

Nitrogen Fertilizer Replacement in Legume Cereal Rotations

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Contents

Introduction	2
A Workflow for Modeling Optimum N Rates	2
Sustainable Cropping System Practices	3
Benefits of Legume Rotation on Cereal Crops	3
Partial Factor Productivity and Nitrogen Use Efficiency	5
Agronomic and Economic Nitrogen Response	5
Rotation-based Nitrogen Adjustment Factor	6
Sensitivity of Rotation-based Nitrogen Response	8
Conclusion	8

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Introduction

Sustainable food production is one of the major global challenges, exacerbated by climate change, increasing population, and natural resource degradation, including soil degradation and loss of biodiversity (Pretty and Bharucha, 2014; Vanlauwe et al., 2014). Cropping systems that specialize in one or two crops, with little attention to crop diversity, may lead to biological and physical soil degradation (Kirschenmann, 2002; Tanaka et al., 2010). Annual cropping systems, which include diverse crops such as cereals, legumes, and oilseeds, may be economically viable options for farmers. Diversifying crops in cropping systems also influences the soil environment and diversity of soil organisms (Williams et al., 2023; Yang et al., 2020). It is crucial to consider the synergistic or antagonistic relationships of crops in cropping systems for sustainability and resilience in agricultural systems (Kirschenmann, 2007).

Legumes play a major role in the sustainability of cropping systems, primarily due to their contribution of biologically fixed N and other beneficial effects, such as breaking pest and disease cycles for non-legume crops (Agegnehu et al., 2014; Peoples et al., 1995; Siddique et al., 2008). In Ethiopia, crops and cropping systems are diverse due to large agroecological and cultural diversity, which in turn leads to variable cropping patterns. The greater reliability of return is the main feature of multiple cropping, compared to monocropping. This report summarizes the contribution of crop rotation to the yield of major cereal crops after major precursor legumes based on legacy research data on cereal-legume rotations. Determining the contribution of major leguminous crops to subsequent cereal crops in terms of yield and soil fertility will help compensate for the rate of nitrogen fertilizer required, thereby enabling integration into digital fertilizer advisory services.

This report aims to assess and analyze the relative contribution of legume rotations to fertilizer requirements for subsequent cereal crops. The analysis is based on data from legacy fertilizer response trials involving cereal legume rotations. However, the data are incomplete to provide the magnitude of N recovery from specific legume crop rotations, which depend on effective N fixation, the amount of biomass produced, and N removed in legume seeds or stubble. In the absence of N recovery data, modeling using machine learning estimates N compensation rates or N fertilizer replacement using yield and agronomic efficiency as a proxy. The model outputs can be translated into a decision support system and used as input for a localized fertilizer advisory tailored to different types of farmers under various cereal-legume rotation patterns.

A Workflow for Modeling Optimum N Rates

Plot-level N-response data were compiled from published experiment reports conducted across diverse agroecological zones and soil types. Each record included experimental site (location and year), rotation or precursor crop, N and P application rates, and observed grain yield. A machine learning workflow in Python consisted of three main modeling stages (response modeling, economic optimization and stability assessment, and multi-metric integrations and decision synthesis). The overall analytical workflow is presented in Figure 1. Across all the target crops (wheat, barley, teff, and maize), yield-N relationships were modeled using quadratic and Mitscherlich functions to determine optimal N rates for the cereal-legume rotation patterns.

The model fit varied between target crops and rotation types. For wheat and barley, the Mitscherlich model provided the best fit, while for teff, a quadratic response was found to be the best fit. Maize crops exhibited strong curvature at higher N rates due to their high nutrient uptake potential. The resulting best-fit functions were then used to drive agronomic optimum nitrogen rate (AONR) and economic optimum nitrogen rates (EONR) for each rotation, forming the basis for rotation-based nitrogen application advisory.

