



**CocoaSoils**

# MULTI-LOCATIONAL NUTRIENT RESPONSE TRIALS FOR THE DEVELOPMENT OF COCOA FERTILIZER RECOMMENDATIONS

Stefan Hauser<sup>1</sup>, Ekatherina Vasquez<sup>2</sup>, Joost van Heerwaarden<sup>2</sup>, Alain Jacques Acka Kotaix<sup>3</sup>, Moses O. Ogunlade<sup>4</sup>, Adolphe Kemga<sup>5</sup>, Didier Begoude<sup>6</sup>, Aka Romain<sup>7</sup>, Kouadio Frederic Oura<sup>8</sup>, Amos Quaye<sup>9</sup>, Eduardo Chavez<sup>10</sup>, Niken Sari<sup>11</sup>, Leonard Rusinamhodzi<sup>12</sup>, Ken E. Giller<sup>2</sup>

<sup>1</sup>International institute of Tropical Agriculture (IITA, Nigeria), <sup>2</sup>Wageningen University (Netherlands), <sup>3</sup>Centre National de Recherche Agronomique (Côte d'Ivoire), <sup>4</sup>Cocoa Research institute of Nigeria (CRIN), <sup>5</sup>International institute of Tropical Agriculture (IITA, Cameroon), <sup>6</sup>Institut de Recherche Agricole pour le Développement (IRAD), <sup>7</sup>Barry Callebaut, Tiassale, Cote d'Ivoire, <sup>8</sup>Nestle, Cote d'Ivoire, <sup>9</sup>Cocoa Research Institute of Ghana, <sup>10</sup>Escuela Superior Politécnica del Litoral (ESPOL) Ecuador, <sup>11</sup>Indonesian Coffee and Cocoa Research Institute (ICCRI), <sup>12</sup>International institute of Tropical Agriculture (IITA, Ghana)



Norad



Transforming African Agriculture



the international  
trade initiative



WAGENINGEN  
UNIVERSITY & RESEARCH



World  
Agroforestry  
Centre



UN  
environment



WCMC



CRA  
CENTRO NACIONAL DE INVESTIGACIONES AGROPECUARIAS



IITA

# Background

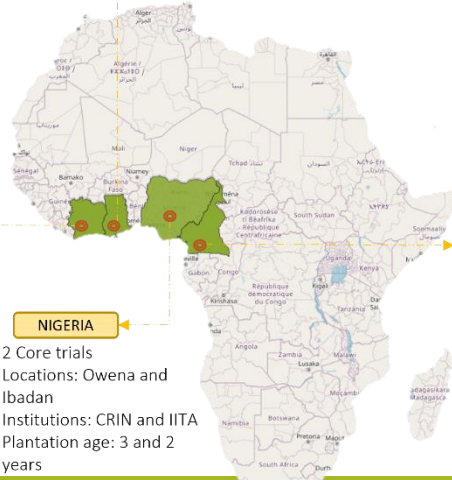
## ECUADOR

- 1 Core trial
- Located in Quito
- Institution: MARS and ESPOL
- Plantation age: 2 years



## GHANA

- 2 Core trials
- Locations: Maabang and Buako
- Institutions: CRIG and Mondelez
- Plantation age: 3 and < 1 years



## COTE D'IVOIRE

- 3 Core trials
- Locations: Divo, Tiassale and Aboisso
- Institutions: CNRA, Barry Callebaut and Nestle
- Plantation age: 2 years (all)

## NIGERIA

- 2 Core trials
- Locations: Owena and Ibadan
- Institutions: CRIN and IITA
- Plantation age: 3 and 2 years

## CAMEROON

- 2 Core trials
- Locations: Nkoemvone and Mbalmayo
- Institutions: IRAD and IITA
- Plantation age: 2 years (all)

## INDONESIA

- 1 Core trial
- Located in Jember
- Institution: Mondelez
- Plantation age: 2 years

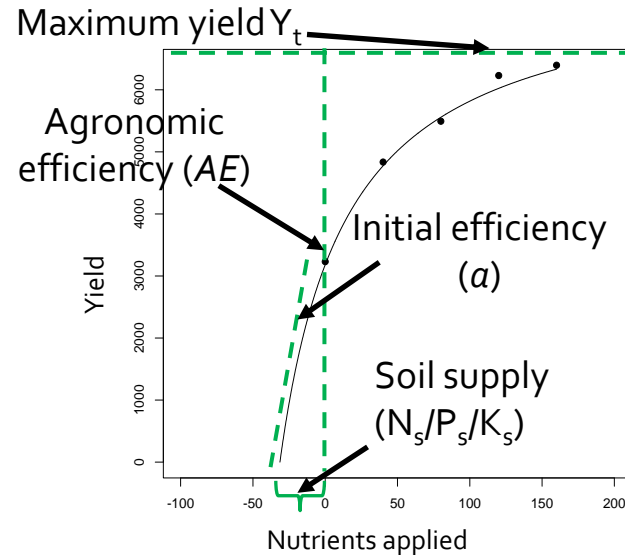
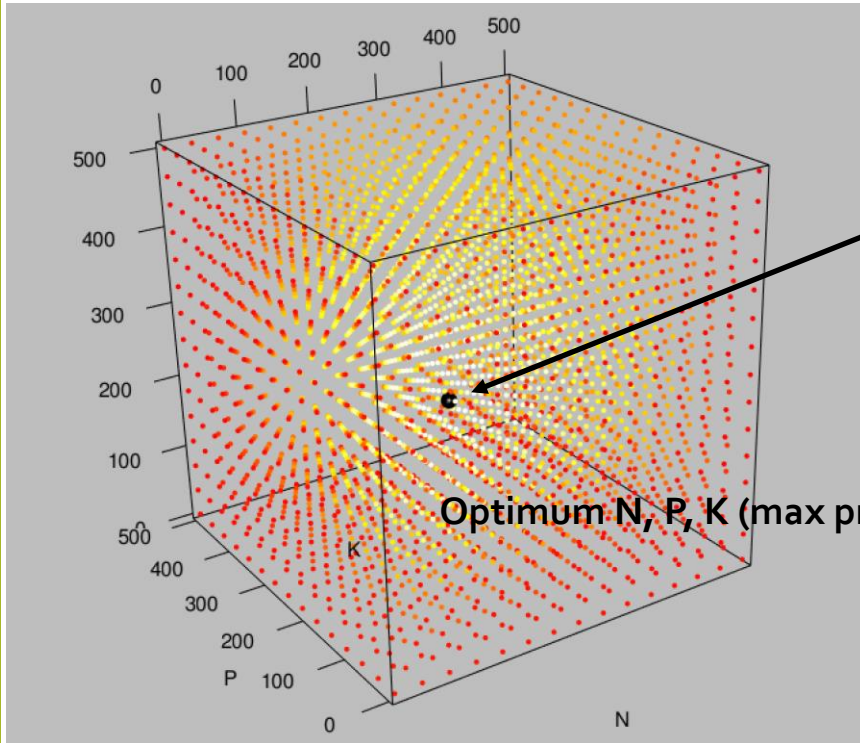


