Efficiency of Rainfed Wheat Production: A Global Assessment Using Data Envelopment Analysis

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A short resume of the presenter

Amir Dadrasi is a Postdoctoral Researcher at the Environment Centre, Charles University, Czech Republic. MY research focuses on environmental economics, sustainable agriculture, and the socio-economic impacts of climate change. I applies quantitative modelling and interdisciplinary approaches to analyses the interactions between agricultural systems, natural resources, and policy frameworks. My work contributes to advancing knowledge on climate adaptation strategies, food security, and the transition towards sustainable resource management at both regional and global scales.

The research interests of my workgroup and the ongoing projects in which we are involved

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GAČR

GRANTOVÁ AGENTURA ČESKÉ REPUBLIKY

Pathways towards Environmental Sustainability (GAČR EXPRO; 2023–2027)

Pathways towards Environmental Sustainability

Project aim is to determine the potential scenarios of future development in technology and consumption, which will ensure national footprints of all countries to be within the downscaled planetary boundaries.

Project period: 1. 1. 2023–31. 12. 2027

Financial support: Grant Agency of the Czech Republic

Project description:

Human society risks exceeding the capacity of several Earth system processes, with the potential to cause irreversible environmental change. Nine planetary boundaries have been suggested to quantify this risk, which might in turn been “downscaled” to a national level to motivate political action. However, there is no systematic allocation of responsibility of nations, no insights into how fast we are approaching the boundaries, and limited foresight into actions that affect multiple earth system processes.

In this project, we will explore a range of mitigation options by changing production technology and consumption on a global level. We will focus on the transgressed planetary boundaries from the consumer responsibility perspective. We will further develop state-of-the-art enviroeconomic models, and scenarios of future development. The outcomes will be policy relevant scenarios of potential future development of production technology and consumption within the capacity of the Earth systems and an insight into trade-offs and synergies of potential technical and behavioral changes.

Coordinator of the project in CUEC:

- Jan Weinzettel

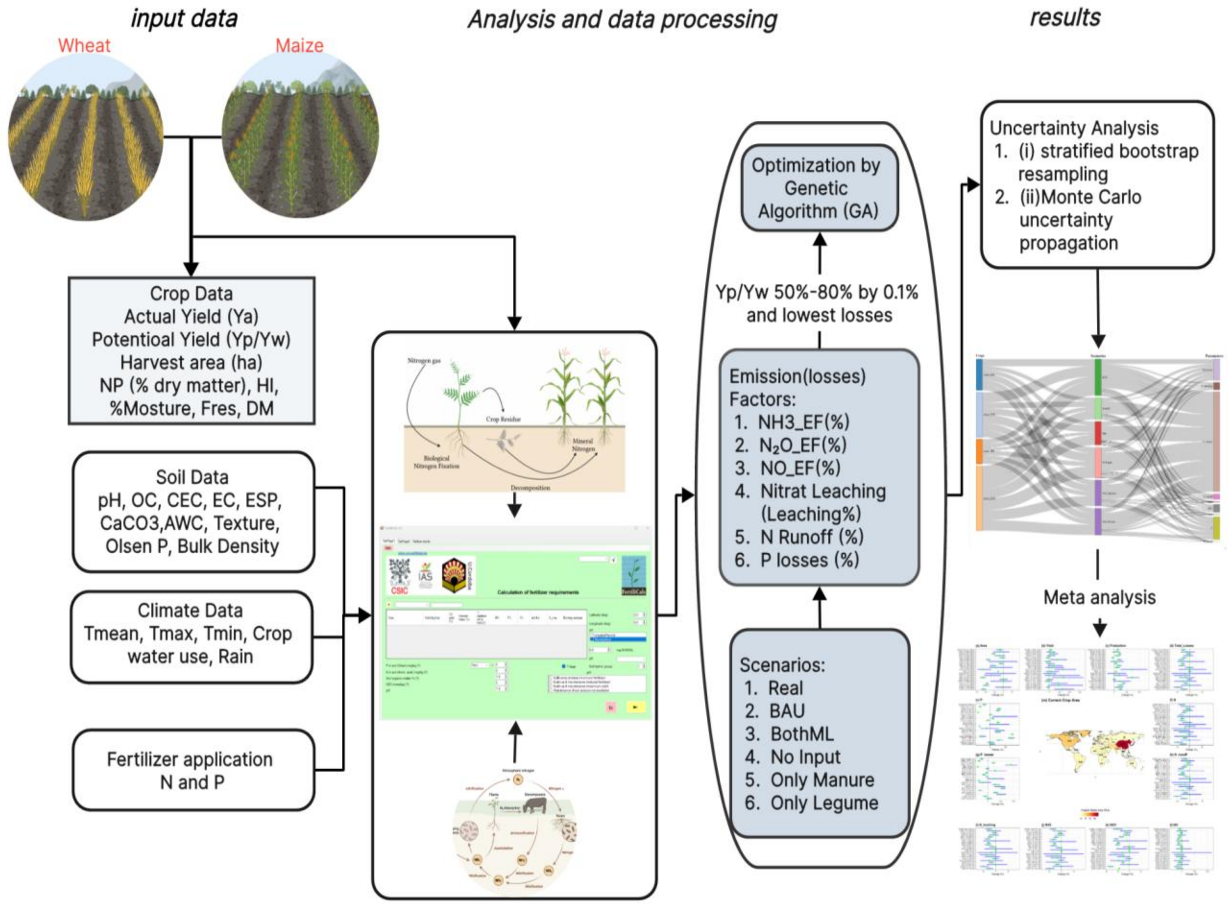
Involved departments:

