Nitrogen Use Efficiency in Ethiopian Wheat Systems: Gap Analysis

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Executive Summary

This synthesis report analyzes 109 studies published between 2010 and 2025 on wheat nitrogen use efficiency (NUE) related research in Ethiopia. Research progress has accelerated after 2016, driven by the national wheat self-sufficiency initiative and the introduction of the new NPS and NPS based blended fertilizers. However, the evidence reveals an imbalanced research landscape. Most studies (over 80%) emphasize agronomic management and fertilizer rate trials, with limited exploration of broader, system-level dimensions such as integrated nutrient management (INM), climate, landscape variability, and socio-economic factors. The analysis highlights NUE related research mainly focused on Vertisols (33%) and Nitisols (19%). Other soil types remain underrepresented. Similarly, research metrics are skewed toward Agronomic Efficiency (AE) and Partial Factor Productivity (PFP), which dominate over 70% of studies. Nevertheless, more integrative indicators such as Recovery Efficiency (RE), Physiological Efficiency (PE), and Internal Efficiency (IE) are seldom reported. To bridge these gaps, coordinated research and extension, and input supply efforts are required to promote site-specific, climate-smart, and socio-economically grounded fertilizer strategies that enhance nitrogen efficiency, reduce environmental losses, and improve farmer profitability.

1. Introduction

Wheat is a strategic crop for Ethiopia's food security and rural livelihoods, supporting millions of smallholder farmers (Silva et al., 2021; Belete et al., 2018a). Despite expansion in cultivated area and adoption of improved varieties, average yields remain below 3 t/ha, compared with potential yields exceeding 6 t/ha under optimal management. Suboptimal nitrogen management mainly drives this yield gap and this resulted in poor returns on fertilizer investment and increased losses to the environment (Erkossa et al., 2022; Lassaletta et al., 2014).

Even though nitrogen is the most important nutrient for increasing productivity and sustainability, it is the most limiting macronutrient for wheat production in Ethiopian soil (Agegnehu et al., 2014; Abebe et al., 2022). The efficient use of nitrogen is expressed through various NUE indicators. These indicators determine how effectively nitrogen inputs are converted into grain yield (Tana et al., 2015; Belete et al., 2018b). Understanding the thematic coverage and methodological gaps in NUE research is vital for designing evidence-based fertilizer policies, improving resource-use efficiency, and ensuring environmentally sustainable intensification. This report synthesizes findings from 109 studies to identify dominant research themes, spatial gaps, methodological imbalances, and opportunities for innovation in Ethiopia's wheat sector.

2. Methodological Overview

The review followed the PRISMA systematic review framework, covering studies from 2010 to 2025 (Page et al., 2021). Literature was sourced from Scopus, Web of Science, PubMed, and Google Scholar. The studies were screened for relevance and then classified into ten thematic areas: Soil type, Fertilizer Rate, Fertilizer Type, Landscape, Agronomic Management, Timing of Application, Integrated Nutrient Management (INM), Genotype Response, Socio-Economic, and Climate-related studies.

A combination of bibliometric, content, and quantitative analyses was performed in Python. These include thematic co-occurrence and triadic pattern, temporal trend, soil-type profiling, and radar–heatmap for mapping of the reported eight NUE metrics. A narrative synthesis summarized dominant themes, methodological gaps, and research trends in Ethiopian wheat NUE studies.

3. Key Findings

1.1. Thematic Structure of Wheat NUE Research in Ethiopia

The analysis shows a strong concentration on input-based studies. Agronomic management accounted for 84% of the reviewed research, followed by fertilizer rate trials (56%) and genotype response (33%) (Figure 1). Themes addressing socio-economic factors, landscape, INM, and climate each represented less than 25% of the studies. This indicates limited integration of contextual and system-level dimensions in nitrogen fertilizer research.

