Legume-Based Agroecology for African Nutrition Security

2023

AGROECOLOGY POLICY REPORT

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Acknowledgements

The authors and contributors of this report are presenting their own views and not the views of their affiliated professional and academic institutions. This work seeks to address what the contributors see as some of the gaps and unintended consequences of those previous efforts.

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- Farmer pictured: Eric Muriithi, smallholder Farmer in Kajiado County, Kenya
- Cover Photo: At the farm of Mrs. M. Onyango, a farmer in the Kakamega area of Kenya. Hurrying to pack up the drying beans before a rain squall hits.
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Methodology

This report began as a case study assessing the economic potential of legumes to mitigate fertilizer supply chain disruptions. A comprehensive literature review was conducted, analyzing existing research, reports, and assessments on fertilizer dependence, crop diversity, and food security. Stakeholder engagement played a crucial role in the report development, with input from diverse contributors across academic, non-governmental, and philanthropic organizations. The research process entailed analyzing existing subsidy programming and agricultural intervention best practices, considering socio-economic and environmental contexts. The research process culminated in a four-tier strategy for legume-based agroecology.

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Executive Summary

This report presents legume-centered agroecological strategies to drive policy transformation, research, and strategic partnerships in Africa.

Contemporary scholarship underscores the widespread adoption of industrialized agriculture, characterized by its heavy reliance on inorganic fertilizers, and subsequent implications for exacerbating food insecurity and environmental degradation.[1] The mid-20th-century Green Revolution promoted cereal crops planted in monoculture fields and dependent on non-renewable inputs that can adversely affect soils, water quality, and biodiversity. The anticipated payoffs of this cereal intensification fall short of expectations due to the high costs and long supply chains of agricultural inputs, insufficient training for input application, soil degradation, and the impacts of climate change.[2]

While monocropping has overtaken food production in many parts of the world, there has also been a shift away from the production of legume crops in favor of cereals. For example, locally adapted legumes are currently less favored in global markets compared to corn.[3] The subsequent shift away from legume production has coincided with a loss of agroecological services such as nitrogen fixation and of dietary contributions that high protein pulses provide. Fertilizer shortages and a growing list of Green Revolution shortcomings demonstrate the need for long-term solutions to challenges in food availability, human nutrition, and cropland regeneration.[4] A promising approach to address these issues is the recentering of legume crops into agricultural systems.

This report provides an in-depth analysis of both the challenges and potential solutions related to agroecological legume crop intensification in Africa. The report highlights the importance of farmer involvement, local food security, and aligning strategies with smallholder farmers' needs and preferences.
The final section proposes a four-point strategy for legume crop intensification in Africa to build independence from unpredictable supply chains: 1) Redirect Subsidies to Support Legume Intercropping 2) Research Underutilized Legumes and Soil Bacteria 3) Harmonize Formal and Informal Seed Sectors, and 4) Integrate Frass and Legume Production.

The intended audience of this report includes policymakers, government agencies, agricultural researchers, food producers, international organizations, and non-governmental organizations working in the realm of agriculture, nutrition security, and sustainable development.

Four point strategy

Redirect subsidies to support agroecology and legume intercropping	**Benefit**: Cost-effective and sustainable management practices	**Impact**: Reduced environmental harm and increased crop yield
Research undertilized legumes and soil bacteria	**Benefit**: Improved soil health and nitrogen fixation	**Impact**: Enhanced agricultural productivity and reduced reliance on synthetic fertilizers
Harmonize formal and informal seed sectors	**Benefit**: Improved access to high-quality, locally adapted seeds	**Impact**: Increased crop diversity and resilience to climate change
Integrate frass and legume production	**Benefit**: Cost-effective and eco-friendly alternative to synthetic fertilizers	**Impact**: Reduced environmental harm and increased crop yield

1. John DA, Babu GR. Lessons From the Aftermaths of Green Revolution on Food System and Health. Front Sustain Food Syst. 2021 Feb 22;5:644559. doi: 10.3389/fsufs.2021.644559. PMID: 34212131; PMCID: PMC7611098.
2. AGRA. (2022, February 28). Piata Evaluation Report. Sustainably Growing Africa's Food Systems. Retrieved from https://agra.org/piata-evaluation/
3. Khoury CK, Bjorkman AD, Dempewolf H, Ramirez-Villegas J, Guarino L, Jarvis A, Rieseberg LH, Struik PC. Increasing homogeneity in global food supplies and the implications for food security. Proc Natl Acad Sci U S A. 2014 Mar 18;111(11):4001-6. doi: 10.1073/pnas.1313490111. Epub 2014 Mar 3. PMID: 24591623; PMCID: PMC3964121.
4. Pretty J, Bharucha ZP. Sustainable intensification in agricultural systems. Ann Bot. 2014 Dec;114(8):1571-96. doi: 10.1093/aob/mcu205. Epub 2014 Oct 28. PMID: 25351192; PMCID: PMC4649696

Definitions

- **Agricultural input** is a common term for various resources used to enhance agricultural productivity such as fertilizers and seeds of specific crop varieties. These inputs include but aren't limited to chemicals, equipment, feed, seed, and energy.[5]
- **Agricultural intensification** involves increasing agricultural production per unit of inputs and can be achieved by increasing productivity or maintaining overall production while reducing specific inputs, such as optimizing fertilizer delivery, improving plant or animal protection, and implementing mixed or relay cropping on smaller fields.[6]
- **Agroecology** is a field of study and agricultural approach that applies principles of ecological and social renewal and health to design and manage food and farming systems. It is context-specific and relies on the co-creation and sharing of knowledge to address challenges in food systems and adapt to climate change.[7]
- **Agroecological transitions** entail a change of the agricultural model in order to implement the elements of agroecology, as well as economic, environmental, social, nutritional, health and cultural sustainability objectives, to assist cross-sector practitioners and advocates in fostering transformative change.[8]
- **Frass** is a byproduct material of insect husbandry, including spent feedstock, insect feces, and cuticles, that can be applied as a natural nutrient enhancement for crops. Frass can be synergistic with legume-intensive agroecological approaches[9] as an eco-friendly alternative or complement to conventional chemical fertilizers, and its application can reduce reliance on synthetic inputs.[10]
- **The Green Revolution** describes the promotion and use of high-yielding cereal varieties (wheat and rice), beginning in the 1960s, to increase food commodity crop production. This method of agricultural production maximizes productivity and economic gain in the form of industrial agriculture. The Green Revolution has had ecological repercussions, causing degradation of water quality, soil health, and biodiversity.[11]
- **Breeders' varieties** of legumes describe the bred cultivars developed by breeders for agricultural production through classical breeding methods or biotechnology.[12]
- **Industrial agriculture,** encompassing the mechanized and commodified production of animals and crops, has boosted worldwide per capita food output since the 1960s. This form of farming often involves mechanization, monocultures, and synthetic inputs like chemical fertilizers, pesticides, and transgenic organisms, prioritizing maximum productivity and economic gain while treating agricultural yields as commodities. Ecologically, it can contribute to the decline of ground and surface water quality, soil vitality, and biodiversity.[13], [14]
- **Input Subsidies** are subsidies for materials such as fertilizers and pesticides intended to stimulate their use.[15] Input subsidy programming (ISPs) via government agricultural agencies may provide free or subsidized distribution of inputs, sometimes through vouchers for farmers to purchase inputs at a subsidized price from authorized suppliers.[16]
- **Legumes** are plant species from the botanical family Fabaceae. Pulses are the edible seeds from legume plants, such as beans, lentils, and peas.[17]
- **Nitrogen fixation** is the conversion of atmospheric nitrogen into more reactive (and often more bioavailable) forms. Legumes, in symbiosis with soil bacteria called rhizobia, can fix nitrogen, a feat few non-leguminous plants are capable of. This can provide benefit the legumes, bacteria, and agroecosystem.[18]
- **Polyculture** is the simultaneous cultivation of two or more crops in a single area for benefits such as yield advantage, yield stability, water conservation, and reduced soil erosion.[19] It enhances biodiversity, deters pests, and often includes nitrogen-fixing plants that enrich soil and improve its structure. This boosts climate resilience, water efficiency, and other advantages.[20] Sometimes used interchangeably, it is differentiated from intercropping, as polyculture can entail intentional cultivation crops with non-crop plant species in a field.[21]
- **Rhizobia** are symbiotic diazotrophic soil bacteria that establish a mutualistic relationship with leguminous plants. They enter the roots of these plants, inducing the formation of root nodules, where they engage in nitrogen fixation.[22]
- **Underutilized or Neglected crops** are crops with the potential to be used to a greater degree to improve food security, nutrition, and agroecological function. Increased cultivation of a small number of staple crops (e.g., rice, wheat, maize) around the world, has led to the decline of many local and traditional crops which have the potential to be reintroduced for various food system benefits.[23]

5. Michelson, H., Gourlay, S., Lybbert, T., & Wollburg, P. (2023). Review: Purchased agricultural input quality and small farms. Food Policy, 116, 102424. https://doi.org/10.1016/j.foodpol.2023.102424
6. Carswell, Grace. (2011). Agricultural Intensification and Rural Sustainable Livelihoods: A "Think Piece.
7. Food and Agriculture Organization of the United Nations. (2023). Co-creation and sharing of knowledge. Agroecology Knowledge Hub. https://www.fao.org/agroecology/knowledge/10-elements/co-creationknowledge/en/?page=36&ipp=5&tx_dynalist_pi1%5Bpar%5D=YToxOntzOjE6Ikwi03M6MToiMCI7fQ%3D%3D
8. Food and Agriculture Organization of the United Nations. (n.d.). What is Agroecology?. Agroecology Knowledge Hub . https://www.fao.org/agroecology/overview/en/
9. Leni, G., Caligiani, A., & Sforza, S. (2021). Bioconversion of agri-food waste and by-products through insects: a new valorization opportunity. Redirecting. Retrieved April 16, 2023, from https://doi.org/10.1016/B978-0-12-824044-1.00013-1
10. Quilliam, Richard & Nuku-Adeku, C. & Pierre-Olivier, Maquart & Little, David & Newton, Richard & Murray, Francis. (2020). Integrating insect frass biofertilisers into sustainable peri-urban agro-food systems. Journal of Insects as Food and Feed. 6. 1-8. 10.3920/JIFF2019.0049.
11. Briggs, J. (2009). Green revolution. International Encyclopedia of Human Geography, 634–638. https://doi.org/10.1016/b978-008044910-4.00099-7
12. National Research Council (US) Board on Agriculture. Genetic Engineering of Plants: Agricultural Research Opportunities and Policy Concerns. Washington (DC): National Academies Press (US); 1984. Crop Improvement. Available from: https://www.ncbi.nlm.nih.gov/books/NBK216396/
13. Gowdy, John & Baveye, Philippe. (2019). An Evolutionary Perspective on Industrial and Sustainable Agriculture. 10.1016/B978-0-12-811050-8.00027-3.
14. TRG(A16.1)/GICM, FAO, 2004; Natural Resources Management and Environment Department, NR, FAO, 2009; Glossary of terms, Making climate-sensitive investments in agriculture, FAO, 2021 (http://www.fao.org/3/cb1067en/cb1067en.pdf)
15. Baltzer, K., & Hansen, H. (2012). (rep.). Agricultural input subsidies in Sub-Saharan Africa (Vol. Evaluation Study, pp. 1–40). Ministry of Foreign Affairs Denmark
16. National Research Council (US) Board on Agriculture. Genetic Engineering of Plants: Agricultural Research Opportunities and Policy Concerns. Washington (DC): National Academies Press (US); 1984. Crop Improvement. Available from: https://www.ncbi.nlm.nih.gov/books/NBK216396/
17. Harvard T.H. Chan School of Public Health. (2022, March 2). Legumes and pulses. The Nutrition Source. Retrieved April 16, 2023, from https://www.hsph.harvard.edu/nutritionsource/legumespulses/#:~:text=A%20legume%20refers%20to%20any,the%20pod%20is%20the%20pulse
18. Zahran HH. Rhizobium-legume symbiosis and nitrogen fixation under severe conditions and in an arid climate. Microbiol Mol Biol Rev. 1999 Dec;63(4):968-89, table of contents. doi: 10.1128/MMBR.63.4.968-989.1999. PMID: 10585971; PMCID: PMC98982.
19. Kiwia A, Kimani D, Harawa R, Jama B, Sileshi GW. Sustainable Intensification with Cereal-Legume Intercropping in Eastern and Southern Africa. Sustainability. 2019;11(10):2891. doi: 10.3390/su11102891. Epub 2019 May 21. PMID: 33552560; PMCID: PMC7839597.
20. Bracken, Matthew. (2018). Monocultures Versus Polycultures. 10.1016/B978-0-12-409548-9.11169-8
21. Stomph, Tjeerd Jan & Dordas, Christos & Baranger, Alain & Rijk, Joshua & Dong, Bei & Evers, Jochem & Gu, Chunfeng & Li, Long & Simon, Johan & Jensen, Erik & Wang, Qi & Wang, Yuyun & Wang, Zishen & Xu, Huasen & Zhang, Chaochun & Zhang, Lizhen & Zhang, Wei-Ping & Bedoussac, Laurent & Van der Werf, Wopke. (2020). Designing intercrops for high yield, yield stability and efficient use of resources: Are there principles?.
22. Kumar, A., Meena, V.S., Roy, P., Vandana, Kumari, R. (2019). Plant Growth Promoting Rhizobacteria for Agricultural Sustainability. Springer, Singapore. https://doi.org/10.1007/978-981-13-7553-8_7
23. Chapman, M., He, Y., & Zhou, M. (2022, March 22). Beyond a reference genome: pangenomes and population genomics of underutilized and orphan crops for future food and nutrition security. New Phytologist. Retrieved April 16, 2023, from https://nph.onlinelibrary.wiley.com/doi/10.1111/nph.18021