- Environmental Footprint Lab

Research team:

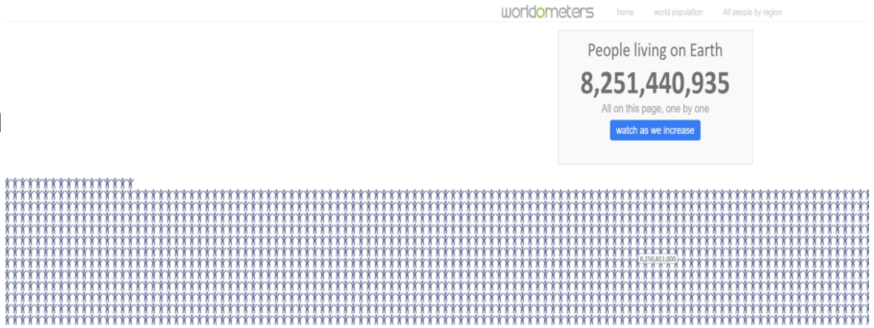
- Jan Weinzettel
- Davina Vačkářová
- Martin Černý
- prof. Richard John Wood
- Jan Matuštík
- Trong Can Nguyen
- Amir Dadrasi
- Eliška Selinger
- Yanhua Shi
- Michael Fridrich
- Guiyu Wei

Running projects



INTRODUCTION

The world population has increased and has now reached 8.25 billion



- We need to produce food with minimal environmental impact.
- **Rainfed wheat** is one of the main crops feeding populations worldwide in various forms.
- To increase wheat or any other crop production, fertilizer like N and P application is necessary.
- However, increasing fertilizer use without considering losses and low efficiency can be harmful to the environment.
- Therefore, it is essential to **identify fertilizer use efficiency** and determine the **optimum range of fertilizer application** for sustainable crop production.