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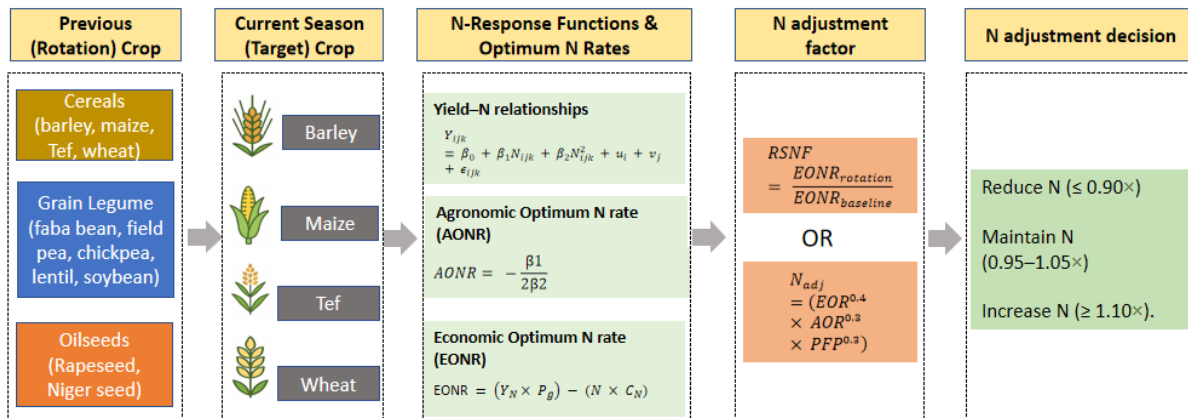


Figure 1. Workflow for deriving rotation-based nitrogen adjustment factors and N fertilizer recommendations

Sustainable Cropping System Practices

Sustainable intensification of agriculture requires the use of multiple agricultural technologies in an integrated manner to enhance productivity while conserving the natural resource base (Kotu et al., 2017). It relies on integrated use of a wide range of technologies to manage plant nutrients, soil and water, pests, crops, and crop varieties. The adoption of sustainable intensification practices is low in many Sub-Saharan African countries, which have been proven to achieve increased outputs from the same cropped areas with reduced negative environmental impacts (Tesfaye et al., 2015). For instance, if improved varieties of maize are used with improved agronomic practices, their contribution to additional income can increase by 14-41% in Ethiopia (Kassie et al., 2015; Tesfaye et al., 2015). However, the adoption of sustainable intensification practices, such as crop rotation and intercropping, is very low in Ethiopia compared to other African countries (Figure 2).

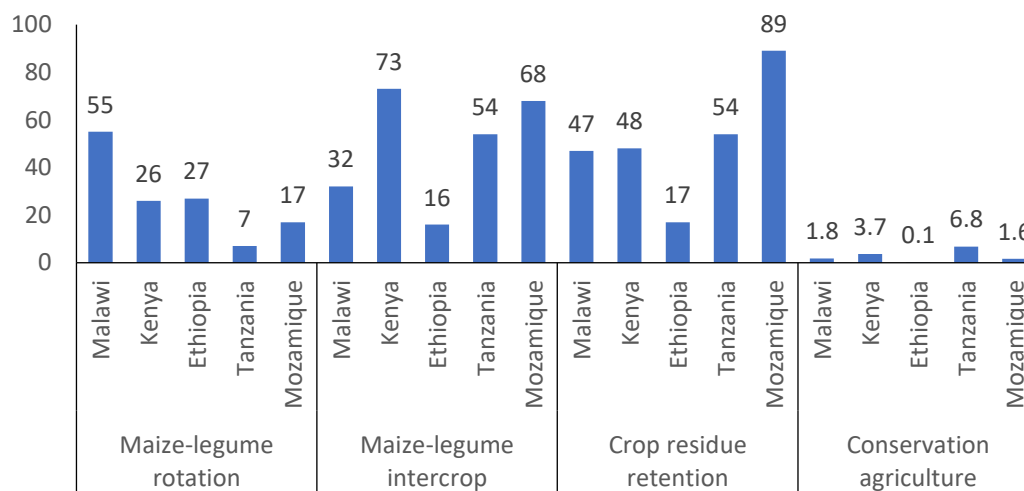


Figure 2. Adoption of sustainable intensification practices in eastern and southern Africa. Source: Kassie et al. (2015); Tesfaye et al. (2015)