Quick Facts

- Inappropriate chemical fertilizer use can degrade soil over time, leading to nitrogen leaching, soil compaction, reduction of organic matter, and carbon loss.[24]
- Increased reliance on chemical fertilizers resulting from Green Revolution policies likely contributed to reductions of traditional reliance on legumes and livestock as sources of soil fertility. The subsidization and programmatic focus on encouraging smallholder utilization of inorganic inputs, such as synthetic fertilizers and pesticides, has led to smallholder farmers shifting their production away from legumes towards these artificial inputs designed for cereal crop cultivation.[25]
- A meta-analysis of 286 agricultural interventions promoting sustainability in 57 low-income countries assessed 37 million hectares (3% of developing countries' farmland) and showed increased productivity on 12.6 million farms. On average, crop yields rose by 79%, with water efficiency gains observed in all crops, especially rainfed ones. Pesticide data showed 77% of projects reduced pesticide use by 71%, while yields grew by 42%.[26]
- Inorganic fertilizer use among smallholders in Sub-Saharan Africa is significantly lower than the global average.[27]
- 80% of African farms are smaller than 2 hectares (ha), with the typical size being less than one ha.[28]
- Crop diversity is positively associated with increased food production and harvest-related cash income in rural Ghana.[29]
- An analysis of data from Ethiopian households revealed a 10% rise in crop diversity correlated with an 18% decrease in the probability of a household being impoverished. The findings indicate that crop diversification, a practice often used with legumes, is linked to poverty reduction.[30]
- Legumes are a keystone crop in African farming systems and contribute to soil fertility through nitrogen fixation.[31] Legumes contribute an average of 15 to 210 kilograms of nitrogen per hectare per cropping season in Africa, depending on ecology, species, and management practices.[32]
- Legumes are rich in dietary fiber, calcium, iron, sodium, phosphorus, magnesium, potassium, and protein.[33]
- International pulse trade increased fourfold over the past twenty years, and projections show increased pulse demand in low-income countries due to population growth and rising per capita incomes.[34]
- Underutilized legumes tend to be regionally adapted and rarely traded internationally. 6,747 underutilized indigenous legume accessions (genetically similar seed collections to be used for preserving genetic diversity, plant breeding, and research) are conserved at the Genetic Resources Center of the International Institute of Tropical Agriculture.[35]
- Frass enhances both plant growth and nutrient levels in crops. It has been shown to surpass the production of actual animal biomass for fertilization by up to 40 times and can potentially substitute synthetic fertilizers due to its rapid breakdown and abundant nutrient availability as an effective natural fertilizer rich in nitrogen, phosphorus, and potassium (NPK).[36]
- Indigenous and underutilized food crops contribute to diverse and resilient African food landscapes as they offer nutritional, environmental, economic, and socio-cultural benefits. Undervaluing these foods and a decrease in passing down knowledge between generations is a challenge for producers and consumers.[37]
- Maize-legume cropping systems in Kenya demonstrate economic advantages as systems incorporating cowpea and pigeon pea rotations were 32-49% more profitable than continuous sole maize production.[38]
- Projections for pulse demand underscore a continued rise, driven by population growth and increasing per capita incomes globally.[39]

24. Lin W, Lin M, Zhou H, Wu H, Li Z, Lin W. The effects of chemical and organic fertilizer usage on rhizosphere soil in tea orchards. PLoS One. 2019 May 28;14(5):e0217018. doi: 10.1371/journal.pone.0217018. PMID: 31136614; PMCID: PMC6538140.
25. See Khoury et al., 2014
26. Pretty, Jules & Noble, Andrew & Bossio, Deborah & Dixon, John & Bragg, Rachel & Vries, F. & Morison, James. (2006). Resource-Conserving Agriculture Increases Yields in Developing Countries. Environmental science & technology. 40. 1114-9. 10.1021/es062733a 27 Lowder, S., Skowet, J., & Raney, T. (2016, February 9). The Number, Size, and Distribution of Farms,
27. Smallholder Farms, and Family Farms Worldwide. World Development. Retrieved from https://www.sciencedirect.com/science/article/pii/S0305750X15002703#b0125
28. Lowder, S., Skowet, J., & Raney, T. (2016, February 9). The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide. World Development. Retrieved from https://www.sciencedirect.com/science/article/pii/S0305750X15002703#b0125
29 . Bellon, Mauricio & Kotu, Bekele Hundie & Azzarri, Carlo & Caracciolo, Francesco. (2020). To diversify or not to diversify, that is the question. Pursuing agricultural development for smallholder farmers in marginal areas of Ghana. World Development. 125. 10.1016/j.worlddev.2019.104682
30. Michler, Jeffrey & Josephson, Anna. (2015). To Specialize or Diversify: Agricultural Diversity and Poverty Dynamics in Ethiopia. World Development. 89. 10.1016/j.worlddev.2016.08.011.
31. Vanlauwe B, Hungria M, Kanampiu F, Giller KE. The role of legumes in the sustainable intensification of African smallholder agriculture: Lessons learnt and challenges for the future. Agric Ecosyst Environ. 2019 Nov 15;284:106583. doi: 10.1016/j.agee.2019.106583. PMID: 33456099; PMCID: PMC7794592.
32. Dakora, F. D., & Keya, S. O. (1998, February 25). Contribution of legume nitrogen fixation to sustainable agriculture in Sub-Saharan africa. Soil Biology and Biochemistry. https://www.sciencedirect.com/science/article/abs/pii/S0038071796002258?via%3Dihub
33. Abberton, Michael & Paliwal, Rajneesh & Faloye, Benjamin & Marimagne, Tchamba & Moriam, Azeez & Oyatomi, Olaniyi. (2022). Indigenous African Orphan Legumes: Potential for Food and Nutrition Security in SSA. Frontiers in Sustainable Food Systems. 6. 708124. 10.3389/fsufs.2022.708124.
34. Joshi, Pramod Kumar and Rao, P. Parthasarathy. 2016. Global and regional pulse economies: Current trends and outlook. IFPRI Discussion Paper 1544. Washington, D.C.: International Food Policy Research Institute (IFPRI). http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/130480
35. See Abberton et al., 2022
36. Poveda, Jorge. (2021). Insect frass in the development of sustainable agriculture. A review. Agronomy for Sustainable Development. 41. 10.1007/s13593-020-00656-x.
37. Akinola R, Pereira LM, Mabhaudhi T, de Bruin FM, Rusch L. A Review of Indigenous Food Crops in Africa and the Implications for more Sustainable and Healthy Food Systems. Sustainability. 2020 Apr 24;12(8):3493. doi: 10.3390/su12083493. PMID: 33520291; PMCID: PMC7116648.
38. Rao, M.R. & Mathuva, M.N.. (2000). Legumes for improving maize yields and income in semi-arid Kenya. Agriculture Ecosystems and Environment. 78. 123-137. 10.1016/S0167-8809(99)00125-5.
39. See Joshi and Rao, 2016

Introduction

The Green Revolution transformed global agriculture with far-reaching consequences for local food systems. Notably, despite the structural push of agricultural subsidies to commercialize external inputs, African farming systems remain characterized by low use of inorganic fertilizers, estimated at 21 kilograms of nutrients added per hectare (kg/ha) of harvested land per year 40 compared to the global average of 146.4 g/ha.[41]

Recent evaluations of Green Revolution initiatives prioritizing cereal monocropping suggest that low-diversity chemical-dependent agriculture produces uneven nutritional gains that in some instances may even exacerbate food precarity and environmental issues.[42] Promotion of input-reliant crop varieties has contributed to ecological degradation and placed long-term nutrition security in a precarious position despite the immediate high-productivity Green Revolution benefits.[43] For example, smallholder dependence on long supply chains for seeds, fertilizer, and pesticides creates vulnerabilities when farmers' access to these inputs is disrupted. Moreover, pesticide run-off and the overexploitation of groundwater for agricultural irrigation have led to a decline in both for direct and indirect purposes.[44]

Emphasis on cereal production around the world[45] has driven the global focus to a small number of crops -- nine plant species accounted for 66% of total crop production in 2019.[46] In many cases, a growing dependence on cereals is correlated with declines in production of traditional legume crops.[47] Legumes have served as key components of Indigenous food systems for thousands of years[48] and traditional agricultural strategies have long leveraged legumes ecosystem benefits to enhance soil fertility.[49] Thus, the reduced cultivation of this soil fertility tool has contributed to a heightened reliance on synthetic fertilizers among smallholder farmers. This presents a growing challenge in Africa, where fragmented fertilizer markets, rising fertilizer prices, and precarious global supply chains make smallholder farmers' access to external inputs inconsistent.

With the decreased production of locally-adapted indigenous crop species that were previously regionally significant, many legumes today are underutilized despite their benefits for human and planetary health. Among the unique benefits of these underutilized or "orphan" legume crops are diverse nutritional profiles, high tolerance to traditional biotic and abiotic stressors, and traits supporting broader ecosystem health.[50] As climate change threatens agricultural systems globally, revitalizing overlooked and hardy crops may be an effective adaptation strategy.

The support of legume crops in African farming and food systems should be carried out in the context of a broader agroecological intensification strategy. As a scientific discipline and practice, agroecology applies social and ecological renewal principles to farming. Agroecological approaches are increasingly gaining attention as a means to address persistent malnutrition and poverty without compromising environmental health.[51] Agroecology often draws from, and builds on, Indigenous and traditional management techniques. Farming communities that have lived in a given environment for generations often hold knowledge, developed over years of observation and experimentation, that contributes to nutritional security and environmental sustainability. Many traditional strategies involving polyculture, cover cropping, and erosion prevention leverage legume production for long-term resilience and fertility.[52] For example, the continued production of locally adapted underutilized legumes in places like Niger, Ethiopia, and Mali provides a rich nutrition source for humans and livestock during drought.[53]

The levels of implementation and impact of Green Revolution policies, technologies, and approaches are uneven across Africa.[54] This variability across regions has permitted some smallholder producers to retain legumes as part of their farming systems.[55] Smallholder farmers who lack the financial resources or access to engage in more input-reliant industrial farming still leverage underutilized legumes for food, income, and nutrition security.[56] While the reintroduction of legume crops into agricultural systems where they have declined is essential, in these areas supporting smallholders to continue and expand legume cultivation is also critical. As part of an agroecological transition, the potential is high to transfer knowledge from such locations where legumes have remained in cultivation to ones where they have been lost, as long as regional variation and local contexts are recognized.

Importantly, soybeans are a legume commodity crop produced in Africa that play a key role in global agricultural production and market systems. However, this report will not focus on soybeans and instead propose alternatives for reducing reliance on the long external input supply chains required for effective soybean production. While commercial soybean production is successfully undertaken across Africa, farmers without access to inputs do not reap maximum benefits[57] and find that soybeans are more vulnerable[58] to numerous pests and climate change compared to native legume species.[59] Sub-Saharan Africa's soybean yield is low due to variability in access to vital soil inputs like fertilizers and rhizobial inoculants, standard in global industrial-scale production.[60] When smallholders have limited access to supply chains and purchasing power, a logical alternative is to capitalize on locally adapted and climate-resilient underutilized legumes, which have been overlooked in favor of cereal crop production.[61]

41. Food and Agriculture Organization. (2020). Fertilizer consumption (kilograms per hectare of arable land). The World Bank DataBank. https://data.worldbank.org/indicator/AG.CON.FERT.ZS
42. AGRA. (2022, February 28). Piata Evaluation Report. Sustainably Growing Africa's Food Systems. Retrieved from https://agra.org/piata-evaluation/
43. John DA, Babu GR. Lessons From the Aftermaths of Green Revolution on Food System and Health. Front Sustain Food Syst. 2021 Feb 22;5:644559. doi: 10.3389/fsufs.2021.644559. PMID: 34212131; PMCID: PMC7611098.
44. Iglesias, A., Garrote L; Quiroga, S. & Moneo, M. 2012. From climate change impacts to the development of adaptation strategies: challenges for agriculture in Europe. Climatic Change, 112: 143–168. DOI 10.1007/s10584-011-0344-x
45. Chibarabada TP, Modi AT, Mabhaudhi T. Expounding the Value of Grain Legumes in the Semi- and Arid Tropics. Sustainability. 2017; 9(1):60. https://doi.org/10.3390/su9010060
46. FAO. 2019. The State of the World's Biodiversity for Food and Agriculture, J. Bélanger & D. Pilling (eds.). FAO Commission on Genetic Resources for Food and Agriculture Assessments. Rome. 572 pp. (http://www.fao.org/3/CA3129EN/CA3129EN.pdf) Licence: CC BY-NC-SA 3.0 IGO
47. Khoury, C.K., Bjorkman, A.D., Dempewolf, H., Ramirez-Villegas, J., Guarino, L., Jarvis, A., Rieseberg, L.H. and Struik, P.C., 2014. Increasing homogeneity in global food supplies and the implications for food security. Proceedings of the national Academy of Sciences, 111(11), pp.4001-4006
48. Global Alliance for the Future of Food, The Politics of Knowledge: Understanding the Evidence for Agroecology, Regenerative Approaches, and Indigenous Foodways. n.p.: Global Alliance for the Future of Food, 2021
49. Snapp, S.S., Blackie, M.J., Gilbert, R.A., Bezner-Kerr, R. and Kanyama-Phiri, G.Y., 2010. Biodiversity can support a greener revolution in Africa. Proceedings of the National Academy of Sciences, 107(48), pp.20840-20845
50. Chapman MA, He Y, Zhou M. Beyond a reference genome: pangenomes and population genomics of underutilized and orphan crops for future food and nutrition security. New Phytol. 2022 Jun;234(5):1583-1597. doi: 10.1111/nph.18021. Epub 2022 Mar 22. PMID: 35318683; PMCID: PMC9994440
51. Wezel, A., Herren, B.G., Kerr, R.B., Barrios, E., Gonçalves, A.L.R. and Sinclair, F., 2020. Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. Agronomy for Sustainable Development, 40, pp.1-13.
52. Ramirez-Santos, A.G., Ravera, F., Rivera-Ferre, M.G. and Calvet-Nogués, M., 2023. Gendered traditional agroecological knowledge in agri-food systems: a systematic review. Journal of Ethnobiology and Ethnomedicine, 19(1), pp.1-19.
53. Abberton et. Al, 2022
54. Dawson, Neil & Martin, Adrian & Sikor, Thomas. (2016). Green Revolution in Sub-Saharan Africa: Implications of Imposed Innovation for the Wellbeing of Rural Smallholders. World Development. 78. 204-218. 10.1016/j.worlddev.2015.10.008.
55. Dawson, Neil & Martin, Adrian & Sikor, Thomas. (2016). Green Revolution in Sub-Saharan Africa: Implications of Imposed Innovation for the Wellbeing of Rural Smallholders. World Development. 78. 204-218. 10.1016/j.worlddev.2015.10.008.
56. Popoola JO, Aworunse OS, Ojuederie OB, Adewale BD, Ajani OC, Oyatomi OA, Eruemulor DI, Adegboyega TT, Obembe OO. The Exploitation of Orphan Legumes for Food, Income, and Nutrition Security in Sub-Saharan Africa. Front Plant Sci. 2022 May 17;13:782140. doi: 10.3389/fpls.2022.782140. PMID: 35665143; PMCID: PMC9156806.
57. Savala CEN, Wiredu AN, Chikoye D and Kyei-Boahen S (2022) Prospects and Potential of Bradyrhizobium diazoefficiens Based Bio-Inoculants on Soybean Production in Different Agro-Ecologies of Mozambique. Front. Sustain. Food Syst. 6:908231. doi: 10.3389/fsufs.2022.908231
58. Engelbrecht, G., Claassens, S., Mienie, C. M. S., & Fourie, H. (2020). South Africa: An Important Soybean Producer in Sub-Saharan Africa and the Quest for Managing Nematode Pests of the Crop. Agriculture, 10(6), 242. MDPI AG. Retrieved from http://dx.doi.org/10.3390/agriculture10060242
59. Gbegbelegbe S, Alene A, Kamara A, Wiebe K, Manyong V, Abdoulaye T, Mkandawire P. Ex-ante evaluation of promising soybean innovations for sub-Saharan Africa. Food Energy Secur. 2019 Nov;8(4):e00172. doi: 10.1002/fes3.172. Epub 2019 May 16. PMID: 32140222; PMCID: PMC7043309.
60. Khojely, Dalia & Ibrahim, Seifeldin & Sapey, Enoch & Han, Tianfu. (2018). History, current status, and prospects of soybean production and research in sub-Saharan Africa. The Crop Journal. 6. 10.1016/j.cj.2018.03.006.
61. Khoury CK, Bjorkman AD, Dempewolf H, Ramirez-Villegas J, Guarino L, Jarvis A, Rieseberg LH, Struik PC. Increasing homogeneity in global food supplies and the implications for food security. Proc Natl Acad Sci U S A. 2014 Mar 18;111(11):4001-6. doi: 10.1073/pnas.1313490111. Epub 2014 Mar 3. PMID: 24591623; PMCID: PMC3964121.