# Aims

What needs to be estimated?

$$\frac{1}{y} = \frac{1}{Y_t} + \frac{1}{aN(N_s + N_f)} + \frac{1}{aP(P_s + P_f)} + \frac{1}{aK(K_s + K)}$$

Greenwood et al. 1971

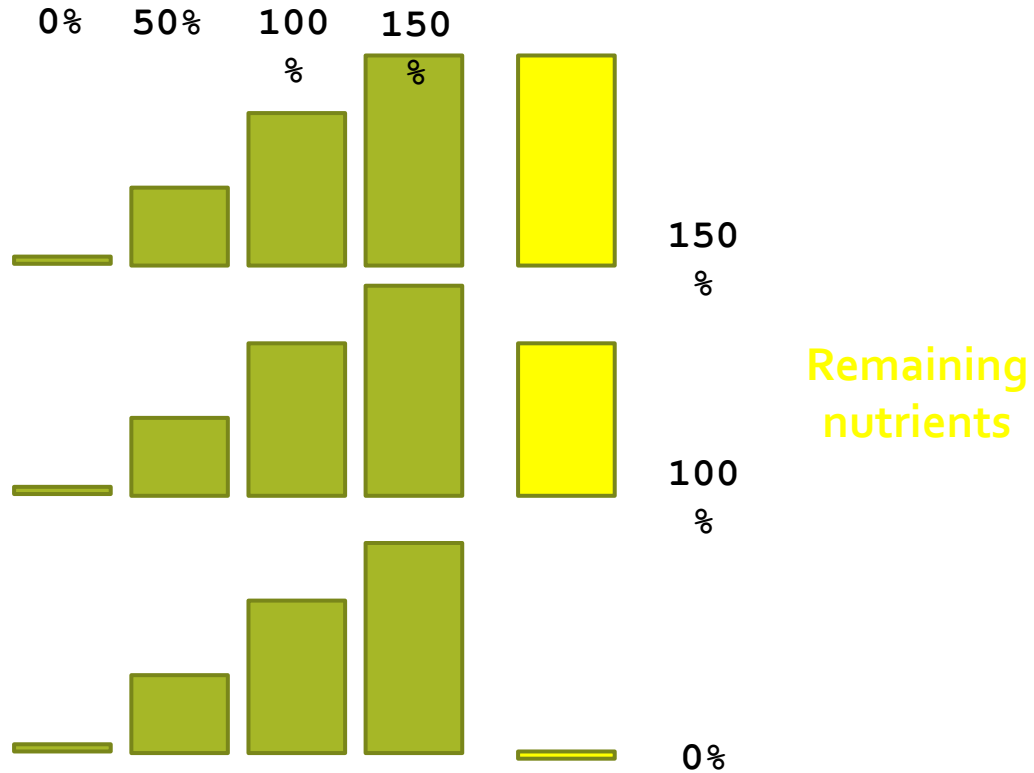


Low

High

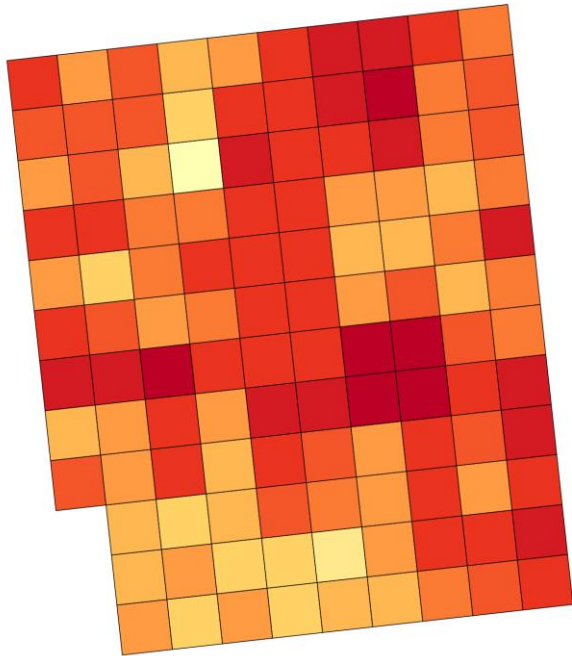
# Design

Target nutrient



# Design

Field heterogeneity  
Previous maize yield  
Soil chemical properties

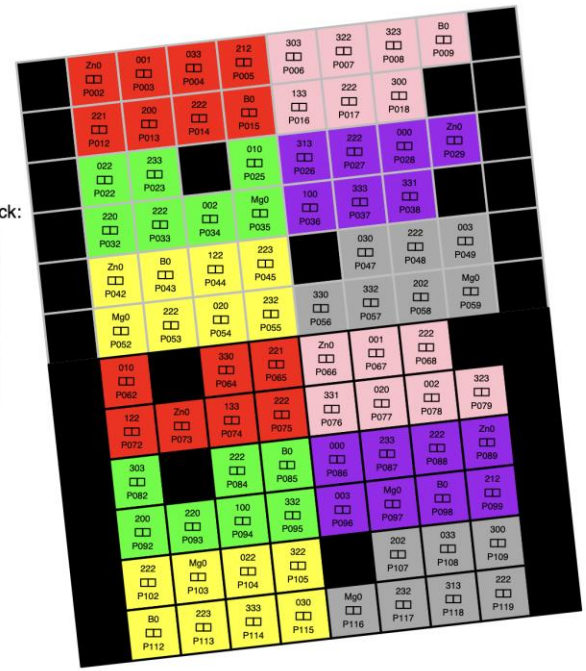


Replication/blocking

CONI002\_Y2020

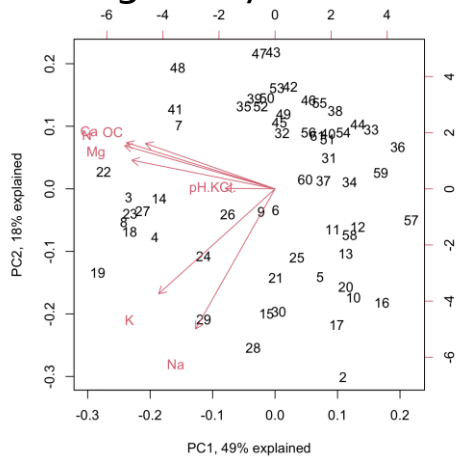
Rep/Blck:

- × 1
- × 2
- 1
- 2
- 3
- 4
- 5
- 6

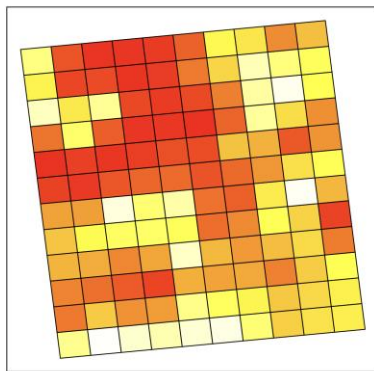


# Early results

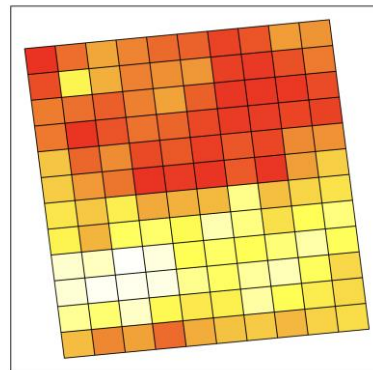
## Soil heterogeneity



soil.pc1.pred



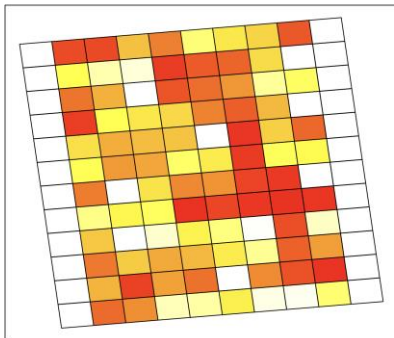
soil.pc2.pred



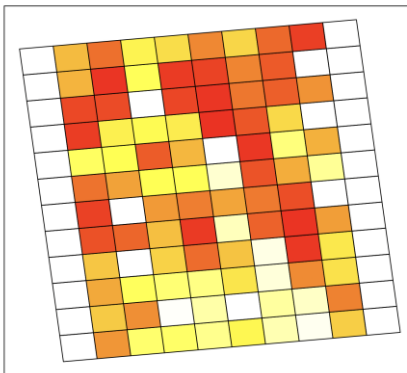
$R^2 = 0.08$   
 $p = 0.01$

## Trait heterogeneity

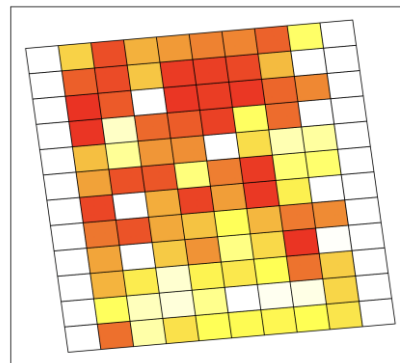
crownradius\_cm

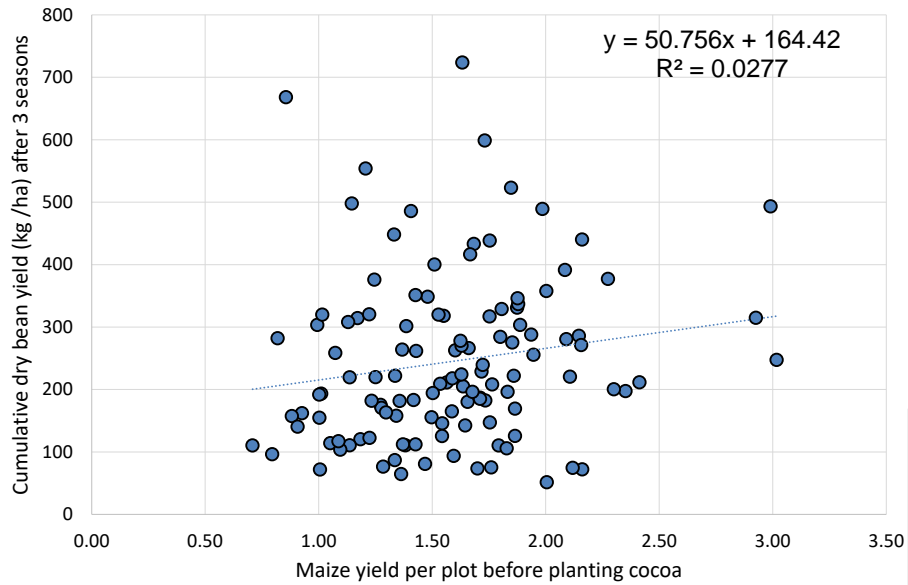


total\_bean\_yield\_ha



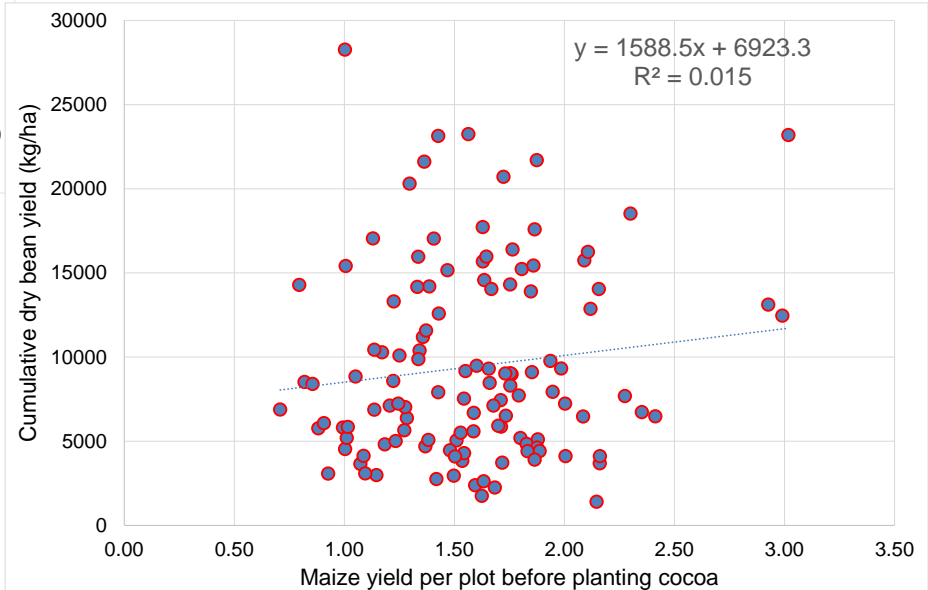
basal\_area\_cm





Relationship between maize yield before planting cocoa and the dry bean yield after three harvest seasons.

