Rethinking agricultural productivity: more than yield and land

Introduction

1. Ralf Seppelt, Stefan Klotz, Edgar Peiter and Martin Volk. 2022. Agriculture and food security under a changing climate: an underestimated challenge. *iScience*, 25(12): art. 105551. https://doi.org/10.1016/j.isci.2022.105551

   Provides general background on the challenges facing agriculture and food security, particularly related to climate change. The Policy Brief[1] focuses on energy productivity as a key metric for evaluating sustainability, which aligns with the idea of addressing climate change.

2. Ralf Seppelt, Ameur M. Maneur, Jianguo Liu, Eli P. Fenichel and Stefan Klotz. 2014. Synchronized peak-rate years of global resources use. *Ecology and Society*, 19(4): 50. http://dx.doi.org/10.5751/ES-07039-190450

   Provides evidence for the finite nature of resources, including land. The Policy Brief emphasizes that while energy, human resources and technology have the potential to increase with innovation, land remains a limiting factor.

Multiple objectives

3. Ralf Seppelt, Channing Arndt, Michael Beckmann, Emily A. Martin and Thomas W. Hertel. 2020. Deciphering the biodiversity–production mutualism in the global food security debate. *Trends in Ecology & Evolution*, 35(11): 1011–1020. https://doi.org/10.1016/j.tree.2020.06.012

   Provides the broader context of the Policy Brief, emphasizing the interconnectedness of biodiversity, production and food security. It supports the need to consider multiple objectives, including biodiversity, when addressing agricultural productivity.

4. David Tilman, Christian Balzer, Jason Hill and Belinda L. Befort. 2011. Global food demand and the sustainable intensification of agriculture. *PNAS*, 108(50): 20260–20264. https://doi.org/10.1073/pnas.1116437108

   Evaluates the environmental impacts of alternative means for meeting global food demand. Per capita demand for crops, when measured as caloric or protein content of all crops combined, has been an increasing function of per capita real income since 1960 but differs by countries' income levels.

5. Teja Tscharntke, Yann Clough, Thomas C. Wanger, Louise Jackson, Iris Motzke, Ivette Perfecto, John Vandermeer and Anthony Whitbread. 2012. Global food security, biodiversity conservation and the future of agricultural intensification. *Biological Conservation*, 151(1): 53–59. https://doi.org/10.1016/j.biocon.2012.01.068

6. Julia Rosa-Schleich, Jacqueline Loos, Oliver Musshoff and Teja Tscharntke. 2019. Ecological-economic trade-offs of diversified farming systems – a review. *Ecological Economics*, 160: 251–263. https://doi.org/10.1016/j.ecolecon.2019.03.002

   Sources 5 and 6 contribute to the Policy Brief's emphasis on agricultural diversification. The authors highlight the ecological and economic trade-offs of different farming systems, which supports the idea of promoting diversified systems that reduce reliance on chemical inputs.

Finite space

7. Wolfram Mauser, Gernot Klepper, Florian Zabel, Ruth Delzeit, Tobias Hank, Birgitta Putzenlechner and Alvaro Calzadilla. 2015. Global biomass production potentials exceed expected future demand without the need for cropland expansion. *Nature Communications*, 6: art. 8946. https://doi.org/10.1038/ncomms9946

   Supports the Policy Brief's statement that land availability is finite. It suggests that increasing production on existing farmland is possible, aligning with the brief's focus on improving agricultural efficiency.

8. IDH et al. 2023. European soy monitor 2021; insights on European uptake of certified, responsible, deforestation, and conversion-free soy in 2021. The Hague: Schuttelaar & Partners. https://thecollaborativesoyinitiative.info/storage/files/idh-soy-monitor-2021-final.pdf

   Provides data for the Policy Brief's statement that only about 24% of soya used in livestock feed in Europe is certified 'deforestation-free'. It directly supports the discussion on the indirect land use change driven by European demand for soya.

1 Ralf Seppelt and Bartosz Bartkowski. 2024. Rethinking agricultural productivity: more than yield and land / Landwirtschaftliche Produktivität neu denken: mehr als Ertrag und Fläche. Helmholtz Centre for Environmental Research / Zentrum für Umweltforschung *Policy brief / Kurzdossier*. Leipzig: UFZ.

9. Lukas Egli, Matthias Schröter, Christoph Scherber, Teja Tscharntke and Ralf Seppelt. 2021. Crop diversity effects on temporal agricultural production stability across European regions. *Regional Environmental Change*, 21: art. 96. https://doi.org/10.1007/s10113-021-01832-9

Provides evidence for the Policy Brief's claim that diversified agriculture enhances yield stability and resilience to climate change. This source specifically focuses on the effects of crop diversity on production stability in Europe, strengthening the argument for diversification.