Benefits of Legume Rotation on Cereal Crops

The importance of crop rotation with legumes is significant in terms of improving soil fertility and benefiting subsequent crops by increasing yields, enhancing nutrient availability, and reducing insect pests, diseases, and weeds. Alternating different legume and cereal crops in a cropping system prevents the depletion of specific soil nutrients and allows for natural replenishment, especially when legumes are included in rotations to fix nitrogen. For instance, an increase in cereal yields after legumes was reported to range from 0.5-3 t ha⁻¹, representing a 30%-350% increase compared to yields in cereal-cereal cropping sequences (Peoples and Craswell, 1992). Modeling tools can be used for assessing the advantages of crop rotation in cropping systems, as they provide a systematic,

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reproducible, and efficient way to analyze the complex, long-term effects of different cropping systems, and simple decision support systems to assist farmers in their choice of legumes in the cropping programs (Bedu et al., 2023; El Fartassi et al., 2025).

Contribution of legumes to nitrogen: Experimental estimates of the proportion of plant N derived from N₂ fixation (P_{fix}) and the amounts of N₂ fixed by important tropical and cool-season crop legumes are presented in Table 1. Although experimental treatments and environmental or nutritional variables have generated a large range of P_{fix} values (0-98%) and inputs of fixed N, it appears that potential biological nitrogen fixation (BNF) for most species is in the range of 200-300 kg N ha⁻¹ crop⁻¹. However, since N-uptake by the crop is partitioned either into seed or vegetative parts at crop maturity, not all of the N₂ fixed is returned to the soil (Peoples et al., 1995).

Table 1. Range of experimental estimates of the proportion (P_{fix}) and amount of N₂ fixed by major pulses and legume oilseeds

Species	Amount N ₂ fixed kg N ha ⁻¹	Amount N ₂ fixed P_{fix} (%)
Cool-season legumes		
Chickpea (<i>Cicer arietinum</i>)	3 - 141	8 - 82
Lentil (<i>Lens culinaris</i>)	10 - 192	39 - 87
Pea (<i>Pisum sativum</i>)	17 - 244	23 - 73
Faba bean (<i>Vicia faba</i>)	53 - 330	64 - 92
Lupin (<i>Lupinus angustifolius</i>)	32 - 288	29 - 97
Grass pea (<i>Lathyrus sativus</i> L.)	85-91	-
Warm-season legumes		
Soybean (<i>Glycine max</i>)	0 - 450	0 - 95
Groundnut (<i>Arachis hypogaea</i>)	37 - 206	22 - 92
Common bean (<i>Phaseolus vulgaris</i>)	0 - 125	0 - 73
Pigeon pea (<i>Cajanus cajan</i>)	7 - 235	10 - 81
Green gram (<i>Vigna radiata</i>)	9 - 112	15 - 63
Black gram (<i>V. mungo</i>)	21 - 140	37 - 98
Cowpea (<i>V. unguiculata</i>)	9 - 201	32 - 89

Source: Peoples et al. (1995)

Grain legume crops such as peas, beans, lupin, lentils, and chickpeas break diseases and provide N to subsequent cereal crops. For instance, the residual N boosts yields of maize and wheat by 35-52% (Liu et al., 2023; N'Dayegamiye et al., 2015) and barley by 43-67% (Agegnehu et al., 2014), similar to the effects of applying adequate N fertilizer. The N fertilizer replacement value was 51-77 kg N ha⁻¹ for maize and up to 37 kg N ha⁻¹ for wheat, depending on the preceding legume crop. This suggests that indirect effects related to improved soil properties positively affected maize and wheat yield and N nutrition. However, the magnitude of the N benefit depends on effective N fixation by the legume, the amount of biomass produced, and how much N is removed in legume seeds or stubble. Since residual N influences both yield and protein content of the following cereals, it is important to consider the N balance of the whole system when attempting to understand cropping sequence effects.