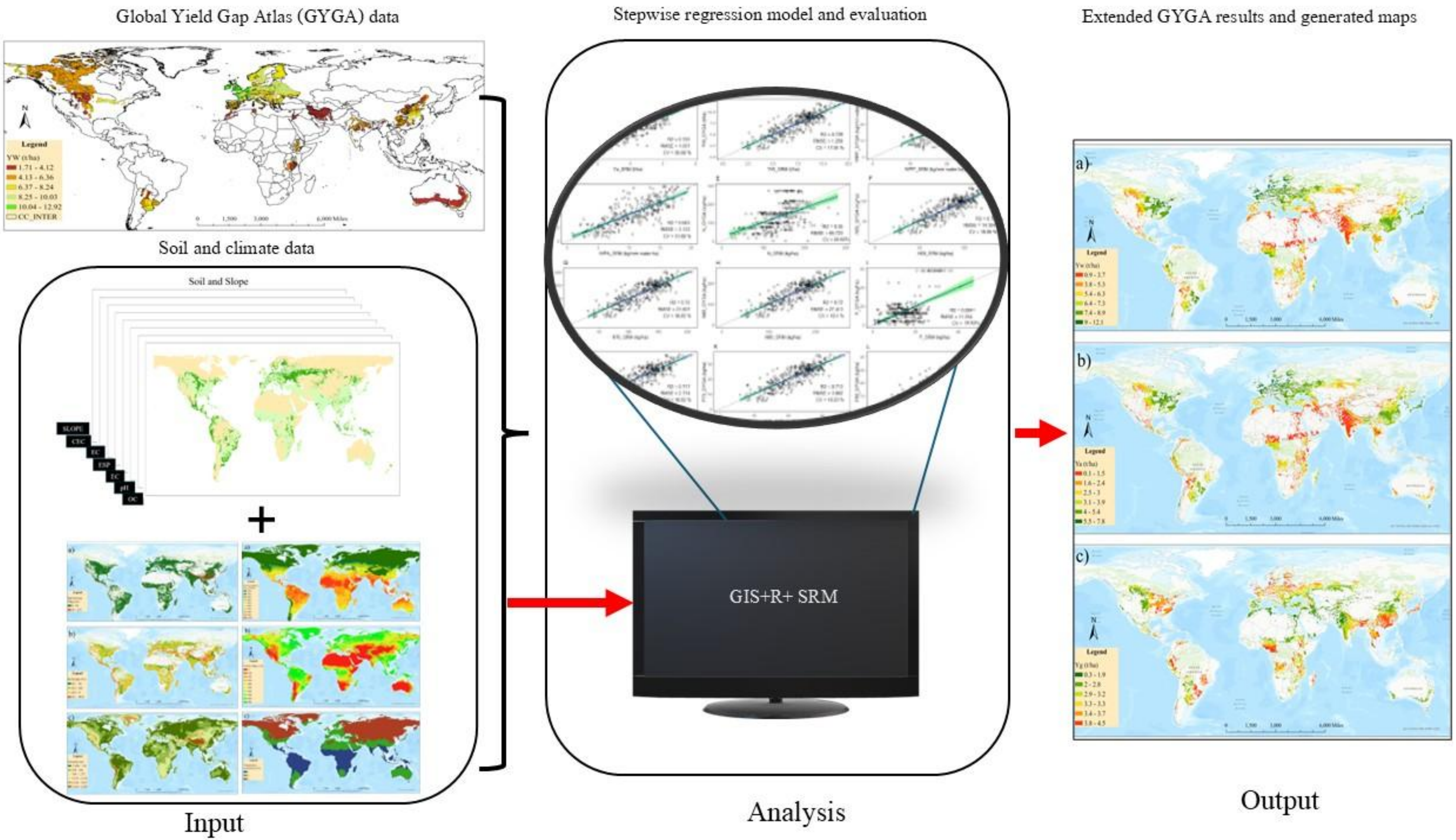
ENVIRONMENT

4,024,180	Forest loss this year (hectares)	[+]
5,417,634	Land lost to soil erosion this year (ha)	[+]
30,755,237,464	CO2 emissions this year (tons)	[+]
9,285,629	Desertification this year (hectares)	[+]
7,577,366	Toxic chemicals released in the environment this year (tons)	[+]

FOOD

891,698,266	Undernourished people in the world	[+]
1,785,086,847	Overweight people in the world	[+]
898,147,452	Obese people in the world	[+]
15,091	People who died of hunger today	[+]
$346,515,386	Money spent for obesity related diseases in the USA today	[+]
$93,284,578	Money spent on weight loss programs in the USA today	[+]

