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Balancing Yield and Soil Health: A Comparative Study of Agroecological and Conventional Farming Systems

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ABSTRACT: Conventional agriculture, while maximizing short-term yields, often compromises soil health and long-term sustainability. This study evaluates trade-offs between soil health and agricultural productivity across Conventional Farming Systems (CFS) and Agroecological Farming Systems (AFS). Using composite Soil Health Index (SHI) scores derived from physical, chemical, and biological indicators, alongside productivity metrics including yield, water use efficiency (WUE), and nutrient use efficiency (NUE), we compared system-level outcomes. Data were collected from categorized plots under CFS and AFS. A composite SHI was constructed using normalized indicators such as bulk density, soil organic carbon, microbial biomass carbon, and earthworm count. Statistical analyses included Principal Component Analysis (PCA) for soil quality differentiation and scatterplots for trade-off visualization. Comparative analysis was conducted using t-tests and Mann–Whitney tests. AFS plots demonstrated significantly higher SHI scores, improved WUE, and long-term soil resilience, while CFS plots maintained slightly higher yields with greater synthetic input reliance. Radar charts and PCA biplots revealed clear ecological advantages in AFS. Yield-SHI scatterplots illustrated the trade-off between productivity and sustainability, favoring AFS in long-term viability. Agroecological systems offer a viable pathway to sustainable agriculture, balancing productivity with ecological integrity. Emphasizing soil health metrics enhances our understanding of agroecosystem performance and supports informed transitions towards resilient farming.

Keywords: Agroecology, Soil Health Index, Sustainable Agriculture, Trade-Offs, Farming Systems, Productivity, Soil Resilience.

INTRODUCTION

Agricultural systems worldwide face an unprecedented challenge: sustaining food production while preserving the integrity of ecosystems. Over the past century, the expansion of conventional farming methods has been associated with a significant increase in agricultural outputs. However, this productivity gain has often come at the expense of environmental quality and long-term soil functionality. Within this context, the present study investigates the trade-offs between agricultural yield and soil health by comparing Conventional Farming Systems (CFS) and Agroecological Farming Systems (AFS). The growing concern over soil degradation and environmental harm caused by intensive agricultural practices has spurred interest in alternatives like agroecology, which promises a more sustainable path forward.

Conventional farming, characterized by high input use and mechanization, has been widely studied for its detrimental effects on soil health. Research has established that conventional agricultural practices lead to significant soil degradation, characterized by reductions in soil organic carbon, nutrient depletion, and disturbances in soil microbial communities. For instance, it is recognized that intensive agricultural management results in a decline in soil quality across multiple metrics, such as soil structure and biological activity, with conventional practices causing a notable decrease in soil health indices, indicative of a partial degradation that undermines the soil's capacity to support sustainable agricultural production (Büchi et al., 2022; Walder et al., 2023). The reliance on synthetic fertilizers and pesticides diminishes microbial diversity and increases the risks associated with soil contamination and the development of resistance among soil organisms (Rashid et al., 2016). Furthermore, the long-term use of these inputs can lead to erosion, compaction, and loss of biodiversity, exacerbating the challenges of sustainable agriculture (Es & Karlen, 2019).

To address these challenges, agroecology has emerged as a promising paradigm. Agroecology emphasizes the integration of ecological principles into agricultural systems, seeking to enhance both productivity and environmental health. By focusing on practices such as crop diversification, organic amendments, minimal tillage, and the use of cover crops, agroecological systems are capable of improving soil structure, increasing biodiversity, and reducing the dependency on chemical inputs (Giller et al., 2021; Rhodes, 2017). Moreover, agroecology supports climate change mitigation through carbon sequestration and enhances the resilience of farming systems to environmental stressors (Tahat et al., 2020). Notably, the adoption of agroecological practices has been positively correlated with increased crop yields and profitability in the long term compared to conventional methods, underscoring the potential of agroecology to support global food security while preserving environmental integrity (Wittwer et al., 2021).

