How Sustainable Agriculture Can Reduce Environmental Damage and Yield Economic Benefits: A perspective – Part 3

Ramanatha Rao V, CL Laxmipathi Gowda, and SV Raghuram Shetty

Section 6: The Indian Scenario

As we discussed and elucidated in Parts 1 and 2 of this 3-part series (which covered Sections 1 to 5), sustainable agriculture is not just an option for India; it is a necessity for securing the nation's future security, its economy, and the well-being of its citizens, while protecting the providers of agricultural produce. This importance stems from the critical challenges posed by climate change and the limitations of conventional farming practices, particularly because over half the nation's population depends on agriculture for its livelihood.

6.1 Why Sustainable Agriculture is Vital for India?

Although many of the global imperatives for SA hold true for India as well, there are distinct interconnected issues across diverse climatic conditions, the diversity of food grown and consumed, and varying economic conditions (low per capita income).

The following points are specifically discussed in this section: (1) Climate change is expected to impact India quite seriously in terms of both heat and water instability and Indian agriculture needs to be resilient. (2) Soil health needs to be maintained/improved in the longer term, to ensure food security. (3) For its agriculture to be sustainable, India needs to balance economic benefits with environmental health. Although food production has increased over the years, affordability and access to food are unequal, resulting in significant malnutrition, which can be addressed only through diversified agriculture.

6.1.1 Climate resilience and water security: Modern agriculture (MA) is highly vulnerable to climate change, with projections showing significant drops in yields (for example, rice yields may fall by 40-47% by 2080, and a 6-10% decline in wheat output expected is soon). Sustainable practices, such as agroforestry and diversified cropping, build resilience by making better use of soil moisture. It is important to recognize that agriculture uses a large percentage of India's freshwater, since India is the world's largest producer of rice, which requires huge amounts of water. Therefore, practices that use water more efficiently, such as drip and sprinkler irrigation, and growing crops that require less water, such as millets, need to be practised to reduce groundwater depletion.**6.1.2 Food security and soil health**: Shifting from MA to SA would also encourage crop diversification toward nutritionally rich and climate-resilient indigenous crops, as well as vegetables and fruits, enhancing nutritional security, which is an important component of food security. Excessive chemical use has degraded India's topsoil, as soil health is damaged from increased atmospheric temperatures, which speed up breakdown of soil organic matter and increase microbial respiration, which depletes essential nutrients in the soil. Some practices that are a part of SA, such as organic farming and crop rotation, restore soil fertility and water retention, making long-term food production more secure.

6.1.3 Economic and environmental benefits: For the 86 percent of smallholder and marginal farmers, SA significantly lowers production costs by replacing expensive external inputs. With an average farm size of about 0.65 ha and nearly 46 percent population dependent on the agricultural sector, the average Indian farmer, who cannot afford protection costs up front, becomes debt laden. Diversified systems provide multiple income streams, reducing market risk. Environmentally, SA cuts chemical run-off into waterways and reduces air pollution through practices such as zero-tillage, thereby protecting India's natural resources and biodiversity. According to the 2024 World Air Quality Report, India is ranked as the 5th most polluted country globally, and as of 2023/2024, 83 of the 100 most polluted cities in the world are in India. Agriculture is a major source of environmental pollution in India [about 19% greenhouse gas (GHG) emissions, to which one can add heavy levels of water pollution from chemical runoff.] Hence, any effort that can bring down environmental protection should figure high up on our agenda.

The future of farming in India hinges on transitioning from input-intensive and ecologically damaging MA practices to SA methods, which include climate-smart agriculture and other nature-friendly practices. The focus needs to shift from predominantly cereal production toward diversification, including crops such as fruits, vegetables, pulses, and millets, with minimal use of external chemical inputs.

6.2 Major Changes SA can Bring to India

Many of the challenges that are (or may be) faced by countries in implementing SA have been described in Sections 2 and 3. Here, we highlight a few issues that are crucial in scaling up SA in India. More specifically, these are (1) the adoption of precision agriculture and new technology; (2) refocusing from agroclimatic zones (ACZs) to agroecological zones (AEZs); and (3) improvements needed in resource management practices.