Partial Factor Productivity and Nitrogen Use Efficiency

Partial factor productivity (PFP), defined as the ratio of grain yield to applied N (kg grain per kg N), provides an integrated measure of agronomic and input efficiency. Analysis of treatment level data across crops revealed large differences among rotation types (Table 2). Legume-based crop rotation recorded superior nitrogen use efficiency. This advantage stemmed from biological N fixation that was added to the fertilizer nitrogen. Cereal-only crop rotation systems depleted soil nitrogen levels, resulting in poor recovery efficiency (Table 2).

Across all target crops, the mean PFP ranged from 55-88 kg grain kg⁻¹ N, with the highest efficiencies in field pea-wheat (88 kg grain kg⁻¹ N) and soybean-maize (85 kg grain kg⁻¹ N) rotations, followed by lentil-teff (82 kg grain kg⁻¹ N) and chickpea-barley (78 kg grain kg⁻¹ N) rotations (Table 2). Continuous cereal sequences showed the lowest PFP (55-63 kg grain kg⁻¹ N). The patterns clearly demonstrate that rotation-driven N carry-over improves N-use efficiency. The PFP supports the arguments that fertilizer N saving in legume crop rotations arises from improved recovery, not yield compromise.

Table 2. Partial Factor Productivity (PFP) across crop rotations

Crop	Rotation	Rotation class	PFP (kg grain kg ⁻¹ N)	Relative to monocrop (%)	Interpretation
Wheat	Field pea–Wheat	Legume	88	36	Strong N carry-over, high NUE
Wheat	Faba Bean–Wheat	Legume	85	32	Improved soil N availability
Wheat	Wheat–Wheat	Cereal	65	—	Baseline (lower efficiency)
Barley	Chickpea–Barley	Legume	78	30	Balanced N supply and uptake
Barley	Faba Bean–Barley	Legume	75	25	Moderate efficiency gain
Barley	Barley –Barley	Cereal	60	—	N-limited recovery
Teff	Lentil–Teff	Legume	82	28	Enhanced N utilization
Teff	Teff–Teff	Cereal	58	—	Low recovery efficiency
Maize	Soybean–Maize	Legume	85	35	Symbiotic N and soil benefit
Maize	Maize–Maize	Cereal	63	—	Low efficiency, high input needs

Agronomic and Economic Nitrogen Response

The Agronomic Optimum Nitrogen Rate (AONR) and Economic Optimum Nitrogen Rate (EONR) were derived using the selected model (Table 3). Across all target crops, yield increased significantly with increasing nitrogen application rates up to a certain threshold, then the marginal returns declined, which indicates the classical diminishing response pattern.

Legume-based rotations achieved their EONR at lower N rates than continuous cereals. For instance, field pea-wheat and Faba bean-wheat rotations reached profitability plateaus at 96-100 kg N ha⁻¹, compared to 120-150 kg N ha⁻¹ for continuous wheat-wheat (Table 3). This corresponds to 30%-40% higher profit, indicating that N inputs beyond this threshold yielded little economic return. A similar pattern was observed in barley, teff, and maize rotations (Table 3). Chickpea-barley and lentil-teff rotations required 20-30 kg N ha⁻¹ less than cereal monocrops, while soybean-maize maintained yield with 25 kg N ha⁻¹ less than maize monocrop.