Despite the recognized benefits of agroecology, a key challenge persists: quantifying and reconciling the trade-offs between yield and ecological integrity. Various studies have observed trade-offs between agricultural yield and ecological integrity, particularly in the context of intensive farming practices. While conventional agriculture often focuses on maximizing yields through high-input systems, this approach tends to compromise ecological health, as evidenced by diminished soil biodiversity and increased pollution (Grijalva et al., 2024; Jasrotia et al., 2023). In contrast, strategies emphasizing ecological integrity, such as organic and conservation agriculture, may yield lower immediate crop outputs but are associated with enhanced soil health and sustainability (Zong et al., 2024). The acceptance of these trade-offs is crucial, as prioritizing ecological integrity through practices like agroecology can result in long-term gains in productivity and resilience against climate variability (Singh et al., 2023).

Understanding how different farming systems perform across a range of sustainability indicators particularly soil health requires the use of robust, integrated measurement frameworks. Effective assessment of soil health relies on a suite of indicators that reflect the biological, chemical, and physical properties of the soil. Key indicators include soil organic matter content, microbial biomass, soil texture, pH, and nutrient availability, each offering insights into the health and fertility of the soil ecosystem (Sharma et al., 2023). Recent studies emphasize the significance of microbial community dynamics as crucial indicators, highlighting their role in nutrient cycling and ecosystem functioning (Sanjay et al., 2023). Additionally, soil enzyme activity, often responsive to management practices, serves as a sensitive indicator of soil health, reflecting the biological activity essential for maintaining soil fertility (Meena et al., 2020). The integration of these indicators into soil health assessments can guide agricultural practices towards more sustainable outcomes (Tahat et al., 2020).

The historical development of agroecology further contextualizes its present relevance. The historical evolution of agroecological practices can be traced back to indigenous agricultural systems that harmonized with local ecosystems. These traditional practices often incorporated techniques such as crop rotation, intercropping, and the use of organic amendments long before the advent of modern synthetic inputs (Thierfelder et al., 2018). The rise of scientific interest in agroecology during the 20th century marked a paradigm shift, as researchers began to document the beneficial relationships between crops and their environments, leading to the development of principles underpinning modern agroecological practices today (Francaviglia et al., 2023). This evolution has been fueled by a growing recognition of the detrimental impacts of conventional practices on global ecosystems, prompting a re-evaluation of agricultural systems centered on sustainability and resilience (Reganold & Wachter, 2016).

The relevance of this research is also underlined by the Sustainable Development Goals (SDGs). Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land), are intrinsically linked to transitions in sustainable farming practices. The promotion of sustainable agriculture is vital for achieving food security and improving livelihoods while mitigating the environmental impacts of farming (Bonfante et al., 2020). Agricultural practices that adhere to these goals often emphasize enhanced productivity through sustainable methods, biodiversity conservation, and soil health improvement (Bonfante et al., 2020). Recognizing soil health as a cornerstone for achieving these SDGs underscores the need for integrated approaches that foster ecological balance while ensuring food and water security for future generations (Lal, 2016). Empowering farmers with knowledge and resources to transition towards sustainable agricultural practices aligns directly with these global objectives, highlighting the multifaceted nature of agricultural innovation (Bonfante et al., 2020).

This study aims to evaluate the trade-offs between soil health and yield outcomes in CFS and AFS through a quantitative, indicator-based framework. By constructing a composite Soil Health Index and comparing it with yield data, this research seeks to provide empirical insights into how farming system choices affect sustainability. The novelty of this study lies in its integrated evaluation of ecological and productivity metrics, offering a scientifically grounded method to inform agricultural transitions. The scope includes soil biological, chemical, and physical properties, input intensity, and productivity measures such as water and nutrient use efficiency. Ultimately, this research aspires to contribute to the discourse on sustainable agriculture by quantifying the benefits and trade-offs inherent in agroecological systems.

METHOD

This chapter outlines the methodology used to assess the trade-offs between soil health and agricultural yield in conventional and agroecological farming systems. The research employed a comparative study design utilizing multiple datasets to analyze soil health indicators, farming practices, and productivity outcomes. It also incorporated a composite Soil Health Index (SHI), multivariate statistical techniques, and trade-off visualization frameworks.

Study Area and Plot Classification

The study was conducted on agricultural plots categorized into two main system types: Conventional Farming Systems (CFS) and Agroecological Farming Systems (AFS). Plots were classified based on specific criteria including the use of synthetic inputs, organic amendments, crop rotation, tillage practices, and cover crop adoption. This binary classification facilitated comparative analysis across ecological and productivity metrics.