6.2.1 Precision agriculture and new technology: The adoption of what has been variously called "Agriculture 4.0" or "Smart Farming", or the fourth agricultural revolution, which integrates digital technologies, IoT, AI, and robotics into farming, will need to be speeded up. This means using the methods of Precision Agriculture, as well as newer technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), drones, and remote sensing. Those tools will help farmers make the appropriate decisions about time of planting, watering, and applying fertiliser, based on science. That would increase the efficiency of resources (using less water and chemicals) and productivity. From there, it can move on to "Agriculture 5.0," the next evolutionary phase in farming, blending advanced technologies like Artificial Intelligence (AI) and robotics with ecological sustainability and human-machine collaboration. This kind of SA goes beyond older methods by using accurate, detailed data, and advanced AI-driven analytics, to help farmers make smart decisions in real time. In the end, Agriculture 5.0 will be a big change in farming that makes it smarter, data-driven, flexible, and much more resilient to economic and environmental stress. These methods may seem far away, but if research and development progress with the right amount of investment, the time it takes could be considerably reduced.

6.2.2 Agroecological zones (AEZs) defined: At present, different agricultural lands are classified, with the focus on agroclimatic zones (ACZ). To successfully implement SA, there is a need for redefine environmental variables affecting different major food crops (for food security) and group the best sites for cultivation of specific crops, to avoid yield losses resulting from their being grown in inappropriate zones. While the ACZ focus almost exclusively on weather patterns, agro-ecological zones (AEZ) provide a more detailed view, by integrating soil and landform data. They will thus help crop diversification in different agroecological zones. These strategies may also be useful for crop improvement scientists to identify appropriate germplasm and improve breeding efforts to maximize future food production.

6.2.3 Improvements in resource management: Until the recent past, natural resource management for the agricultural field has been a mixed bag, with excessive use of water, intensive cropping, etc. In recent years, however, there has been a significant shift toward regenerative practices, digital precision, and decentralized community-led models. The management of soil, water, and biodiversity is increasingly integrated under the umbrella of climate-resilient agriculture. Sustainable practices are focusing intensely on water-use efficiency (e.g., drip irrigation), soil health management (e.g., organic farming, crop rotation), and efficient seed (new varieties developed, using modern breeding methods). However, these changes are happening very slowly and need to be accelerated and scaled up (see 6.3, next).

6.3 Are Indian Farmers Following SA Practices Already?

Quantifying the exact number of farmers who follow SA practices India is a complex exercise, as "sustainable agriculture" encompasses a wide range of methods. However, studies provide some key statistics on the adoption of specific practices, such as crop diversification and crop rotation, natural farming, organic farming, agroforestry, precision- and micro-irrigation, and rainwater harvesting, Integrated Pest Management (IPM), and System of Rice Intensification (SRI). We provide here some information in that context.

A study by the Council on Energy, Environment and Water (CEEW) indicated that as of 2021, less than 4% of Indian farmers had adopted SA practices and systems.

6.3.1 Adoption of specific practices: While the overall percentage is low, some practices have a higher adoption rate:

- Crop Rotation: This is one of the most popular practices, covering around 30 [1]million hectares and adopted by approximately 15 million farmers.
- Natural Farming: This is noted as one of the fastest-growing practices, adopted by around 800,000 farmers by 2021.
- Organic Farming: It covered about 2.8 million hectares (or 2% of the net sown area) as of 2021. Government schemes such as the PKVY) are actively promoting this.
- Integrated Pest Management (IPM): This practice has achieved a coverage area of 5 million hectares after decades of promotion.
- Agroforestry and Rainwater Harvesting also have high coverage in terms of land area (25 million ha and 20-27 million ha, respectively).

6.3.2 How the Government of India promotes SA:

The adoption of these practices is increasing, albeit slowly, owing to growing awareness, climate-resilient technology, and governmental support in the form of finance and incentives. The financial incentive appears, understandably, to be the key for adoption of SA, given the poverty level of farmers. The most direct financial benefit for the farmer is an output-based annual incentive. Beyond the direct financial incentive, the National Mission on Natural Farming (NMNF) provides a complete ecosystem for sustainable agriculture with financial incentives, local Bio-input Resource Centres (BRC), and trained Krishi Sakhis. Natural on-farm concoctions, diversified cropping, and local cow-based livestock integration reduce the use of chemicals. The mission (NMNF) offers highly structured and localised support through several ways:

- Financial assistance and direct support: Based on the area adopted for NF, farmers are given cash support for 2 years to facilitate training, livestock maintenance, and input preparation.
- Bio-Input Resource Centres (BRC): Under the scheme, 10,000 BRCs are being set up to function as local enterprises and provide easy access to natural farming inputs to the farmers who do not produce them on-farm.
- Training and on-field handholding: More than 70,000 Krishi Sakhis, scientists, and master trainers have been trained to provide localised education, awareness, and demonstration of Natural Farming Model Farms.
- Certification and Market Access: A simple and easy certification system and a dedicated national brand to sell chemical-free produce directly in local markets, APMC Mandis, and district haats (traditional open-air, weekly, rural market or village fairs) are in place.
- Livestock Integration: The approach emphasises integrating multi-cropping systems with indigenous desi cows and other cattle, whose dung and urine are used for making vital fertility concoctions, such as Jeevamrit and Beejamrut

[1] The figures on adoption of practices are as noted in a CEEW survey, some in absolute numbers and some in percentages, because the estimated number of farmers in India varies from 38 million to 177 million!

The Indian government actively promotes sustainable farming through several initiatives, such as the following:

National Mission for SA (NMSA): This mission supports climate-resilient and resource-efficient farming in rainfed areas, with a focus on Integrated Farming Systems, water-use efficiency, and soil health management.

Paramparagat Krishi Vikas Yojana (PKVY): This program promotes organic farming by offering financial assistance of up to ₹31,500 per hectare for a 3-year period. It relies on a cluster-based, Participatory Guarantee System (PGS) approach.

National Mission on Natural Farming (NMNF): A dedicated mission that promotes chemical-free, traditional farming methods. It has allocated over ₹4,600 crore to expand natural farming to 12 lakh hectares by 2025.

Soil Health Card Scheme: Provides farmers with soil analysis and nutrient management recommendations to improve soil health and productivity.

Pradhan Mantri Krishi Sinchayee Yojana (PMKSY): Aims to increase irrigation coverage and improve water-use efficiency, vital for climate-resilient agriculture.

6.4 Challenges for Expansion of SA in India

The review of adoption of SA in India so far indicates a few major challenges including—high costs, fragmented land holdings, knowledge gaps, and lower yields—during the transition from MA to SA.

- High costs: Some sustainable practices and inputs can have higher upfront costs, creating a barrier for small and marginal farmers.
- Fragmented land holdings: Small, scattered land parcels make large-scale adoption of some sustainable practices difficult.
- Knowledge gaps: Many farmers lack awareness or training regarding modern sustainable techniques.

Lower yields during transition: The shift from conventional to sustainable methods can temporarily lower yields, which is a significant risk for farmers reliant on immediate income.

6.5 Will SA change Farmer Demographics, Workforce, and Income?

SA is steadily reshaping Indian farming by transitioning from a largely unskilled, heavily marginalized demographic profile to a more knowledge-intensive, tech-driven workforce. While initial shifts favour educated youth and larger landholders who can afford the transition, sustainable methods stabilize incomes long-term by reducing chemical costs and improving crop resilience against climate shocks (see https://www.ifad.org/en/w/countries/india). Some of these changes are discussed next.

6.5.1 Changes in farmer demographics: Sustainable practices are reshaping gender roles, age distribution, and structural size of farms in India. Here are some salient points to be noted:

- Reverse migration to urban areas: Tech-savvy, educated rural youth are being lured back from cities to rural areas with high-tech sustainable systems like precision drone farming, micro-irrigation networks, and automated polyhouses.
- Recognition of the role of women: Women perform most of the manual work in Indian agriculture. Programmes such as the National Mission on Natural Farming (NMNF) increase localised bio-input production, upgrading women from casual labourers to managers of rural enterprise clusters.
- Enhanced role for FPOs: Most of the 85% of India's small and marginal landholders cannot absorb transition risks on their own. "Demographic survival is very much reliant on Farmer Producer Organisations (FPOs), which pool resources for certification and green machinery.

6.5.2 Workforce change: In sustainable practices, high-volume chemical dependencies are substituted with intensive knowledge and continuous labour deployment, and the following changes result:

- Eliminating under employment: Seasonal machinery depends heavily on chemical farming. Sustainable practices, such as intercropping, agroforestry, and the system of rice intensification (SRI), require constant management of the field throughout the year, thereby converting underemployed family labour into productive manpower.
- Emergence of agricultural specialists: SA generates localised, skilled job markets for irrigation technicians, data analysts, and managers of custom hiring centres.
- Decentralized manufacturing inputs: The adoption of bio-fertilizers and organic compost shifts the supply chain workforce from large chemical manufacturing plants to small processing hubs in rural villages.

