Inorganic fertilizer use and its association with rice yield gaps in sub-Saharan Africa

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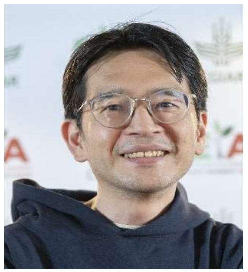

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- Where and in which countries should improving inorganic fertilizer use in rice fields in sub-Saharan Africa (SSA) be given higher priority?

- Rice is an important staple food in many parts of SSA.
- Rice productivity is still low in SSA (2.2 Mg ha^{-1}) vs. Asia (4.8 Mg ha^{-1} and South America (6.1 Mg ha^{-1})
- Large average yield gap: 5.0 Mg ha^{-1}
- Inorganic fertilizer use on arable land is generally low in sub-Saharan Africa (SSA).

Introduction

- Increasing its use is essential for improving productivity.
- Relatively little research has analyzed the correlation between nutrients applied through inorganic fertilizers by smallholder farmers and the rice yield and yield gap in SSA
- A comprehensive and African continental-wide analysis of the past three decades is missing.

Research questions

- **(i) Which regions, rice-growing environments,** and **agroecological zones exhibit higher** or **lower fertilizer application?**
- **(ii) How the correlations between fertilizer rates and yield, and yield gap are affected by the growing environment?**
- **(iii) What are the impacts of key nutrients and environmental factors, such as agroecological zones and growing environments on the partial factor productivity of applied nutrients?**

Methods

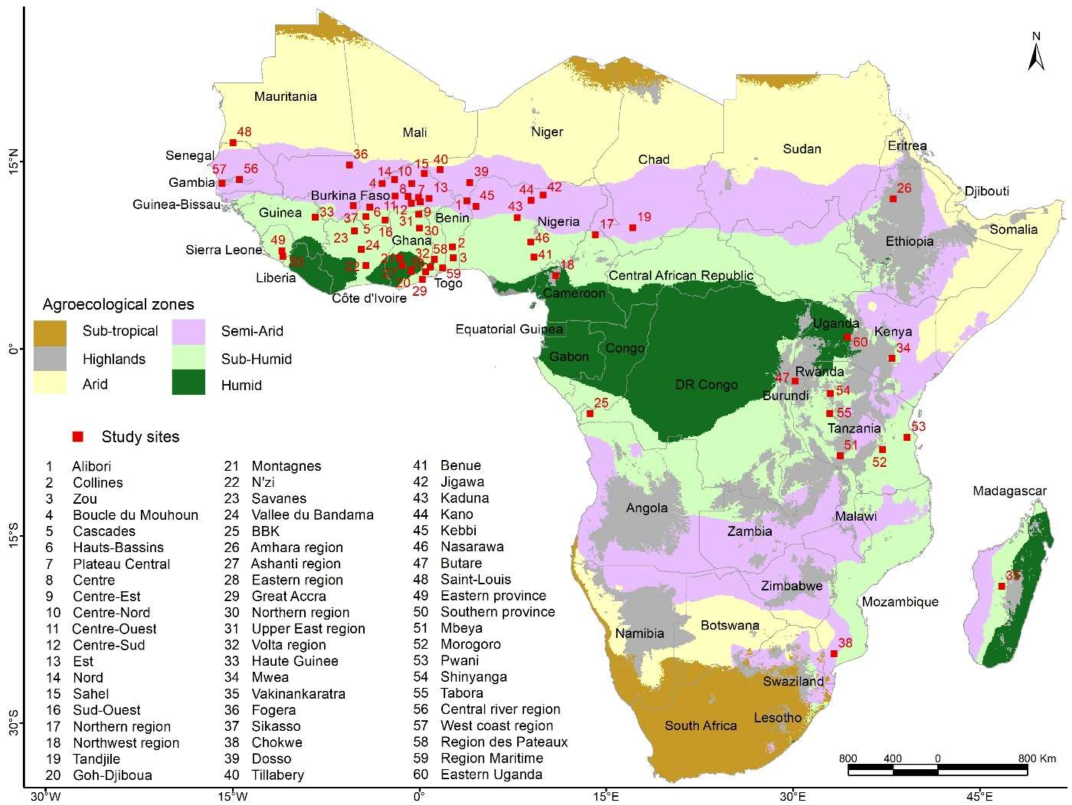
- **Systematic literature review** (studies published before August 20th, 2021)
- **Inclusion** or the **exclusion** criteria:
    1. Survey or farmers' field trials carried out in smallholder farmers' fields in SSA where **fertilizer management** (fertilizer type, application time and rates) was done **according to local practices** were included
    2. Studies reporting data on **recommended application rates from research-managed trials** conducted in research station or farmers' fields were **excluded**
    3. Studies reporting **pot experiments** were also **excluded.**

Methods

- **Study variables**: Country, location name, year, season, rice-growing environment, N, P, and K application rates, and grain yield.

- **Potential yield** in IL systems or the **water-limited potential yield** in rainfed systems.

- **Calculation & Statistical analysis** (Descriptive analysis, Kruskal-Wallis test, correlation analysis, multinomial logistic regression, cluster analysis).