Data Sources and Variable Selection

The research utilized three integrated datasets:

1. Farming Practice Dataset included variables such as fertilizer (kg/ha), organic input (t/ha), pesticide application (L/ha), rotation and cover crop practices (Yes/No), and tillage intensity (Scale).
2. Soil Health Dataset recorded physical (bulk density), chemical (SOC, total nitrogen, pH, CEC), and biological (microbial biomass carbon, respiration, earthworm count) properties across soil depths.
3. Productivity Dataset captured yield (ton/ha), water use efficiency (WUE), and a pre-calculated soil health index.

Construction of the Soil Health Index (SHI)

To provide a holistic evaluation of soil quality, a composite SHI was developed by aggregating multiple indicators that reflect biological, chemical, and physical dimensions of soil health. This approach follows established methodologies for SHI construction (Gazdag et al., 2019).

Indicator Selection: The SHI incorporated key indicators such as soil organic matter, nutrient availability, microbial activity, and soil texture. These were selected for their relevance to ecosystem function and sensitivity to management changes.

Normalization and Weighting: Each indicator was normalized using min–max scaling to allow comparability across different units. Weighting of indicators was performed using both expert judgment and Principal Component Analysis (PCA) to reflect their variability and contribution to overall soil health (Zwetsloot et al., 2020).

Aggregation: The normalized and weighted indicators were aggregated to form the SHI. The index provides a composite score (0 to 1) that reflects overall soil functionality.

Validation: SHI values were validated against benchmark soils in long-term trials to ensure that they reflect realistic soil performance levels (Tamburini et al., 2016).

Statistical Analysis

Comparative Tests: Independent t-tests and Mann–Whitney U tests were used to compare CFS and AFS plots across individual variables such as yield, WUE, and SHI.

Principal Component Analysis (PCA): PCA was conducted to identify the principal dimensions of variation in soil health indicators and differentiate between CFS and AFS management effects.

PCA has proven effective in reducing complexity and enhancing interpretability in soil quality assessments (Vrebos et al., 2020).

PCA Advantages:

- Reduced correlated indicators into principal components
- Differentiated soil health outcomes across management systems
- Identified underlying relationships between indicators and ecological functions such as nutrient cycling and water retention (Tamburini et al., 2016)

Trade-Off Analysis Framework

Trade-offs were assessed using scatterplots of yield vs SHI to visualize the balance between productivity and ecological outcomes.

Best Practices Employed:

- Multidimensional Evaluation: A multi-criteria analysis integrated productivity, biodiversity, and ecological service provision to capture system-wide impacts.
- Systems Thinking: Recognized interdependencies within agroecosystems, revealing tensions between inputs, outputs, and sustainability.
- Longitudinal Considerations: Although the study used cross-sectional data, methodological planning included protocols for future temporal tracking.
- Stakeholder Engagement: Stakeholder priorities and regional knowledge informed the interpretation of SHI thresholds and sustainability outcomes.
- Adaptive Management: The study framework allows for methodological refinement based on new insights and contextual dynamics, in line with adaptive management strategies.

This methodology establishes a replicable and scientifically grounded approach to evaluating farming system sustainability, bridging empirical soil assessments with broader ecological and productivity dimensions.

RESULT AND DISCUSSION

Input Practices

Table 1. Comparison of Input Practices between CFS and AFS

Practice	CFS	AFS
Synthetic Fertilizer	High	None
Organic Inputs	None or Low	High
Pesticide Use	High	Minimal or None
Crop Rotation	Absent	Present
Cover Crops	Not Applied	Applied
Tillage Intensity	High	Low to Medium

The data show a clear divergence in input management between CFS and AFS. CFS relies heavily on synthetic fertilizers and pesticides, with minimal or no use of organic inputs, crop rotation, or cover crops. AFS, conversely, employs a diversified input strategy, prioritizing organic matter and ecological practices like rotations and mulching. These distinctions form the foundation for observed differences in soil health and productivity indicators in subsequent sections.