6.5.3 Re-shaping of farm income: Correcting the systemic high-input cost structures that have historically led to farm debt is leading to improved net margins. The following factors are relevant in this regard:

- Reduction in cost of cultivation: Precision resource mapping eliminates over-application of urea and pesticide. It thus cuts operating costs upfront, which stabilises cash flows in the near term.
- Diversification of risk: Transition through RAD (Rainfed Area Development) model creates multiple and parallel streams of income. A household that combines staple farming with livestock, horticulture, or fisheries is no longer wiped out completely by one crop failure.

- Bridging the transition gap: Policy frameworks, such as NMNF, provide localised financial cushions to sustain household income during the transition phase to offset the initial 1-to-3-year yield drop experienced during soil rehabilitation.
- Reverse migration to urban area: Tech-savvy, educated rural youth are being lured back from cities to rural areas with high-tech sustainable systems like precision drone farming, micro-irrigation networks, and automated polyhouses.
- Recognition of role of women: Women perform most of the manual work in Indian agriculture. Programmes such as the National Mission on Natural Farming (NMNF) increase localised bio-input production, upgrading women from casual labourers to managers of rural enterprise clusters.
- Enhanced role for FPOs: The 85% of India’s small and marginal landholders cannot absorb transition risks on their own. ‟Demographic survival is very much reliant on Farmer Producer Organisations (FPOs) to pool resources for certification and green machinery.

6.5.4. Re-shaping of farm income: Correcting the systemic high-input cost structures that have led to farm debt historically is leading to improved net margins, as evident in the following:

- Reduction in cost of cultivation: Precision resource mapping eliminates over-application of urea and pesticide; That cuts operating costs upfront, which stabilises cash flows in the near term.
- Diversification of risk: Transition through RAD (Rainfed Area Development) model creates multiple parallel streams of income. A household that combines staple farming with livestock, horticulture or fisheries is no longer wiped out completely by one crop failure.
- Bridging the transition gap: Policy frameworks e.g., NMNF etc. provide localised financial cushions to sustain household income during the transition phase to offset the initial 1-to-3-year yield drop experienced during soil rehabilitation.

6.6 Evaluation of Efforts to Promote SA in India: Some Suggestions

India's current strategy centres on moving away from the chemical-intensive model of the Green Revolution, particularly in vulnerable regions, by promoting organic, natural, and climate-resilient farming practices. Key government schemes include the Paramparagat Krishi Vikas Yojana (PKVY), which promotes organic farming in clusters, the National Mission on Sustainable Agriculture (NMSA), which focuses on climate resilience, and the newer National Mission on Natural Farming (NMNF). Some of the successes (Table 4) and the challenges that remain to be addressed (Table 5) are shown below.

Table 4. Successes in Sustainable Agriculture in India

Success Area	Key Achievement and Impact
Increased Organic/Natural Area & Farmer Numbers	India boasts the largest number of organic farmers globally. Schemes such as PKVY have enrolled millions of farmers and covered a significant area (around 1.5 million hectares).
Improved Livelihoods and Reduced Costs	Studies on PKVY beneficiaries show a significant positive impact on farmers' livelihoods, including increased income from farming, reduced costs, and improved asset ownership. Farmers in organic clusters report lower costs (10-19%), compared to conventional farming.
Soil Health Focus	The Soil Health Card Scheme distributed over 23 crore cards since 2015, providing data-driven guidance on nutrient management, which is a crucial first step in reducing indiscriminate chemical use.
Community and Local Certification	PKVY's promotion of the Participatory Guarantee System (PGS-India) has provided a cost-effective, decentralized, and trustworthy organic certification mechanism for domestic markets, empowering farmer groups.
Water Conservation	Schemes such as the Pradhan Mantri Krishi Sinchai Yojana promote micro-irrigation (drip and sprinkler), vital for conserving water in agriculture, which accounts for over 80% of India's freshwater use.