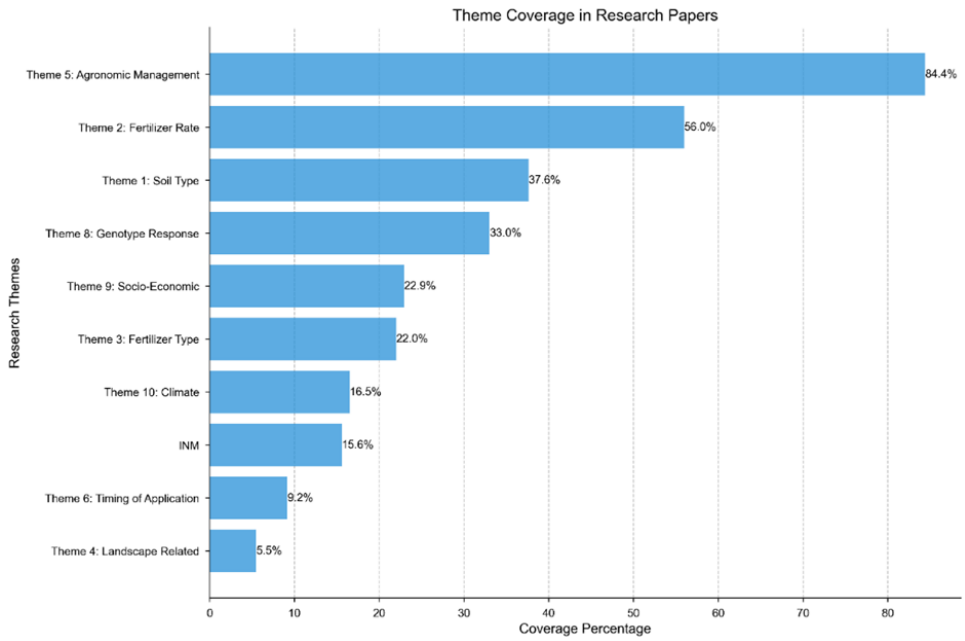

Figure 1. Proportional representational of ten research themes in wheat yield and NUE studies. Bar show the percentage of studies per theme, total exceeds 100 % due to multiple classifications.

Soil-type analysis revealed that Vertisols (33%) and Nitisols (19%) dominate wheat NUE-related research. While Cambisols, which are moderately fertile and well-suited for highland wheat production, remain among the least studied. Other soil types, such as Luvisols, Andosols, Regosols, and Fluvisols, each represent less than 20% of studies (Figure 2).

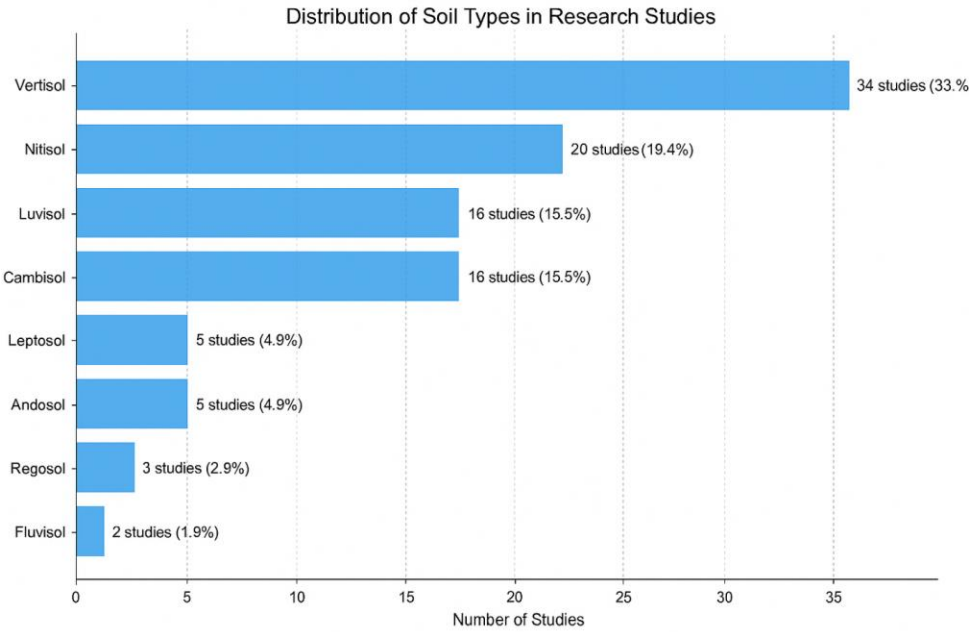

Figure 2. Soil type distribution across reviewed NUE studies: Vertisol dominates, while other soil types remain underrepresented.