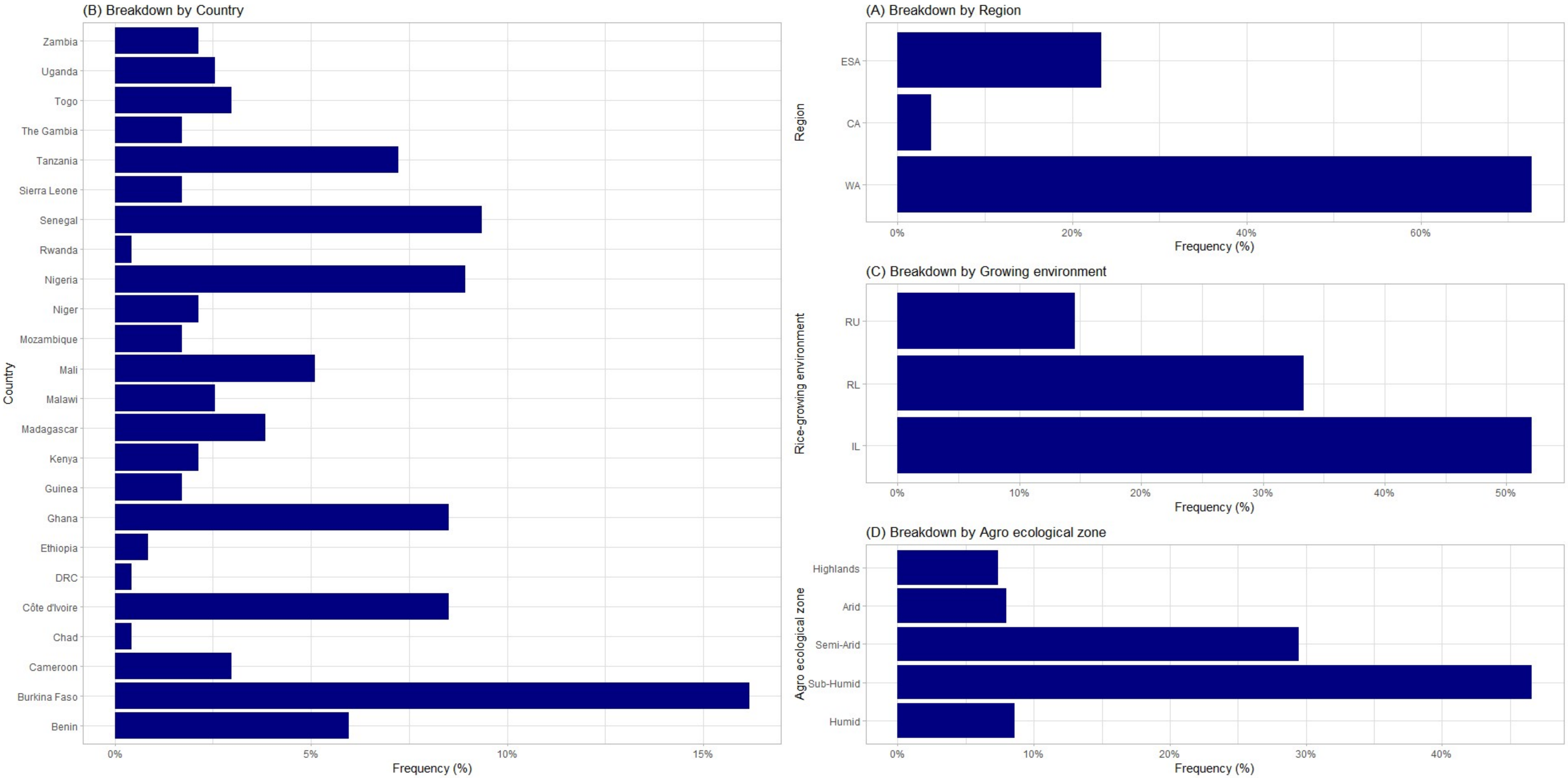
❑ **235 data points** from studies conducted between 1995 and 2020

❑ **24** SSA **countries**

❑ **3** different growing environments systems: irrigated lowland (**IL**), rainfed lowland (**RL**) & rainfed upland (**RU**)

❑**5 AEZs**: Humid, sub-humid, semi-Arid, Arid & Highlands

Results



Data points of fertilizer application rates

- Burkina Faso, Senegal, Nigeria, Côte d'Ivoire, and Ghana were the countries having more data points

Research questions

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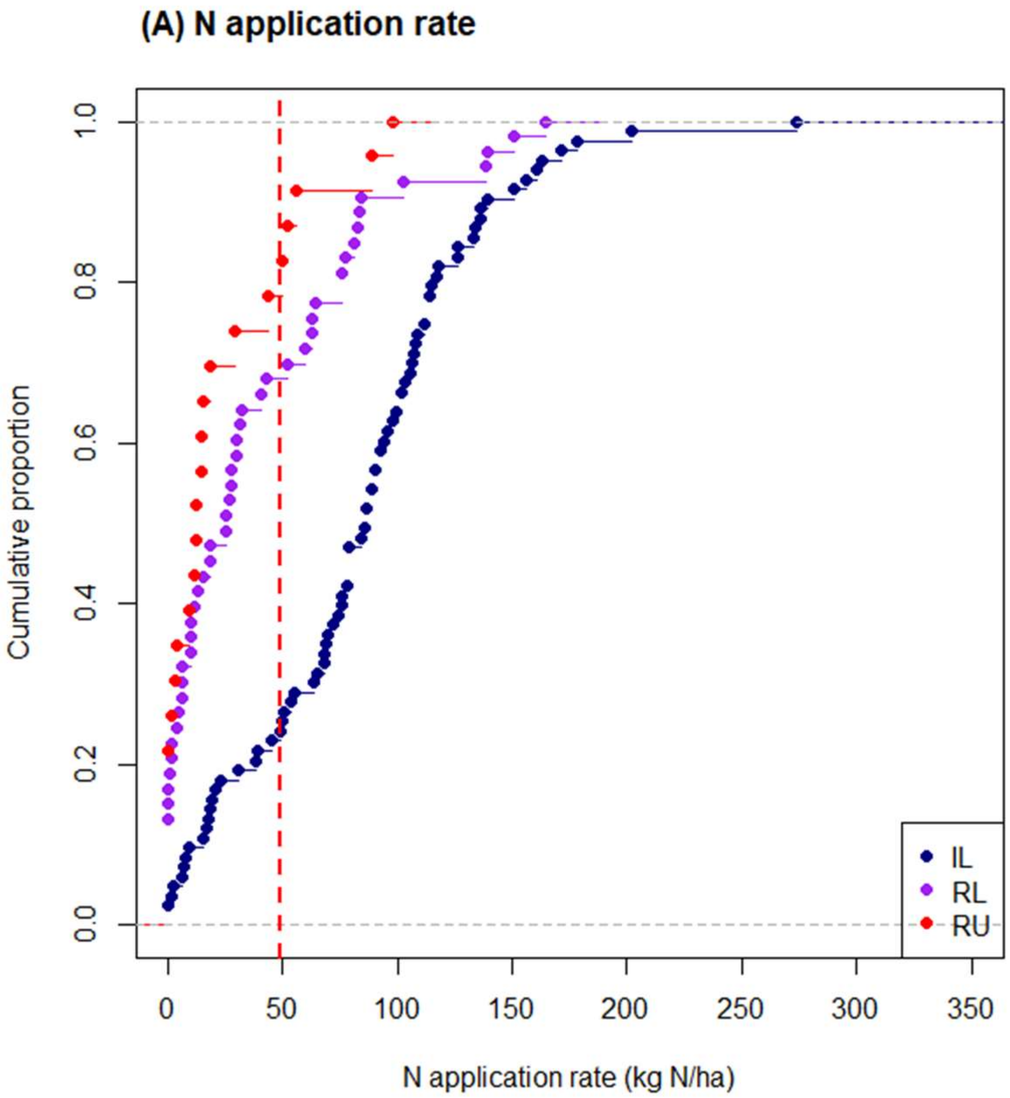
- (iii) What are the impacts of key nutrients and environmental factors, such as agroecological zones and growing environments on the partial factor productivity of applied nutrients?