Relationship between maize yield before planting cocoa and the dry bean yield after six harvest seasons.



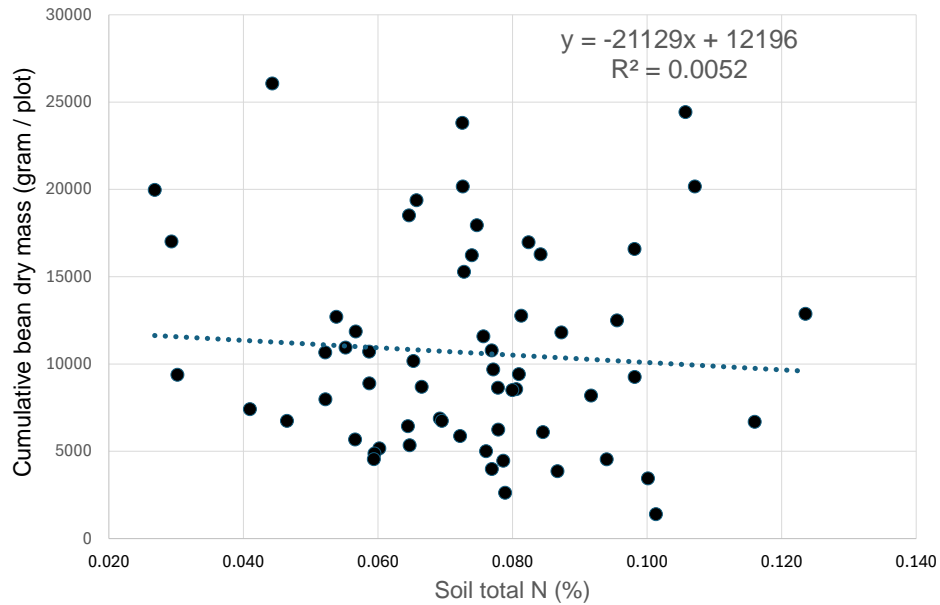
17016	21763	12868	25520	20161	17010	10702	6855	3985	6361
25863	12492	5798	16582	5383	8554	5748	11856	8754	6433
10660	4662	5669	5133	1398	2812	5342	8697	7405	6156
7315	5161	10100	9255	7337	3440	5800	8885	3561	4997
6681	16809	11803	6327	6872	4663	2621	7709	4540	4324
15375	16278	7825	10168	10746	16965	4057	5872	8922	8684
8503	6612	4866	6062	6742	10476	3855	2663	9375	17829
19089	12694	14882	6091	3200	12763	3381	4541	8366	8187
9417	18207	9680	15810	10933	8128	23801	1892	15275	10841
19470	17945	23947	24421	16351	10774	17209	4459	8118	8635
20165	26492	11576	31400	19379	12164	16226	21881	6233	5545
17513	19965	20944	26058	15096	7970	15165	18508	10102	6736

Cumulative bean dry mass (gram)

0.029		0.124		0.107		0.059		0.077	
	0.096		0.098		0.081		0.057		0.064
0.052		0.057		0.101		0.065		0.041	
	0.060		0.098		0.100		0.059		0.076
0.116		0.087		0.069		0.079		0.094	
	0.084		0.065		0.082		0.072		0.067
0.080		0.059		0.046		0.087		0.030	
	0.054		0.085		0.081		0.059		0.092
0.081		0.077		0.055		0.073		0.073	
	0.075		0.106		0.077		0.079		0.078
0.073		0.076		0.066		0.074		0.078	
	0.027		0.044		0.052		0.065		0.070

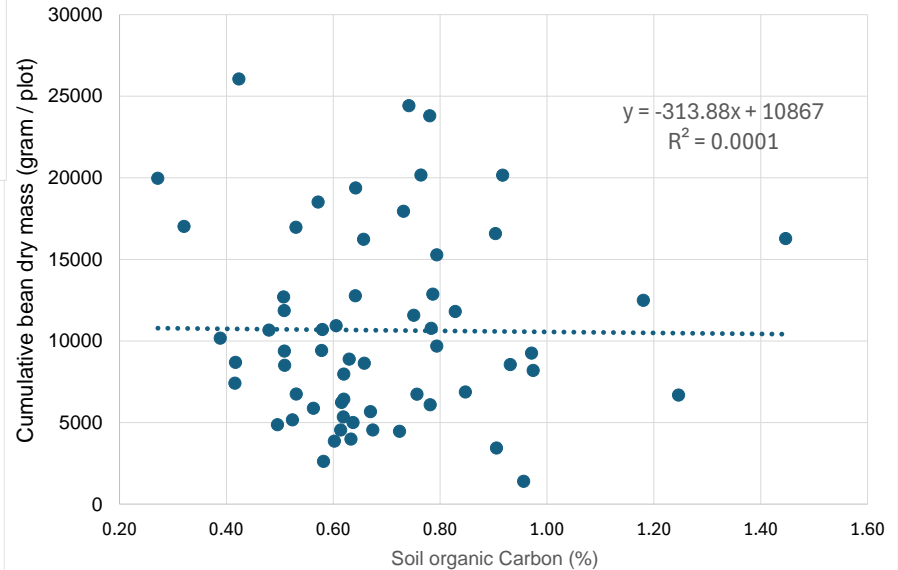
Soil N concentration 0-30 cm (%)





Relationship between the cumulative bean dry matter yield (gram / plot) and the initial soil total N concentration (%).