Soil Health Profiles

Table 2. Soil Health Indicators across Farming Systems

Indicator	Unit	CFS (Mean)	AFS (Mean)
Bulk Density	g/cm^3	1.45	1.25
Soil Organic Carbon (SOC)	%	1.2	2.6
Total Nitrogen (N)	%	0.10	0.21
Microbial Biomass Carbon	mg/kg	180	350
Soil Respiration	mg CO_2/g/day	1.2	2.4
Earthworm Count	n/m^2	20	75
pH	-	5.5	6.6
Cation Exchange Capacity	cmol/kg	8	14

Soil health indicators reveal substantial advantages in AFS over CFS. Biological indicators such as microbial biomass and respiration nearly double in AFS plots. Chemical indicators (SOC, nitrogen, pH) and physical factors (bulk density) also favor AFS. Earthworm presence, a key biological indicator, is more than three times higher in AFS, reinforcing the system's superior ecological quality and biological activity.

Yield and Resource Efficiency

Table 3. Productivity and Efficiency Metrics

Metric	Unit	CFS (Mean)	AFS (Mean)
Yield	ton/ha	6.2	5.3
Water Use Efficiency	kg/m^3	1.4	2.2
Nutrient Use Efficiency	%	48	65

While CFS maintains a yield advantage (6.2 vs. 5.3 ton/ha), AFS demonstrates greater efficiency in resource use. WUE and NUE values are significantly higher in AFS, indicating more productive use of water and nutrients. These outcomes highlight the ecological performance benefits of AFS, which compensates for its slightly lower yields by ensuring sustainable input use.

Trade-Off Visualization

Table 4. Yield vs. SHI Summary by System Type

System Type	Yield (ton/ha)	SHI (0–1)
CFS	6.2	0.52
AFS	5.3	0.78

This table illustrates the yield-soil health trade-off. CFS plots score lower on SHI despite higher yields, while AFS plots, though yielding less, exhibit higher SHI scores. This trade-off confirms that prioritizing ecological integrity may involve moderate productivity compromises but yields substantial environmental benefits.

The findings of this study reinforce the premise that agroecological systems outperform conventional ones in achieving a sustainable balance between productivity and soil health. Enhanced soil biology, a hallmark of AFS plots, serves as a cornerstone for agricultural resilience, particularly under conditions of climatic stress. The complex interactions among microbial communities including bacteria, fungi, and macrofauna such as earthworms contribute significantly to nutrient cycling, organic matter decomposition, and water retention (Wezel et al., 2020). These functions are critical for maintaining soil structure and porosity, especially during periods of drought or extreme precipitation (Jarvie et al., 2017).

Diversified agroecosystems exhibit an ability to buffer climate variability while sustaining yields. Practices such as reduced tillage, organic amendments, and cover cropping enhance microbial diversity, which, in turn, improves the soil's adaptability to environmental changes (Sun et al., 2017). The higher microbial biomass and respiration observed in AFS not only indicate greater biological activity but also contribute to nutrient availability and plant health, supporting stable yields under stress (Wezel et al., 2020).

Equally important are the long-term benefits of reduced input intensity. While synthetic fertilizers and pesticides offer immediate yield boosts in CFS, their prolonged use degrades soil quality and disrupts microbial ecosystems (Montoya et al., 2019). In contrast, AFS demonstrates that reducing reliance on chemical inputs promotes the gradual build-up of organic matter and improves overall soil fertility. This transition supports economic sustainability by reducing input costs and enhancing soil productivity over time (Sun et al., 2017). Higher soil organic carbon levels in AFS also improve water retention and mitigate nutrient leaching, resulting in long-term agronomic and ecological gains.

The synergy between agroecology and regenerative agriculture principles further validates the effectiveness of AFS. Both systems emphasize biodiversity, crop diversification, and minimal disturbance elements that not only support soil regeneration but also enhance the resilience of the broader agroecosystem (Montoya et al., 2019; Wezel et al., 2020). Regenerative agriculture's focus on restoring degraded soils, increasing soil organic matter, and leveraging natural cycles aligns seamlessly with agroecological objectives. Thus, AFS not only offers a practical application of regenerative concepts but also provides a measurable framework via SHI and yield trade-offs to assess their impact.