Materials and Methods



Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Closing global yield gap of rainfed wheat by optimizing nitrogen and phosphorus inputs

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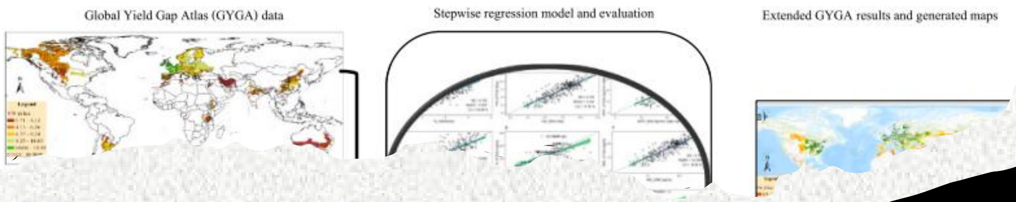
HIGHLIGHTS

- Predictive equations link crop yield to climate and soil factors independently.
- Nitrogen and phosphorus needs for

GRAPHICAL ABSTRACT

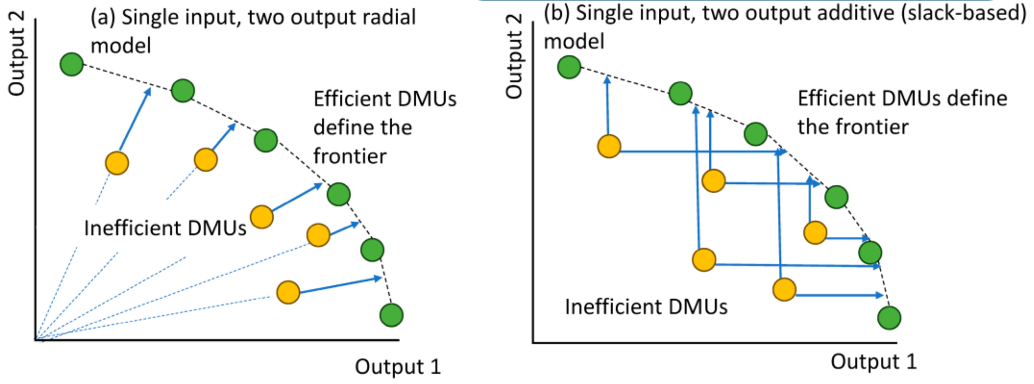


2.3. DATA ENVELOPMENT ANALYSIS (DEA)

DEA introduced by Charnes et al. [18], is a nonparametric linear programming technique employed to estimate production functions and assess the efficiency of multiple DMUs [19]. Its primary objective is to optimize efficiency by achieving maximum output with minimum input, either by enhancing output while maintaining input constant or obtaining a specific output with minimal input. The choice between these options depends on the particular DMUs under consideration. This study adopts an input-oriented approach with multiple inputs and outputs. DEA is utilized to evaluate DMUs' efficiency [20][21].

The DEA was conducted using the deaR package [22] in R (version 4.3.2).

The analysis was based on the annual precipitation, and the application of N and P fertilizers in each climate zone of each country, to achieve the actual yield, as well as 50%, 70%, and 80% of the water-limited potential yield as input and crop yield, crop production, water productivity, N use efficiency, P use efficiency were as output in CCR model.



A specific equation was used in the DEA to estimate the efficiency value in each country and climate zone. The CCR model is a specific variant of DEA used to evaluate the relative efficiency of DMUs in converting inputs into outputs. In the CCR model, the efficiency of each DMU is assessed under the assumption of Variable Returns to Scale (VRS), allowing for scale efficiency to be considered.