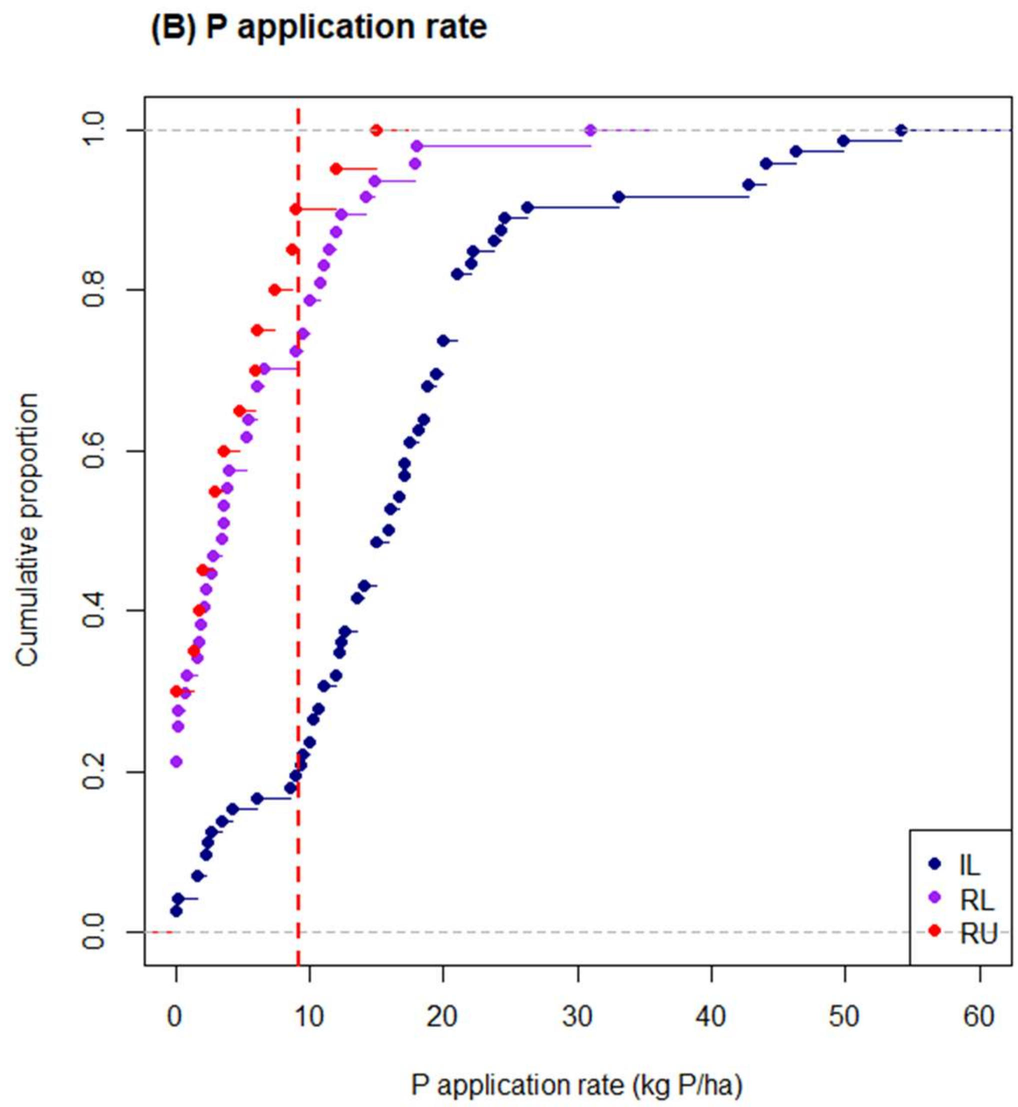
Results

- On average across 3 rice growing environments, **N**, **P**, and **K** rates are **49**, **9**, and **8** kg/ha, respectively, with their large variation (CV ~ 110 - 140%).
- **N rate** was **higher** in **IL** than in **RL** and **RU**.



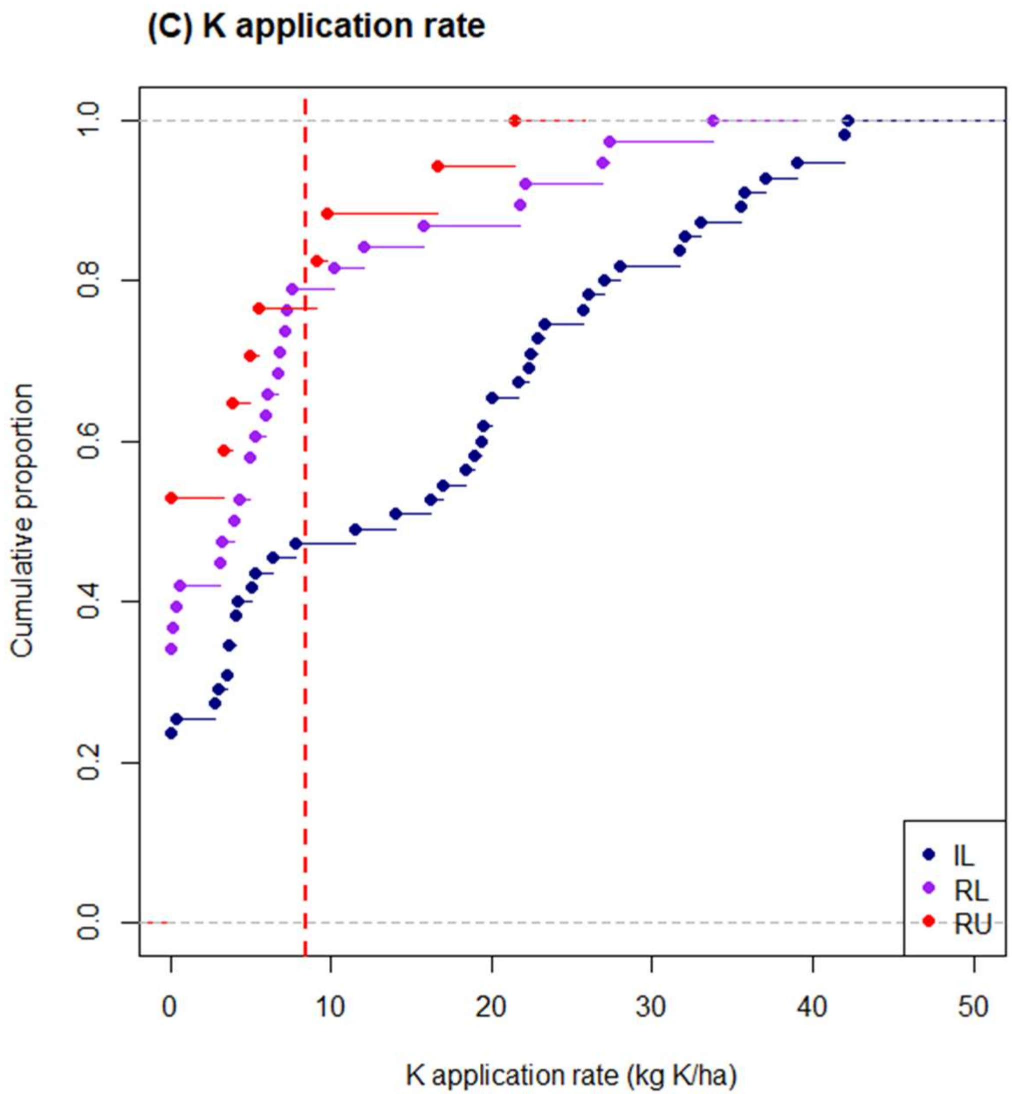
Results

- On average across 3 rice growing environments, **N**, **P**, and **K** rates are **49**, **9**, and **8** kg/ha, respectively, with their large variation (CV ~ 110 - 140%).
- **P rate** was **higher** in **IL** than in **RL** and **RU**.