The results demonstrate that agronomic efficiency and profitability were heavily influenced by the type of crop rotation adopted for a given target crop. Therefore, nitrogen fertilizer advisory systems must integrate crop rotation contributions to provide more precise and applicable recommendations that are acceptable to the context of the farmers.

Table 3. Agronomic and economic optimum nitrogen rate (AONR and EONR), profitability, and advisory decisions across major crop rotation practices

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Target Crop	Rotation	Rotation Class	AONR (kg N ha ⁻¹)	EONR (kg N ha ⁻¹)	Profit (USD ha ⁻¹)	Advisory Decision
Wheat	Field pea–Wheat	Legume	120	100	3,108	Reduce
Wheat	Faba Bean–Wheat	Legume	130	96	4,016	Reduce
Wheat	Rapeseed–Wheat	Oilseed	135	115	3,566	Maintain
Wheat	Wheat–Wheat	Cereal	150	120	2,250	Maintain
Barley	Chickpea–Barley	Legume	140	100	2,148	Reduce
Barley	Faba Bean–Barley	Legume	145	110	2,265	Reduce
Barley	Barley–Barley	Cereal	160	135	2,012	Increase
Teff	Lentil–Teff	Legume	145	115	3,069	Reduce
Teff	Teff –Teff	Cereal	155	135	2,667	Increase
Maize	Soybean–Maize	Legume	150	120	3,982	Reduce
Maize	Maize–Maize	Cereal	165	140	3,617	Increase

Profit converted using the exchange rate 1 USD = 136.9 ETB.

Rotation-based Nitrogen Adjustment Factor

The nitrogen adjustment factor (NadjF) expresses how rotation influences N fertilizer needs. It was calculated by dividing the economic optimum nitrogen rate (EONR) of each rotation by that of its monocrop control (Table 4). This ratio reflects both the crop yield responses and the residual nitrogen carried over in the soil, capturing how the preceding crop modifies soil fertility, organic matter turnover, and recovery efficiency. The analysis result showed a clear trend. For example, field pea-wheat, chickpea-barley, and lentil-teff rotations produced the NadjF values between 0.69 and 0.9. This indicates that crop rotation using legume crops reduced nitrogen demand by 10-30 % without any significant yield loss (Figure 3; Table 4). Oilseed crop rotation, such as rapeseed-wheat, Niger seed-teff, had NadjF value close to one (0.95 to 1.0), indicating a nutrient-neutral effect. In contrast, continuous cereal crop rotations produced NadjF value > 1.0 to 1.16, reflecting soil N depletion and the need for compensatory fertilization.

The magnitude of N reduction was about 20-35% in wheat and barley. Similarly, for teff and maize crops, this reduction was found to be 15-25%. These findings emphasize the agronomic value of legumes in cropping systems and confirm patterns long recognized in Ethiopian cereal systems. Figure 3 (Lollipop plot) illustrates these differences: rotations fall below unity for legumes (efficient), around unity for oilseeds (neutral), and above unity for cereals (intensive).