Considering j = 1, 2, 3, m DMUs using Xi| i = 1, 2, 3, ., n inputs to produce Yr | r = 1, 2, 3, ., outputs and Ya or Yw (multipliers) Vi and Ur associated with those inputs and outputs, we can also formalize the efficiency expression in (1) as the ratio of weighted outputs to weighted inputs:

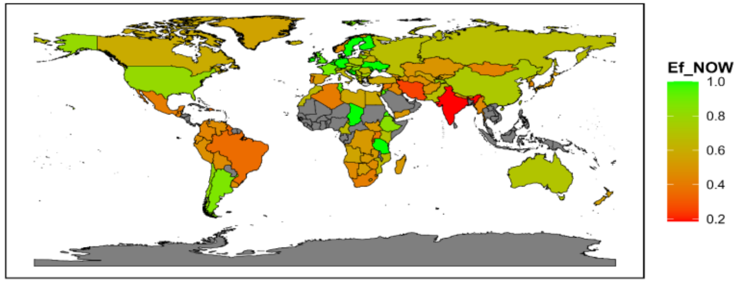
$$Efficiency = \frac{\sum_{r=1}^{\delta} \mu ryjr}{\sum_{i=1}^{n} \gamma ix\, ji} \qquad (1)$$

Following the analysis, we obtained efficiency scores ranging from 0 to 1, which reflect the relative efficiency of each Decision-Making Unit (DMU), such as countries or specific climate zones within countries.

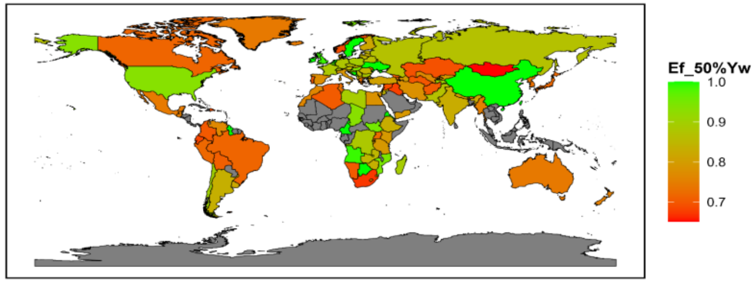
An efficiency score close to 1 indicates that a DMU is performing efficiently, while scores below 1 suggest varying levels of inefficiency.

Results

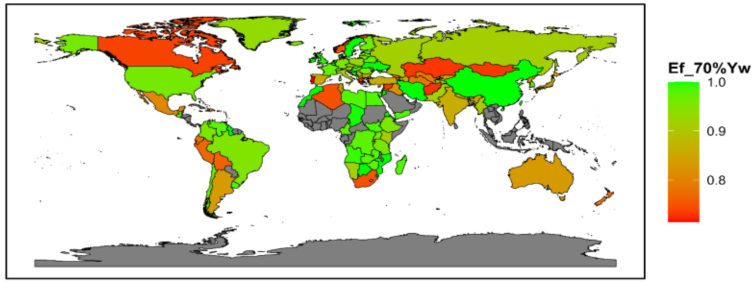
Efficiency Current (A)



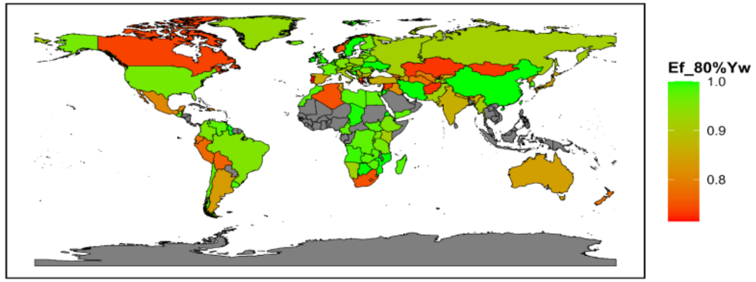
Efficiency_50%Yw (B)



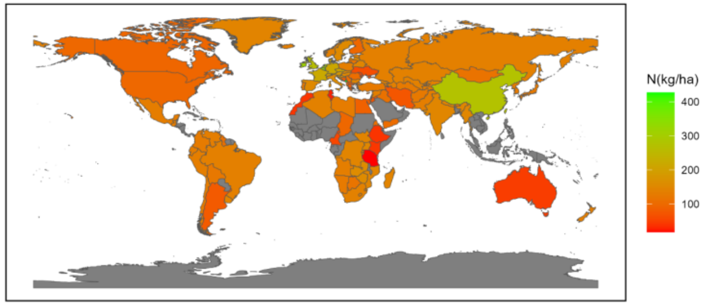
Efficiency_70%Yw (C)