1.2. Triadic Theme Frequency and Research Integration Gaps

A total of 36 distinct three-theme combinations (triads) were identified. The majority of wheat NUE-related studies mainly focused on Fertilizer Rate × Agronomic Management × Genotype Response and Soil Type × Fertilizer Rate × Agronomic Management (Figure 3). This reflects that most of the studies have a narrow focus on input optimization and lack system-level integration. Themes combining climate, INM, landscape, or socio-economic dimensions appeared fewer than three times. This limited overlap suggests weak interdisciplinary collaboration and minimal linkage between agronomic, environmental, and socio-economic research domains.

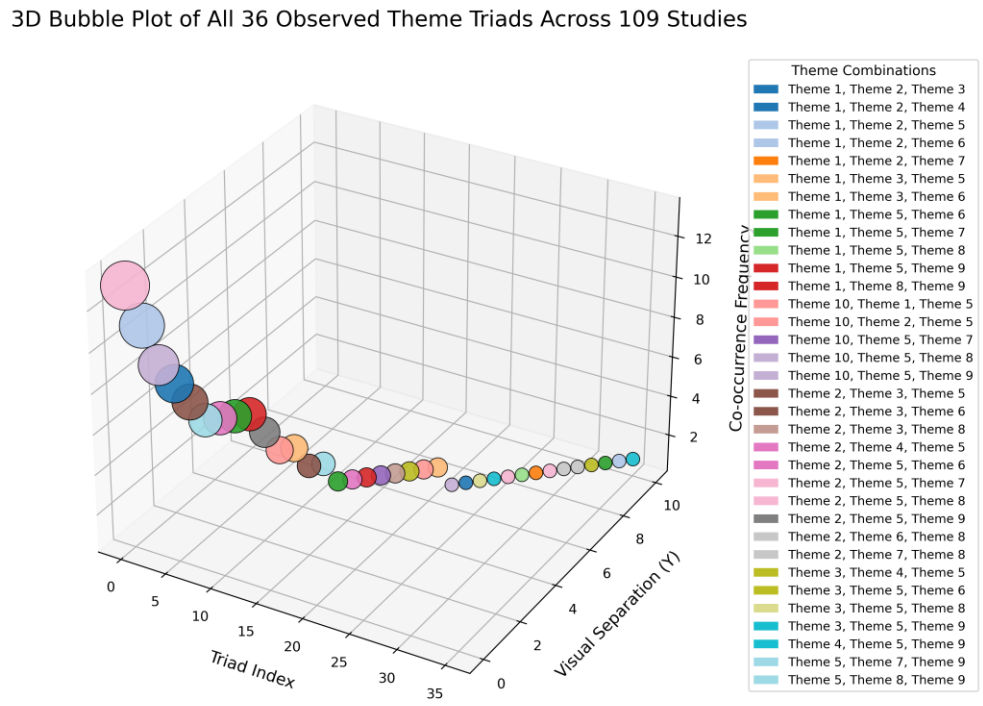

Figure 3. 3D bubble plot of 36 theme triads in Wheat NUE Literature. Bauble size indicates co-occurrence frequency across the 109 studies. Theme 1= Soil Type, 2 = Fertilizer rate, 3 = Fertilizer Type, 4 = Landscape, 5 = Agronomic Management, 6 = Timing, 7 = INM, 8 = Genotype Response, 9 = Socio-Economic, 10 = Climate

1.3. Temporal Trends (2010–2025)

Research activity increased sharply after 2016 and peaked between 2020 and 2022 (Figure 4). This is because of the wheat self-sufficiency program, donor support, and the development of EthioSIS soil fertility atlases. A temporary decline in 2021 corresponded with COVID-19 restrictions and regional conflicts that delayed fieldwork and publication. However, despite this growth, the major focus remains input-oriented. While fertilizer rate and agronomic management themes expanded, there was little progress in INM, socio-economic, and climate-related research.