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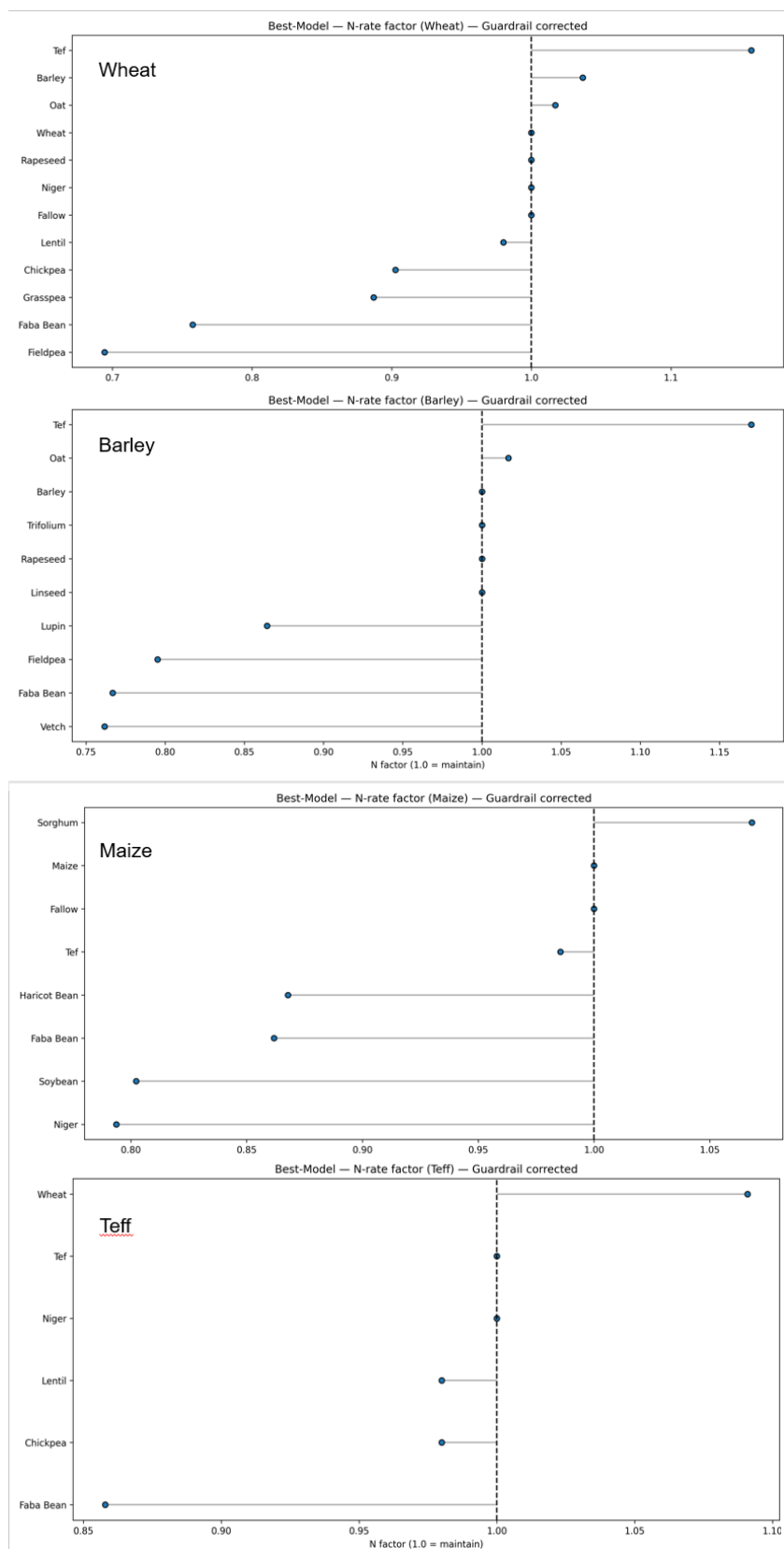


Figure 3. Rotation-Based Nitrogen Adjustment Factors (N-Factors) Across Four Major Cereal Crops

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Our findings are consistent with established carry-over effects in cereal systems. Legume rotations enriched soil mineral N and organic matter, supporting microbial activity and longer-term fertility. In contrast, cereal and oilseeds extracted residual N, gradually lowering soil reserves. These field-level patterns prove the need for rotation-specific N recommendations rather than fixed blanket rates. Continuous cereal sequences showed declining soil N and lower partial factor productivity. Both AONR and EONR increased, indicating reduced nitrogen-use efficiency. The integration of legumes in rotation could restore soil fertility and improve the sustainability of N management across sites.

Table 4. Rotation-based nitrogen adjustment Factors across rotation classes.