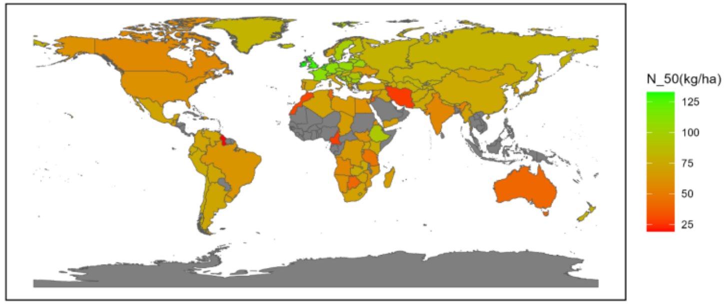
Efficiency_80%Yw (D)



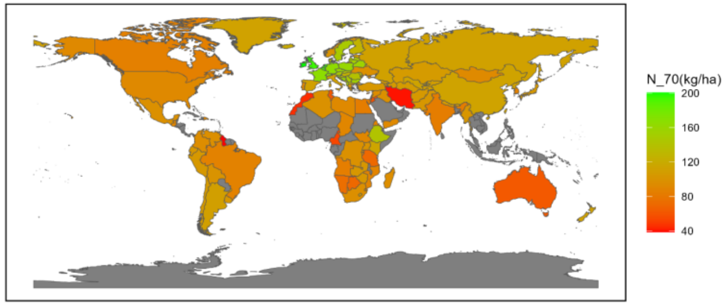
Current N fertilizer for Actual yield (A)



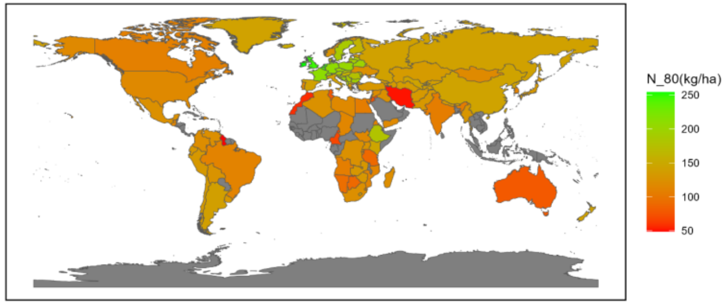
Estimated N fertilizer for 50%YW (B)



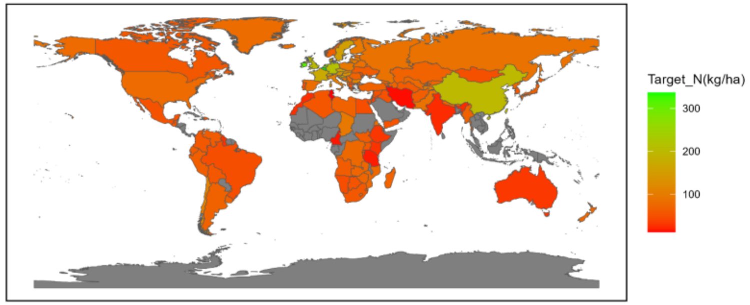
Estimated N fertilizer for 70%YW (C)



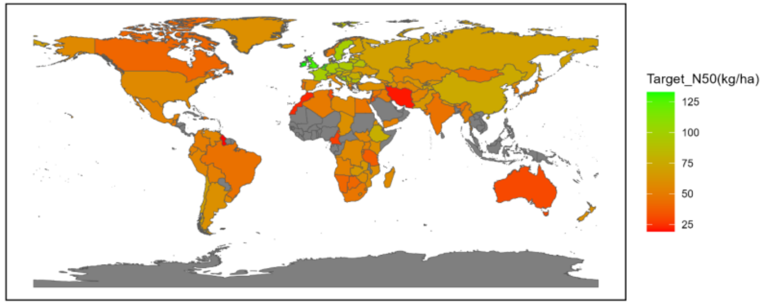
Estimated N fertilizer for 80%YW (D)