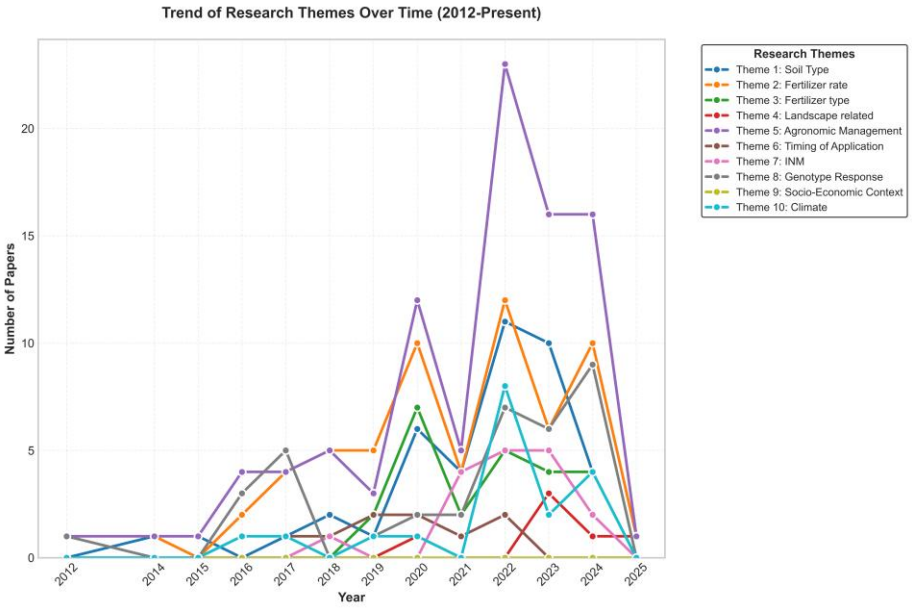

Figure 4. Yearly trends (2010-2025) in ten research themes on wheat yield and NUE. INM and fertilizer rate show increasing attention post-2018.

1.4. Research Coverage of NUE Metrics

Across the ten themes, the methodological distribution of NUE metrics was highly uneven. AE and PFP are the two NUE metrics that cover more than 70% of studies, particularly on fertilizer rate and agronomic management trials (Figure 5). Other metrics like RE, PE, and IE were reported in fewer than 10% of studies. This imbalance reflects a tendency to measure input response rather than the full nitrogen cycle or system efficiency.

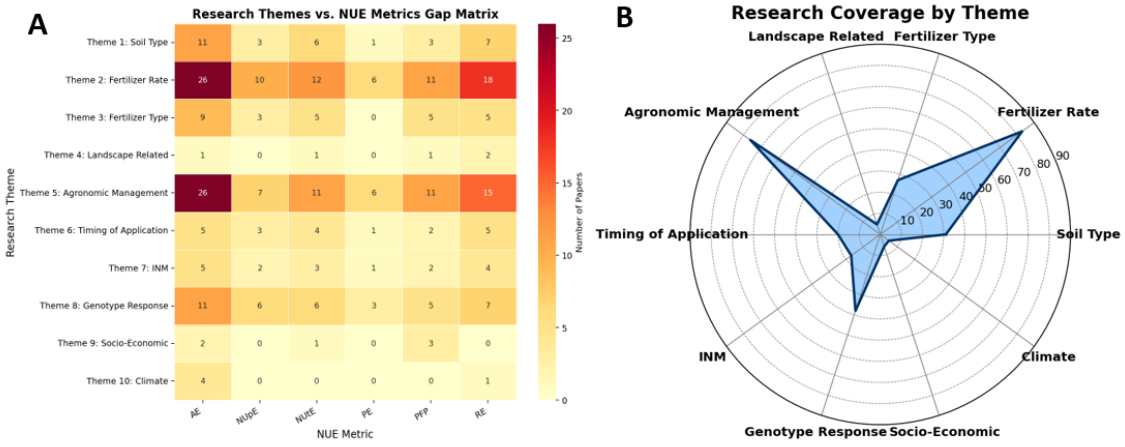

Figure 5. (A) Heatmap of NUE metrics reported across ten themes; darker shade indicates higher coverage. (B) Radar plot of theme level coverage; long spike represents stronger research focus, with Fertilizer Rate and Agronomic Management dominate, while Landscape, climate, and Socio-Economic Context remain Underrepresented.