Rotation Class	Example Rotations	N-Factor Range	Advisory Class	Interpretation and Mechanism
Legume	Field pea–wheat, chickpea–barley, lentil–teff, soybean–maize	0.69–0.90	Reduce N	Residual N fixation, enhanced soil N availability, and microbial biomass turnover
Oilseed	Rapeseed–wheat, Niger seed–teff	0.95–1.00	Maintain N	Nutrient-neutral, intermediate soil C and N turnover
Cereal	Wheat–wheat, barley–barley, teff–teff, maize–maize	1.05–1.16	Increase N	Residual depletion, lower N recovery, and higher fertilizer demand

Sensitivity of Rotation-based Nitrogen Response

The sensitivity test, which adjusted the cost of nitrogen and grain price by $\pm 20\%$ showed that rotation-based nitrogen recommendations remained stable for wheat, teff, barley, and maize. EONR fluctuated by less than 10%, while profits changed by less than 12%. Legume rotations were the most stable, varying with $\pm 5\%$ for EONR and $\pm 8\%$ for profit. Oilseed crop rotation systems changed little ($< \pm 3\%$), whereas continuous cereals were comparatively more vulnerable to price shifts, showing 8–10% variations in EONR and 10–12 % in profit. Across the target crops, legume > oilseed > cereal formed a consistent stability gradient, providing a practical basis for rotation-specific nitrogen adjustment factors in nitrogen fertilizer advisory systems. Such integration can increase nitrogen-use efficiency, safeguard profits, and reduce farmers' vulnerability to price shocks (Table 5).

Table 5. Sensitivity of economic optimum nitrogen rate (EONR) and profitability to $\pm 20\%$ variation in nitrogen cost and grain price across major crop rotation systems.

Crop	Rotation Type	Δ EONR Low (%)	Δ EONR High (%)	Δ Profit Low (%)	Δ Profit High (%)	Stability Class
Wheat	Field pea–wheat	–4.3	+3.8	–5.0	+4.5	Stable
Wheat	Rapeseed–wheat	0	0	–2.1	+2.4	Very stable
Barley	Chickpea–barley	–6.0	+5.5	–7.8	+8.2	Stable
Barley	Barley–barley	–9.5	+10.1	–10.5	+11	Moderately sensitive
Teff	Lentil–teff	–4.8	+4.3	–6.5	+7.1	Stable
Teff	Teff–teff	–9.0	+9.8	–9.5	+10.3	Sensitive
Maize	Soybean–maize	–3.8	+3.5	–4.5	+5.0	Very stable
Maize	Maize–maize	–8.4	+8.9	–9.2	+10.8	Moderately sensitive

Conclusion

Integration of legumes in a rotation increases subsequent cereal yields and reduces the need for inorganic N fertilizer, offering economic and environmental benefits. Producers should consider the costs of the N source and methods of application, as these can yield different economically optimal N rates. The benefits of higher cereal yields and lower N needs for cereals grown in rotation with legumes should be considered in the context of economic benefits to all crops in the rotation, as well as marketing, environment, and sustainability issues. The most important

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socio-economic criteria of farmers for decision-making on which legumes to integrate into their temporal and spatial niches of the cropping system include land productivity, farm size, land ownership, access to market, and need for livestock feed. Such information can be used to design cropping sequence packages or to develop decision guides for integrating legumes into multiple cropping systems for any site within an area that has a high chance of success in Ethiopian mixed highland farming systems and the East African Highlands region.