At a policy level, facilitating the transition toward agroecological systems demands robust institutional support. Financial incentives, such as subsidies for organic amendments and diversified cropping systems, can ease the initial burden of transition. Training programs and farmer-centered decision-making frameworks further support knowledge transfer and localized innovation (Haryanto et al., 2024). Creating market access for sustainably produced goods reinforces the economic case for agroecological farming. In parallel, policy coherence through national sustainability strategies, supported by multi-stakeholder collaboration, is essential to scale these practices (Struik & Kuyper, 2017).

Ultimately, this study's integrated trade-off analysis between yield and soil health reveals that while AFS may incur slight short-term yield penalties, these are offset by significant ecological and long-term economic benefits. The resilience of AFS, demonstrated through higher SHI values and efficient resource use, positions it as a viable pathway for sustainable agricultural development. Embracing soil health as a foundational metric in agroecosystem evaluation ensures that sustainability assessments move beyond yield-centric paradigms and acknowledge the multifunctional role of healthy soils in supporting food security, ecosystem services, and climate adaptation.

CONCLUSION

This study provides compelling evidence that Agroecological Farming Systems (AFS) offer more favorable trade-offs between soil health and productivity than Conventional Farming Systems (CFS). Through the integration of biological, chemical, and physical soil indicators into a composite Soil Health Index (SHI), we demonstrated that AFS plots consistently outperformed CFS in long-term sustainability metrics. Although yields in AFS were marginally lower, the improved water and nutrient use efficiencies, combined with enhanced microbial activity and organic matter content, support the long-term resilience of agroecosystems.

Key findings reveal that AFS practices such as organic amendments, cover cropping, crop rotation, and minimal tillage not only reduce environmental impact but also regenerate soil health. These systems showed greater microbial biomass, respiration, and earthworm populations, all indicative of robust soil biological function. Visual tools such as PCA and radar charts effectively distinguished system-level performance and reinforced the ecological advantages of AFS.

Moreover, this research aligns with broader sustainability objectives, including the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land). The findings advocate for a shift in agricultural assessment frameworks, moving beyond yield-centric measures to include soil health and ecological resilience as essential indicators of system performance.

In terms of scientific contribution, this study advances the methodology for quantifying sustainability trade-offs in agriculture by operationalizing SHI and linking it with productivity outcomes. The insights offered here can guide future research, policy development, and practical applications aimed at fostering agroecological transitions.

Future research should focus on longitudinal studies across diverse agroecological zones to further validate SHI as a predictive tool for sustainability. Additionally, exploring socio-economic dimensions, including farmer livelihoods and policy impacts, will strengthen the applicability of agroecological models in real-world contexts.

REFERENCE

Bonfante, A., Basile, A., & Bouma, J. (2020). Targeting the Soil Quality and Soil Health Concepts When Aiming for the United Nations Sustainable Development Goals and the EU Green Deal. *Soil*, *6*(2), 453–466. https://doi.org/10.5194/soil-6-453-2020

Büchi, L., Walder, F., Banerjee, S., Colombi, T., Marcel G. A. van der Heijden, Keller, T., Charles, R., & Six, J. (2022). Pedoclimatic Factors and Management Determine Soil Organic Carbon and Aggregation in Farmer Fields at a Regional Scale. *Geoderma*, *409*, 115632. https://doi.org/10.1016/j.geoderma.2021.115632

Es, H. M. v., & Karlen, D. L. (2019). Reanalysis Validates Soil Health Indicator Sensitivity and Correlation With Long‐term Crop Yields. *Soil Science Society of America Journal*, *83*(3), 721–732. https://doi.org/10.2136/sssaj2018.09.0338

Francaviglia, R., Almagro, M., & Vicente‐Vicente, J. L. (2023). Conservation Agriculture and Soil Organic Carbon: Principles, Processes, Practices and Policy Options. *Soil Systems*, *7*(1), 17. https://doi.org/10.3390/soilsystems7010017

Gazdag, O., Kovács, R., Parádi, I., Füzy, A., Ködöböcz, L., Mucsi, M., Szili-Kovács, T., Inubushi, K., & Takács, T. (2019). Density and Diversity of Microbial Symbionts Under Organic and Conventional Agricultural Management. *Microbes and Environments*, *34*(3), 234–243. https://doi.org/10.1264/jsme2.me18138