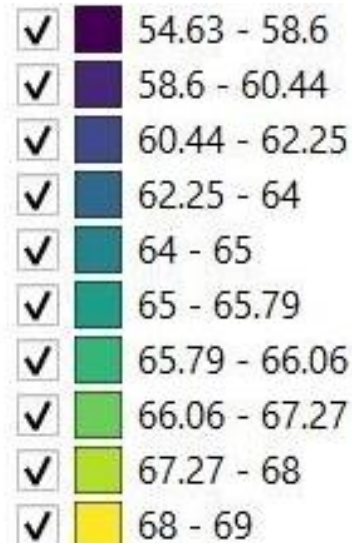
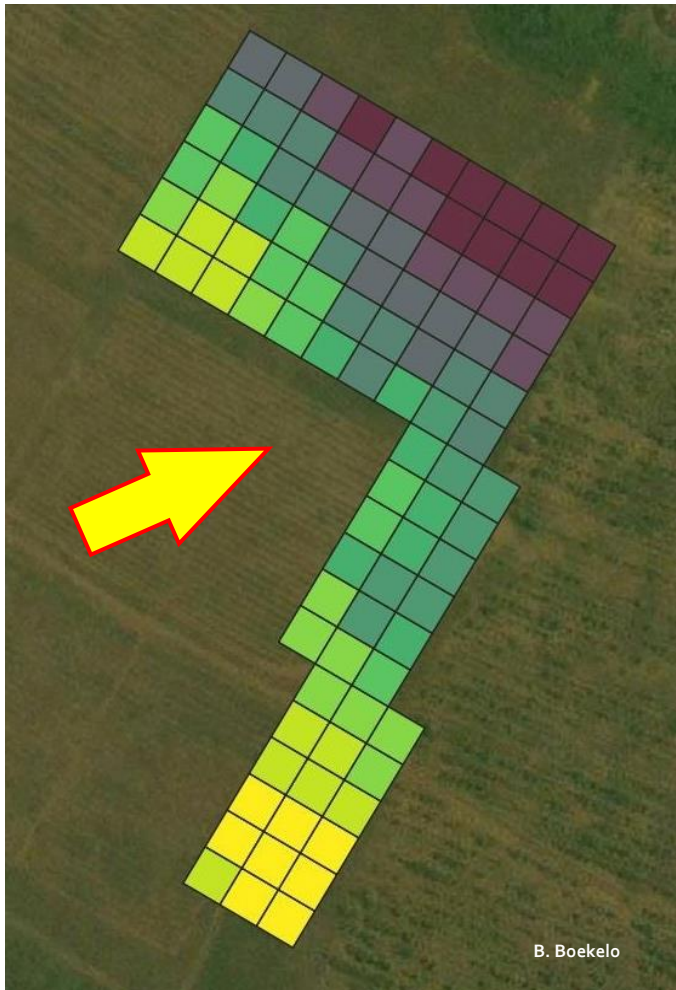
Relationship between the cumulative bean dry matter yield (gram / plot) and the initial soil organic carbon concentration (%).

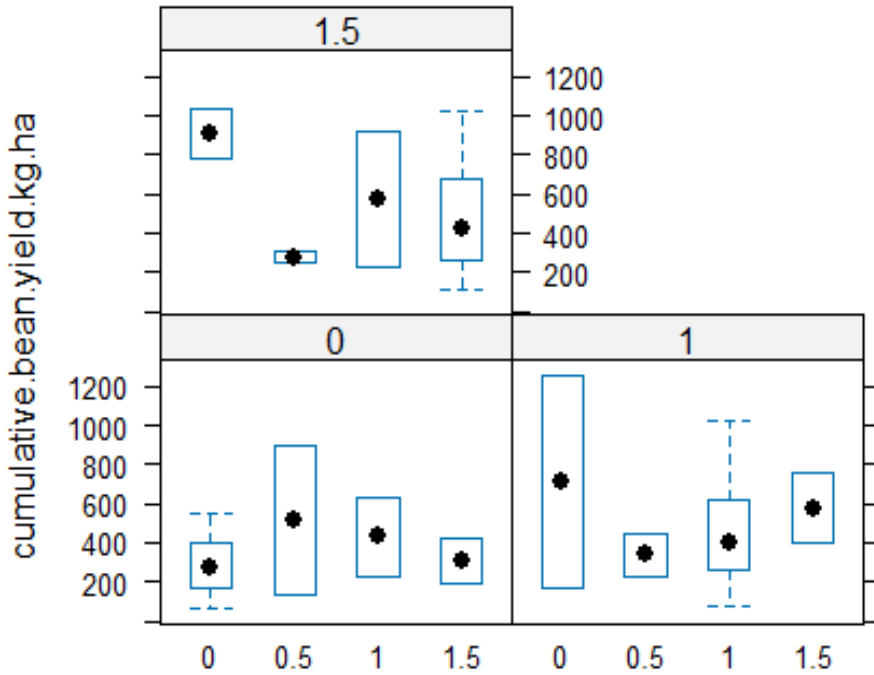


# Spatial variability – Tiassalé, elevation

The slope of the trial sites might affect the bean yield at this early stages and under stress conditions more severely than the fertilizer.

At Tiassalé, tree performance is better at the lower end of the slope – similar to the situation at Ibadan.

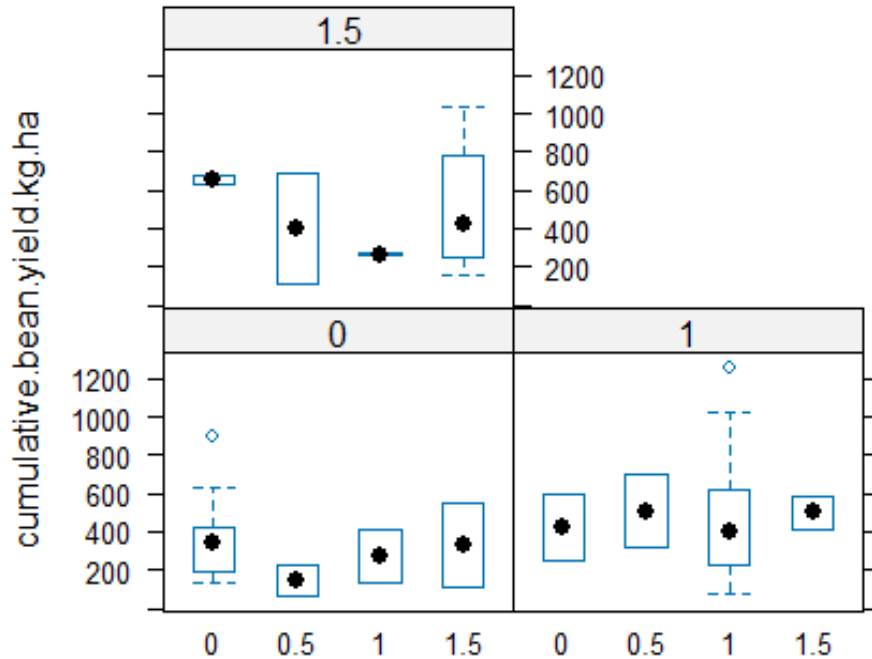




Cumulative bean yield response to N fertilizer application relative to the application of P and K.