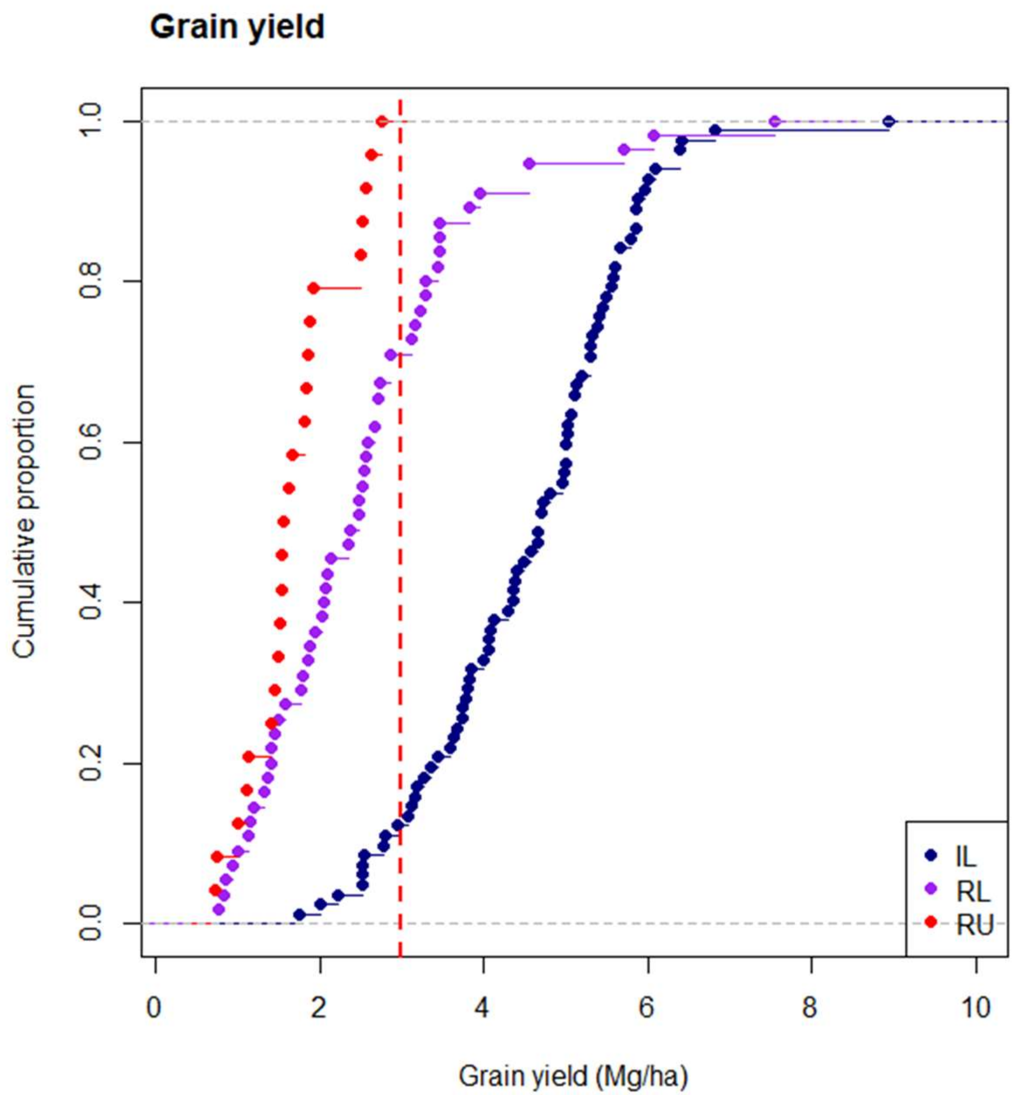
Results

- On average across 3 rice growing environments, **N**, **P**, and **K** rates are **49**, **9**, and **8** kg/ha, respectively, with their large variation (CV ~ 110 - 140%).
- **K rate** was **higher** in **IL** than in **RL** and **RU**.

