance indices as covariables for improving crop protection field trial analysis

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Addressing heterogeneity in field trials beyond blocks, rows and columns

- Soil properties explain small-scale spatial variability in plant growth – however, rarely follow rectangular and linear gradients
- Measuring soil properties can be challenging and their effect on plant growth interacts with seasonal conditions
- Spectral reflectance indices (SRI) reflect plant growth directly

Hypothesis: SRI before first application capture appreciable part of heterogeneity and clearly separate environment from treatment effects

image generated using AI

Groß, J., Gentsch, N., Boy, J. et al. Influence of small-scale spatial variability of soil properties on yield formation of winter wheat. Plant Soil 493, 79–97 (2023).
Cabrera-Bosquet, L., Molero, G., Stellacci, A., Bort, J., Nogués, S., & Araus, J. (2011). NDVI as a potential tool for predicting biomass, plant nitrogen content and growth in wheat genotypes subjected to different water and nitrogen conditions. Cereal Research Communications, 39(1), 147–159.

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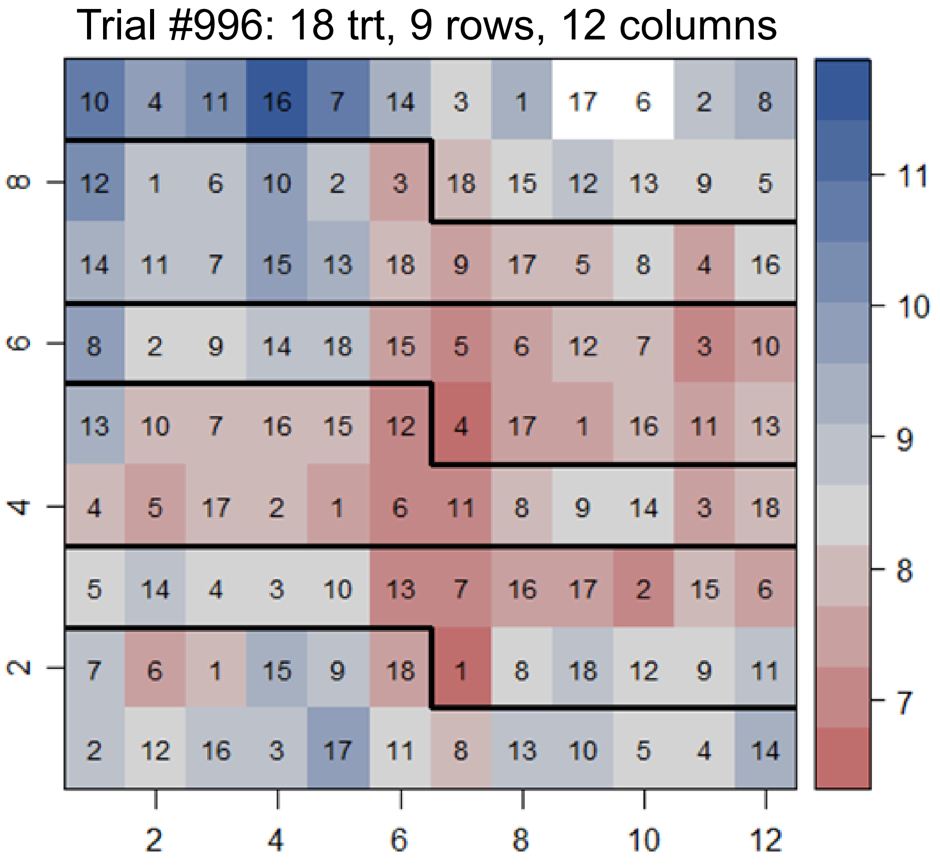
Example trial



Layout of trial […]-996: 18 Treatments in six replicates.
Numbers show treatments, colors show fresh matter yield.
The solid black lines show the complete replicates (blocks).