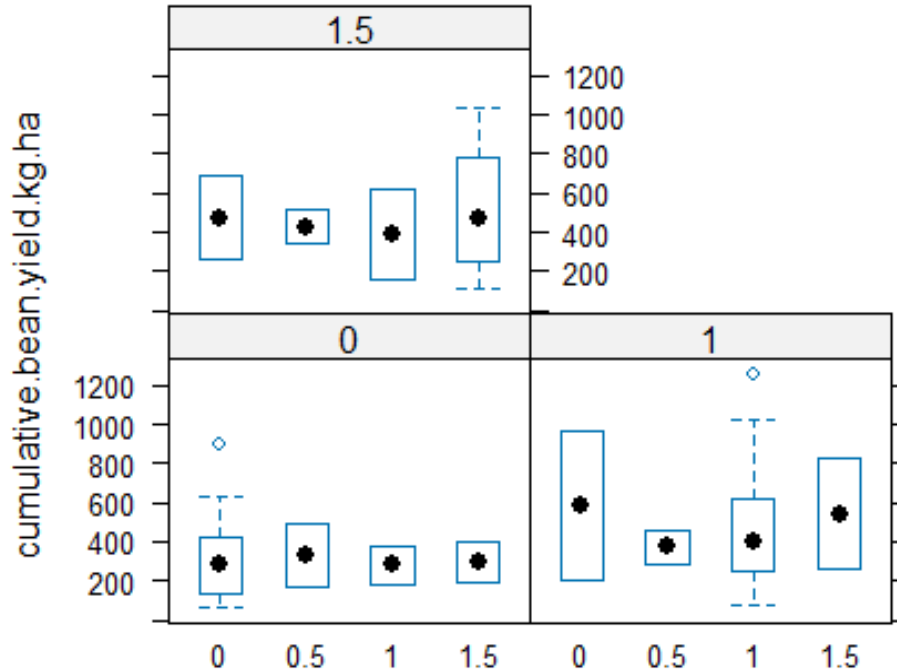
N fertilizer application level according to the off-take model at 0, 50 (0.5), 100 (1) and 150 (1.5) % of the recommended rate.

Cumulative bean yield response to P fertilizer application relative to the application of N and K.



P fertilizer application level according to the off-take model at 0, 50 (0.5), 100 (1) and 150 (1.5) % of the recommended rate.

Cumulative bean yield response to K fertilizer application relative to the application of N and P.



K fertilizer application level according to the off-take model at 0, 50 (0.5), 100 (1) and 150 (1.5) % of the recommended rate.

# Abiotic challenges



Tree death as a consequence of extreme dry season conditions 2022-23. About 400 trees shed all leaves within 2 weeks in January 2023 at Ibadan, most of them died.



Tree stems exposed to direct sun lost their bark. Possible consequence appear infections with fungi and ants settling under the detached bark.



# Biotic challenges

Over the last two years an increasing frequency of stem borer attacks were noticed. There are at least 3 species drilling into stems and branches.

This problem is generally observed in all West African core trials. Control is labour intensive and not necessarily effective.



# Field maintenance and treatment application Ecuador

Pruning (March-June-December 2023)