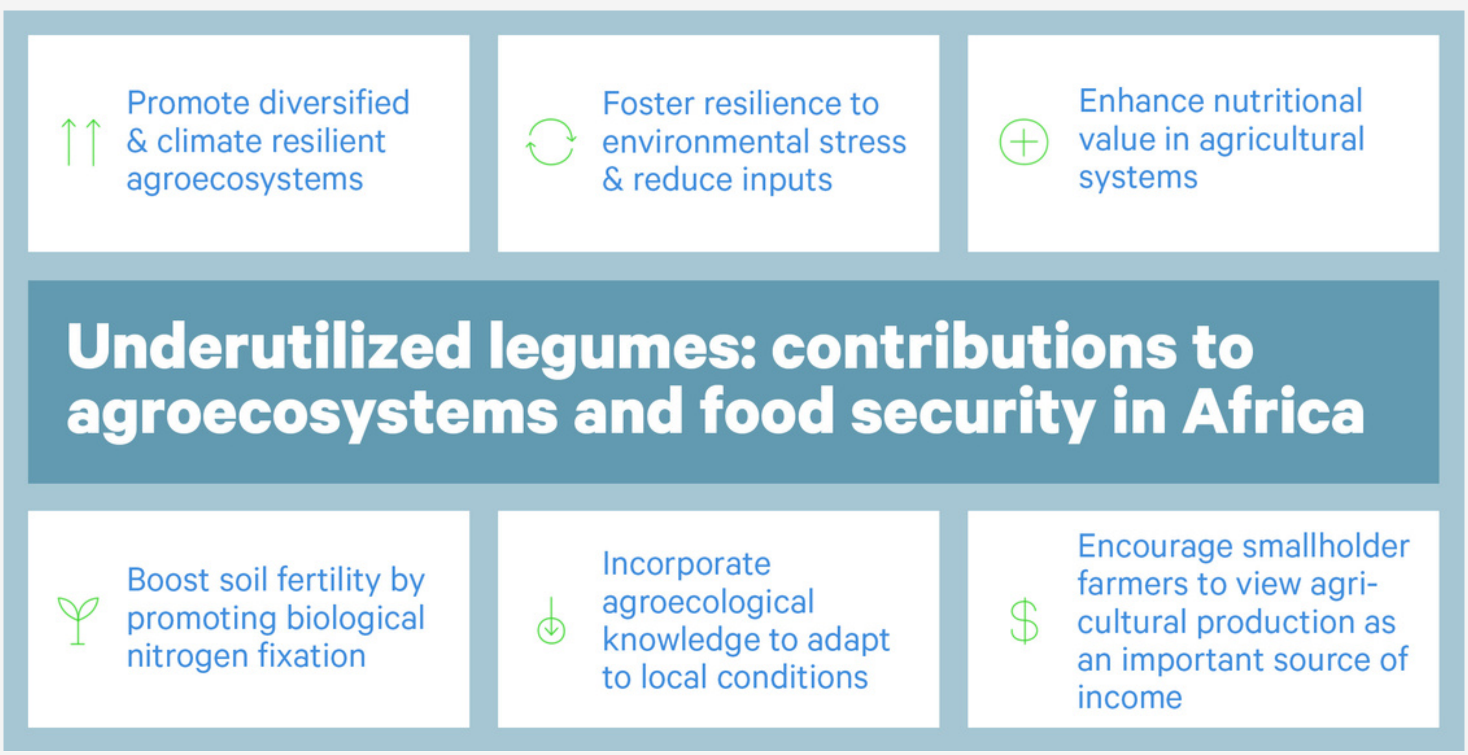
Legumes for Human and Planetary Health

This section presents a scientific basis and agricultural management strategies for re-introducing and promoting legumes as a solution to human and environmental health challenges across Africa.

Legumes are a rich source of essential dietary nutrients, including protein, dietary fiber, vitamins, and minerals, and have been linked to reduced risk of heart disease.[62] Legumes also present an alternative or complement to animal-based proteins, and their intensification can play a role in greenhouse gas (GHG) emission mitigation strategies,[63] as legume consumption results in significantly lower emissions per kilogram of protein compared to any animal product. Recent data demonstrates that producing one kilogram of beef emits 60 kilograms of CO2-equivalent GHGs, while the production of a kilogram of peas emits just 1 kilogram of CO2-equivalent GHGs.[64]

Leguminous crops can also reduce the need for synthetic fertilizers by enriching the soil with nitrogen, contributing to weed suppression, aiding in soil conditioning, and reducing the risks of soil erosion. Deep root systems and nitrogen fixation further contribute to drought resilience and adaptability of underutilized and breeders' varieties of legumes.[65]

Indigenous legume species developed by farmers through selection over time in response to their local environments often exhibit resilience to marginal or extreme conditions. High levels of genetic diversity in localized landrace forms can further facilitate rapid adaptation to changing conditions, particularly as genetically diverse legumes are more resilient to biotic and abiotic stressors compared to their bred cultivar counterparts.[66]



62. Afshin, A., Micha, R., Khatibzadeh, S. and Mozaffarian, D., 2014. Consumption of nuts and legumes and risk of incident ischemic heart disease, stroke, and diabetes: a systematic review and meta-analysis. The American journal of clinical nutrition, 100(1), pp.278-288
63. Prudhomme, R., Brunelle, T., Dumas, P., Le Moing, A. and Zhang, X., 2020. Assessing the impact of increased legume production in Europe on global agricultural emissions. Regional Environmental Change, 20, pp.1-13.
64. Poore J, Nemecek T. Reducing food's environmental impacts through producers and consumers. Science. 2018 Jun 1;360(6392):987-992. doi: 10.1126/science.aaq0216. Erratum in: Science. 2019 Feb 22;363(6429): PMID: 29853680.
65. Kocira A, Staniak M, Tomaszewska M, Kornas R, Cymerman J, Panasiewicz K, Lipińska H. Legume Cover Crops as One of the Elements of Strategic Weed Management and Soil Quality Improvement. A Review. Agriculture. 2020; 10(9):394. https://doi.org/10.3390/agriculture10090394
66. See Abberton et al. 2022

Nitrogen Fixation in Legumes: A Symbiotic Relationship and its Agricultural Impact

Agroecological legume production is a sustainable and cost-effective solution to fix nitrogen into soil and reduce reliance on external inputs. In the intricate process of biological nitrogen fixation, atmospheric nitrogen gas (N_2) is harnessed and made available to legumes by soil bacteria called rhizobia. The term 'fixation' here denotes the conversion of inert atmospheric nitrogen into a biologically accessible form, thus fortifying the soil's nutrient content. These rhizobia establish a symbiotic relationship with legume plants, where nitrogen from the atmosphere can more easily enter specialized structures within the legume's root system known as nodules. Nitrogen from the atmosphere is absorbed through these nodules with the aid of rhizobia. The legume experiences facilitated nitrogen-based growth, while the rhizobia acquire carbon and nutrients as byproducts from the legume's photosynthesis.[67]

For every ton of dry matter produced by crop legumes, approximately 30–40 kg of nitrogen on average is fixed on a whole plant basis.[68] This nitrogen fixation process naturally fertilizes the soil and can increase crop yield, directly benefiting farmers.[69] Importantly, the nature of the legume-rhizobia symbiosis is affected by legume species, geographical location, and prevailing climatic conditions.[70]

The capacity for nitrogen fixation is mostly limited to leguminous plants. Rare exceptions include alder trees, bayberry, and a variety of maize called olotón.[71] Aside from olotón, nitrogen fixation is not known to occur in cereals. The scientific community has yet to develop cereal crops for nitrogen fixation. If achieved, genetically uniform cereal varieties are likely to become the initial available crop to market. The likely substantial costs of nitrogen-fixing cereal seeds will limit accessibility for smallholders, and such engineered lines will be genetically homogenous and likely highly reliant upon inputs such as inoculants.[72]

Legume Diversity and Production Practices

Legume crops encompass a remarkable diversity of species, varieties, and cultivation methods, making them a versatile addition to agricultural systems and diets. Crops produced globally such as the soybean, pea, and chickpea are well-known, but thousands of less-utilized species like lupins, lablab, and grasspea exhibit further variation to be exploited agronomic and culinary properties.[73]

In production, legume crops can play a crucial role in agroecological systems, particularly through the practices of polyculture and crop rotation. In legume intercropping systems, nitrogen fixation can benefit neighboring crops, while in rotation, legumes can enhance soil fertility through the same process for subsequent yields.[74] Legume intercropping can also deter pests and buffer production against climate variability and extreme weather events.[75] Diverse intercropping systems are used today around the world, from sub-Saharan and Central Africa to North and South America, Asia, and Northern Europe.[76] Archaeobotanical research demonstrates that legume intercropping has been a key element of traditional African farming systems for millennia.[77] Across the continent today, introduced cereal crops like maize are intercropped alongside native legumes such as the common bean, cowpea, and groundnut.[78] Legume cover crops can provide livestock with high-quality forage, simultaneously improving soil health through animal waste and nitrogen fixation inputs.[79]

Index Table 1 presents selected underutilized legume species, detailing their significance, species, production potential, resilience, nutritional composition, and origin and production region.

67. Vanlauwe B, Hungria M, Kanampiu F, Giller KE. The role of legumes in the sustainable intensification of African smallholder agriculture: Lessons learnt and challenges for the future. Agric Ecosyst Environ. 2019 Nov 15;284:106583. doi: 10.1016/j.agee.2019.106583. PMID: 33456099; PMCID: PMC7794592.
68. Peoples, M.B., Brockwell, J., Herridge, D.F. et al. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis 48, 1–17 (2009). https://doi.org/10.1007/BF03179980
69. Soumare A, Diedhiou AG, Thuita M, Hafidi M, Ouhdouch Y, Gopalakrishnan S, Kouisni L. Exploiting Biological Nitrogen Fixation: A Route Towards a Sustainable Agriculture. Plants (Basel). 2020 Aug 11;9(8):1011. doi: 10.3390/plants9081011. PMID: 32796519; PMCID: PMC7464700
70. Wang Q, Liu J and Zhu H (2018) Genetic and Molecular Mechanisms Underlying Symbiotic Specificity in Legume-Rhizobium Interactions. Front. Plant Sci. 9:313. doi: 10.3389/fpls.2018.00313
71. Santi, C., Bogusz, D. and Franche, C., 2013. Biological nitrogen fixation in non-legume plants. Annals of botany, 111(5), pp.743-767.
72. Rosenblueth M, Ormeño-Orrillo E, López-López A, Rogel MA, Reyes-Hernández BJ, Martínez-Romero JC, Reddy PM and Martínez-Romero E (2018) Nitrogen Fixation in Cereals. Front. Microbiol. 9:1794. doi: 10.3389/fmicb.2018.01794
73. Ruelle, M.L., Asfaw, Z., Dejen, A., Tewolde-Berhan, S., Nebiyu, A., Tana, T. and Power, A.G., 2019. Inter-and intraspecific diversity of food legumes among households and communities in Ethiopia. PloS One, 14(12), p.e0227074
74. Andrade, Sara & Mazzafera, Paulo & Favarin, Jose. (2021). Editorial: Intercropping Systems in Sustainable Agriculture. Frontiers in Sustainable Food Systems. 5. 634361. 10.3389/fsufs.2021.634361.
75. Aluja, Martín & Birke, Andrea & Ceymann, Maria & Guillén, Larissa & Arrigoni, Eva & Baumgartner, Daniel & Pascacio-Villafán, Carlos & Samietz, Jörg. (2014). Agroecosystem resilience to an invasive insect species that could expand its geographical range in response to global climate change. Agriculture, Ecosystems & Environment. 186. 54–63. 10.1016/j.agee.2014.01.017.
76. CGIAR. (2023, April 4). Mixed Farming Systems Initiative. Research Initiatives . Retrieved April 17, 2023, from https://www.cgiar.org/initiative/mixed-farming-systems/
77. Champion L, Fuller DQ, Ozainne S, Huysecom É, Mayor A. Agricultural diversification in West Africa: an archaeobotanical study of the site of Sadia (Dogon Country, Mali). Archaeol Anthropol Sci. 2021;13(4):60. doi: 10.1007/s12520-021-01293-5. Epub 2021 Mar 8. PMID: 33758626; PMCID: PMC7937602
78. Odendo, M., Bationo, A., Kimani, S. (2011). Socio-Economic Contribution of Legumes to Livelihoods in Sub-Saharan Africa. In: Bationo, A., Waswa, B., Okeyo, J., Maina, F., Kihara, J., Mokwunye, U. (eds) Fighting Poverty in Sub-Saharan Africa: The Multiple Roles of Legumes in Integrated Soil Fertility Management. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-1536-3_2
79. Kocira, A.; Staniak, M.; Tomaszewska, M.; Kornas, R.; Cymerman, J.; Panasiewicz, K.; Lipińska, H. Legume Cover Crops as One of the Elements of Strategic Weed Management and Soil Quality Improvement. A Review. Agriculture 2020, 10, 394. https://doi.org/10.3390/agriculture10090394

Evidence for the Efficacy of Legume Production

Fostering agroecological practices and legume production provides a means of enhancing fertility and nutrition security without sacrificing sustainability.[80] Thousands of climate-resilient and locally adapted legume varieties exist, and farmers hold intergenerational knowledge of traditional food crops and how to leverage them into broader nutritional security for their communities.[81]

Field studies conducted in various agroecological zones of Ghana reveal that rotating pigeonpea with maize can boost maize yields by 75–200% compared to predominantly maize-based farming systems.[82] In Ethiopia, there is evidence that households which practice intercropping are less likely to be poor than households that specialize in one type of crop production.[83]

Furthermore, studies have revealed the economic benefits of intercropping practices in Africa. Intercropping maize with legumes has demonstrated that intercropping maize with legumes demonstrates a significant capacity for weed suppression and can lead to an average increase of 23% in maize yields. This improvement translates to a substantial gross income boost for farmers, averaging around US $172 per hectare.[84] However, increasing legume production among smallholder farmers at scale depends on a strong knowledge base for ecologically tailored management practices across diverse environments and farming systems.[85]

Intercropping underutilized legumes could help transform African smallholder agriculture. Legumes improve soil fertility and nutritional security while reducing reliance on potentially ecologically damaging and expensive chemical inputs with precarious supply chains.