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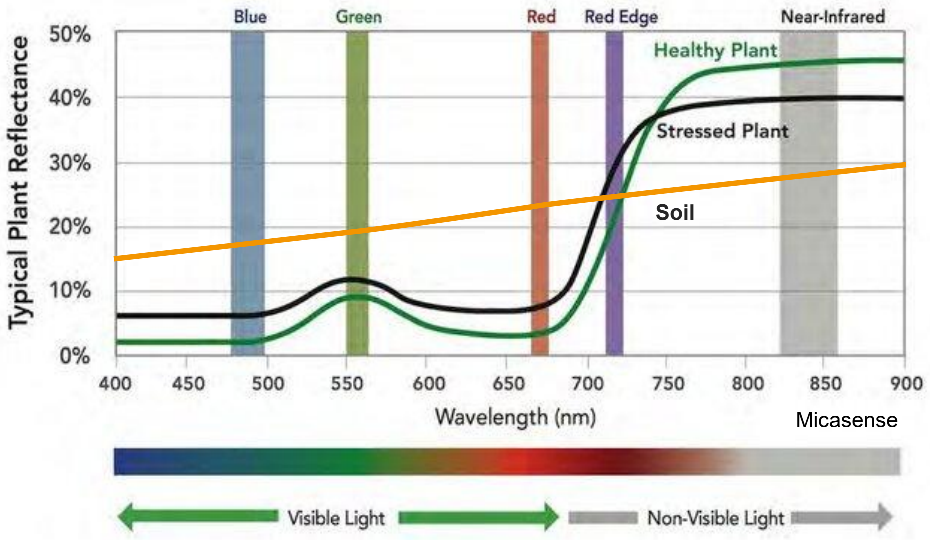
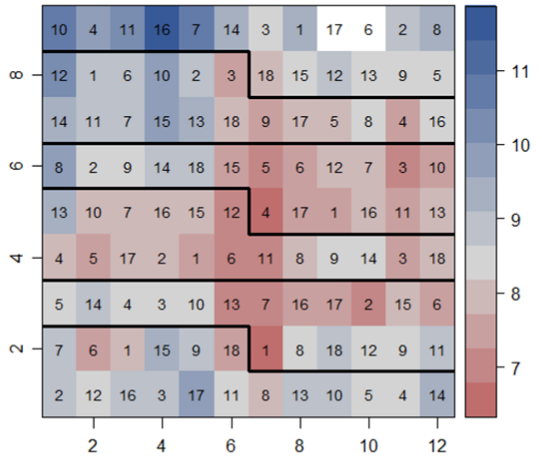
Example trial





Layout of trial […]-996: 18 Treatments in six replicates.
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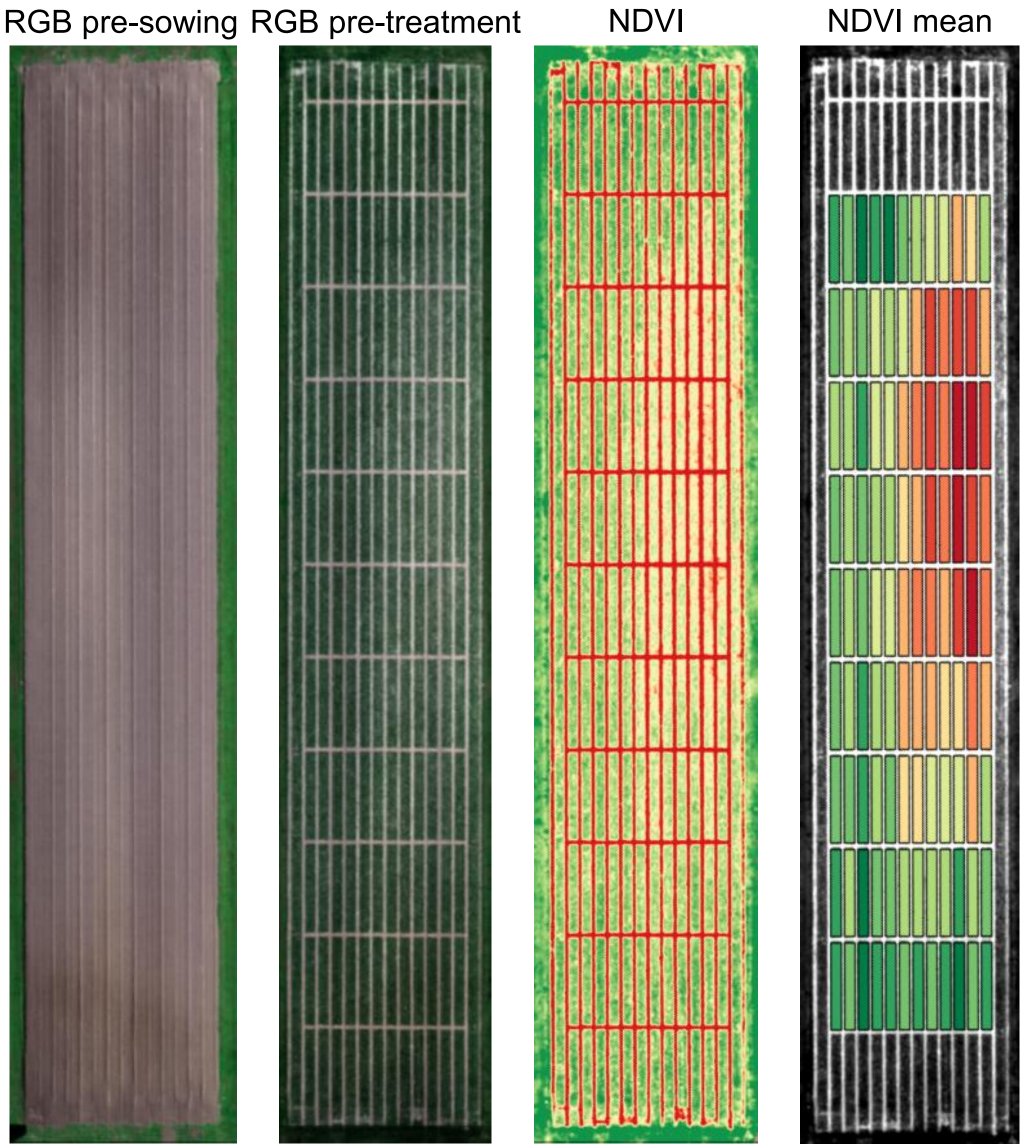