Giller, K. E., Hijbeek, R., Andersson, J., & Sumberg, J. (2021). Regenerative Agriculture: An Agronomic Perspective. *Outlook on Agriculture*, *50*(1), 13–25. https://doi.org/10.1177/0030727021998063

Grijalva, L. S., Ochoa-Hueso, R., Veen, G. F., Repeto-Deudero, I., Rijssel, S. Q. v., Koorneef, G. J., & Wim H. van der Putten. (2024). Normalized Difference Vegetation Index Analysis Reveals Increase of Biomass Production and Stability During the Conversion From Conventional to Organic Farming. *Global Change Biology*, *30*(8). https://doi.org/10.1111/gcb.17461

Haryanto, R., Suwondo, S., Juandi, Siregar, S. H., & Risaundi, D. D. (2024). Peatlands and Their Relationship With Poverty Levels in Riau Province. *International Journal of Sustainable Development and Planning*, *19*(11), 4349–4360. https://doi.org/10.18280/ijsdp.191123

Jarvie, H. P., Johnson, L. T., Sharpley, A. N., Smith, D. R., Baker, D. B., Bruulsema, T., & Confesor, R. (2017). Increased Soluble Phosphorus Loads to Lake Erie: Unintended Consequences of Conservation Practices? *Journal of Environmental Quality*, *46*(1), 123–132. https://doi.org/10.2134/jeq2016.07.0248

Jasrotia, P., Kumari, P., Malik, K., Kashyap, P. L., Kumar, S., Bhardwaj, A. K., & Singh, G. P. (2023). Conservation Agriculture Based Crop Management Practices Impact Diversity and Population Dynamics of the Insect-Pests and Their Natural Enemies in Agroecosystems. *Frontiers in Sustainable Food Systems*, *7*. https://doi.org/10.3389/fsufs.2023.1173048

Lal, R. (2016). Soil Health and Carbon Management. *Food and Energy Security*, *5*(4), 212–222. https://doi.org/10.1002/fes3.96

Meena, R. S., Kumar, S., Datta, R., Lal, R., Vijayakumar, V., Brtnický, M., Sharma, M. P., Yadav, G. S., Jhariya, M. K., Jangir, C. K., Pathan, S. I., Dokulilová, T., Pecina, V., & Marfo, T. D. (2020). Impact of Agrochemicals on Soil Microbiota and Management: A Review. *Land*, *9*(2), 34. https://doi.org/10.3390/land9020034

Montoya, D., Haegeman, B., Gaba, S., Mazancourt, C. d., Bretagnolle, V., & Loreau, M. (2019). Trade-offs in the Provisioning and Stability of Ecosystem Services in Agroecosystems. *Ecological Applications*, *29*(2). https://doi.org/10.1002/eap.1853

Rashid, M. I., Mujawar, L. H., Shahzad, T., Almeelbi, T., Ismail, I. M., & Oves, M. (2016). Bacteria and Fungi Can Contribute to Nutrients Bioavailability and Aggregate Formation in Degraded Soils. *Microbiological Research*, *183*, 26–41. https://doi.org/10.1016/j.micres.2015.11.007

Reganold, J. P., & Wachter, J. M. (2016). Organic Agriculture in the Twenty-First Century. *Nature Plants*, *2*(2). https://doi.org/10.1038/nplants.2015.221

Rhodes, C. J. (2017). The Imperative for Regenerative Agriculture. *Science Progress*, *100*(1), 80–129. https://doi.org/10.3184/003685017x14876775256165

Sanjay, M. A., Rai, S., Patil, A. A., Nengparmoi, Th., Devi, K. B., Dora, H. S. V., & Sharma, Y. (2023). Environmental Sustainability Through Soil Conservation: An Imperative for

Future Generations. *International Journal of Environment and Climate Change*, *13*(10), 1700–1707. https://doi.org/10.9734/ijecc/2023/v13i102826

Sharma, S., Lishika, B., Shubham, S., & Kaushal, S. (2023). Soil Quality Indicators: A Comprehensive Review. *International Journal of Plant & Soil Science*, *35*(22), 315–325. https://doi.org/10.9734/ijpss/2023/v35i224139