10. Ratana Sapbamrer and Ajchamon Thammachai. 2021. A systematic review of factors influencing farmers' adoption of organic farming. *Sustainability*, 13(7): art. 3842. https://doi.org/10.3390/su13073842

11. Verena Seufert, Navin Ramankutty and Jonathan A. Foley. 2012. Comparing the yields of organic and conventional agriculture. *Nature*, 485: 229–232. https://doi.org/10.1038/nature11069

Sources 10 and 11 provide background on organic farming as one type of diversified agriculture. The Policy Brief recommends promoting diversification through methods such as agroecology, which includes organic farming.

12. Olivia M. Smith, Abigail L. Cohen, Cassandra J. Rieser, Alexandra G. Davis, Joseph M. Taylor, Adekunle W. Adesanya, Matthew S. Jones, Amanda R. Meier, John P. Reganold, Robert J. Orpet, Tobin D. Northfield and David W. Crowder. 2019. Organic farming provides reliable environmental benefits but increases variability in crop yields: a global meta-analysis. *Frontiers in Sustainable Food Systems*, 3. https://doi.org/10.3389/fsufs.2019.00082

This source (along with 11) provides evidence for the Policy Brief's statement that organic systems have lower and more variable crop yields (per area in use) but are superior in terms of environmental richness and stability. They support the idea that while yield may be lower in some diversified systems, there are significant environmental benefits.

Finite energy

13. J. Poore and T. Nemecek. 2018. Reducing food's environmental impacts through producers and consumers. *Science*, 360(6392): 987–992. https://doi.org/10.1126/science.aaq0216

14. M. Crippa, E. Solazzo, D. Guizzardi, F. Monforti-Ferrario, F.N. Tubiello and A. Leip. 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, 2: 198–209. https://doi.org/10.1038/s43016-021-00225-9

Sources 13 and 14 back up the Policy Brief's call for reducing energy use in agriculture with rich data on the environmental impacts of today's food system capturing the entire production chain from farm to fork, particularly its large carbon footprint.

15. Timothy D. Searchinger, Stefan Wirsenius, Tim Beringer and Patrice Dumas. 2018. Assessing the efficiency of changes in land use for mitigating climate change. *Nature*, 564: 249–253. https://doi.org/10.1038/s41586-018-0757-z

Provides information on the link between land use change and climate change mitigation. The Policy Brief mentions the greenhouse gas (GHG) emissions associated with land clearance for agriculture, which connects to the broader theme of mitigating climate change through sustainable land use.

16. Yunhu Gao and André Cabrera Serrenho. 2023. Greenhouse gas emissions from nitrogen fertilizers could be reduced by up to one-fifth of current levels by 2050 with combined interventions. *Nature Food*, 4: 170–178. https://doi.org/10.1038/s43016-023-00698-w

Supports the Policy Brief's discussion on reducing energy inputs, specifically fertilizers. It highlights the potential for reducing GHG emissions from nitrogen fertilizers, emphasizing the environmental benefits of reducing such inputs.

17. Michael A. Clark, Nina G.G. Domingo, Kimberly Colgan, Sumil K. Thakrar, David Tilman, John Lynch, Inês L. Azevedo and Jason D. Hill. 2020. Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. *Science*, 370(6517): 705–708. https://doi.org/10.1126/science.aba7357

Adds further evidence for the significant contribution of food systems to GHG emissions. It strengthens the Policy Brief's argument that improving agricultural efficiency is paramount in mitigating climate change.

Reducing inputs with enough energy for all

18. Amartya Sen. 1981. *Poverty and famines: an essay on entitlement and deprivation*. Oxford: Clarendon Press. https://scholar.harvard.edu/sen/publications/poverty-and-famines-essay-entitlement-and-deprivation

Provides background on socioeconomic inequalities and their impact on food security. The Policy Brief mentions the four-fold gap in food consumption between rich and poor countries and highlights socioeconomic inequalities as a key issue.

19. Sriram Marimuthu, Akuleti Saikumar and Laxmikant S. Badwaik. 2024. Food losses and wastage within food supply chain: a critical review of its generation, impact, and conversion techniques. *Waste Disposal & Sustainable Energy*. https://doi.org/10.1007/s42768-024-00200-7

Provides details on food loss and waste, supporting the Policy Brief's statement that they account for about a third of agricultural production. It also contributes to the understanding of the distribution inefficiencies mentioned in the Policy Brief.