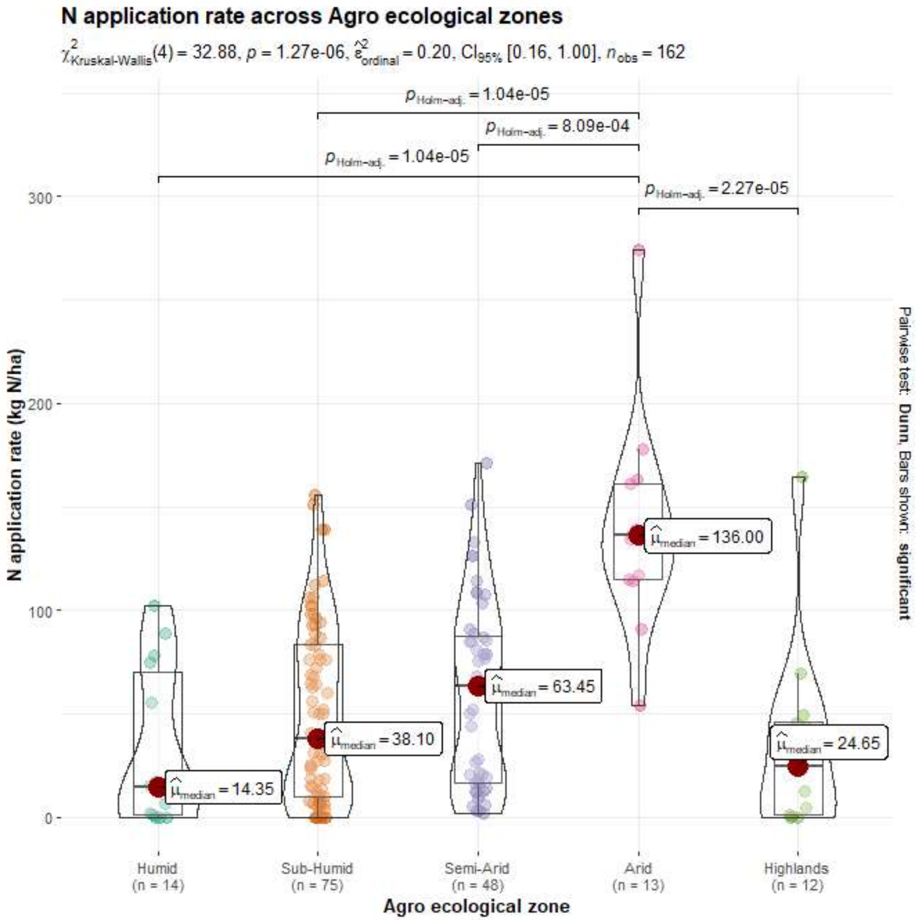


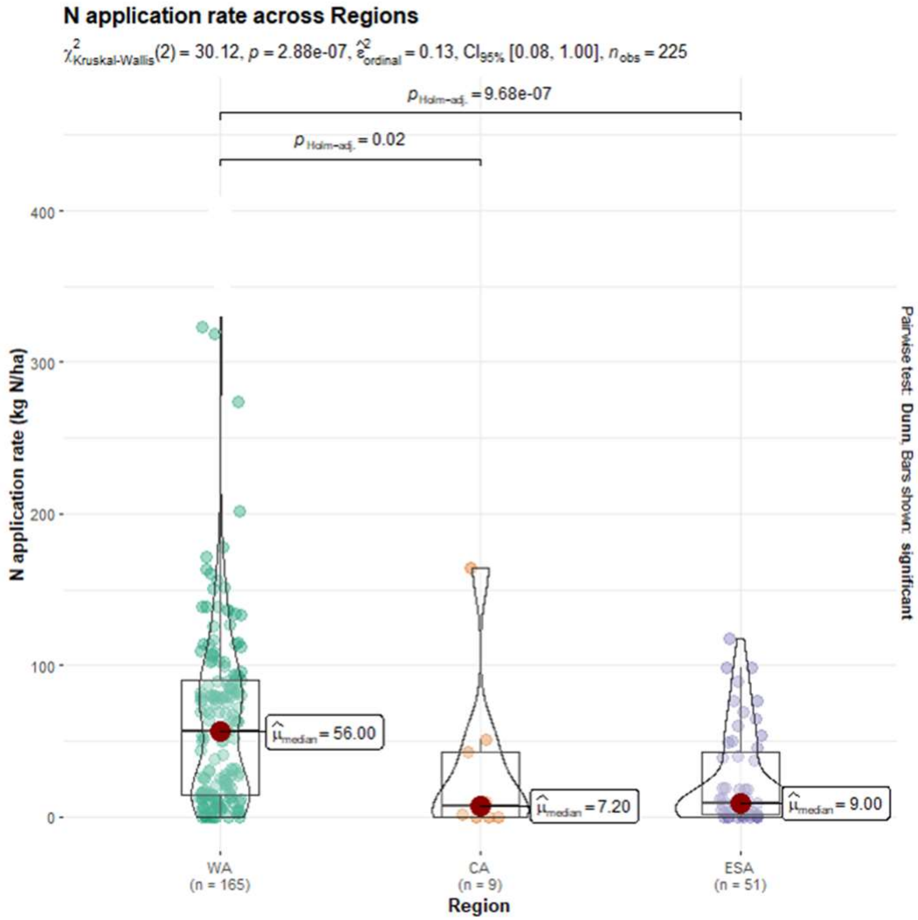
Results

- On average across 3 rice growing environments, **grain yield** are **2.98** Mg/ha
- **Grain yield** was **higher** in **IL** than in **RL** and **RU**.



Results





- ❑ **N rate** was **higher** in **Arid** than in **humid zone**.
- ❑ Same case for **P** rate (data not shown).
- ❑ **N rate** was **higher** in **WA** than in **CA** and **ESA**.

Research questions

- (i) Which regions, rice-growing environments, and agroecological zones exhibit higher or lower fertilizer application?
- **(ii) How the correlations between fertilizer rates and yield, and yield gap are affected by the growing environment?**
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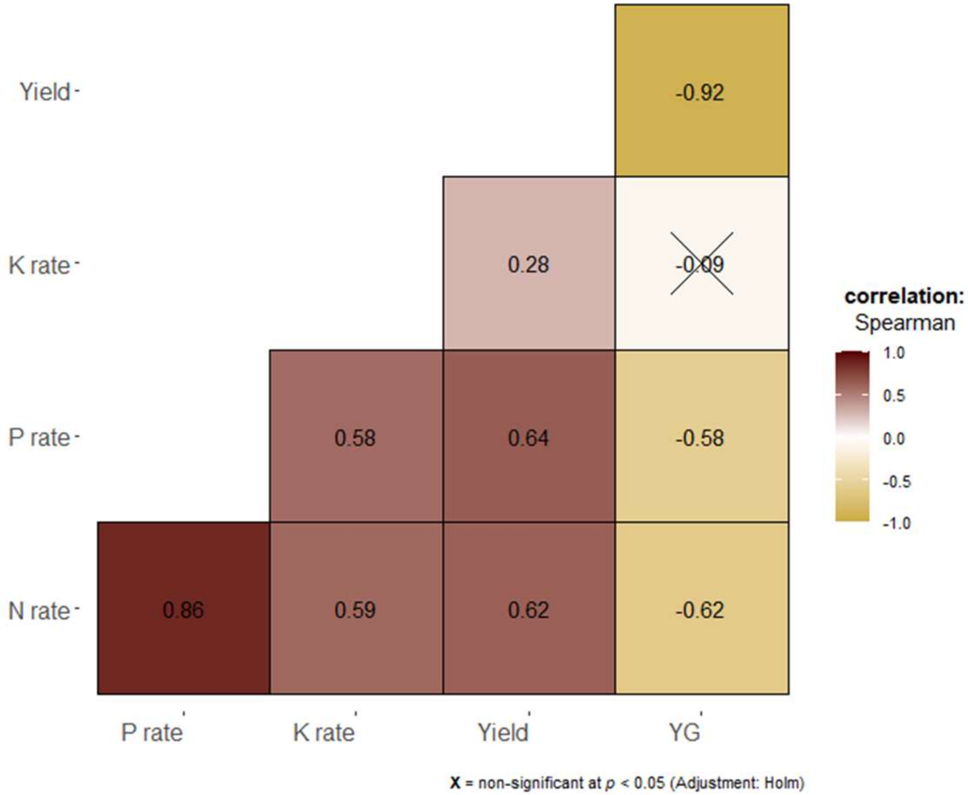
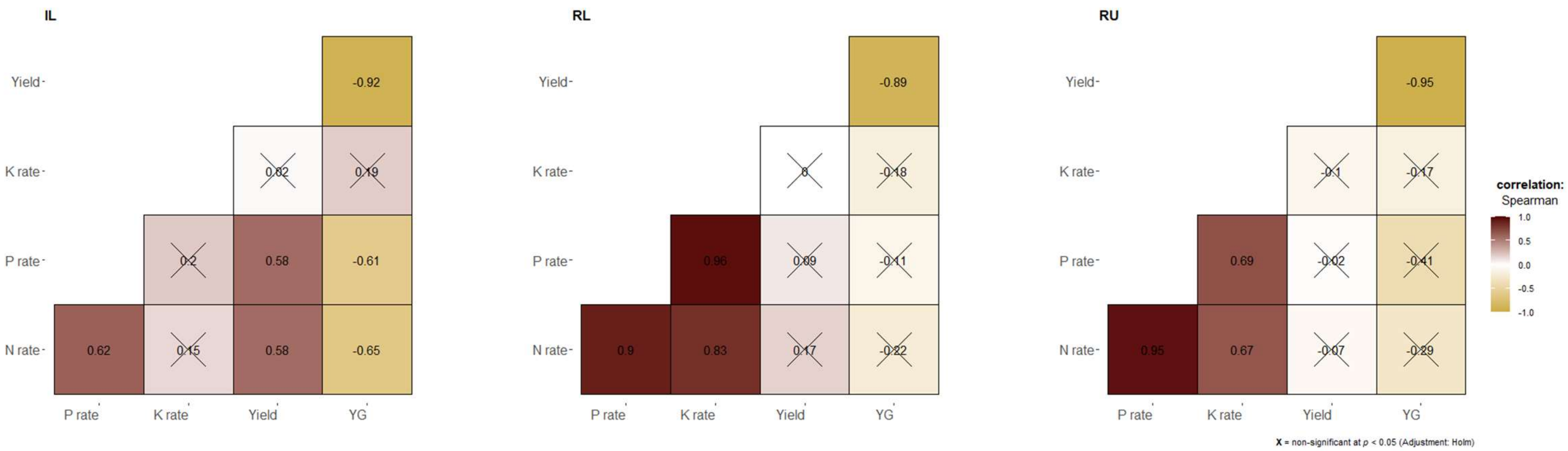