Table 5. Challenges remaining

Failure/Challenge Area	Description and Impact
Policy Inconsistency and Budget Allocation	The Green Revolution legacy persists, with massive subsidies on chemical fertilizers (e.g., ₹1.75 lakh crore in 2023-24), disincentivizing the shift to organic/natural farming. The budget for NMSA remains a small fraction of the total agriculture budget.
Low Adoption Rate	Despite schemes, sustainable agriculture practices (SAPs), such as agroforestry, mulching, and precision farming, are adopted by less than 5% of the net sown area, showing limited mainstreaming.
Initial Yield Dip and Transition Costs	The transition period (3-5 years) for organic farming often involves an initial yield decline (estimated 4-5%) and high upfront costs, which smallholder and marginal farmers (over 86% of Indian farmers) struggle to bear without adequate support.
Market and Value Chain Gaps	There is a lack of assured Minimum Support Price (MSP) or premium pricing for organic/natural produce, and an unorganized supply chain, making it difficult for farmers to secure remunerative prices and a consistent market

Failure/Challenge Area	Description and Impact
Knowledge and Extension Gap	There is an awareness gap, with a small fraction of farmers knowledgeable about schemes such as PKVY or Natural Farming techniques. The extension system often lacks the manpower and expertise to provide the intensive handholding required for agro-ecological systems.

6.6.3 Suggestions for Future Action

While we already made some broad suggestions in Section 5 (covered in Part 2 of this 3-part series), we now name a few specific actions that are needed for establishing a supportive ecosystem that makes SA economically viable and less risky for Indian farmers. They are specifically listed next.

1. Realigning the budget and supporting the market: We need to move away from subsidizing chemical fertilisers, towards a "Green Incentive" model. That would include providing money to support bio-inputs and giving farmers a per-hectare transition payment, to make up for temporary losses in yield during the early years of transition. We also need to consider providing for ecological services that can enable farmers to practice SA, as they not only contribute to food security but also go toward ensuring a secure future.

2. Strengthen value chains and procurement: We need to set up a Sustainable Produce Procurement Fund to give millets, pulses, and oilseeds price premiums or a minimum support price (MSP). At the same time, we need to ensure that these local, sustainable crops are added to the Public Distribution System (PDS) and the School Mid-Day Meal programs in stages, and to put money into storage and processing infrastructure at the rural hubs.

3. Participatory research and new ideas: We need to instil the participatory research approach, done on farms and with farmers, and create a "Scientific Packages of Practice" for India's varying agro-ecological zones, with a focus on net economic returns, labour efficiency, and soil health metrics.

4. Breeding for sustainability: We need greater use of both innovative genomic tools and traditional knowledge to create and test improved varieties that are resistant to pests, drought, and have improved nutrient-use efficiency. This will reduce the need for external chemical inputs.

5. Extension, technology, and building capability: We need to practise the 'Localisation of Knowledge' and expand the "Krishi Sakhi" network, by giving Krishi Vigyan Kendras (KVKs) the power to give intensive, localised training. We need to then use successful early adopters as "Master Trainers" for peer-to-peer learning, and to make sure that scientific credibility is backed up by on-farm demonstrations. Putting environmental stewardship and sustainable food systems into the formal education system is a way to make them a part of everyday life, and it will help create a new generation of scientists and farmers who see sustainability as the norm, rather than an option.

6. Precision agriculture 5.0: We need to use Agri-Tech (drones, IoT, and AI) to make farming more sustainable and less work-intensive. We need to use these tools to manage nutrients and water with precision. This would help the shift from Agriculture 4.0 to the more human-centred, resilient models of Agriculture 5.0.

7. Public awareness and integrated policy: We need to make sure that national missions (such as NMSA, PKVY, NMNF) work together with water and climate programs. Such an approach would include moving from one-time grants to a long-term, planned Sustainable Agriculture Budget, and adding environmental stewardship to the curricula of rural schools and colleges.

Concluding Remarks

In Part 1 of this 3-part series, we emphasised how soil erosion, chemical pollution, and significant greenhouse gas emissions from industrial, high-input farming—which has historically been productive—are currently harming the planet's life-support systems. The transition into socioeconomic (reducing food waste, assisting family farms, and creating wealth) and biophysical (healthy soils, precision fertilisation, and agroforestry) factors were elaborated.