4. Gap Analysis by Stakeholder

For Policymakers

- Fertilizer recommendations in Ethiopia remain largely blanket and uniform, neglecting variations in soil type, slope, and climate.

- Weak translation of research outputs into extension guidelines limits on-farm adoption.
- Climate, gender, and socio-economic dimensions are poorly integrated in fertilizer recommendation and policy frameworks.

For Researchers

- Over-reliance on AE and PFP has limited understanding of nitrogen fate and efficiency.
- Few long-term and interdisciplinary studies integrate soil, genotype, and environmental data.
- Minimal use of digital tools, geospatial analysis, and climate modeling for site-specific recommendations.

For Donors and Development Partners

- Funding has concentrated on fertilizer rate and agronomic trials, with limited investment in INM, climate resilience, and socio-economic studies.
- Future investments should promote integrated, farmer-centered projects linking research, extension, and policy action.

5. Policy and Research Implications

- Standardize NUE metrics across research institutions to ensure comparability and comprehensive reporting.
- Expand INM-focused and climate-smart research, emphasizing organic–inorganic synergies and adaptive management.
- Develop site-specific fertilizer recommendations using soil, slope, and agro-ecological data layers.
- Enhance collaboration among researchers, extension agents, and policymakers to accelerate knowledge translation.
- Leverage geospatial and digital tools for precision nutrient management and fertilizer advisory systems.
- Incorporate socio-economic factors like affordability, gender, and labor dynamics in fertilizer research and policy.

6. Conclusion

Wheat NUE related research in Ethiopia has advanced but remains input-focused and fragmented. Majority of the research was on fertilizer rate and agronomic management on Vertisols and Nitisols. Other themes like INM, landscape, socio-economic and climate dimensions are largely overlooked.

Methodologically, most of the studies relies on AE and PFP for evaluating NUE, with limited use of RE, PE and others. This weakens our understanding of nitrogen recovery and utilization pathways. This gap also limits the scientific basis for designing accurate fertilizer recommendation and advisory system. This in turn leads to generalized recommendations that overlook site-specific efficiency losses.

Therefore, there is a need for integrated, data-driven, and landscape-based fertilizer advisory system grounded in INM and compressive NUE metrics to enhance efficiency, close yield gaps, and achieve sustainable intensification and national food security.

7. References

Abebe, T., et al. (2022). Soil fertility decline and nutrient balances across smallholder systems in Ethiopia. Sustainability, 14(4), 2154.

Agegnehu, G., van Beek, C. L., & Bekele, A. (2014). Crop productivity and land-use systems in the Ethiopian highlands: Long-term soil fertility management impacts. Soil & Tillage Research, 136, 1–9.

Belete, F., et al. (2018b). Effects of split nitrogen application on nitrogen uptake and use efficiency of bread wheat in Ethiopia. Journal of Agronomy, 17(3), 152–162.

Belete, F., Nigussie, D., Getachew, T., & Ayalneh, T. (2018a). Yield and nitrogen use efficiency of bread wheat under different nitrogen levels in Ethiopia. African Journal of Agricultural Research, 13(10), 452–463.

Erkossa, T., et al. (2022). Site-specific nutrient management and performance of fertilizer recommendations in Ethiopia. Nutrient Cycling in Agroecosystems, 123(2), 341–360.

Lassaletta, L., Billen, G., Romero, E., Garnier, J., & Aguilera, E. (2014). How nitrogen use efficiency varies globally and the consequences for food and the environment. Environmental Research Letters, 9(11), 111002.
Page, M. J., Moher, D., Bossuyt, P. M., et al. (2021). PRISMA 2020 explanation and elaboration: Updated guidance and examples for reporting systematic reviews. BMJ, 372, n160.
Silva, J. V., Reidsma, P., & van Ittersum, M. K. (2021). Yield gaps in wheat: A review of modeling studies and implications for food security. Agricultural Systems, 190, 103–123.
Tana, T., Ayalew, A., & Woldeab, G. (2015). Nitrogen use efficiency and productivity of wheat as affected by nitrogen and weed management. Journal of Plant Nutrition, 38(13), 2067–2083.