Image description: Bush bean (Phaseolus vulgaris L), Kenya.
Photo courtesy of Dr. Chrysantus Mbi Tanga

80. See Abberton et al., 2022
81. Mbow, Cheikh & Rosenzweig, Cynthia & Tubiello, Francesco & Benton, Tim & Herrero, Mario & Pradhan, Prajal & Barioni, Luis & Krishnapillai, Murukesan & Liwenga, Emma & Rivera-Ferre, Marta & Sapkota, Tek & Xu, Yinlong. (2019). IPCC Special Report on Land and Climate Change. Chapter 5: Food Security.
82. S. Adjei-Nsiah, "Role of Pigeonpea Cultivation on Soil Fertility and Farming System Sustainability in Ghana", International Journal of Agronomy, vol. 2012, Article ID 702506, 8 pages, 2012. https://doi.org/10.1155/2012/702506
83. Michler, Jeffrey and Josephson, Anna, (2017), To Specialize or Diversify: Agricultural Diversity and Poverty Dynamics in Ethiopia, World Development, 89, issue C, p. 214-226, https://EconPapers.repec.org/RePEc:eee:wdevel:v:89:y:2017:i:c:p:214- 226.
84. Midega, Charles & Salifu, Daisy & Bruce, Toby & Pittchar, Jimmy & Pickett, John & Khan, Zeyaur. (2014). Cumulative effects and economic benefits of intercropping maize with food legumes on Striga hermonthica infestation. Field Crops Research. 155. 144–152. 10.1016/j.fcr.2013.09.012.
85. See Vanlauwe et al., 2019

Fostering Agroecological Legume Production: Economic and Strategic Context

The agricultural productivity, food security, and environmental sustainability benefits of agroecological legume production ought to be incentivized by smart policies and economic instruments. Subsidies that promote sustainable practices may pose economic and on-farm benefits such as soil health improvement and agricultural resilience.

At present, agricultural subsidies overwhelmingly favor cereal monocropping, causing unsustainable farm dependency on external inputs.[86] Governments or agriculture agencies may provide free or subsidized distribution of inputs, such as through vouchers for farmers to purchase inputs at a subsidized price from authorized suppliers. Additionally, financial institutions or governments may offer smallholder farmers access to low or zero-interest loans to buy agricultural inputs.[87]

The design of subsidy schemes is critical to effectively reach farmers, given that subsidies can be susceptible to inefficiencies, biases, and corruption within the contexts of low- and middle-income countries.[88] Unlike traditional subsidies favoring monoculture cereals and chemical inputs, investing in legume-based agroecology can improve soil health, agricultural resilience, and food security.

To redirect subsidy programming effectively, piloting, monitoring, and evaluating legume-based agroecological intensification plans is needed to assess impacts, opportunity costs, and the long-term effects on farmer livelihoods.[89] While in many cases pulses are used for home consumption in smallholder systems, for those aiming to take their crops to market, pulses often involve long and complex value chains for harvest and processing. Legumes undergo various post-harvest processing to preserve the quality, nutritional value, and marketability of the harvested pulses. Each additional stage of storage,post-harvest processing, trading, and transportation along the value chain results in an increased gap between producer and end-consumer prices, leaving smallholders from capturing much of the value of their products.[90] These economic insights highlight areas where subsidies should be leveraged to support legume production and post-harvest processes.

Challenges of Input-Reliant Agricultural Development: Examining Implications and Alternatives in African Context

Agricultural development programs can undermine smallholder livelihoods when yields and availabililty of inputs are prioritized above human and planetary health.[91] As Green Revolution policies prioritized cereal monocropping globally, the provision of agricultural inputs to farmers reduced crop diversification and legume consumption in Africa's semi-arid and arid tropics.[92] While fertilizer input subsidy programs (ISPs) have been shown to temporarily increase food output during periods where inputs flow cheaply and bountifully to smallholders, the reliance they create is not economically or environmentally sustainable.[93] Fertilizer supply chain disruptions driven by political and economic forces can further jeopardize yields of staple cereal crop varietals bred for heavy nitrogen supplementation. Even prior to the fertilizer shortages and supply chain disruptions stemming from the global COVID-19 pandemic and Russian invasion of Ukraine, ISPs across the continent demonstrated mixed results due to inconsistent farmer access to the inputs promoted by the subsidy, incorrect seed-input pairing and technical assistance, and uneven distribution of input resources both spatially and over time.[94]

86. Jayne, T. S., & Rashid, S. (2013). Input subsidy programs in sub-Saharan africa: A synthesis of recent evidence. Agricultural Economics, 44(6), 547–562. https://doi.org/10.1111/agec.12073
87. Hemming, D.J., Chirwa, E.W., Dorward, A., Ruffhead, H.J., Hill, R., Osborn, J., Langer, L., Harman, L., Asaoka, H., Coffey, C. and Phillips, D. (2018), Agricultural input subsidies for improving productivity, farm income, consumer welfare and wider growth in low- and lower-middle-income countries: a systematic review. Campbell Systematic Reviews, 14: 1-153. https://doi.org/10.4073/csr.2018.4
88. Hemming, David & Chirwa, Ephraim & Dorward, Andrew & Ruffhead, Holly & Hill, Rachel & Osborn, Janice & Langer, Laurenz & Harman, Luke & Asaoka, Hiro & Coffey, Chris & Phillips, Daniel. (2018). Agricultural input subsidies for improving productivity, farm income, consumer welfare and wider growth in low- and lower-middle-income countries: a systematic review. Campbell Systematic Reviews. 14. 1-153. 10.4073/csr.2018.4.
89. Baltzer, K., & Hansen, H. (2012). Agricultural input subsidies in Sub-Saharan Africa . Organisation for Economic Co-operation and Development. https://www.oecd.org/derec/49231998.pdf
90. Rawal, V. & Navarro, D. K., eds. 2019. The Global Economy of Pulses. Rome, FAO. https://www.fao.org/3/i7108en/I7108EN.pdf
91. Dawson, Neil & Martin, Adrian & Sikor, Thomas. (2016). Green Revolution in Sub-Saharan Africa: Implications of Imposed Innovation for the Wellbeing of Rural Smallholders. World Development. 78. 204-218. 10.1016/j.worlddev.2015.10.008.
92. Chibarabada TP, Modi AT, Mabhaudhi T. Expounding the Value of Grain Legumes in the Semi- and Arid Tropics. Sustainability. 2017; 9(1):60. https://doi.org/10.3390/su9010060
93. Jayne, Thomas & Mason, Nicole & Burke, William & Ariga, Joshua. (2018). Taking stock of Africa’s second-generation agricultural input subsidy programs. Food Policy. 75. 1-14. 10.1016/j.foodpol.2018.01.003
94. Holden, S. T. (2019, March 8). Economics of Farm Input Subsidies in Africa. Retrieved from https://www.annualreviews.org/doi/10.1146/annurev-resource-100518-094002

Challenges of Input-Reliant Agricultural Development: Examining Implications and Alternatives in African Context Cont.

Resource allocation to promote input-dependent agriculture can intensify challenges related to food insecurity and environmental sustainability.[95] While cereal crops dominate global production, cereal production in Africa is failing to meet smallholders' nutritional needs, likely due to the high cost and suboptimal application of agricultural inputs.[96] Grain crops requiring heavy nitrogen inputs have higher yields but at the cost of environmental health, climate resilience, nutritional outcomes, and biodiversity.[97] Currently, government subsidies support cereal monocropping over agroecological legumes in part because production of the latter is slower to reach high yields and demands more farmer training and labor for production and processing. This dynamic deters smallholder farmers from pursuing legume production.[98]

AGRA, a prominent international alliance founded in 2006 to propel agricultural transformation throughout Africa, has encountered the limitations of cereal monocropping in efforts to provide grants and technical expertise to farmers. Many AGRA programs focused on increasing staple grain crop production levels, rather than optimizing for self-sufficiency and yield stability under unpredictable conditions. These programs promoted the increased use of external inputs such as commercial seeds and fertilizers to boost short-term yields, potentially leaving farmers financially worse off and causing land degradation in the long-term.[99] Critics of these programs' concerns revolve around the shift of agricultural profits from farmers to corporations, as the yield-increasing methods are typically corporate proprietary products.[100] Furthermore, an independent report revealed a 30% rise in undernourished people within AGRA's focus countries from 2006 to 2020.[101] Generally, for African smallholders, there is little evidence supporting the idea that increased crop commercialization immediately improves nutritional status.[102]

One example of a cereal agricultural intervention with mixed results is AGRA-led Partnership for Inclusive Agricultural Transformation in Africa (PIATA) program, launched in 2017 with an aim to increase agricultural productivity, livelihoods, and value chains. PIATA favored cereal production which decreased crop diversity and failed to enhance farmer livelihoods substantially,[103] and showed limited success in maize yield growth across six countries.[104] PIATA achieved certain successes like policy reforms, partnerships, and extension programs, but it is notable that income and productivity gains were more pronounced among younger, wealthier, male farmers, than they were for women farmers.[105]

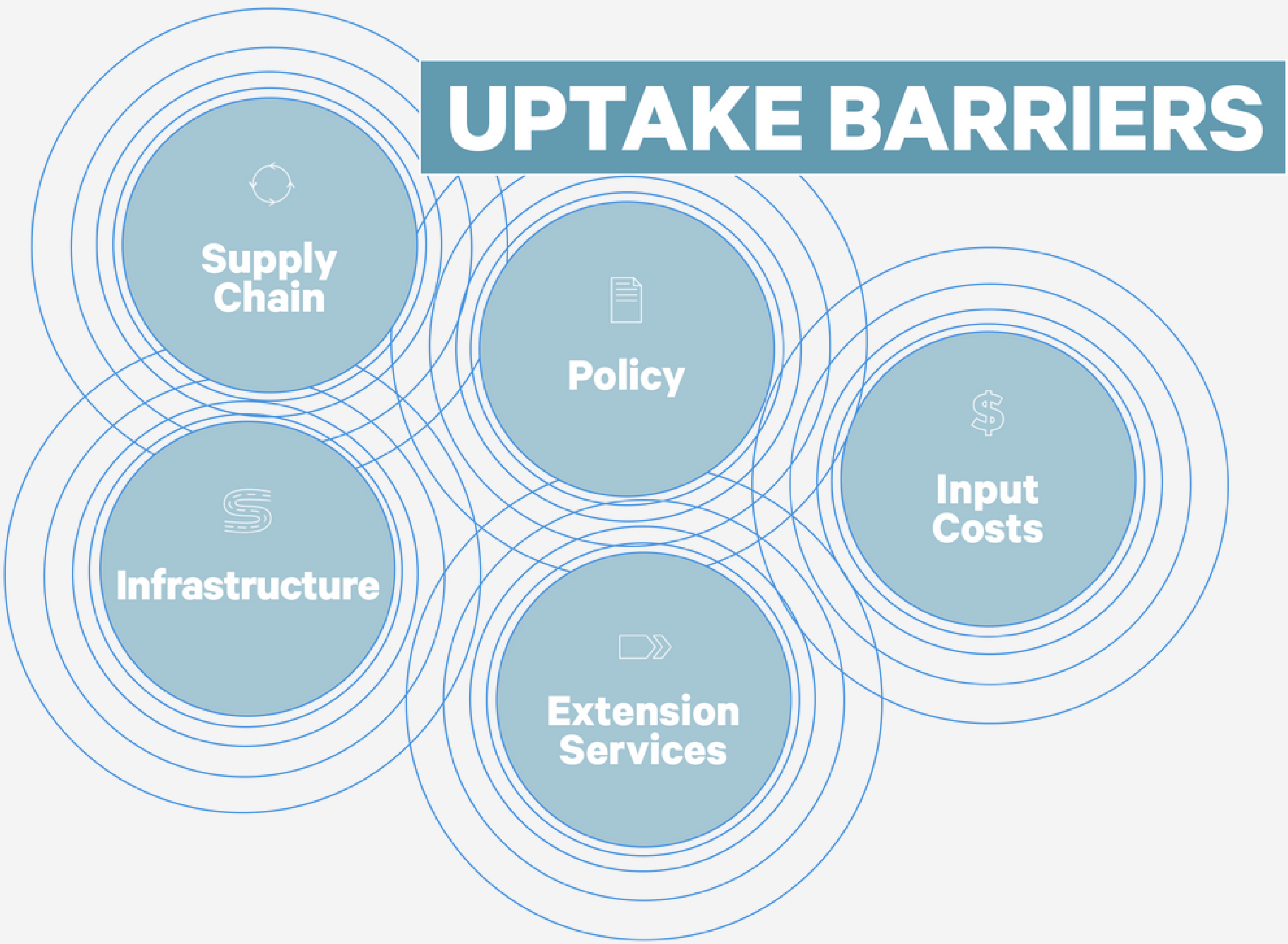
Importantly, advocates of AGRA highlight the potential to use its network and relationships to support transitions from those short-term-oriented farming strategies to agroecological ones that favor localized and affordable production for long-term sustainability for farmers and their ecological environment.[106] Currently, AGRA and other international partnerships and approaches are increasingly prioritizing legumes. In 2022, AGRA participated in the Beans is How global launch, an initiative seeking to double the worldwide consumption of beans and other legumes by 2028 as an affordable and accessible solution to address global health and climate challenges. AGRA also engaged in discussions regarding promoting and integrating climate-resilient African crops within broader food systems, emphasizing the need for research investment, value addition, and improved market linkages.[107]