In Part 2, we described the inherent tension between immediate financial gain and long-term resilience as a major and recurrent theme. We explained how MA generates an "environmental debt," though it provides fast capital and steady returns. On the other hand, SA presents challenges such as initial yield dips (during a 3–5-year transition), financial uncertainty, and an "infrastructure lock-in" that is intended for monocultures, despite providing systemic resilience and lower input costs.

In Part 3, we discussed the case of India, pointing out that although only 4% of farmers have embraced SA yet, the need is critical, considering that 46% of the population is employed in agriculture. To ensure future food security, the specific policy recommendations that emerge would include investing in "Agriculture 5.0" (AI and IoT), realigning subsidies away from chemicals toward "green incentives," and utilising both traditional knowledge and modern genomics.

Summing up more broadly, SA is essential for India's future. It is not an option but a critical need, driven by climate change risks and the limitations of input-intensive farming. With over half the population relying on agriculture, SA is vital for building climate resilience (preventing a projected 47% decrease in rainfed rice yield), ensuring water security (by promoting efficient use), and restoring soil health. By replacing expensive chemical inputs, SA lowers production costs for smallholder farmers, boosts their income, and encourages crop diversification (growing of millets, pulses, oilseeds, etc.).

It is heartening to note that in the Global Tipping Points (2025) reports, two developments in India are shown as positive tipping points in the present scenario of global climate change: (1) collaborative community action to repair and maintain traditional water harvesting methods/structures; and (2) ongoing efforts to make smallholder farms more sustainable. The scaling up SA requires accelerating Precision Agriculture (Agri 4.0 and 5.0), rebalancing massive fertilizer subsidies towards green incentives, and strengthening farmer and community organisations, such as FPOs, to create profitable, climate-smart food systems.

Acknowledgements:

The authors would like to acknowledge the significant contributions of **Dr. D.R. Mohan Raj** for his meticulous rearrangement of the chapters and his excellent editing, which enhanced the paper's readability.

Suggested Further Reading (For all 3 Parts)

Altieri, M.A. and Nicholls, C.I., 2017. The adaptation and resilience strategies of Western Guatemalan smallholder farmers to climate change. [online] Available at: https://agroecology.org/

Bodirsky, B.L., Popp, A., and others (2025) 'The levers for a sustainable food system: a large-scale model study on limiting global warming to 1.85°C', Nature Food. https://www.nature.com/articles/s43016-025-01268-y

CEEW, 2021. Sustainable Agriculture in India: National Programme for Sustainable Agriculture (NMSA) and Beyond. New Delhi: Council on Energy, Environment and Water. [online] Available at: https://www.ceew.in/publications/sustainable-agriculture-india

Citation: Xu, J., Li, Y., Zhang, M., and Zhang, S. (2026) 'Sustainable agriculture in the digital era: Past, present, and future trends by bibliometric analysis', Heliyon, 10(1), e34612. https://www.sciencedirect.com/science/article/pii/S2405844024106433

Falconer, K., 2000. Farm-level constraints on agri-environmental scheme participation: a transactional analysis. Journal of Rural Studies, 16(3), pp.379-394. [online] Available at: https://doi.org/10.1016/S0743-0167(99)00065-

FAO and IFAD, 2019. United Nations Decade of Family Farming 2019-2028. Global Action Plan. Rome: FAO. [online] Available at: https://www.fao.org/3/ca4672en/ca4672en.pdf

FAO, 2018. The Benefits and Risks of Solar-Powered Irrigation - A Global Overview. Rome: Food and Agriculture Organization of the United Nations. [online] Available at: https://www.fao.org/3/I9047EN/i9047en.pdf

FAO, 2018. The State of the World's Biodiversity for Food and Agriculture. Rome: FAO Commission on Genetic Resources for Food and Agriculture Assessments. [online] Available at: https://www.fao.org/3/CA3129EN/CA3129EN.pdf

FAO, 2019. The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction. Rome: Food and Agriculture Organization of the United Nations. [online] Available at: https://www.fao.org/3/ca6030en/ca6030en.pdf

Feder, G. and Umali, D.L., 1993. The adoption of agricultural innovations: A review. Technological Forecasting and Social Change, 43(3-4), pp.215-239. [online] Available at: https://doi.org/10.1016/0040-1625(93)90053-A