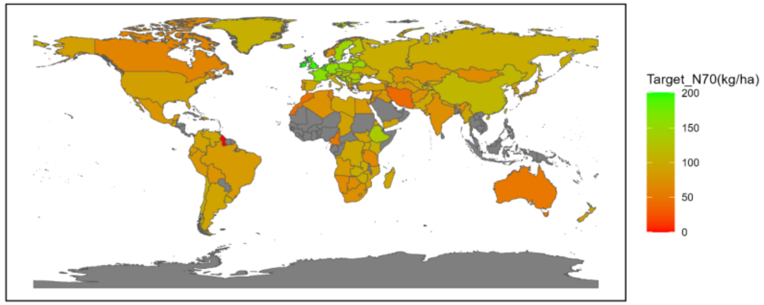
Optimal N fertilizer for Actual yield (A1)



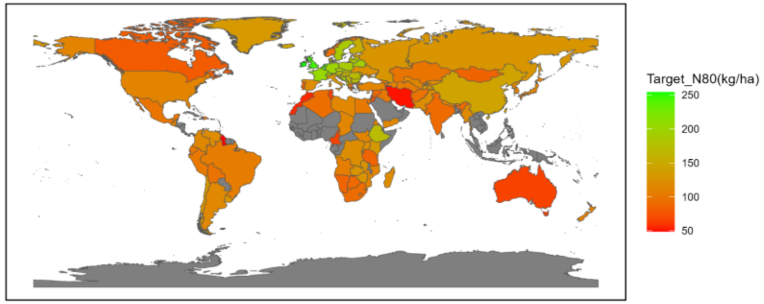
Optimal N fertilizer for 50%YW (B1)

