Meta-analysis reveals the effect of fertilizer application on upland rice cultivation in Africa

Rainfed upland is one of the dominant ecosystems for rice production in sub-Saharan Africa, where yields are very low (approx. 2.1 t ha^{-1}). To overcome such low productivity, fertilizer application is necessary, and its effective use is key for improving rice yield and farmer's livelihood. Previous studies often reported that fertilizer application did not result in sufficient yield increase. It is partly because yield gain with fertilizer could be affected by biophysical factors such as precipitation and soil texture; however, their interaction remained poorly understood. Hence, a meta-analysis was performed for the dataset collected from fertilizer trials conducted in 8 countries in sub-Saharan Africa, where the environmental backgrounds varied considerably, in order to quantify the effect of soil texture and precipitation on yield gain with fertilizer.

The dataset was composed of 151 paired observations of control and fertilizer treatment from fertilizer trials using NERICA 4 from 8 countries (Table 1). Soils were classified into low clay soil (≤ 20% clay content) and high clay soil (> 20% clay content). Yield gain with fertilizer application (YG), i.e., the yield difference between fertilizer treatment and control, was evaluated in relation to nitrogen (N), phosphorus (P) and potassium (K) fertilizer application rates and the amount of precipitation. Regression analysis showed no correlation between YG and P and K fertilization rates ($p > 0.05$, data not shown). Precipitation closely correlated with YG, irrespective of soil type ($p < 0.001$, Fig. 1 left). N fertilizer rate was correlated with YG in high clay soil, ($p < 0.001$, Fig. 1 right,) but not in low clay soil ($p > 0.05$). Bayesian estimation clarified that YG would increase by 0.168 and 0.145 t ha^{-1} for low and high clay soil with a 100 mm increase in precipitation (Table 2). YG was also expected to increase by 0.653 t ha^{-1} in high clay soil with a 100 kg increase in N fertilizer rate, but in low clay soil, 95% posterior credibility intervals included zero, indicating that YG did not always increase with N fertilizer rate. Overall, these results recommend the fine-tuning of N fertilizer input based on soil type and expected precipitation.

The obtained results will allow the policy maker or private sector to predict the fertilizer-suitable areas for technical dissemination and commercial sale at the regional and/or national level. However, trends at the regional level may not be directly applicable to individual fields or to regions where the yields are constrained by other nutrient deficiencies such as phosphorus deficiency etc. In addition, further assessments are required for varieties other than NERICA 4.

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Table 1. Description of fertilizer trials using upland rice (NERICA 4) in 8 countries in Africa

Country	Num.	Soil type (clay content)[2)]		Fertilizer effect			
		Low clay (≤20%)	High clay (>20%)	NPK	N	P	K
Gambia	4	4	0	4	0	0	0
Guinea	2	2	0	2	0	0	0
Mali	2	2	0	2	0	0	0
Benin	65	65	0	53	12	0	0
Uganda	50	0	50	20	10	10	10
Nigeria	15	3	12	0	13	1	1
Kenya	12	12	0	2	6	4	0
Madagascar	1	0	1	1	0	0	0
Total	151	88	63	84	41	15	11

[1)] Database：https://ars.els-cdn.com/content/image/1-s2.0-S0378429021002306-mmc1.xlsx

[2)] Tanaka et al. (2017)

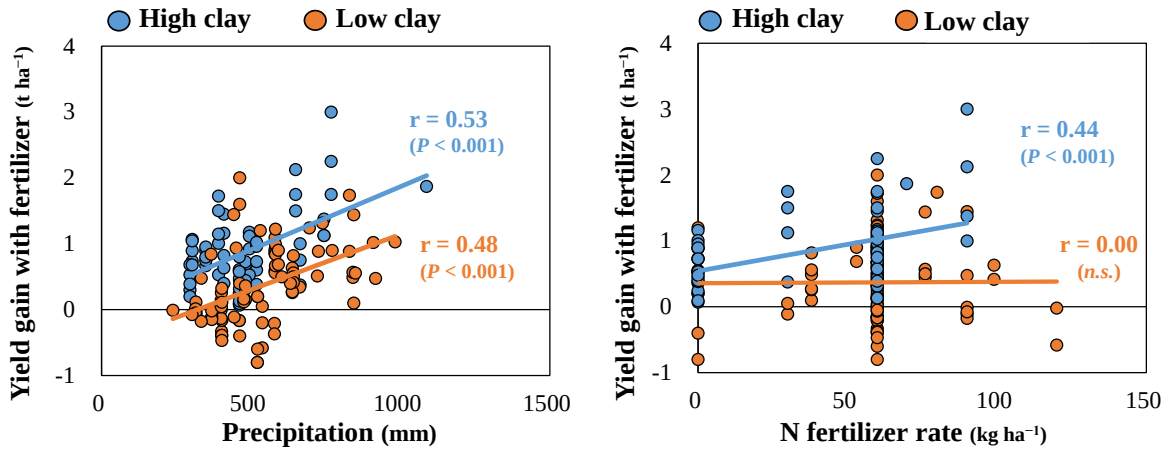

Fig. 1. The relationship of yield gain with fertilizer (YG) with precipitation (left) and N fertilizer application rate (right)

Table 2. Posterior probability distribution of the effect of precipitation and N fertilizer rate on yield gain with fertilizer under different soil types

Soil type	Precipitation (t ha^{-1} 100mm^{-1})			N fertilizer rate (t ha^{-1} 100kg^{-1})		
	Average	95% credible interval [1)]		Average	95% credible interval [1)]	
		2.5%	97.5%		2.5%	97.5%
High clay	0.145	0.068	0.22	0.653	0.253	1.05
Low clay	0.168	0.103	0.236	0.164	−0.352	0.679

[1)] Credible interval is the range containing a 95% percentage of probable values estimated by Bayesian statistics.

Reference: Asai et al. (2021) *Field Crops Research* 272: 108284. https://doi.org/10.1016/j.fcr.2021.108284