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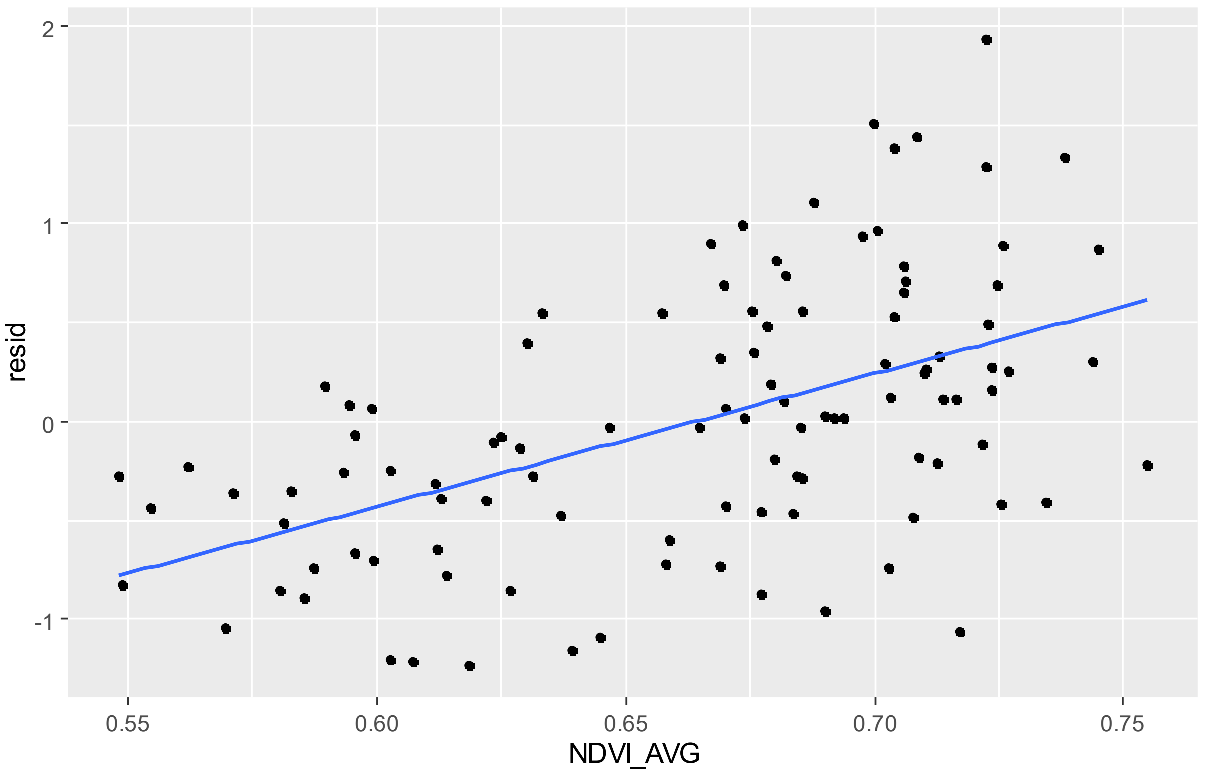
Requirements for the use of pre-treatment-NDVI as covariable