95. AGRA. (2022, February 28). Piata Evaluation Report. Sustainably Growing Africa's Food Systems. Retrieved from https://agra.org/piata-evaluation/
96. Wise, T. (2020, July 28). Africa's choice: Africa's Green Revolution has failed, time to change course. IATP. Retrieved from https://www.iatp.org/africas-choice
97. Balmford A, Amano T, Bartlett H, Chadwick D, Collins A, Edwards D, Field R, Garnsworthy P, Green R, Smith P, Waters H, Whitmore A, Broom DM, Chara J, Finch T, Garnett E, Gathorne-Hardy A, Hernandez-Medrano J, Herrero M, Hua F, Latawiec A, Misselbrook T, Phalan B, Simmons BI, Takahashi T, Vause J, Zu Ermgassen E, Eisner R. The environmental costs and benefits of high-yield farming. Nat Sustain. 2018 Sep 14;1(9):477-485. PMID: 30450426; PMCID: PMC6237269
98. Ngigi PB, Mouquet-Rivier C, Amiot M-J, Termote C and Pallet D (2022) Increasing pulse agrobiodiversity to improve food security and sustainable agriculture in Sub-Saharan Africa. Front. Sustain. Food Syst. 6:948808. doi: 10.3389/fsufs.2022.948808
99. Wise, T. (2020, July). Failing Africa's Farmers: An Impact Assessment of the Alliance for a Green Revolution in Africa. Global Development and Environment Institute. https://sites.tufts.edu/gdae/files/2020/07/20-01_Wise_FailureToYield.pdf
100. Westengen, Ola & Haug, Ruth & Guthiga, Paul & Macharia, Eric. (2019). Governing Seeds in East Africa in the Face of Climate Change: Assessing Political and Social OutcomesData_Sheet_1.xlsx. Frontiers in Sustainable Food Systems. 3. 10.3389/fsufs.2019.00053.
101. Mkindi , A., Maina, A., Urhahn, J., Koch, J., Bassermann, L., Goïta, M., Nketani, M., Herre , R., Tanzmann , S., & Wise, T. (2020, July). False Promise: The Alliance for a Green Revolution in Africa. https://www.rosalux.de/fileadmin/rls_uploads/pdfs/Studien/False_Promises_AGRA_en.pdf
102. Carletto C, Corral P, Guelfi A. Agricultural commercialization and nutrition revisited: Empirical evidence from three African countries. Food Policy. 2017 Feb;67:106-118. doi: 10.1016/j.foodpol.2016.09.020. PMID: 28413250; PMCID: PMC5384450.
103. Blair, R., Kimbugwe, K., Koleros, A., Mangheni, M., Narayan, T., & Usmani, F. (2021, December 8). Partnership for Inclusive Agricultural Transformation in Africa, Final Evaluation. Mathematica. https://mathematica.org/api/sitecore/MediaLibrary/ActualDownload?fileId=%7B864e09d9-712c-4789-b2a5-bbf7f3f3fe9b%7D&fileName=PIATA%20Final%20Evaluation%20Report%20Volume%20I.pdf&fileData=PIATA%20Final%20Evaluation%20Report%20Volume%20I.pdf%20-%20%7B864e09d9-712c-4789-b2a5-bbf7f3f3fe9b%7D&fileMime=application%2Fpdf
104. Blair, R., Usmani, F., Koleros, D., & Narayan, T. (2022, March 25). Uncovering insights about agricultural transformation in Africa. Mathematica. https://www.mathematica.org/blogs/uncovering-insights-about-agricultural-transformation-in-africa
105. See Blair et al., 2021
106. Akanmu, Akinlolu & Akol, Anne & Ndolo, Dennis & Kutu, Funso & Babalola, Olubukola. (2023). Agroecological techniques: adoption of safe and sustainable agricultural practices among the smallholder farmers in Africa. Frontiers in Sustainable Food Systems. 7. 10.3389/fsufs.2023.1143061.
107. AGRA. (2022). Increase the consumption of healthy alternative protein. AGRA CONTENT HUB. https://agra.org/news/increase-the-consumption-of-healthy-alternative-protein/

Challenges and Dynamics of Fertilizer Manufacturing and Supply in Africa

Dependence on fertilizer supply chains has created deep systemic vulnerabilities due to uncertain policy environments, high fertilizer retail prices, and limited financial access.[108] Russia's war in Ukraine has exacerbated pre-existing constraints to fertilizer production, trade, and consumption in Africa.[109]

The onus is on policymakers and funders to consider transitions away from long, unstable, and costly agricultural input supply chains. Agroecology encompasses localized, easy-to-implement, and affordable approaches that can generate stable income and employment without creating farmer dependency on agribusiness inputs or reducing biodiversity, particularly by producing underutilized legumes.



108. United Nations Economic Commission for Africa. (2019, July). PROMOTION OF FERTILIZER PRODUCTION, CROSSBORDER TRADE, AND CONSUMPTION IN AFRICA. African Union. Retrieved from https://www.afdb.org/sites/default/files/2019/10/21/cross-border_study.pdf
109. Malpass, D. (2022, December 21). A transformed fertilizer market is needed in response to the food crisis in Africa. World Bank Blogs. Retrieved from https://blogs.worldbank.org/voices/transformed-fertilizer-market-neededresponse-food-crisis-africa

Ecological Considerations: The Need to Explore an Agroecological Legume-Focused Transition

Structural Barriers

Fertilizer manufacturing in Africa hinges precariously on global supply chains, where specific fertilizer nutrients are sourced internationally before processing at blending plants across the continent. Most African fertilizer manufacturing plants specialize in blending imported inputs of nitrogen, phosphorus, and potassium compounds required by local farmers.[110] In North Africa, Morocco plays an important role in fertilizer production and blending for the whole continent. Additionally, in April 2022, a $2.5B urea and ammonia fertilizer plant was opened in Lagos, Nigeria.[111] Despite this new plant, fertilizer production in sub-Saharan Africa as a whole significantly declined in 2022 as rising input prices challenge manufacturer's cost-effectiveness.[112] Furthermore, interruptions and delays in the supply chains of specific input compounds needed at fertilizer blending plants disrupt farming operations as farmers are deprived of specific nutrients for unknown periods. Moreover, global suppliers lack incentives to supply fertilizer to Africa due scalability challenges and low market prices.[113]

In addition to fertilizer access and uptake, precarious agricultural input supply chains threaten food security when farmers rely on them for bred cultivars and related inputs for their livelihoods. Infrastructural constraints, such as inadequate roads, railways, and port facilities, as well as transportation costs, limit the quantity of fertilizer that farmers, especially smallholders and those with fewer resources, are able to access. The onset of Russia's war in Ukraine exemplified the precarity of relying on long fertilizer supply chains as high input costs curbed outputs at fertilizer blending plants in sub-Saharan Africa in 2022.[114]

Regulatory and Financial Barriers

Other challenges in demand the African fertilizer industry faces include limited market information, technical barriers, and poor regulatory frameworks.[115] For example, farmers' access to fertilizer varies based on how national governments or other actors purchase and subsidize inputs for local implementation.

Farmers face challenges in effectively utilizing fertilizers, mainly stemming from inadequate access to proper extension services and training resources, as well as difficulties in securing funds for timely procurement during different seasons. Moreover, the absence of a futures market for fertilizers results in suppliers imposing significant premiums to mitigate the inherent risk that smallholder farmers may not have adequate capital to access loans and purchase necessary inputs.

The ineffective procurement and distribution of fertilizers can be traced back to misaligned timing, where governments and larger-scale farmers tend to acquire fertilizers during periods of peak demand in the northern hemisphere. This exacerbates the challenges faced by farmers and further underscores the need for strategic planning and support in the agricultural supply chain.

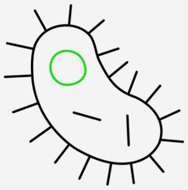
Finally, credit is often difficult for low-income farmers to acquire to accelerate fertilizer flow among African countries, meaning rising input costs exacerbate existing accessibility barriers. Low-income farmers may not have access to credit for purchasing adequate fertilizers, pesticides, resilient seeds, and other farming inputs.[116]

110. Hebebrand, C., & Laborde, D. (2022, April 25). High fertilizer prices contribute to rising global food security concerns. IFPRI Blog. https://www.ifpri.org/blog/high-fertilizer-prices-contribute-rising-global-food-security-concerns 111.Hebebrand, Charlotte; and Laborde Debucquet, David. 2023. High fertilizer prices contribute to rising global food security concerns. In The Russia-Ukraine Conflict and Global Food Security, eds. Joseph Glauber and David Laborde Debucquet. Section One: A Conflict with Global Consequences, Chapter 7, Pp. 38-42. https://doi.org/10.2499/9780896294394_07
112. Gitau, M. (2022, January 29). African food crisis and fertilizer price rises. Bloomberg Markets. Retrieved from https://www.bloomberg.com/news/articles/2022-01-29/surging-fertilizer-prices-set-to-exacerbate-african-food-crisis? leadSource=uverify+wall
113. See Hebebrand and Laborde, 2022
114. Malpass, D. (2022, December 21). A transformed fertilizer market is needed in response to the food crisis in Africa. World Bank Blogs. https://blogs.worldbank.org/voices/transformed-fertilizer-market-needed-response-food-crisis-africa
115. See United Nations Economic Commission for Africa. (2019)
116. Whitehouse, D. (2022, June 14). Stop blaming Russia-ukraine war for Africa's fertiliser woes. Supply Chain Revolution. Retrieved from https://www.theafricareport.com/212484/stop-blaming-russia-ukraine-war-for-africas-fertiliser-woes/

Four Point Strategy to Advance Legume-Centered Agroecology

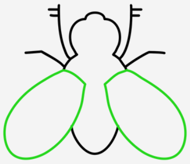
This section presents a four-point strategy of cost-effective and agroecology-centered sustainable management practices to guide policymakers. Shifting toward agroecological transitions accomplishes numerous sustainability objectives, encompassing economic, environmental, social, nutritional, health, and cultural aspects of food production to nourish people and planet. These solutions should be tailored to diverse environmental and cultural contexts.[117]

1. Redirect Subsidies to Support Legume Intercropping



2. Research Underutilized Legumes and Soil Bacteria

3. Harmonize Formal and Informal Seed Sectors



4. Integrate Frass and Legume Production

117. Food and Agriculture Organization of the United Nations. (2023). What is Agroecology?. Agroecology Knowledge Hub . https://www.fao.org/agroecology/overview/en/

1. Redirect Subsidies to Support Legume Intercropping

Current agricultural input subsidy programs may be minimally effective or even reduce African smallholders' use of sustainable agriculture practices.[118] A study on fertilizer subsidy effects on cowpea production and crop diversity in Malian villages found that input subsidies are strongly and negatively associated with the cultivation of legumes as a primary or a secondary crop.[119] Extended cultivation reliant upon inorganic fertilizers can make soils unsuitable for cultivation without continued fertilizer inputs due to changes in soil structure, chemistry, and microbial composition.[120] Particularly in times where supply chain disruptions do not constrain access, subsidies supporting excessive fertilizer application can thus impede farmers' ability to reintroduce legumes as a natural source of soil fertility.

Context

Importantly, subsidies could instead stimulate the re-adoption of Indigenous technologies among recipients and their social networks.[121] Such novel subsidy programs can encourage climate-smart agricultural practices through extension services to support smallholders' effective legume use for sustainable agricultural management. In implementing this recommendation, policymakers should be wary of supplanting pre-existing traditional legumes, prioritizing existing localized management practices and Indigenous technologies in supporting the resurgence of underutilized crop production.[122]

Based on concerns over the past efficacy of fertilizer inputs at improving farmer well-being as well as looming fertilizer shortages, novel subsidy programs should prioritize effective legume crop diversification practices. They should aim to broaden farmers' understanding of the impact of plant-sourced nitrogen on crop performance, subsidize legume seed access for farmers, while respecting local cultural preferences.

Solution

Relationship building and collaborative exchanges between smallholder farmers and the public, private, and philanthropic sectors are necessary to advocate for funding and develop extension programming to support agroecological transitions. Educational initiatives and technical assistance for farmers to better leverage the nitrogen fixation capacity of legumes can improve soil health and offer other direct benefits through human consumption and animal fodder.[123]

A major challenge smallholder producers face is a lack of regular technical assistance and support when adopting new practices.[124] Legume-based agroecological transitions can take 5-6 years to complete, but can be achieved through training programming, peer support, agricultural extension to participants, and long-term knowledge-sharing programs.[125] In redirecting subsidies to support legume production, it is crucial to consider both the gender impacts as well as the energy use associated with legume cultivation, processing, and preparation.

118. Jayne, T.S., Sitko, N.J., Mason, N.M., Skole, D. (2018). Input Subsidy Programs and Climate Smart Agriculture: Current Realities and Future Potential. In: Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S., Branca, G. (eds) Climate Smart Agriculture . Natural Resource Management and Policy, vol 52. Springer, Cham. https://doi.org/10.1007/978-3-319-61194-5_12
119. Assima, A., Smale, M., & Kone, B. (2021, August 11). Fertilizer subsidy effects on cowpea areas and spatial crop diversity in Malian villages. Feed the Future Innovation Lab for Legume Systems Research. Retrieved from https://www.canr.msu.edu/news/fertilizer-subsidy-effects-on-cowpea-areas-and-spatial-crop-diversity-in-malian-villages
120. Sharma, N., & Singhvi, R. (2017). Effects of chemical fertilizers and pesticides on human health and environment: a review. International journal of agriculture, environment and biotechnology, 10(6), 675-680.
121. Carter, Michael, Rachid Laajaj, and Dean Yang. 2021. "Subsidies and the African Green Revolution: Direct Effects and Social Network Spillovers of Randomized Input Subsidies in Mozambique." American Economic Journal: Applied Economics, 13 (2): 206-29.
122. Freyer, B., Bingen, J. (2021). Resetting the African Smallholder Farming System: Potentials to Cope with Climate Change. In: Oguge, N., Ayal, D., Adeleke, L., da Silva, I. (eds) African Handbook of Climate Change Adaptation. Springer, Cham. https://doi.org/10.1007/978-3-030-45106-6_267
123. Baudron, F., Corbeels, M., Monicat, F. et al. Cotton expansion and biodiversity loss in African savannahs, opportunities and challenges for conservation agriculture: a review paper based on two case studies. Biodivers Conserv 18, 2625–2644 (2009). https://doi.org/10.1007/s10531-009-9663-x
124. Fan, S., Rue, C. (2020). The Role of Smallholder Farms in a Changing World. In: Gomez y Paloma, S., Riesgo, L., Louhichi, K. (eds) The Role of Smallholder Farms in Food and Nutrition Security. Springer, Cham. https://doi.org/10.1007/978-3-030-42148-9_2
125. See Global Alliance for the Future of Food (2021).