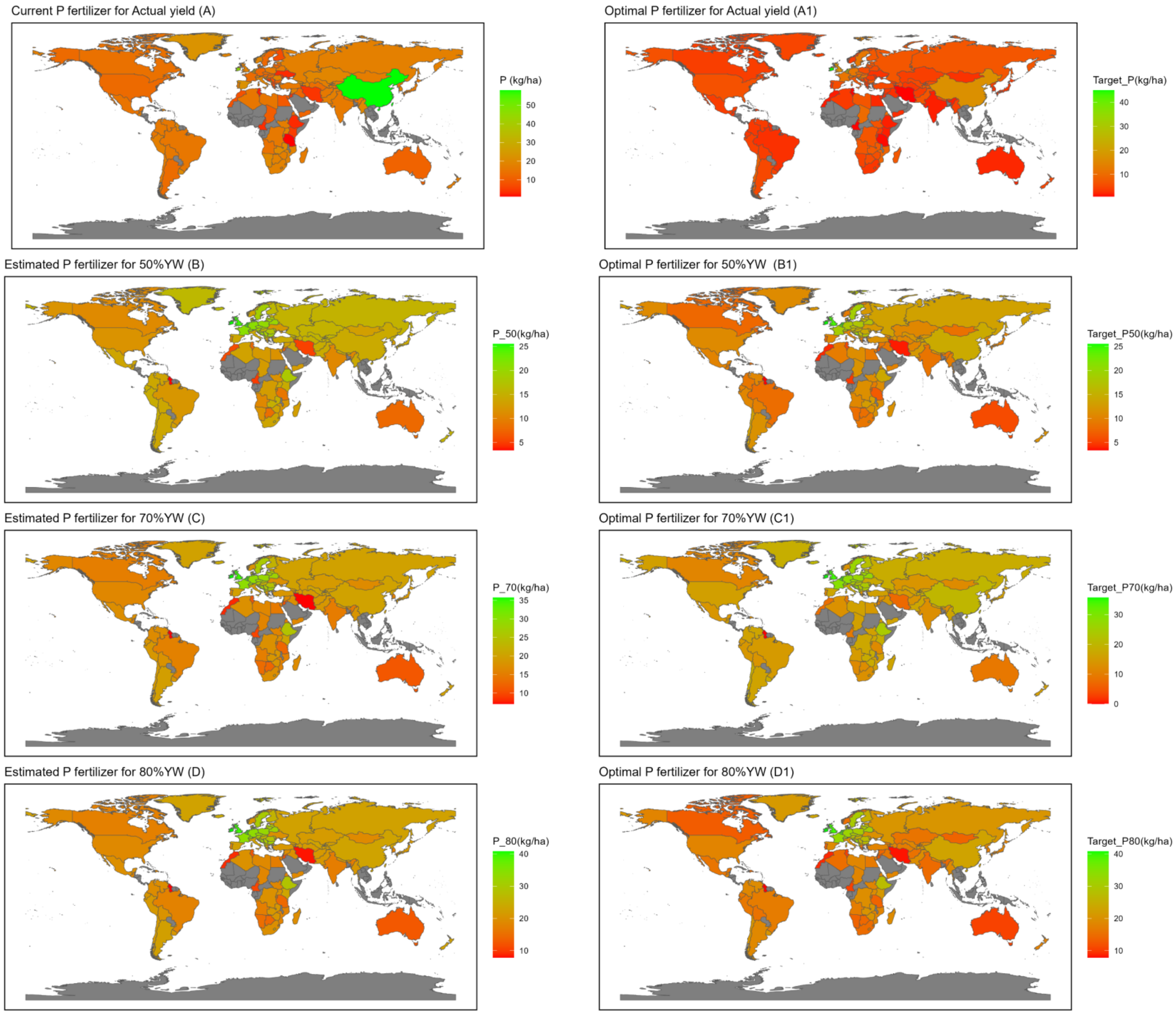


Optimal N fertilizer for 70%YW (C1)



Optimal N fertilizer for 80%YW (D1)




Current P fertilizer for Actual yield (A)
P (kg/ha)
50
40
30
20
10
Optimal P fertilizer for Actual yield (A1)
Target_P(kg/ha)
40
30
20
10
Estimated P fertilizer for 50%YW (B)
P_50(kg/ha)
25
20
15
10
5
Optimal P fertilizer for 50%YW (B1)
Target_P50(kg/ha)
25
20
15
10
5
Estimated P fertilizer for 70%YW (C)
P_70(kg/ha)
35
30
25
20
15
10
Optimal P fertilizer for 70%YW (C1)
Target_P70(kg/ha)
30
20
10
0
Estimated P fertilizer for 80%YW (D)
P_80(kg/ha)
40
30
20
10
Optimal P fertilizer for 80%YW (D1)
Target_P80(kg/ha)
40
30
20
10

CONCLUSION AND FUTURE WORK

The findings of this investigation provide a comprehensive assessment of the efficiency of N and P fertilizer application in rainfed wheat producers globally. The analysis revealed significant disparities in efficiency, with the highest levels observed in countries including Sweden, Ukraine, Ireland, Finland and Belgium which they attained the maximum efficiency (1.0), whereas other countries demonstrated lower levels of efficiency, these countries include India, Iran, the Dominican Republic, Guyana, Brazil, and Burundi demonstrated efficiency scores within the range of 0.18 to 0.37. The results indicate the necessity of optimizing N and P applications to achieve specific yield targets, such as those of 50%, 70%, and 80% YW, with the objective of optimizing overall productivity while minimizing the environmental impact. in the other classification, European countries demonstrated an average efficiency of 0.61 under current conditions, which improved to 0.74, 0.75, and 0.76 for the 50%Yw, 70%Yw, and 80%Yw scenarios, respectively. Similarly, African nations enhanced their efficiencies from 0.57 to 0.78, 0.79, and 0.79 across the same scenarios, while Asian countries showed notable improvements from 0.36 to 0.66, 0.68, and 0.68. American countries and Australia also experienced efficiency gains, increasing from 0.47 to 0.71, 0.75, and 0.76.

ACKNOWLEDGMENTS

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Thank you