- Check if NDVI provides useful information and is independent of the treatment effect

```
 Response: ERTRFR
             Df  Sum Sq Mean Sq F value    Pr(>F)
trt          17 11.436  0.6727  0.9273    0.5464
NDVI_AVG      1 19.031 19.0308 26.2319 2.556e-06 ***
trt:NDVI_AVG 17  3.245  0.1909  0.2631    0.9983
Residuals    70 50.784  0.7255
```

- NDVI explains yield & is independent of the treatment effect
- SRI captured before first treatment application → independence check not required



Residuals of ERTRFR ~ trt vs. NDVI_AVG pre-treatment

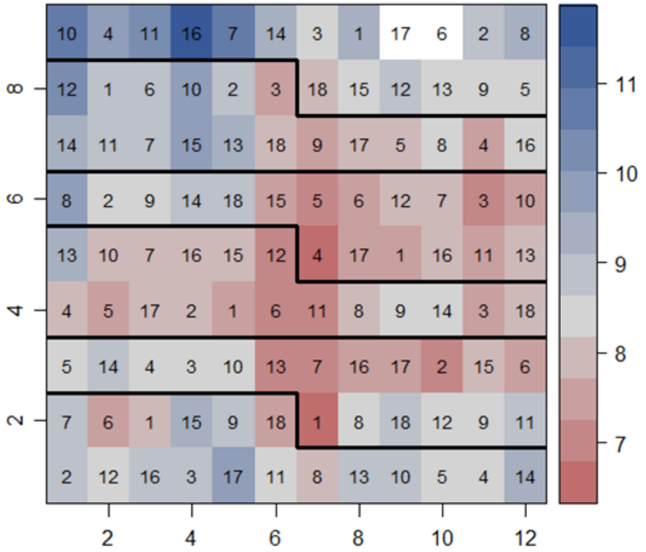
Results Trial 996

```
Model 1: ERTRFR ~ rep + trt
Model 2: ERTRFR ~ rep + trt + NDVI_AVG
Model 3: ERTRFR ~ rep + trt + col + row
Model 4: ERTRFR ~ rep + trt + col + row + NDVI_AVG
  Res.Df    RSS Df Sum of Sq        F    Pr(>F)
1     83 48.128
2     82 26.590  1   21.5383 204.3112 < 2.2e-16 ***
3     66  7.160 16   19.4301  11.5195 2.339e-13 ***
4     65  6.852  1    0.3077   2.9185   0.09234 .
```

```
df        AIC
mod1 24 265.12071
mod2 25 204.22716
mod3 41  97.15112
mod4 42  94.49549
```

StdErr of trt comparisons (s.e.d.) for different models

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
mod1	0.4396	0.4396	0.4396	0.4447	0.4396	0.4816
mod2	0.3288	0.3290	0.3297	0.3335	0.3320	0.3602
mod3	0.1969	0.2062	0.2096	0.2107	0.2156	0.2297
mod4	0.1944	0.2039	0.2075	0.2086	0.2130	0.2265



25% reduction in stderr_of_diff by using NDVI as covariable
53% reduction in stderr_of_diff by post-blocking with row & col