2. Research Underutilized Legumes and Soil Bacteria

Different legume species require specific rhizobia species to form nodules and fix nitrogen. Rhizobia also vary widely across African contexts and despite recent increases in research on these species, there are still large gaps in the scientific knowledge of legume-rhizobia interactions.[126] Developments in our understanding of microbial interactions with underutilized legumes require measuring these relationships in the contexts of natural settings[127] and expanding knowledge of the nitrogen fixation mechanism.[128]

Context

Local environment-specific research on the interactions between underutilized legumes and naturally occurring rhizobia is needed. The distribution and ecology of indigenous African rhizobia is not well understood and[129] with more information on interactions between underutilized legumes and microbes, smallholders may be able to increase crop yield with minimal intervention.[130]

For example, while novel research has assessed rhizobial biodiversity and nodule functioning among cowpeas to some degree, further studies should assess symbiotic functioning and Bradyrhizobium biodiversity among diverse underutilized legume species.[131] Most legumes are capable of fixing ample nitrogen through naturally occurring rhizobial populations, including cowpeas (Vigna unguiculata), lentils (Lens culinaris), chickpeas (Cicer arietinum).[132] However, inoculation with prepared rhizobia can be beneficial where there may be limitations in natural local rhizobia populations. Legume-bacteria interactions are complex, and legume inoculation requirements vary by species, abiotic soil conditions, and compatible rhizobia strains present in the soil. Inoculation with specific rhizobia strains can augment effective nodulation and nitrogen fixation.[133]

Solution

Future research should investigate local legume varieties and rhizobia interactions. Identifying locally adapted rhizobia strains may inform future management practices to build natural nitrogen-fixing capabilities in underutilized legumes.[134] Public, private, and NGO sector organizations should coordinate to support country-specific national programs that support rhizobium collection and evaluation. Ethnobotanical surveys[135] may be conducted to assess the traditional planting, processing, and cooking methods and technologies to reduce anti-nutrient factors.[136]

Additionally, public sector research via national university agricultural program grant funding could encourage capacity development for regulators and extension agents for rural development programming on enhancing legume production in local contexts. Locally conducted research should focus on ecological and cultural diversity to move beyond a one-size-fits-all approach to agroecological legume production.

126. Grönemeyer JL, Reinhold-Hurek B. Diversity of Bradyrhizobia in Subsahara Africa: A Rich Resource. Front Microbiol. 2018 Sep 20;9:2194. doi: 10.3389/fmicb.2018.02194. PMID: 30294308; PMCID: PMC6158577
127. Ishaq SL. Plant-microbial interactions in agriculture and the use of farming systems to improve diversity and productivity. AIMS Microbiol. 2017 May 11;3(2):335-353. doi: 10.3934/microbiol.2017.2.335. PMID: 31294165; PMCID: PMC6605018
128. Nag P, Shriti S, Das S. Microbiological strategies for enhancing biological nitrogen fixation in nonlegumes. J Appl Microbiol. 2020 Aug129. (2):186-198. doi: 10.1111/jam.14557. Epub 2020 Jan 1. PMID: 31858682.
129. See Grönemeyer and Reinhold-Hurek B 2018.
130. Pule-Meulenberg, F. (2014). Root-Nodule Bacteria of Legumes Growing in Semi-Arid African Soils and Other Areas of the World. In: Maheshwari, D. (eds) Bacterial Diversity in Sustainable Agriculture. Sustainable Development and Biodiversity, vol 1. Springer, Cham.
131. Pule-Meulenberg, F., Belane, A.K., Krasova-Wade, T. et al. Symbiotic functioning and bradyrhizobial biodiversity of cowpea (Vigna unguiculataL. Walp.) in Africa. BMC Microbiol 10, 89 (2010). https://doi.org/10.1186/1471-2180-10-89
132. Zahran HH. Rhizobium-legume symbiosis and nitrogen fixation under severe conditions and in an arid climate. Microbiol Mol Biol Rev. 1999 Dec;63(4):968-89, table of contents. doi: 10.1128/MMBR.63.4.968-989.1999. PMID: 10585971; PMCID: PMC98982.
133. Chibeba AM, Kyei-Boahen S, Guimarães MF, Nogueira MA, Hungria M. Feasibility of transference of inoculation-related technologies: A case study of evaluation of soybean rhizobial strains under the agro-climatic conditions of Brazil and Mozambique. Agric Ecosyst Environ. 2018 Jul 1;261:230-240. doi: 10.1016/j.agee.2017.06.037. PMID: 29970951; PMCID: PMC5946691.
134. See Abberton et al. 2022
135. Cullis C, Chimwamurombe P, Barker N, Kunert K, Vorster J. Orphan Legumes Growing in Dry Environments: Marama Bean as a Case Study. Front Plant Sci. 2018 Aug 15;9:1199. doi: 10.3389/fpls.2018.01199. PMID: 30158948; PMCID: PMC6104163
136. Nnamani CV, Ajayi SA, Oselebe HO, Atkinson CJ, Igboabuchi AN, Ezigbo EC. Sphenostylis stenocarpa (ex. A. Rich.) Harms., a Fading Genetic Resource in a Changing Climate: Prerequisite for Conservation and Sustainability. Plants (Basel). 2017 Jul 12;6(3):30. doi: 10.3390/plants6030030. PMID: 28704944; PMCID: PMC5620586

3. Harmonize Formal and Informal Seed Sectors

Many African governments regulate a formal commercial seed market to facilitate farmer access to improved cereal seeds. Constraints of farmer access to commercial seeds include the limited variety of seeds available in commercial markets, the urban locations of distributors, and a high sum of initial capital needed to purchase a sufficient amount of seed.[137] The select farmers who benefit from a formal seed market own larger farms and had more capital to maintain their reliance on inputs. Still, fertilizer disruptions affect all farmers, though disproportionately more so for smallholders during supply chain interruptions.

In response to the obstacles of accessing breeders' varieties, many smallholders cultivate underutilized legumes for their farming practices. It is estimated that 80-90% of all African seeds planted are sourced through unregulated informal systems which support a diversity of environmentally adapted seeds and reach remote areas through social networks.[138] Additionally, due to the rural nature of smallholders, they can be difficult to reach with extension programming.

Context

While farmers rely on formal and informal systems for different crops, many legumes tend to be farm-saved or informally distributed in local markets.[139] Additionally, bred legume cultivars vary in their ability to meet households' cultural and nutritional needs due to the costly nature of purchasing seed and associated inputs, particularly when compared to cost-effective and locally adapted cultivars.[140]

Harmonizing and integrating seed systems entails leveraging regulated commercial seed markets and unregulated informal systems to enhance agricultural practices while maintaining cultural continuity, improving access to underutilized and resilient seeds, and encouraging collaboration between farmers and research sectors for sustainable and inclusive agriculture.[141]

Seed system integration complements cultural continuity and Indigenous knowledge preservation to harmonize formal and informal systems, catering to local farming contexts.[142]

Solution

Rather than restructuring seed networks, development programs, and commercial seed distributors should adopt a pluralistic approach to build on existing informal sector capacities of smallholder farmers and distributor knowledge and trade networks.[143] Local informal market seed distributors can reach rural smallholder farmers and foster relationships with external stakeholders for extension services and research. With the support and consent of local communities to research underutilized crop seeds, these partnerships would entail new supply chains via local informal seed distributors who can access rural farmers for intervention efforts and to access underutilized crops for research.[144] Seed sector unification and stakeholder partnerships would build on existing informal seed supply chains to access rural farmers and provide research and development opportunities for legume seed and rhizobia research.[145]

The intended effect of this recommendation is not to replace indigenous systems and informal supply chains but rather to revitalize systems threatened by erasure. While novel approaches to harmonize seed sectors and re-introduce underutilized crops are important, well-intentioned projects should refrain from supplanting local knowledge and indigenous crops. By building on existing seed networks, ethical development will pave the way for farmers to pursue affordable and effective management solutions.[146] Care should be taken not to make farmers dependent on an additional supply chain but to encourage community-scale self-sufficiency.

137. Louwaars, Niels & de Boef, Walter & Edeme, Janet. (2013). Integrated Seed Sector Development in Africa: A Basis for Seed Policy and Law. Journal of Crop Improvement. 27. 186–214. 10.1080/15427528.2012.751472
138. Coomes, O. T., McGuire, S. J., Garine, E., Caillon, S., McKey, D., Demeulenaere, E., Jarvis, D., Aistara, G., Barnaud, A., Clouvel, P., Emperaire, L., Louafi, S., Martin, P., Massol, F., Pautasso, M., Violon, C., & Wencélius, J. (2015). Farmer Seed Networks make a limited contribution to agriculture? Four common misconceptions. Food Policy, 56, 41-50. https://doi.org/10.1016/j.foodpol.2015.07.002
139. Louise Sperling, Patrick Gallagher, Shawn McGuire & Julie March (2021) Tailoring legume seed markets for smallholder farmers in Africa, International Journal of Agricultural Sustainability, 19:1, 71-90, DOI: 10.1080/14735903.2020.1822640
140. Samal I, Bhoi TK, Raj MN, Majhi PK, Murmu S, Pradhan AK, Kumar D, Paschapur AU, Joshi DC, Guru PN. Underutilized legumes: nutrient status and advanced breeding approaches for qualitative and quantitative enhancement. Front Nutr. 2023 May 18;10:1110750. doi: 10.3389/fnut.2023.1110750. PMID: 37275642; PMCID: PMC10232757.
141. Westengen OT, Dalle SP, Mulesa TH. Navigating toward resilient and inclusive seed systems. Proc Natl Acad Sci U S A. 2023 Apr 4;120(14):e2218777120. doi: 10.1073/pnas.2218777120. Epub 2023 Mar 27. PMID: 36972436; PMCID: PMC10083617.
142. Louwaars, Niels & de Boef, Walter & Edeme, Janet. (2013). Integrated Seed Sector Development in Africa: A Basis for Seed Policy and Law. Journal of Crop Improvement. 27. 186–214. 10.1080/15427528.2012.751472
143. Branca, Giacomo & Cacchiarelli, Luca & Haug, Ruth & Sorrentino, Alessandro. (2022). Promoting sustainable change of smallholders' agriculture in Africa: Policy and institutional implications from a socio-economic cross-country comparative analysis. Journal of Cleaner Production. 358. 10.1016/j.jclepro.2022.131949.
144. See Alliance for Food Sovereignty in Africa, 2022
145. McGuire, S., Sperling, L. Seed systems smallholder farmers use. Food Sec. 8, 179–195 (2016). https://doi.org/10.1007/s12571-015-0528-8
146. Basdew, Myuri & Jiri, Obert & Mafongoya, Paramu. (2017). Integration of Indigenous and scientific knowledge in climate adaptation in KwaZulu- Natal, South Africa. Change and Adaptation in Socio-Ecological Systems. 3. 10.1515/cass-2017-0006

4. Integrate Frass and Legume Production

Supplemental fertilization with insect frass can maximize soil health benefits and legume production by complementing legumes' inherent nitrogen fixation capacity. Frass is an innovative agroecological solution to drive the recycling of nutrients and biomass by reintroducing byproducts and waste generated from insect rearing and processing (including spent feedstock, insect feces, and cuticles) into a fertilizer as an affordable and sustainable solution to meet soil nutrient needs and shorten long synthetic input supply chains.[147] In regions with limited access to conventional fertilizers, frass offers a sustainable and locally available alternative. Frass also contains nitrogen-fixing and nitrifying bacteria that differ from the microbes in legume-rhizobia symbiosis.[148]

Context

Frass can be a beneficial addition to legume-intensive agroecological approaches[149] as an alternative or complement to conventional chemical fertilizers.[150] In addition to providing easily accessible nitrogen, frass can promote crop growth[151] by adding microorganisms to the soil and can reduce crop vulnerability to abiotic stress and pests.[152] Notably, the microbes and high phosphorus levels present in frass enhance soil nitrogen availability for plants and complement nitrogen-fixing legumes, further reducing the need for input fertilizers while simultaneously regenerating soils.[153]

Frass application also benefits legume crops due to its efficacy in suppressing soil-borne pathogens, reducing soil acidity and salinity, and increasing the availability of nutrients in the soil.[154] For example, mealworm frass application on legumes increased abiotic stress tolerance and promoted plant growth.[155]

There is no consensus on a singular most effective frass; however, the black soldier fly (Hermetia illucens) is a well-studied species containing high levels of nutrients, including nitrogen, phosphorus, and potassium, essential for plant growth.[156] The following recommendation focuses on the black soldier fly (BSF) frass, which can increase soil macronutrient contents more than manure.[157]

Solution

Integrating frass fertilizer into legume-intensive agroecology requires evaluating its compatibility with local agricultural practices, assessing application challenges, and understanding the perceptions and attitudes of the local smallholders toward novel frass fertilization methods. Frass fertilizer efficacy varies depending on the insect species and diet.

BSF frass has demonstrated the fast-acting efficacy similar to ammonium nitrate when implemented in research plots.[158] Furthermore, its production is simple, requires little space, and is cost-effective. Additionally, BSF is commonly produced for animal feed, with leftovers going to waste. Those leftovers could be leveraged to develop quality fertilizer and animal feed, maximizing on-farm efficiency.

Additionally, BSF frass effectively induced disease resistance in cowpeas to protect against yield loss. Chitin is a product of exoskeletons of insect larvae present in insect frass biofertilizers which contains fragments that can trigger disease resistance in crop plants when used as a soil amendment, potentially enhancing cowpea's ability to resist diseases.[159] Utilizing frass as an organic fertilizer presents great potential as an alternative to agrochemicals while supporting legume resilience for enhanced nutrient security.[160] Further funding and research on BSF production is needed to better understand the effects variation in nutrient contents in BSF-legume systems.[161]