Singh, I., Hussain, M., Manjunath, G., Chandra, N., & Ravikanth, G. (2023). Regenerative Agriculture Augments Bacterial Community Structure for a Healthier Soil and Agriculture. *Frontiers in Agronomy*, *5*. https://doi.org/10.3389/fagro.2023.1134514

Struik, P. C., & Kuyper, T. W. (2017). Sustainable Intensification in Agriculture: The Richer Shade of Green. A Review. *Agronomy for Sustainable Development*, *37*(5). https://doi.org/10.1007/s13593-017-0445-7

Sun, J., Ma, B., & Lu, X. (2017). Grazing Enhances Soil Nutrient Effects: Trade-offs Between Aboveground and Belowground Biomass in Alpine Grasslands of the Tibetan Plateau. *Land Degradation and Development*, *29*(2), 337–348. https://doi.org/10.1002/ldr.2822

Tahat, M. M., Alananbeh, K. M., Othman, Y. A., & Leskovar, D. I. (2020). Soil Health and Sustainable Agriculture. *Sustainability*, *12*(12), 4859. https://doi.org/10.3390/su12124859

Tamburini, G., Simone, S. D., Sigura, M., Boscutti, F., & Marini, L. (2016). Soil Management Shapes Ecosystem Service Provision and Trade-Offs in Agricultural Landscapes. *Proceedings of the Royal Society B Biological Sciences*, *283*(1837), 20161369. https://doi.org/10.1098/rspb.2016.1369

Thierfelder, C., Baudron, F., Setimela, P. S., Nyagumbo, I., Mupangwa, W., Mhlanga, B., Lee, N., & Gérard, B. (2018). Complementary Practices Supporting Conservation Agriculture in Southern Africa. A Review. *Agronomy for Sustainable Development*, *38*(2). https://doi.org/10.1007/s13593-018-0492-8

Vrebos, D., Jones, A., Lugato, E., O'Sullivan, L., Schulte, R. P., Staes, J., & Meire, P. (2020). Spatial Evaluation and Trade-off Analysis of Soil Functions Through Bayesian Networks. *European Journal of Soil Science*, *72*(4), 1575–1589. https://doi.org/10.1111/ejss.13039

Walder, F., Büchi, L., Wagg, C., Colombi, T., Banerjee, S., Hirte, J., Mayer, J., Six, J., Keller, T., Charles, R., & Marcel G. A. van der Heijden. (2023). Synergism Between Production and Soil Health Through Crop Diversification, Organic Amendments and Crop Protection in Wheat-based Systems. *Journal of Applied Ecology*, *60*(10), 2091–2104. https://doi.org/10.1111/1365-2664.14484

Wezel, A., Herren, B., Kerr, R. B., Barrios, E., Gonçalves, A. L., & Sinclair, F. (2020). Agroecological Principles and Elements and Their Implications for Transitioning to Sustainable Food Systems. A Review. *Agronomy for Sustainable Development*, *40*(6). https://doi.org/10.1007/s13593-020-00646-z

Wittwer, R., Bender, S. F., Hartman, K., Hydbom, S., Lima, R. A. A., Loaiza, V., Nemecek, T., Oehl, F., Olsson, P. A., Petchey, O. L., Prechsl, U. E., Schlaeppi, K., Scholten, T., Seitz, S., Six, J., & Marcel G. A. van der Heijden. (2021). Organic and Conservation Agriculture Promote Ecosystem Multifunctionality. *Science Advances*, *7*(34). https://doi.org/10.1126/sciadv.abg6995

Zong, D., Zhou, Y., Zhou, J., Hu, X., & Wang, T. S. (2024). Land Use Patterns Influence in the Soil Microbial Composition. *Environmental Research Communications*, *6*(7), 075011. https://doi.org/10.1088/2515-7620/ad5b3e

Zwetsloot, M. J., Leeuwen, J. P. v., Hemerik, L., Martens, H., Josa, I. S., Broek, M. V. d., Debeljak, M., Rutgers, M., Sandén, T., Wall, D. P., Jones, A., & Creamer, R. (2020). Soil Multifunctionality: Synergies and Trade-offs Across European Climatic Zones and Land Uses. *European Journal of Soil Science*, *72*(4), 1640–1654. https://doi.org/10.1111/ejss.13051