Food and Agriculture Organization of the United Nations (2025) Transforming agrifood systems through climate science: updates on linkages between climate, agriculture, and food systems. White Paper. Rome: FAO. https://www.fao.org/climate-change/news/news-detail/cop30---new-fao-report-updates-evidence-base-on-linkages-between-climate-agriculture-and-food-systems/en

Fuchs, R., Brown, C. and Rounsevell, M., 2020. Europe's Green Deal offshores environmental damage to other nations. Nature, 586, pp.671-673. [online] Available at: https://www.nature.com/articles/d41586-020-02991-1

Global Tipping Points, 2023. The Global Tipping Points Report 2023. University of Exeter & Bezos Earth Fund. [online] Available at: https://global-tipping-points.org/

Gupta, N., et al., 2021. Sustainable Agriculture in India 2021: What we know and how to scale up. New Delhi: Council on Energy, Environment and Water. [online] Available at: https://www.ceew.in/publications/sustainable-agriculture-india-202

HLPE, 2019. Agroecological and other innovative approaches for sustainable agriculture and food systems. Rome: High Level Panel of Experts on Food Security and Nutrition. [online] Available at: https://www.fao.org/3/ca5602en/ca5602en.pdf

Horrigan, L., Lawrence, R.S. and Walker, P., 2002. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environmental Health Perspectives, 110(5), pp.445-456. [online] Available at: https://doi.org/10.1289/ehp.02110445

IFAD, 2021. Rural Development Report: Transforming food systems for rural prosperity. Rome: International Fund for Agricultural Development. [online] Available at: https://www.ifad.org/en/rural-development-report/

International Food Policy Research Institute (2025) 2025 Global Food Policy Report: Food Policy for a Changing World. Washington, DC: IFPRI. https://www.google.com/url?q=https%3A%2F%2Fhdl.handle.net%2F10568%2F174108

IPBES, 2019. Global assessment report on biodiversity and ecosystem services. Bonn: IPBES Secretariat. [online] Available at: https://doi.org/10.5281/zenodo.383167

IPCC, 2022. Climate Change 2022: Mitigation of Climate Change. Cambridge: Cambridge University Press. [online] Available at: https://www.ipcc.ch/report/ar6/wg3/

IPCC, 2023. Climate Change 2023: Synthesis Report. Geneva: IPCC. [online] Available at: https://www.ipcc.ch/report/ar6/syr/

IPES-Food, 2016. From Uniformity to Diversity: A paradigm shift from industrial agriculture to diversified agroecological systems. [online] Available at: https://www.ipes-food.org/reports/

IQAir, 2024. 2023 World Air Quality Report. [online] Available at: https://www.iqair.com/world-most-polluted-countries

Jose, S., 2009. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems, 76(1), pp.1-10. [online] Available at: https://link.springer.com/article/10.1007/s10457-009-9221-7

Kassam, A., Friedrich, T. and Derpsch, R., 2019. Global spread of Conservation Agriculture. International Journal of Environmental Studies, 76(1), pp.29-51. [online] Available at: https://doi.org/10.1080/00207233.2018.1498157

Knoke, T., et al., 2020. The economics of agriculture and forestry under environmental change. Review of Environmental Economics and Policy, 14(1). [online] Available at: https://doi.org/10.1093/reep/rez011

Lal, R., 2020. Managing soils for negative emissions and positive outcomes. Soil and Tillage Research, 196, 104421. [online] Available at: https://doi.org/10.1016/j.still.2019.104421

Lawrence, D. and Vandecar, K., 2015. Effects of tropical deforestation on climate and agriculture. Nature Climate Change, 5, pp.27-36. [online] Available at: https://www.nature.com/articles/nclimate2430

Magrini, M.B., et al., 2016. Why are grain-legumes rarely present in cropping systems? Frontiers in Plant Science, 7, p.1923. [online] Available at: https://doi.org/10.3389/fpls.2016.01923

Ministry of Agriculture & Farmers Welfare, 2023. Annual Report 2022-23. Government of India. [online] Available at: https://agricoop.nic.in/en/AnnualReport

Mondéjar, M.E. et al. (2025) 'Advancing sustainable agriculture for goal 2: zero hunger - a comprehensive overview of practices, policies, and technologies', Agroecology and Sustainable Food Systems, 49(1). (Several articles at https://www.tandfonline.com/toc/wjsa21/49/1

NITI Aayog, 2022. Compendium of Success Stories: Natural Farming in India. [online] Available at: https://www.niti.gov.in/publications