147. Food and Agriculture Organization of the United Nations. (n.d.). Circular and solidarity economy. Agroecology Knowledge Hub . https://www.fao.org/agroecology/knowledge/10-elements/circular-economy/en/?page=3&ipp=5&tx_dynalist_pi1%5Bpar%5D=YToxOntzOjE6Ikwi03M6MToiMCI7fQ%3D%3D
148. Gold, M., Von Allmen, F., Zurbrügg, C., Zhang, J., & Mathys, A. (2020). Identification of bacteria in two food waste black soldier fly larvae rearing residues. Frontiers in Microbiology, 11, 582867.
149. See Leni et al., 2021
150. Quilliam, R. S., Nuku-Adeku, C., Maquart, P., Little, D., Newton, R., & Murray, F. (2020). Integrating insect frass biofertilisers into sustainable peri-urban agro-food systems. Journal of Insects as Food and Feed, 6(3), 315–322. https://doi.org/10.3920/jiff2019.0049
151. Beesigamukama, D., Subramanian, S. & Tanga, C.M. Nutrient quality and maturity status of frass fertilizer from nine edible insects. Sci Rep 12, 7182 (2022). https://doi.org/10.1038/s41598-022-11336-z
152. Watson, Conor & Houben, David & Wichern, Florian. (2022). Editorial: Frass: The Legacy of Larvae -Benefits and Risks of Residues From Insect Production. Frontiers in Sustainable Food Systems. 6. 889004. 10.3389/fsufs.2022.889004.
153. Basri, N. E. A., Azman, N. A., Ahmad, I. K., Suja, F., Jalil, N. A. A., & Amrul, N. F. (2022). Potential Applications of Frass Derived from Black Soldier Fly Larvae Treatment of Food Waste: A Review. Foods, 11(17), 2664. MDPI AG. Retrieved from http://dx.doi.org/10.3390/foods11172664
154. Basri, N. E. A., Azman, N. A., Ahmad, I. K., Suja, F., Jalil, N. A. A., & Amrul, N. F. (2022). Potential Applications of Frass Derived from Black Soldier Fly Larvae Treatment of Food Waste: A Review. Foods, 11(17), 2664. MDPI AG. Retrieved from http://dx.doi.org/10.3390/foods11172664
155. Poveda, Jorge. (2021). Insect frass in the development of sustainable agriculture. A review. Agronomy for Sustainable Development. 41. 10.1007/s13593-020-00656-x.
156. Beesigamukama D, Mochoge B, Korir NK, Fiaboe KKM, Nakimbugwe D, Khamis FM, Subramanian S, Dubois T, Musyoka MW, Ekesi S, Kelemu S, Tanga CM. Exploring Black Soldier Fly Frass as Novel Fertilizer for Improved Growth, Yield, and Nitrogen Use Efficiency of Maize Under Field Conditions. Front Plant Sci. 2020 Sep 23;11:574592. doi: 10.3389/fpls.2020.574592. PMID: 33072150; PMCID: PMC7539147
157. Gärttling, D., Schulz, H. Compilation of Black Soldier Fly Frass Analyses. J Soil Sci Plant Nutr 22, 937–943 (2022). https://doi.org/10.1007/s42729-021-00703-w
158 . Klammsteiner, T.; Turan, V.; Fernández-Delgado Juárez, M.; Oberegger, S.; Insam, H. Suitability of Black Soldier Fly Frass as Soil Amendment and Implication for Organic Waste Hygienization. Agronomy 2020, 10, 1578
159. Quilliam, R. S., Nuku-Adeku, C., Maquart, P., Little, D., Newton, R., & Murray, F. (2020a). Integrating insect frass biofertilisers into sustainable peri-urban agro-food systems. Journal of Insects as Food and Feed, 6(3), 315–322. https://doi.org/10.3920/jiff2019.0049
160. Poveda, Jorge & Jiménez Gómez, Alejandro & Saati Santamaría, Zaki & Usategui-Martin, Ricardo & Rivas, Raúl & Garcia-Fraile, Paula. (2019). Mealworm frass as a potential biofertilizer and abiotic stress tolerance-inductor in plants. Applied Soil Ecology. 142 10.1016/j.apsoil.2019.04.016
161. V.; Fernández-Delgado Juárez, M.; Oberegger, S.; Insam, H. Suitability of Black Soldier Fly Frass as Soil Amendment and Implication for Organic Waste Hygienization. Agronomy 2020, 10, 1578. 108. S

Barriers and Constraints to Strategy Implementation

While the proposed four tier strategy is tailored to meet local conditions and agricultural needs for sustainable food systems, it is not without its limitations. There is little data on the various timelines and farmer support needed to transition to agroecological management practices.[162]

The authors acknowledge the multifaceted challenges inherent in real-world contexts that could pose unanticipated obstacles. Strategies must be rooted in the local milieu, with implementation embraced by local populations, based on their assessment of value and utility.

Ensuring that any transition does not cause major disruption to livelihoods will be crucial. Moreover, research and extension capabilities, labor input needs, and anti-nutritional factors of legumes are all limitations that require consideration when developing cost-effective and agroecology-centered sustainable management practices.

1. Limited Data and Information

Limited data necessitates context-specific frameworks for smallholder agriculture transitions.

2. R&D Infrastructure

Challenges to implement extension services and locally based research and development.

3. Labor Inputs

Soils may be non-responsive and the labor inputs of legume production can be quite high.

4. Legume Antinutritional Factors

Specific processing and cooking are needed for legume health benefits due to the existence of anti-nutrients that affect absorption.

162. See Global Alliance for the Future of Food, The Politics of Knowledge, 2021

Barriers and Constraints to Strategy Implementation

Transition Challenges & Dynamics

Data on smallholder agriculture transition timelines are minimal.[163] Moreover, context-specific frameworks for agroecological transitions must be tailored to local knowledge, practices, and ecological conditions. Charting paths away from highly input-reliant agriculture will require careful balance for smallholders and promote legume-forward agroecological approaches for a food-secure future. An anticipated increase in demand for legumes due to their soil-building qualities and nutrient density may present challenges if sustainable production transitions do not have adequate oversight. Legume-forward crop diversification will support biodiversity and soil health without extensively reducing cereal production. [164] Across research and policy, there is an informed consensus of increased legume production as a strategy to help mitigate current health and environmental-related global crises.[165] Commercializing local crops sometimes creates unintended consequences, including surges in demand and prices, which render traditional food unaffordable in local contexts.[166]

The market supply of legumes tends to rise in response to increased production.[167] If legume demand fails to increase proportionately, the increased supply can result in a surplus, leading to downward pressure on prices, particularly in local markets where legumes are predominantly sold. Lower prices for legumes may affect the income and livelihoods of smallholder farmers who rely on legume cultivation as a source of income. It can also impact the economic viability of legume farming, potentially discouraging farmers from continuing or expanding legume production. Trade policies, market infrastructure, and value-added processing also have the potential to mitigate adverse farmer livelihood effects of increased legume production.

Balancing Innovation, Sustainability, and Local Needs in Agricultural Management

Challenges to researching agricultural management practices include extension compatibility with local farm systems, access to underutilized crop varieties[168], and unsustainable dependence on foreign private sectors for research and extension funding.[169] Moreover, there is great potential for legume seed research and development. If done in appropriate contexts and sensitive to the needs and desires of local farmers, genome editing poses a unique opportunity to enhance grain legume varieties and re-domesticate lost species to deepen our understanding of crop resilience.

There is tension in introducing bred legume varieties in contrast to supporting the intensification or re-introduction of underutilized crops. Agronomic studies have found that disease resistance-related genes can be lost during the legume domestication processes, implying that resistance-conferring alleles may be lost in domesticated populations.[170] Introgression breeding (genetic modification of one species by another through hybridization) successfully transfers beneficial alleles from wild to domesticated accessions in legumes. Molecular mapping tools can enable the further transfer of advantageous genes.

163. Africa Regenerative Agriculture Study Group. (n.d.). Regenerative Agriculture: An opportunity for businesses and society to restore degraded land in Africa. FoodFlow. https://foodflow.enviu.org/1378-2/
164. Douyon, A., Worou, O. N., Diama, A., Badolo, F., Denou, R. K., Touré, S., Sidibé, A., Nebie, B., & Tabo, R. (2022). Impact of crop diversification on household food and nutrition security in southern and central Mali. Frontiers in Sustainable Food Systems, 5. https://doi.org/10.3389/fsufs.2021.751349
165. Squire, G. R., Quesada, N., Begg, G. S., & Iannetta, P. P. (2019). Transitions to greater legume inclusion in cropland: Defining opportunities and estimating benefits for the nitrogen economy. Food and Energy Security, 8(4). https://doi.org/10.1002/fes3.175
166. Squire et al., 2019
167. Smith, B. M., Gathorne-Hardy, A., Chatterjee, S., & Basu, P. (2018). The last mile: Using local knowledge to identify barriers to sustainable grain legume production. Frontiers in Ecology and Evolution, 6. https://doi.org/10.3389/fevo.2018.00102
168. Falck-Zepeda, J. B., Gruère, G., & Sithole-Niang, I. (2013). Genetically modified crops in Africa: Economic and policy lessons from countries south of the Sahara. International Food Policy Research Institute., 183–207. https://doi.org/10.2499/9780896297951
169. Bala, Abdullahi & Karanja, Nancy & Chiduwa, Mazvita & Lwimbi, L. & Abaidoo, Robert & Giller, Ken. (2011). Production and use of Rhizobial inoculants in Africa.
170. Zhang H, Mascher M, Abbo S, Jayakodi M. Advancing Grain Legumes Domestication and Evolution Studies with Genomics. Plant Cell Physiol. 2022 Nov 22;63(11):1540-1553. doi: 10.1093/pcp/pcac062. PMID: 35534441; PMCID: PMC9680859.

Barriers and Constraints to Strategy Implementation Cont.

Labor Inputs and Gender Dynamics

In specific ecological contexts, the yield improvement from agroecological practices on nutrient stocks and soil organic matter content can be small compared to the labor input requirements. Legume harvesting and transport, as well as green manure cover cropping practices, are labor-intensive practices where mechanization is only sometimes possible.[171] Additionally, sometimes soils are non-responsive, meaning that physical, chemical, or biological properties in soil limit the nitrogen fixation ability of legume plants.[172]

Across African agricultural contexts, women play significant roles in planting, harvesting, processing, and cooking. Thus, it is crucial to consider how new strategies leveraged to promote underutilized legume production and utilization hold implications for the gender division of labor borne by women so as not to exacerbate existing gender inequalities.[173] Additionally, legume cultivation, processing, and preparation require non-human energy inputs, such as fuel for agricultural machinery or cooking. Understanding the energy use associated with these activities is vital for assessing legume production systems' overall sustainability or reliance on external inputs.

Research on gender gaps regarding legume production in Malawi demonstrates that policy orientation to support female smallholders in producing different crops will require culturally sensitive and relevant subsidies and extension services.[174] Furthermore, cultivating specific legumes is often viewed as gendered activity, potentially limiting smallholder interest or support for expanding the cultivation of particular underutilized legume crops based on cultural contexts.[175]

Antinutritional Factors in Legumes

Antinutrients are compounds that interfere with nutrient absorption and protein digestibility.[176] Examples of antinutrients in legumes include phytic acid, tannins, and lectins.[177] Eliminating antinutrients can be challenging across many smallholder contexts as traditional cooking and processing methods to remove antinutrients, such as soaking, fermenting, and cooking, can be labor-intensive and time-consuming.[178] For example, grasspea, an underutilized legume, can spur the development of a neurological disease known as lathyrism in humans and animals. Lathyrism is characterized by spastic weakness of the legs and is still prevalent in some regions of Asia and Africa.[179] Certain antinutritional factors of legumes have been well-understood for thousands of years, as demonstrated through culturally relevant cooking and processing practices.

171. Pretty J, Bharucha ZP. Sustainable intensification in agricultural systems. Ann Bot. 2014 Dec;114(8):1571-96. doi: 10.1093/aob/mcu205. Epub 2014 Oct 28. PMID: 25351192; PMCID: PMC4649696.
172. Asei R, Abaidoo RC, Opoku A, Adjei-Nsiah S and Antwi-Agyei P (2021) Use of Limiting Nutrients for Reclamation of Non-responsive Soils in Northern Ghana. Front. Soil Sci. 1:674320. doi: 10.3389/fsoil.2021.674320
173. Odey, Goodness & Adegbite, Moriam & Denkyira, Salomey & Alhaj, Samar & III, Don. (2022). Women and food security in Africa: The double burden in addressing gender equality and environmental sustainability. 10.1016/bs.af2s.2022.07.001.
174. Joe-Nkamuke, U., Olagunju, K.O., Njuguna-Mungai, E. et al. Is there any gender gap in the production of legumes in Malawi? Evidence from the Oaxaca–Blinder decomposition model. Rev Agric Food Environ Stud 100, 69–92 (2019). https://doi.org/10.1007/s41130-019-00090-y
175. Smale, Melinda & Theriault, Veronique & Allen, Andrea & Sissoko, Mamadou. (2022). Is cowpea a 'women's crop' in Mali? Implications for value chain development. 17. 157-170. 10.53936/afjare.2022.17(2).11.
176. Astley, S., & Finglas, P. (2016). Nutrition and health. Reference Module in Food Science. https://doi.org/10.1016/b978-0-08-100596-5.03425-9
177. Nayak, S. P., Lone, R. A., Fakhrah, S., Chauhan, A., Sarvendra, K., & Mohanty, C. S. (2022). Mainstreaming underutilized legumes for providing nutritional security. Future Foods, 151–163. https://doi.org/10.1016/b978-0-323-91001-9.00023-2
178. Sharma A. A review on traditional technology and safety challenges with regard to antinutrients in legume foods. J Food Sci Technol. 2021 Aug;58(8):2863-2883. doi: 10.1007/s13197-020-04883-8. Epub 2020 Nov 27. PMID: 34294949; PMCID: PMC8249542.
179. Costa, L. G., & Aschner, M. (2014). Chickpea Intoxication. In Encyclopedia of the Neurological Sciences Elsevier Inc.. https://doi.org/10.1016/B978-0-12-385157-4.00255-

Conclusion

Highlight 1	Local and ecologically tailored legume-agroecology management practices are climate resilient and improve soil health, nutrient security, and farmer livelihoods through crop diversification.
Highlight 2	Governments & civil society actors should direct subsidies, grants, and loans toward legume-centered crop diversification and culturally appropriate production methods among smallholders.
Highlight 3	Areas for agroecology-supporting research development include underutilized legume crops, soil microbial interactions, and frass fertilizer production.

Conclusion

The relatively untapped potential of agroecological intensification practices can radically improve nutrition security, sustainability, and climate-resilient farming practices in Africa via underutilized legume research. This involves linking agricultural and health policies in a multisector approach to change the subsidies and policies that marginalize sustainable food production. Integrating legume crops has the potential to rekindle thousands of years of agroecological traditions and address challenges of nutrition security, agricultural input supply chains, and cropland regeneration in Africa.

Traditional production systems, such as legume intercropping, can be paired with new ecologically tailored and regenerative agricultural innovations for sustainable and nourishing livelihoods. Multilateral stakeholder investment and community-based participatory interventions will catalyze the application of agroecological knowledge to improve human and planetary health.

Community, public, private, and academic stakeholders must leverage cross-sector collaboration for educational initiatives and national programming in supporting the resurgence of long-held knowledge systems and practices. The reconciliation of formal and informal knowledge structures will happen through creative, multi-stakeholder exchanges to support sustainable agriculture development practices. Sustainable agricultural management practices must be prioritized to support smallholder farmers and local knowledge systems for resilient African food systems.

The four point strategy of redirecting input subsidy programming to support agroecological management practices and legume intercropping, underutilized legume, and rhizobia research, integrating formal and informal seed sectors, and frass fertilizer production can be adapted for implementation across diverse ecological contexts.

Image Description: Common Bean Variety at Market, Ethiopia
Photo courtesy of Dr. Alex McAlvay

Table 1: Drought Tolerant and Protein Rich Underutilized Legume Crops

Species presented in Table 1 were selected after a review of existing literature and research landscaping the widespread use and potential for production, domestication origins, and genetic diversity of specific underutilized legumes. Key species presenting the most agronomic potential were selected for incorporation in Table 1. Information was synthesized to highlight the scientific and common names, summary of relevance, center of origin and current production area, nutritional composition, and drought tolerance.