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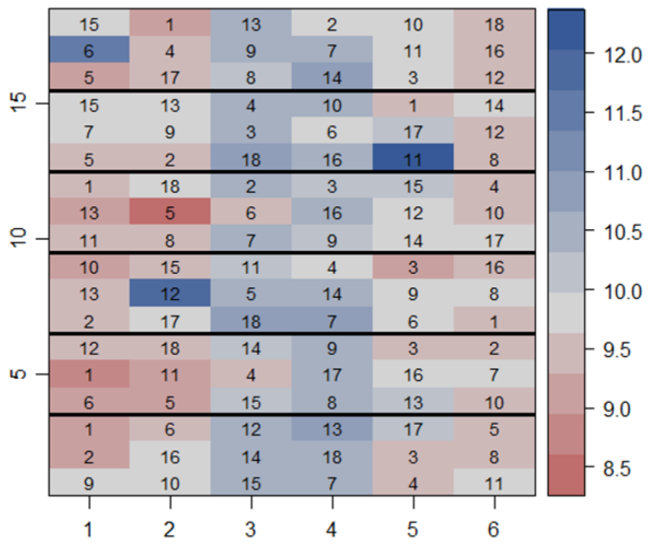
Results Trial 997

```
Model 1: ERTRFR ~ rep + trt
Model 2: ERTRFR ~ rep + trt + NDVI_AVG
Model 3: ERTRFR ~ rep + trt + col + row
Model 4: ERTRFR ~ rep + trt + col + row + NDVI_AVG
  Res.Df    RSS Df Sum of Sq       F    Pr(>F)
1     85 29.322
2     84 23.963  1    5.3589 27.2746 1.877e-06 ***
3     68 14.427 16    9.5364  3.0335   0.00076 ***
4     67 13.164  1    1.2624  6.4249   0.01360 *
```

```
 df       AIC
mod1 24 213.6805
mod2 25 193.8834
mod3 41 171.0801
mod4 42 163.1905
```



StdErr of trt comparisons (s.e.d.) for different models

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
mod1	0.3391	0.3391	0.3391	0.3391	0.3391	0.3391
mod2	0.3084	0.3085	0.3090	0.3095	0.3101	0.3175
mod3	0.2703	0.2890	0.2954	0.2951	0.3001	0.3166
mod4	0.2605	0.2803	0.2857	0.2853	0.2891	0.3084

9% reduction in stderr_of_diff by using NDVI as covariable
13% reduction in stderr_of_diff by post-blocking with row & col

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Which SRI to use? Combining multiple SRI's?

```
model <- lm(ERTRFR ~ rep + col + row + trt + NDVI_AVG + CCCI_AVG + NDRE_AVG + LAI_AVG +
MCARI2_AVG + MSAVI2_AVG + VARI_AVG)

stepAIC(model, scope = list(lower = ~ rep + trt), direction = "both")
```

```
Model 1: ERTRFR ~ rep + trt + col + row + NDVI_AVG
Model 2: ERTRFR ~ rep + col + row + trt + CCCI_AVG + MCARI2_AVG + MSAVI2_AVG +
    VARI_AVG
  Res.Df    RSS Df Sum of Sq      F   Pr(>F)
1     65 6.8522
2     62 5.5243  3    1.3279 4.9677 0.00374 **
```

StdErr of trt comparisons (s.e.d.) for different models

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
mod1	0.1944	0.2039	0.2075	0.2086	0.2130	0.2265
mod2	0.1791	0.1908	0.1947	0.1957	0.2003	0.2128

6% reduction in stderr_of_diff by using AIC optimized multi-SRI-model

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Experiments with other response variables than yield

```
530 septoria infection
Model 1: SEPTTR.INFECT ~ trt + rep
Model 2: SEPTTR.INFECT ~ trt + rep + row + col
Model 3: SEPTTR.INFECT ~ trt + rep + row + NDVI_AVG + CCCI_AVG + NDRE_AVG
  Res.Df    RSS Df Sum of Sq      F    Pr(>F)
1     45 7925.3
2     30 1833.7 15    6091.7 8.6206 9.153e-07 ***
3     27 1271.9  3     561.7 3.9745   0.01814 *
```

```
017 alomy control
Model 1: ALOMY.CONTROL ~ trt + rep
Model 2: ALOMY.CONTROL ~ trt + rep + row + col
Model 3: ALOMY.CONTROL ~ trt + rep + row + col + CCCI_AVG + NDRE_AVG + LAI_AVG
  Res.Df     RSS Df Sum of Sq      F Pr(>F)
1     33 15.0735
2     23  9.6974 10    5.3762 1.3129 0.2889
3     20  8.1895  3    1.5079 1.2275 0.3258
```

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Conclusions

- SRI's can be used to explain variability of assessments in crop protection trials.
- Captured before first trial application SRI's are independent of the treatment effect and limited to environmental effects
- Compared to post-blocking rows and columns SRI's contributed less (management!)
- Other SRI's than NDVI and combinations might explain non-treatment variance better
- The use and selection of SRI's as covariables could potentially be automated (stepAIC)

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