References

- Agegehu, G., Lakew, B., and Nelson, P. N. (2014). Cropping sequence and nitrogen fertilizer effects on the productivity and quality of malting barley and soil fertility in the Ethiopian highlands. *Archi. Agron. Soil Sci.* **60**, 1261-1275.
- Bedu, M., Lefèvre, L., Dupont, A., Dubrulle, P., Reau, R., Debaeke, P., Guinet, M., Jeuffroy, M. H., Maury, P., Schneider, A., Schoving, C., Thiébeau, P., Voisin, A. S., and Parnaudeau, V. (2023). Adding a diversity of legumes to a crop decision-support system: Maintaining satisfactory accuracy while keeping the model simple. *European Journal of Agronomy* **151**, 126999.
- El Fartassi, I., Milne, A. E., Oulaid, B., Bezrhoud, Y., Metcalfe, H., Alonso Chavez, V., Coleman, K., Diarra, A., El Alami, R., Prout, J., Waine, T., Zawadzka, J., and Corstanje, R. (2025). Trade-offs associated with changing cropping patterns in semi-arid areas of Morocco. *Science of The Total Environment* **979**, 179492.
- Kassie, M., Teklewold, H., Jaleta, M., Marennya, P., and Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land use policy* **42**, 400-411.
- Kirschenmann, F. (2002). Why American agriculture is not sustainable. *Renew Resour J* **20**, 6-11.
- Kirschenmann, F. L. (2007). Potential for a new generation of biodiversity in agroecosystems of the future. *Agronomy Journal* **99**, 373-376.
- Kotu, B. H., Alene, A., Manyong, V., Hoeschle-Zeledon, I., and Larbi, A. (2017). Adoption and impacts of sustainable intensification practices in Ghana. *International Journal of Agricultural Sustainability* **15**, 539-554.
- Liu, C., Feng, X., Xu, Y., Kumar, A., Yan, Z., Zhou, J., Yang, Y., Peixoto, L., Zeng, Z., and Zang, H. (2023). Legume-based rotation enhances subsequent wheat yield and maintains soil carbon storage. *Agronomy for Sustainable Development* **43**, 64.
- N'Dayegamiye, A., Whalen, J. K., Tremblay, G., Nyiraneza, J., Grenier, M., Drapeau, A., and Bipfubusa, M. (2015). The Benefits of Legume Crops on Corn and Wheat Yield, Nitrogen Nutrition, and Soil Properties Improvement. *Agronomy Journal* **107**, 1653-1665.
- Peoples, M. B., and Craswell, E. T. (1992). Biological nitrogen fixation: investments, expectations and actual contributions to agriculture. *Plant and soil* **141**, 13-39.
- Peoples, M. B., Herridge, D. F., and Ladha, J. K. (1995). Biological nitrogen fixation: an efficient source of nitrogen for sustainable agricultural production? *Plant and Soil* **174**, 3-28.
- Pretty, J., and Bharucha, Z. P. (2014). Sustainable intensification in agricultural systems. *Annals of Botany* **114**, 1571-1596.
- Siddique, K., Johansen, C., Rao, J., and Ali, M. (2008). Legumes in sustainable cropping systems. In "Proceedings of the fourth international food legumes research" (M. C. Kharkwal, ed.). ISGPB, New Delhi, India.
- Tanaka, D. L., Liebig, M. A., Krupinsky, J. M., and Merrill, S. D. (2010). Crop sequence influences on sustainable spring wheat production in the northern Great Plains. *Sustainability* **2**, 3695-3709.
- Tesfaye, K., Cairns, J. E., Kassie, M., Misiko, M., Stirling, C., Abate, T., Prasanna, B. M., and Mekuria, M. (2015). Potential for taking climate smart agricultural practices to scale: Examples from Sub-Saharan Africa. In "Global Science: Climate Smart Agriculture", Montpellier, France.
- Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., Nziguheba, G., Schut, M., and Van Asten, P. (2014). Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability* **8**, 15-22.
- Williams, A., Birt, H. W. G., Raghavendra, A., and Dennis, P. G. (2023). Cropping System Diversification Influences Soil Microbial Diversity in Subtropical Dryland Farming Systems. *Microbial Ecology* **85**, 1473-1484.
- Yang, T., Siddique, K. H. M., and Liu, K. (2020). Cropping systems in agriculture and their impact on soil health-A review. *Global Ecology and Conservation* **23**, e01118.

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