NMNF, 2023. Operational Guidelines for National Mission on Natural Farming. New Delhi: Department of Agriculture and Farmers Welfare. [online] Available at: https://naturalfarming.dac.gov.in/

Nordhaus, T. and Shah, S., 2022. In Sri Lanka, Organic Farming Went Catastrophically Wrong. Foreign Policy. [online] Available at: https://foreignpolicy.com/2022/03/05/sri-lanka-organic-farming-crisis/

OECD, 2023. Agricultural Policy Monitoring and Evaluation 2023. Paris: OECD Publishing. [online] Available at: https://doi.org/10.1787/b4a39855-en

Pingali, P., et al., 2019. Transforming Food Systems for a Rising India. London: Palgrave Macmillan. [online] Available at: https://link.springer.com/book/10.1007/978-3-030-14409-8

Pingali, P.L., 2012. Green Revolution: Impacts, limits, and the path ahead. Proceedings of the National Academy of Sciences, 109(31), pp.12302-12308. [online] Available at: https://doi.org/10.1073/pnas.0912953109

Ponisio, L.C., et al., 2015. Diversification practices reduce organic to conventional yield gaps. Proceedings of the Royal Society B: Biological Sciences, 282(1799). [online] Available at: https://doi.org/10.1098/rspb.2014.1396

Pretty, J. and Bharucha, Z.P., 2014. Sustainable intensification in agricultural systems. Annals of Botany, 114(8), pp.1571-1596. [online] Available at: https://doi.org/10.1093/aob/mcu205

Pretty, J., 2020. Social capital and the collective management of resources. Science, 302(5652), pp.1912-1914. [online] Available at: https://www.science.org/doi/10.1126/science.1090847

Ricciardi, V., et al., 2018. How much of the world's food do smallholders produce? Global Food Security, 17, pp.64-72. [online] Available at: https://doi.org/10.1016/j.gfs.2018.05.002

Salzman, J., et al., 2018. The global status and trends of Payments for Ecosystem Services (PES). Nature Sustainability, 1, pp.136-144. [online] Available at: https://www.nature.com/articles/s41893-018-0033-0

Sear hinger, T., et al., 2019. Creating a Sustainable Food Future. Washington, DC: World Resources Institute. [online] Available at: https://www.wri.org/research/creating-sustainable-food-future

Seufert, V., Ramankutty, N. and Foley, J.A., 2012. Comparing the yields of organic and conventional agriculture. Nature, 485, pp.229-232. [online] Available at: https://www.nature.com/articles/nature11069

Tilman, D., et al., 2011. Global food demand and the sustainable intensification of agriculture. PNAS, 108(50), pp.20260-20264. [online] Available at: https://doi.org/10.1073/pnas.1116437108

Tittel, P., 2014. Livelihood strategies, land use and Meso-scale optimization of sugarcane production. Agricultural Systems, 126, pp.10-23. [online] Available at: https://doi.org/10.1016/j.agsy.2013.01.001

UNEP, 2024. Food Waste Index Report 2024. Nairobi: United Nations Environment Programme. [online] Available at: https://www.unep.org/resources/report/food-waste-index-report-2024

Vollert, S.E., et al., 2020. Fertility, mortality, migration, and population scenarios for 195 countries and territories. The Lancet, 396(10258), pp.1285-1306. [online] Available at: https://doi.org/10.1016/S0140-6736(20)30677-2

Willett, W., et al., 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet, 393(10170), pp.447-492. https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(18)31788-4/abstract

GRSV Web papers

Gowda, CLL () Can organic agriculture sustainably feed the future world population? https://grsvconsulting.com/wp-content/uploads/dlm_uploads/2018/09/Can-Organic-Agriculture-Alone-Sustainably-Feed-the-World.pdf

Shetty, SVR. RAINFED AGRICULTURE: RESOURCE BASE, TECHNOLOGIES AND SOCIETAL IMPERATIVES https://grsvconsulting.com/wp-content/uploads/dlm_uploads/2020/05/SVR_Rainfed-agriculture_Resource-base-technologies-and-social-imperatives.pdf

Shetty, SVR, MVK Sivakumar, S Huda, and J Harikrishna. Holistic Natural resources management needed for sustainable Agriculture. https://grsvconsulting.com/Perspectives.pdf