20. Alessandro Gatto and Maksym Chepeliev. 2024. Global food loss and waste estimates show increasing nutritional and environmental pressures. *Nature Food*, 5: 136–147. https://doi.org/10.1038/s43016-023-00915-6

Provides information on the impacts of global food loss along the production chain from farm to fork accounting for around a third of agricultural production. It unpacks data "for 121 countries and 20 composite regions".

Policy recommendations

21. Teja Tscharntke, Ingo Grass, Thomas C. Wanger, Catrin Westphal and Péter Batáry. 2021. Beyond organic farming – harnessing biodiversity-friendly landscapes. *Trends in Ecology & Evolution*, 36(10): 919–930. https://doi.org/10.1016/j.tree.2021.06.010

22. Teja Tscharntke et al. 2024. Mixing on- and off-field measures for biodiversity conservation. *Trends in Ecology & Evolution*, 39(8), 726–733. https://doi.org/10.1016/j.tree.2024.04.003

Sources 21 and 22 provide further information on biodiversity-friendly farming practices, contributing to the Policy Brief's recommendation to promote agricultural diversification.

23. Martin Lechenet, Fabrice Dessaint, Guillaume Py, David Makowski and Nicolas Munier-Jolain. 2017. Reducing pesticide use while preserving crop productivity and profitability on arable farms. *Nature Plants*, 3: art. 17008. https://doi.org/10.1038/nplants.2017.8

Provides further evidence for the feasibility of reducing pesticide use while maintaining productivity. It supports the Policy Brief's argument that promoting diversification, which includes moving away from high dependence on pesticides, is achievable.

24. Aastha Sethi, Chien-Yu Lin, Indira Madhavan, Mark Davis, Peter Alexander, Michael Eddleston and Shu-Sen Chang. 2022. Impact of regional bans of highly hazardous pesticides on agricultural yields: the case of Kerala. *Agriculture & Food Security*, 11: art. 9. https://doi.org/10.1186/s40066-021-00348-z

Supports the Policy Brief's recommendation to implement regulations limiting the use of agrochemicals. It provides a case study demonstrating the potential impact of such regulations, highlighting the feasibility of reducing pesticide use.

25. Rosa Isabella Cuppari, Allan Branscomb, Maggie Graham, Fikeremariam Negash, Angelique Kidd Smith, Kyle Proctor, David Rupp, Abiyou Tilahun Ayalew, Gizaw Getaneh Tilaye, Chad W. Higgins and Majdi Abou Najm. 2024. Agrivoltaics: synergies and trade-offs in achieving the Sustainable Development Goals at the global and local scale. *Applied Energy*, 362: art. 122970. https://doi.org/10.1016/j.apenergy.2024.122970

Provides examples of innovative agricultural technologies, supporting the Policy Brief's recommendation to invest in research and development for energy-efficient technologies.

26. Achim Walter, Robert Finger, Robert Huber and Nina Buchmann. 2017. Smart farming is key to developing sustainable agriculture. *PNAS*, 111(24): 6148–6150. https://doi.org/10.1073/pnas.1707462114

Supports the Policy Brief's recommendation to invest in research and development for precision agricultural technologies that optimize resource use. It aligns with the overall emphasis on promoting energy-efficient and sustainable agricultural practices.

27. GlobalData. 2024. Top 10 food & grocery retailers in the world in 2021 by sales. https://www.globaldata.com/companies/top-companies-by-sector/retail-wholesale/global-food--grocery-retailers-by-sales/

Provides data to support the Policy Brief's discussion on the dominance of a few retail companies in the food supply chain. It helps identify the specific large retailers mentioned in the Policy Brief, such as Walmart, Aldi, Carrefour, Tesco and Nestlé.

Case study

28. Sarah Duddigan, Chris D. Collins, Zakir Hussain, Henny Osbahr, Liz J. Shaw, Fergus Sinclair, Tom Sizmur, Vijay Thallam and Leigh Ann Winowiecki. 2022. Impact of Zero Budget Natural Farming on crop yields in Andhra Pradesh, SE India. *Sustainability*, 14(3): art. 1689. https://doi.org/10.3390/su14031689

29. S. Galab, P. Prudhvikar Reddy, D. Sree Rama Raju, C. Ravi and A. Rajani. 2020. *Impact assessment of Zero Budget Natural Farming in Andhra Pradesh – consolidated report 2018-19. A comprehensive approach using crop cutting experiments*. Hyderabad: Centre for Economic and Social Studies. https://www.idsap.in/assets/reports/3%20Consolidated%20Report%202018-19.pdf

These sources offer further insights into the implementation and impacts of Zero Budget Natural Farming (ZBNF).

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