SPECIES	OVERVIEW	NUTRITIONAL COMPOSITION INFORMATION	CENTER OF ORIGIN AND CURRENT PRODUCTION AREA	CITATIONS
African Yam bean *(Sphenostylis stenocarpa)*	The Yam bean is cultivated across East, West, and Southern African countries, making it a local market staple. However, limited data exists on its production, harvest, and market values. Research in Nigeria has shown its income generation potential for rural households.	Fiber (2.47–9.57%) Carbohydrates (49.88–63.51%) Protein (19.53–29.53%)	Likely domesticated in Ethiopia. Primarily Cultivated across West Africa, including Cameroon, Côte d'Ivoire, Ghana, Nigeria and Togo.	1. Popoola JO, Aworunse OS, Ojuederie OB, Adewale BD, Ajani OC, Oyatomi OA, Eruemulor DI, Adegboyega TT and Obembe OO (2022) The Exploitation of Orphan Legumes for Food, Income, and Nutrition Security in Sub-Saharan Africa. Front. Plant Sci. 13:782140. doi: 10.3389/fpls.2022.782140 2. Adewale BD and Nnamani CV (2022) Introduction to food, feed, and health wealth in African yam bean, a locked-in African indigenous tuberous legume. Front. Sustain. Food Syst. 6:726458. doi: 10.3389/fsufs.2022.726458 3. Klu, G. Y. P., Amoatey, H. M., Bansa, D., & Kumaga, F. K. (2018). Cultivation and use of African yam bean (Sphenostylis stenocarpa) in the Volta Region of Ghana. Bulletin de ressources phytogénétiques - cultivation and use of African yam bean (sphenostylis stenocarpa) in the Volta Region of Ghana. https://www.bioversityinternational.org/fileadmin/PGR/article-issue_124-art_3-lang_fr.html#:~:text=The%20African%20yam%20bean%20is,farmers%20as%20a%20security%20crop.
Bambara groundnut *(Vigna subterranea)*	The Bambara groundnut is an indigenous tropical African legume that thrives in marginal soils. With its potential to boost immunity in humans, it is gaining international research attention. Countries like Madagascar, South Africa, and Nigeria export this crop. Women play a significant role in its production and processing.	Fiber (5.5%) Carbohydrates (64.4%) Protein (23.6%)	Likely domesticated in Botswana. Cultivated across the semi-arid sub-Saharan Africa regions.	1. Olanrewaju OS, Oyatomi O, Babalola OO and Abberton M (2022) Breeding Potentials of Bambara Groundnut for Food and Nutrition Security in the Face of Climate Change. Front. Plant Sci. 12:798993. doi: 10.3389/fpls.2021.798993 2. Tan XL, Azam-Ali S, Goh EV, Mustafa M, Chai HH, Ho WK, Mayes S, Mabhaudhi T, Azam-Ali S and Massawe F (2020) Bambara Groundnut: An Underutilized Leguminous Crop for Global Food Security and Nutrition. Front. Nutr. 7:601496. doi: 10.3389/fnut.2020.601496 3. Popoola JO, Aworunse OS, Ojuederie OB, Adewale BD, Ajani OC, Oyatomi OA, Eruemulor DI, Adegboyega TT and Obembe OO (2022) The Exploitation of Orphan Legumes for Food, Income, and Nutrition Security in Sub-Saharan Africa. Front. Plant Sci. 13:782140. doi: 10.3389/fpls.2022.782140
Cowpea *(Vigna unguiculata)*	Widely cultivated across Africa, Asia, and the Americas, Cowpeas serve as drought-tolerant leguminous crops that provide sustenance for both humans and livestock. Rich in protein, dietary fiber, phytochemicals, vitamins, and minerals, they outperform cereal and root crops nutritionally.	Fiber (11%) Carbohydrates (60%) Protein (24%)	Likely domesticated in both Eastern and Western Africa. Cultivated across the entire continent, and especially in dry savanna areas.	1. Affrifah, N., Phillips, R. D., & Saalia, F. K. (2022, September). Cowpeas: Nutritional profile, processing methods and products—A review. Legume Science. Retrieved April 15, 2023, from https://onlinelibrary.wiley.com/doi/10.1002/leg3.131 2. Panzeri D, Guidi Nissim W, Labra M, Grassi F. Revisiting the Domestication Process of African Vigna Species (Fabaceae): Background, Perspectives and Challenges. Plants (Basel). 2022 Feb 16;11(4):532. doi: 10.3390/plants11040532. PMID: 35214865; PMCID: PMC8879845. 3. Singh, R., Singh, G.S. Traditional agriculture: a climate-smart approach for sustainable food production. Energ. Ecol. Environ. 2, 296–316 (2017). https://doi.org/10.1007/s40974-017-0074-7
Dolichos *(Lablab purpureus)*	Native to Africa, this tropical food source is also known for nitrogen fixation abilities and fodder used as forage, hay, and silage for cattle. It is consumed in a myriad of ways, including boiled, roasted, or ground into flour.	Fiber (67%) Carbohydrates (47%) Protein (43%)	Likely domesticated in both eastern and southern Africa. Cultivated across Africa, Asia, and the Caribbean.	1. Maass BL, Knox MR, Venkatesha SC, Angessa TT, Ramme S, Pengelly BC. Lablab purpureus-A Crop Lost for Africa? Trop Plant Biol. 2010 Sep;3(3):123-135. doi: 10.1007/s12042-010-9046-1. Epub 2010 Mar 28. PMID: 20835399; PMCID: PMC2933844. 2. Sheahan, C.M. 2012. Plant guide for lablab (Lablab purpureus). USDA-Natural Resources Conservation Service, Cape May Plant Materials Center. Cape May, NJ. 08210. 3. United States Department of Agriculture. (2019, January 4). FoodData Central Search Results. FoodData Central. Retrieved April 15, 2023, from https://fdc.nal.usda.gov/fdc-app.html#/food-details/175210/nutrients
Grass pea *(Lathyrus sativus)*	The Grass pea is a cost-effective and highly nutritious legume, commonly used as forage. However, its consumption without proper processing may lead to lathyrism, a neurological disorder. In West Africa, it contributes significantly to the rural economy.	Fiber (17%) Carbohydrates (41%) Protein (31%)	Domesticated in the Balkan Peninsula. Cultivated across South Asia, Africa, and the Mediterranean.	1. Aletor, V., El-Moneim, A. A., & Goodchild, A. (1994, June). Evaluation of the seeds of selected lines of three Lathyrus spp for β-N-oxalylamino-L- alanine (BOAA), tannins, trypsin inhibitor activity and certain in-vitro characteristics. Wiley Online Library. Retrieved April 15, 2023, from https://onlinelibrary.wiley.com/doi/10.1002/jsfa.2740650204 2. Gonçalves, L., Rubiales, D., Bronze, M. R., & Vaz Patto, M. C. (2022). Grass Pea (Lathyrus sativus L.)—A Sustainable and Resilient Answer to Climate Challenges. Agronomy, 12(6), 1324. MDPI AG. Retrieved from http://dx.doi.org/10.3390/agronomy12061324 3. Lambein, F., Travella, S., Kuo, YH. et al. Grass pea (Lathyrus sativus L.): orphan crop, nutraceutical or just plain food?. Planta 250, 821–838 (2019). https://doi.org/10.1007/s00425-018-03084-0
Kersting's Groundnut *(Macrotyloma geocarpum)*	In West Africa, the crop provides substantial income for the rural population. Kersting's Groundnut has several medicinal uses and cultural values as well. However, because of its intensive labor requirement, low yield and non-availability of improved varieties, its cultivation is declining and it is even disappearing gradually in some growing areas.	Fiber (6.2%) Carbohydrates (61.53–73.3%) Protein (21.3%)	Likely domesticated in: Cultivated across: Western Africa, specifically in Benin and surrounding regions	1. Ayenan, M.A.T., Ezin, V.A. Potential of Kersting's groundnut [Macrotyloma geocarpum (Harms) Maréchal & Baudet] and prospects for its promotion. Agric & Food Secur 5, 10 (2016). https://doi.org/10.1186/s40066-016-0058-4 2. Ajayi, O. B., & Oyetayo, F. L. (2009, March 20). Potentials of kerstingiella geocarpa as a health food. Journal of Medicinal Food. Retrieved April 17, 2023, from https://www.liebertpub.com/doi/10.1089/jmf.2008.0100 3. Aremu, M. O., Osenfade, B. G., Basu, S. K., & Ablaku, B. E. (2011, December 12). Development and nutritional quality evaluation of Kersting's Groundnut-Ogi for African weaning diet. Science Alert. Retrieved April 17, 2023, from https://scialert.net/fulltext/?doi=ajft.2011.1021.1033
Horse gram *(Macrotyloma uniflorum)*	Horse gram has historical significance as a food source, traditional medicine, and animal fodder. Resilient in marginal environments, it serves as an important crop for crop diversification.	Fiber (5.3%) Carbohydrates (57.2%) Protein (22%)	Domesticated in India. Cultivated largely across Asia and Africa.	1. Aditya, J.P., Bhartiya, A., Chahota, R.K. et al. Ancient orphan legume horse gram: a potential food and forage crop of future. Planta 250, 891–909 (2019). https://doi.org/10.1007/s00425-019-03184-5 2. Bhartiya, Anuradha & Aditya, Jodumuntala & Kant, Lakshmi. (2015). Nutritional and remedial potential of an underutilized food legume horsegram (Macrotyloma uniflorum): A review. Journal of Animal and Plant Sciences. 25. 908-920. 3. Kingwell-Banham, E., Fuller, D.Q. (2014). Horse Gram: Origins and Development. In: Smith, C. (eds) Encyclopedia of Global Archaeology. Springer, New York, NY. https://doi.org/10.1007/978-1-4419-0465-2_2322
Jack bean *(Canavalia ensiformis)*	Traditionally grown in Sub-Saharan African farming systems, the Jack bean is used as fodder and can be rendered edible through boiling. It contains canatoxin, an insecticidal protein.	Fiber (9.4–10.9) Carbohydrates (55%) Protein (20% to 34%)	Domesticated across tropical Africa. Cultivated across Africa, South, and Central America and generally naturalized and cultivated worldwide.	1. Akpapunam MA, Sefa-Dedeh S. Jack bean (Canavalia ensiformis): nutrition related aspects and needed nutrition research. Plant Foods Hum Nutr. 1997;50(2):93-9. doi: 10.1007/BF02436029. PMID: 9201744. 2. Popoola JO, Aworunse OS, Ojuederie OB, Adewale BD, Ajani OC, Oyatomi OA, Eruemulor DI, Adegboyega TT and Obembe OO (2022) The Exploitation of Orphan Legumes for Food, Income, and Nutrition Security in Sub-Saharan Africa. Front. Plant Sci. 13:782140. doi: 10.3389/fpls.2022.782140
Marama bean *(Tylosema esculentum)*	Native to Southern Africa, the Marama bean is a nutrient-rich plant used for both human and livestock consumption. Its oil is valued in cosmetics and culinary uses. It also possesses anti-diarrheal properties in traditional medicine.	Fiber (19–27%) Carbohydrates (33%) Protein (29–38%)	Domesticated in the Kalahari Desert, Botswana, Namibia, and South Africa. Cultivated across southern Africa.	1. Jackson JC, Duodu KG, Holse M, Lima de Faria MD, Jordaan D, Chingwaru W, Hansen A, Cencic A, Kandawa-Schultz M, Mpotokwane SM, Chimwamurombe P, de Kock HL, Minnaar A. The morama bean (Tylosema esculentum): a potential crop for southern Africa. Adv Food Nutr Res. 2010;61:187-246. doi: 10.1016/B978-0-12-374468-5.00005-2. PMID: 21092905. 2. Mosele MM, Hansen AS, Engelsen SB, Diaz J, Sørensen I, Ulvskov P, Willats WG, Blennow A, Harholt J. Characterisation of the arabinose-rich carbohydrate composition of immature and mature marama beans (Tylosema esculentum). Phytochemistry. 2011 Aug;72(11-12):1466-72. doi: 10.1016/j.phytochem.2011.03.027. Epub 2011 May 3. PMID: 21543095. 3. Omotayo, A. O., & Aremu, A. O. (2021, February 3). Marama Bean [Tylosema Esculentum (Burch.) A. Schreib.]: An indigenous plant with potential for food, nutrition, and Economic Sustainability. Food & Function. Retrieved April 17, 2023, from https://doi.org/10.1039/D0FO01937B
Moth bean *(Vigna aconitifolia)*	Originating from arid and semi-arid regions of India, the Moth bean is drought-resistant and provides a reliable source of protein. It is also used as a cover crop to prevent soil erosion and has medicinal uses.	Fiber (4.5%) Carbohydrates (60.1%) Protein (20 to 23%)	Domesticated in India. Cultivated and commonly produced in semi-arid regions in Africa and across India.	1. Bagmare, P. A., Swami, S. B., & Pujari, K. H. (2019, November 27). Comparative Study of Physico-Chemical Properties of Moth Bean Flour and Moth Bean Malt. http://www.jakraya.com/journal/jref 2. Bhadkaria, A., Narvekar, D.T., Gupta, N. et al. Moth bean (Vigna aconitifolia (Jacq.) Marechal) seeds: A review on nutritional properties and health benefits. Discov Food 2, 18 (2022). https://doi.org/10.1007/s44187-022-00019-3 3. Heuzé V., Tran G., Lebas F., 2020. Moth bean (Vigna aconitifolia). Feedipedia, a programme by INRAE, CIRAD, AFZ and FAO. https://www.feedipedia.org/node/237 Last updated on October 27, 2020, 14:38
White Lupin *(Lupinus albus)*	White lupin stands out for its resilience to pests and diseases due to a combination of factors like alkaloids, genetic diversity, and physical barriers. With lower levels of anti-nutritive compounds, it serves as a viable option for animal and human consumption.	Fiber (34.2%) Carbohydrates (48%) Protein (32.9%.)	Domesticated around the Mediterranean and along the Nile valley. Cultivated across the world.	1. Munier-Jolain, N. M., Julier, B., Huyghe, C., Clapham, W. M., Atkins, C. A., Beneytout, J. L., Brillouet, J., Chaves, M. M., Cowling, W. A., Crochemore, M. L., Deroo, C., Desmaison, A. M., Ginkelaker, B., Dracup, M., Duthion, C., Evans, A. J., Fao/who, Faluyi, M. A., Gent, M. P. N., ... Harzic, N. (1998, January 5). White Lupin (Lupinus albus L.). Field Crops Research. Retrieved April 17, 2023, from https://www.sciencedirect.com/science/article/pii/S0378429097000282?via%3Dihub 2. Mohamed, A. A., & Rayas-Duarte, P. (1995). Composition of Lupinus albus. Retrieved from https://www.cerealsgrains.org/publications/cc/backissues/1995/documents/72_643.pdf

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