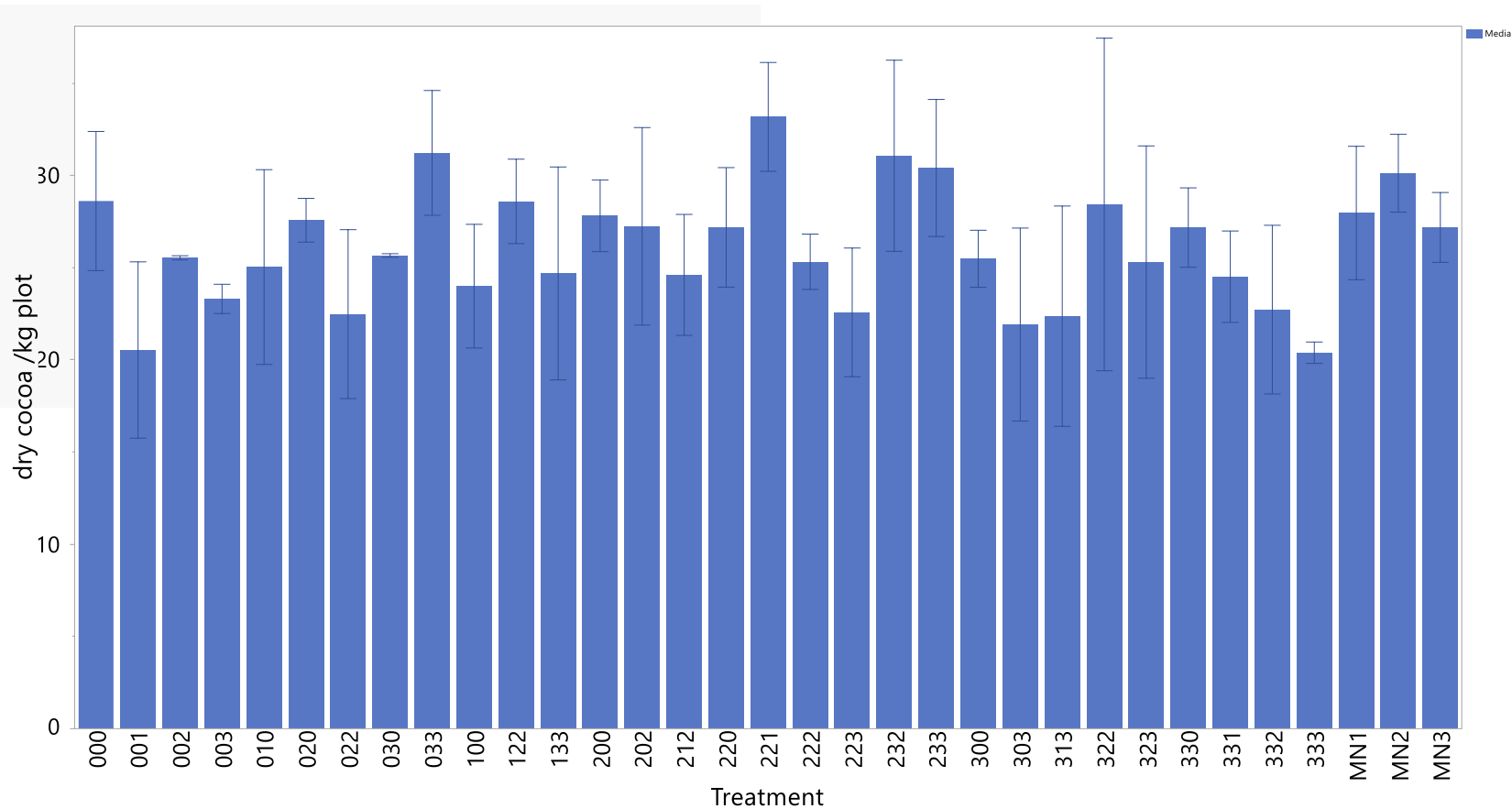


# Treatment application (June-August-September-October 2023)





# Yield data affected by treatments



As for most core trials we only have one year of bean yield data, the results are not yet relevant nor reliable.

To attain reliable results, a maximum of biotic and abiotic stress factors need to be excluded or at least minimized.

Regular data uploads of tree evaluation, and harvest data will help monitor progress and facilitate data analyses.



**THANK YOU FOR YOUR ATTENTION**

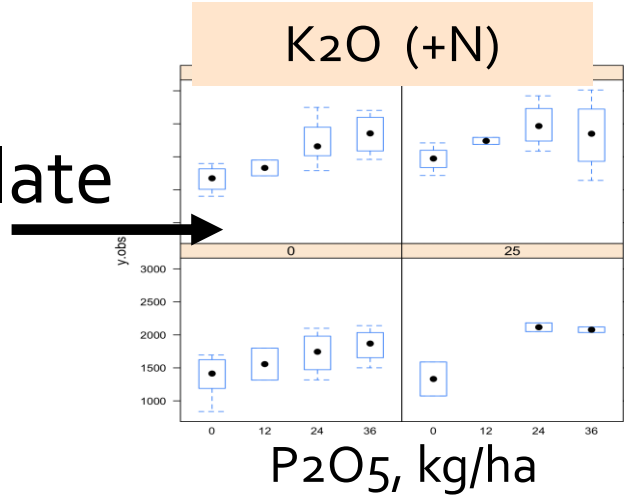
---



# Theoretical proof of concept

$$y_{obs} = \frac{1}{\frac{1}{\bar{Y}_t} + \frac{1}{aN(N_s + N_f)} + \frac{1}{aP(P_s + P_f)} + \frac{1}{aK(K_s + K)}} + Error_{(rep)} + Error_{(block)} + Error_{(plot)}$$

Simulate



Estimate

$$y_{obs} = \frac{1}{\frac{1}{\bar{Y}_t} + \frac{1}{aN(N_s + N_f)} + \frac{1}{aP(P_s + P_f)} + \frac{1}{aK(K_s + K)}} + \dots$$

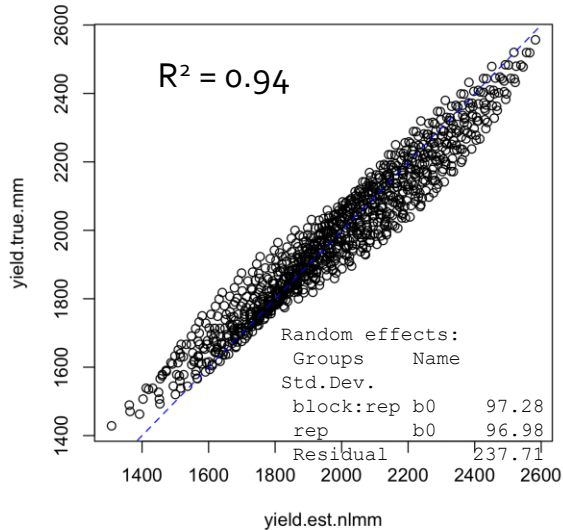
$$y_{obs} \sim N+P+K+N:P+N:K+P:K+N^2+P^2+K^2 + \dots$$

Full model (hard)

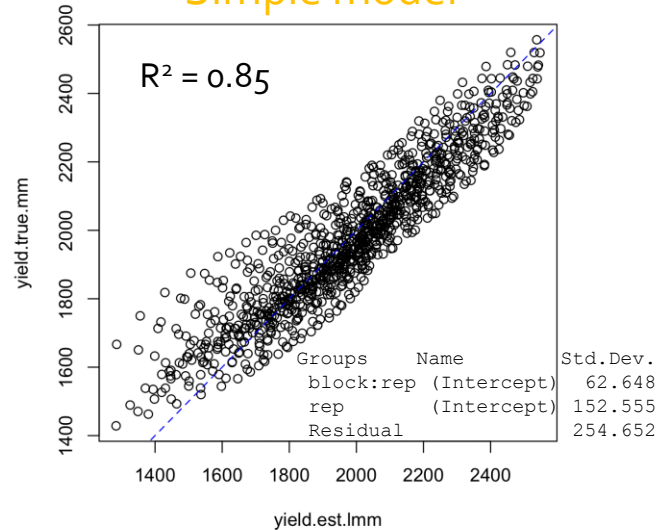
Simple model (easy)