❑ **Higher N** and **P fertilizer** application **rates** were associated with **higher yield** and **lower yield gap**

Results



- ❑ **Higher N** and **P fertilizer** application **rates** were associated with **higher yield** and **lower yield gap** in **IL**
- ❑ **No clear relationship** between N, P, and K rates and **yield** as well as **yield gap** in **rainfed systems.**

Research questions

- (i) Which regions, rice-growing environments, and agroecological zones exhibit higher or lower fertilizer application?
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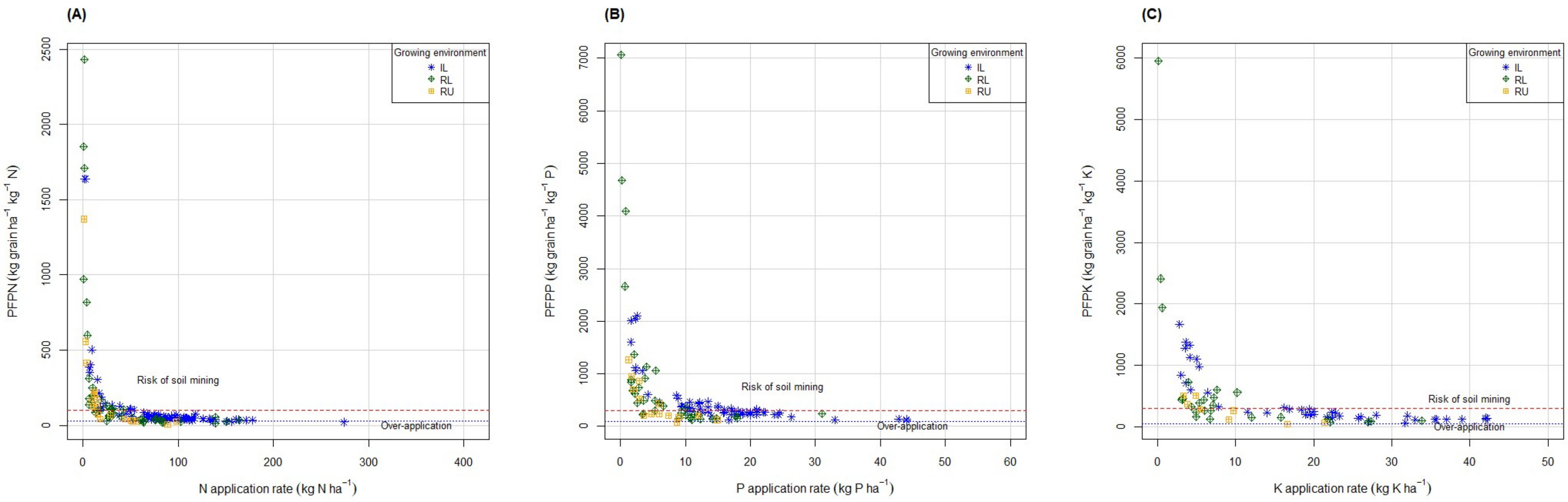
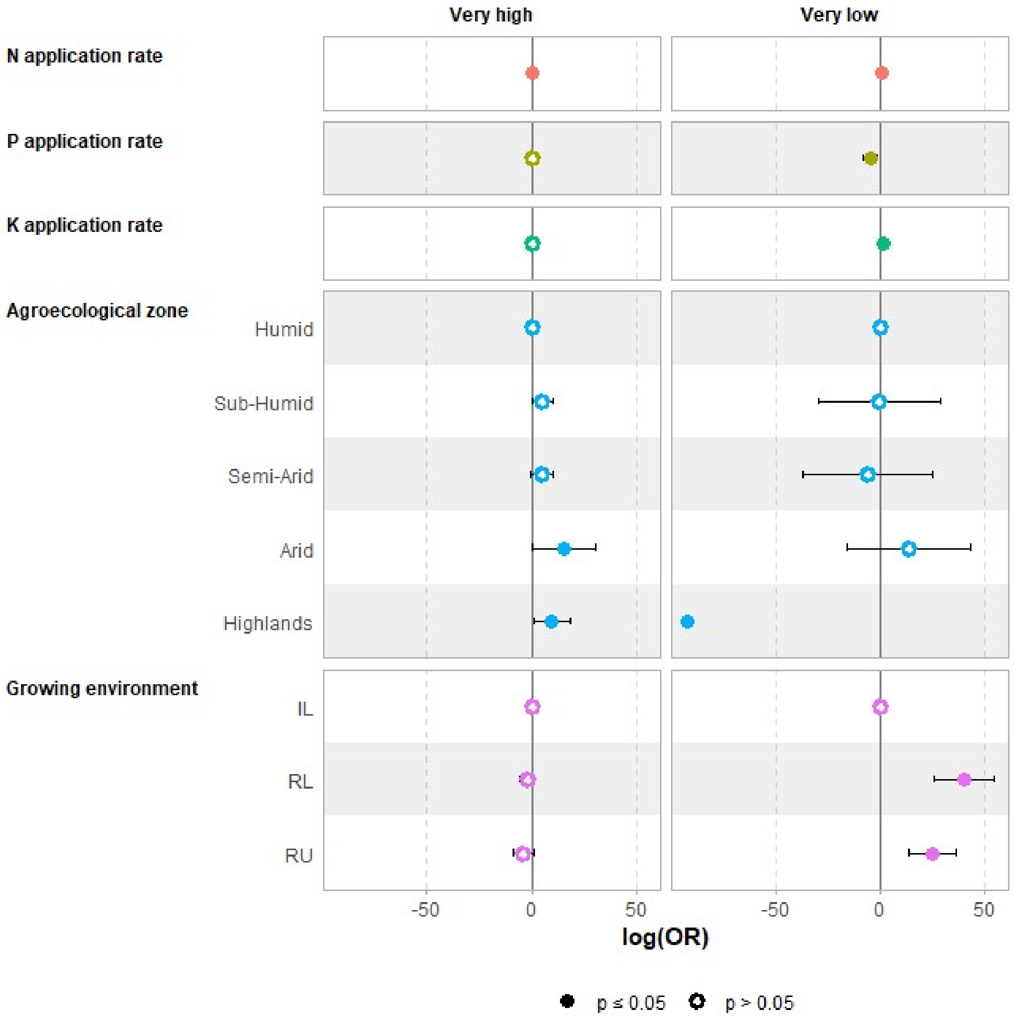


- ❑ **40%** of the **data points** had **high PFPN, PFPP, PFPK compared to the optimum level,**
- ❑ **Insufficient supply of fertilizer**
- ❑ **High risk of soil nutrient mining**

❑ **Irrigated system** tended to have **higher PFPN** than **rainfed systems**

❑ **Higher P rate** improved **PFPN**



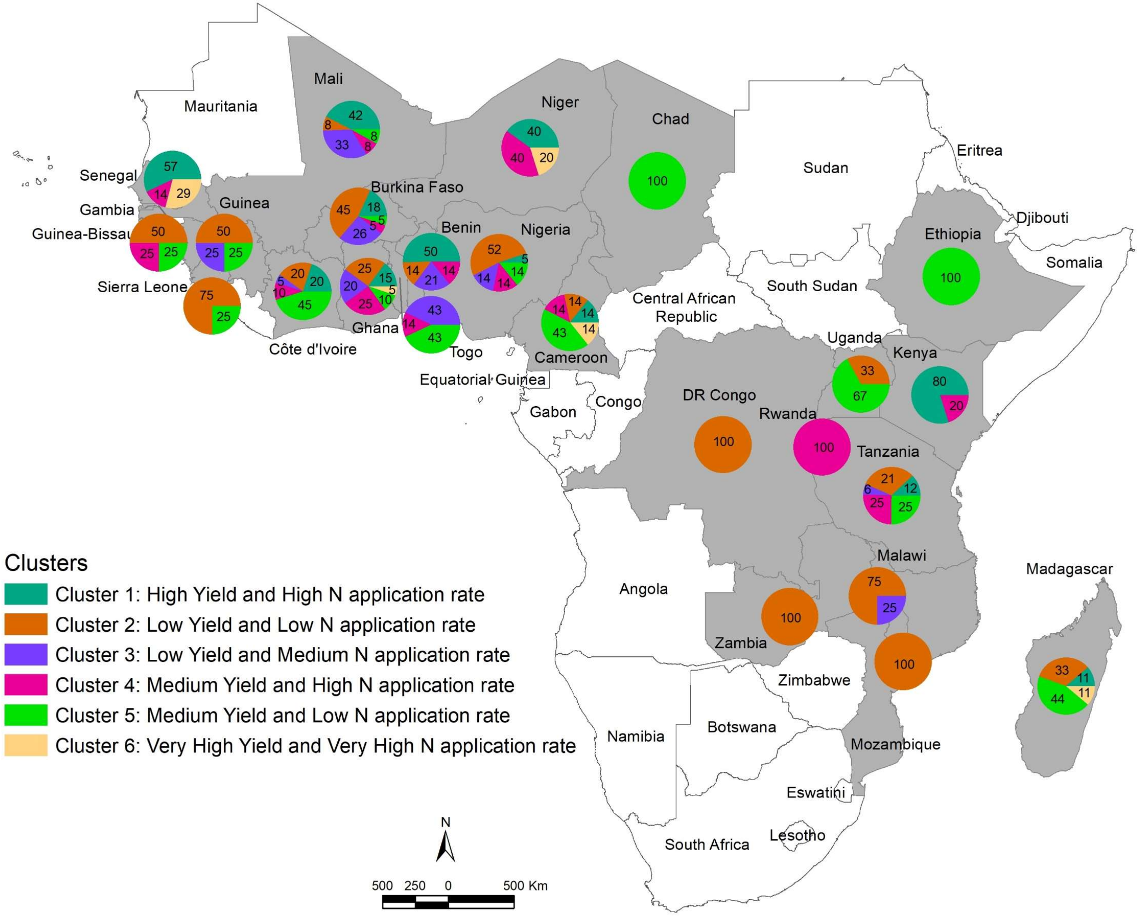
Estimated parameters of multinomial logistic regression: effects of the nutrients application rates and the environmental conditions on the optimum levels of PFPN

Results

Research and Development recommendations for the six groups identified by cluster analysis

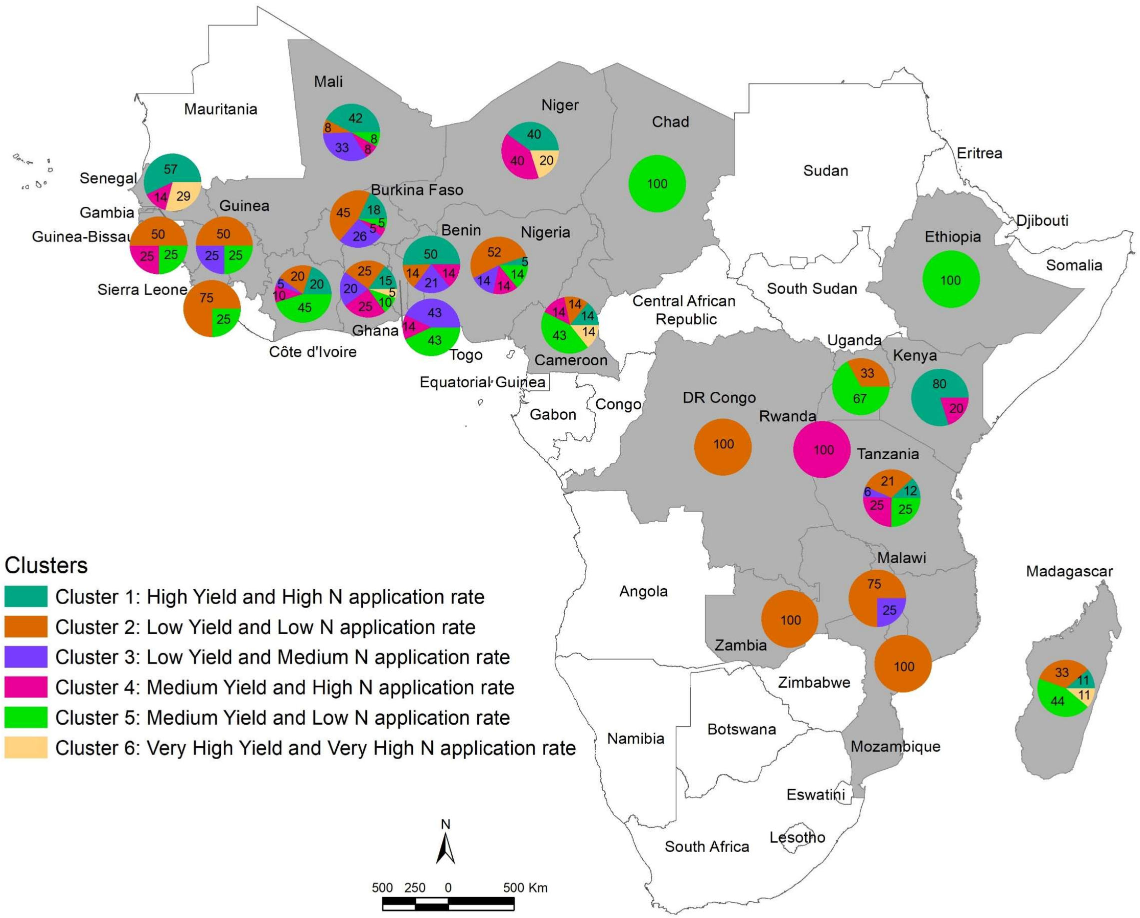
Cluster	Research and Development recommendation
Cluster 1: **High Yield** and **High N application rate** (HYHN)	Little room for yield improvement. Focus on increasing nutrient use efficiency.
Cluster 2: **Low Yield** and **Low N application rate** (LYLN)	Low socio-economic relevance i.e., Research and Development actions have a limited impact on farmers' livelihoods and the economic development of the community. Unraveling the causes of low yields could provide the way forward.
Cluster 3: **Low Yield** and **Medium N application rate** (LYMN)	High socio-economic relevance i.e., Research and Development actions could have substantial implications for improving farmers' well-being, addressing socio-economic inequalities, and contributing to economic growth in the area. Research institutes should investigate the yield gap, causes of low yield, and possible solutions. Site-specific nutrient management (SSNM) solutions should be tested. Then, governments/agencies should disseminate and promote good agricultural practices and SSNM solutions.
Cluster 4: **Medium Yield** and **High N application rate** (MYHN)	High socio-economic relevance. Research institutes should investigate the yield gap, causes of medium yield, and possible solutions. Site-specific nutrient management (SSNM) solutions should be tested. Then, governments/agencies should disseminate and promote good agricultural practices and SSNM solutions.
Cluster 5: **Medium Yield** and **Low N application rate** (MYLN)	Potential for further increasing fertilizer inputs; Research institutes should investigate reasons for low fertilizer inputs. Then, if relevant and according to the country's priorities, governments could establish policies facilitating access to fertilizer for smallholder farmers.
Cluster 6: **Very High Yield** and **Very High N application rate** (VHYVHN)	Little room for yield improvement. Focus on increasing input use efficiency.