# Theoretical proof of concept

Full model



Simple model



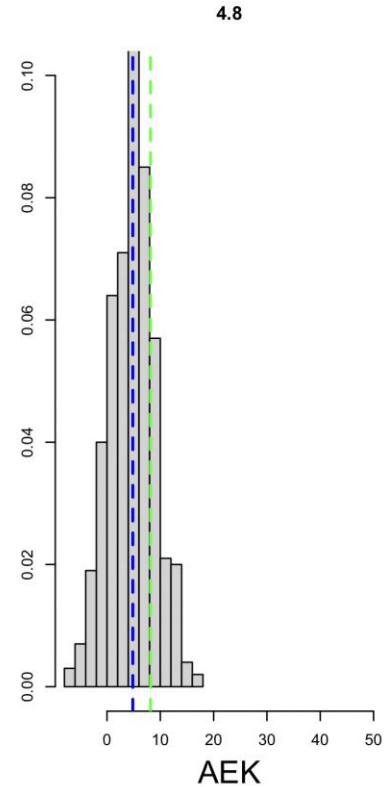
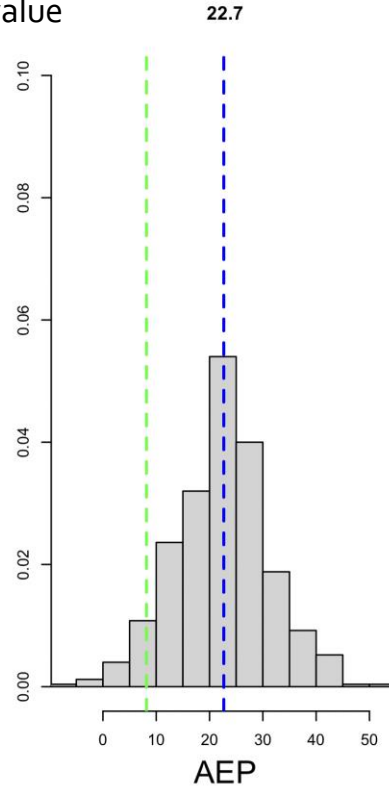
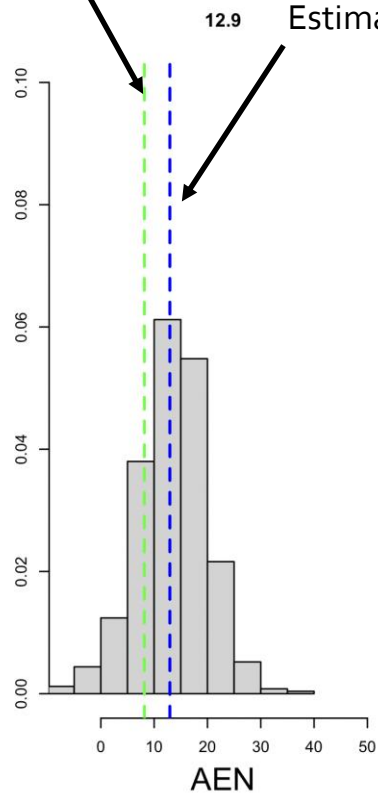
Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)
<b>N</b>	288495	144247	2	57.674	2.2244	0.11733
<b>P</b>	640078	320039	2	57.531	4.9352	<b>0.01052</b> *
<b>K</b>	527255	263627	2	55.226	4.0653	<b>0.02254</b> *
N:P	64556	64556	1	58.299	0.9955	0.32253
N:K	90186	90186	1	54.787	1.3907	0.24338
P:K	38992	38992	1	58.721	0.6013	0.44120



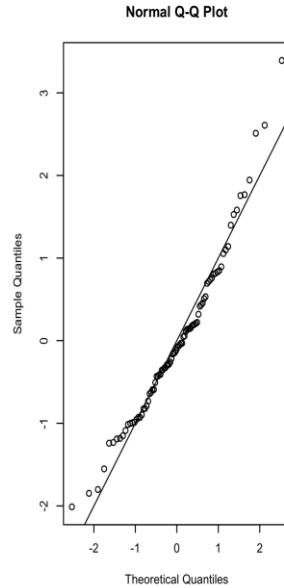
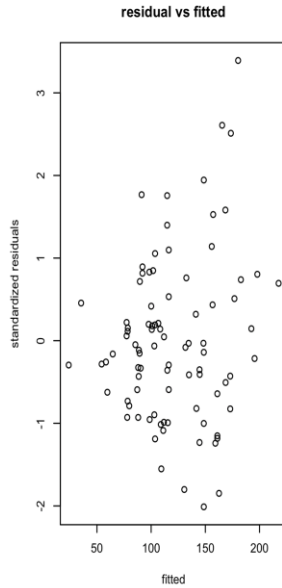
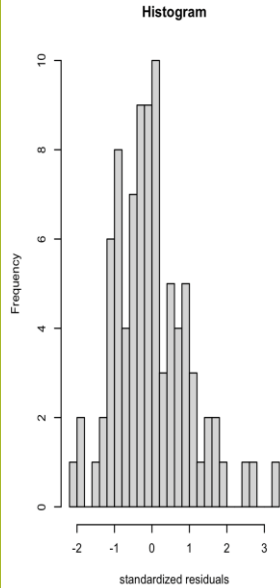
# Theoretical proof of concept

True value  
(8)



# Early results

Data quality



Blocking useful

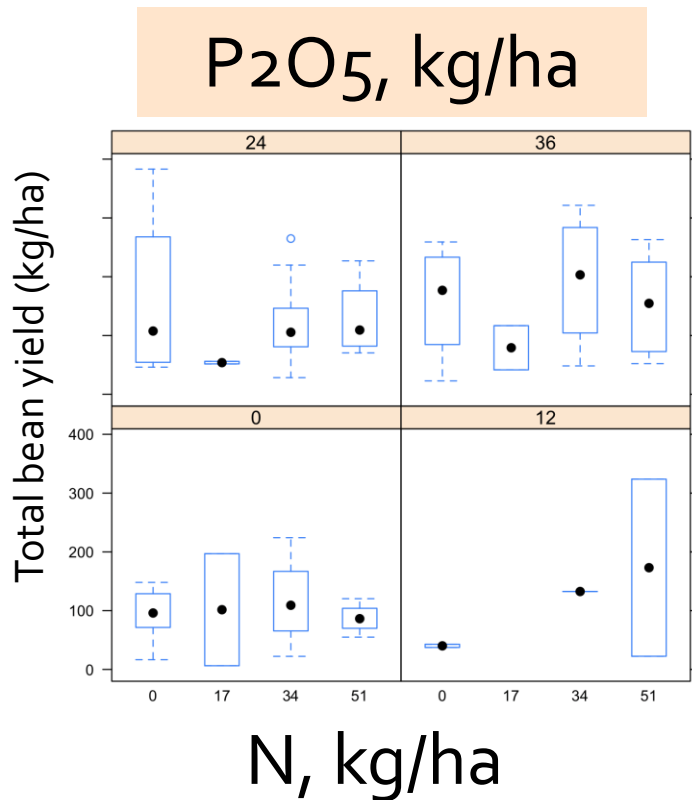
Random effects:

Level	Variance	Std.Dev.
<b>block:rep</b>	<b>1131.8</b>	<b>33.64</b>
<b>rep</b>	<b>673.7</b>	<b>25.96</b>
Residual	4393.4	66.28

Non-systematic  
variation accounted for

# Early results (Ibadan, Nigeria)

Observed responses



Estimates of AE