Discussion

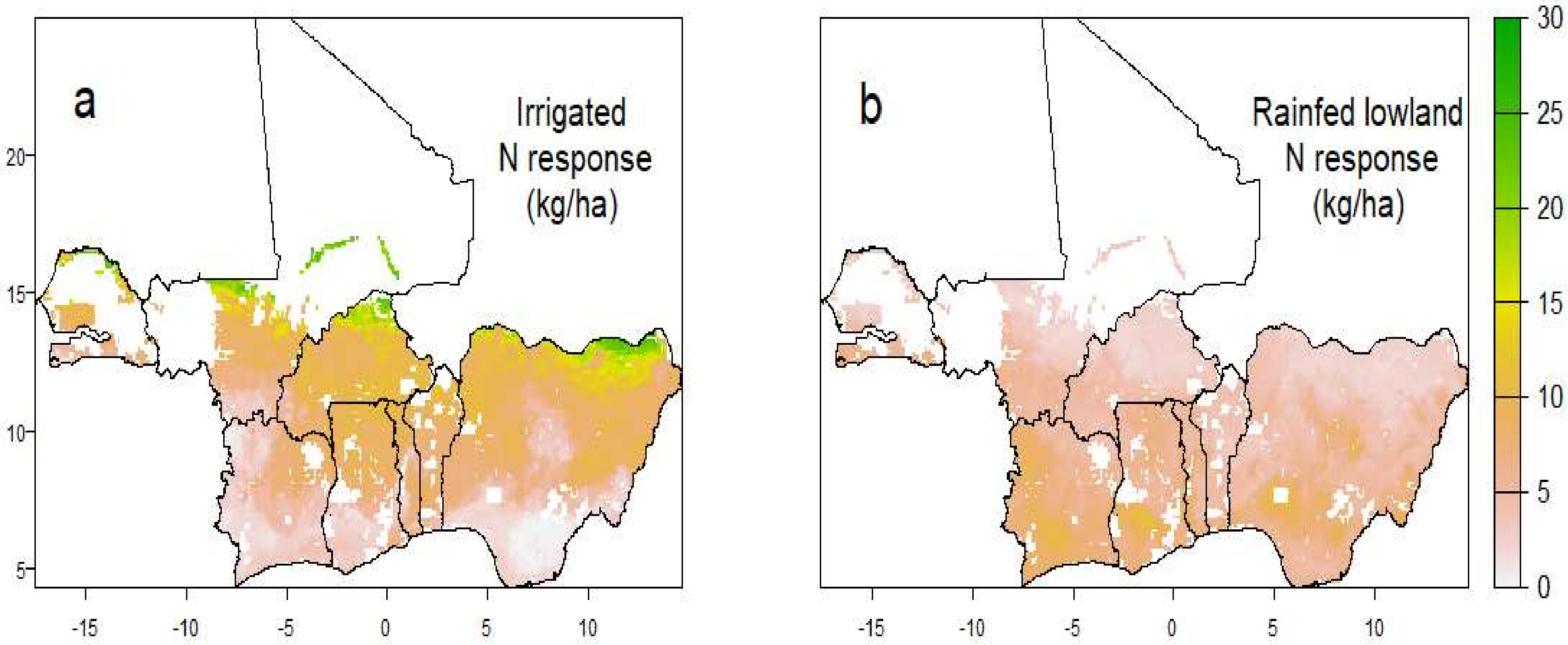


- In Rwanda, Togo, Ghana, Mali, and Niger, more than 40% of the data points belong **Clusters 3** & **4**
- National and/or international research institutes should **investigate the causes of low** and **medium yields**
- **Dissemination of validated site-specific nutrient management (SSNM) solutions** and **good agricultural practices**

Discussion



- A high proportion (> 40%) of data points from Ethiopia, Chad, Uganda, Côte d'Ivoire, Togo, and Cameroon belong to **Cluster 5**
  - **Investigate reasons for low fertilizer inputs.**
  - **For irrigated lowland sites, if relevant** and according to the **country's priorities, governments** could **establish policies facilitating access to fertilizer** for smallholder farmers



Average rice response (kg grain kg^{-1} N) for **irrigated and rainfed lowland systems** in **West Africa**

Ongoing work

- ❑ **Current dataset** & **Fertiliser response data** → **Ongoing study** with colleagues from **CIMMYT**
- ❑ **Quantifying** the **impact** of **location-specific environmental** and **economic conditions** on **returns on fertilizer investments**
- ❑ **Open to new collaborations**

- **N** and **P** rates were **higher** in **irrigated lowlands** and **arid** zones.
- **Higher N** and **P rates** were associated with a **lower yield gap** in **irrigated rice systems**.
- **Higher P rates** improved **PFPN**.
- ~**40%** of the data points showed a **high risk of soil nutrient mining**.
- An **increase in nutrient input** is **needed** to improve yields while reducing soil nutrient depletion

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