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Net-Zero Agriculture: Myth or Reality? Climate-Smart Pathways for the Farms of North India

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In a village outside Karnal, a wheat farmer checks his phone for the third time before sunrise, not for messages but for the weather. The last three winters have not behaved the way his father's diaries said they should: warm spells arrive early, a cold snap follows, and the wheat crop that once knew exactly when to flower now seems confused. A few hundred kilometres west, in Punjab's Malwa belt, another farmer watches a haze settle over his fields every October and November, the smoke from burnt paddy stubble mixing with diesel fumes from tube wells running almost continuously to chase a falling water table. These are not isolated scenes. They are the daily reality of farming in North India in the 2020s, a region that feeds the nation but is now on the front line of a warming climate it did comparatively little to create.

Agriculture sits at an unusual crossroads in the climate story. It is both a victim of climate change and, through the greenhouse gases released by livestock, flooded rice paddies, fertiliser use, and burnt residues, a contributor to it. Globally, agriculture, forestry, and other land use accounted for roughly a fifth of all human-caused greenhouse gas emissions between 2010 and 2019 (IPCC, 2022). At the same time, nowhere is the food system's vulnerability to a changing climate more visible than in the Indo-Gangetic Plain, where heat waves, groundwater depletion, and erratic monsoons are already reshaping how, when, and what farmers grow.

Into this picture comes an ambitious idea: net-zero agriculture, a food system that removes as much greenhouse gas as it emits. India itself has pledged to reach economy-wide net-zero emissions by 2070, one of the five commitments Prime Minister Narendra Modi announced at the COP26 summit in Glasgow as the country's 'Panchamrit', or five nectar elements, of climate action (Press Information Bureau, 2021). Agriculture, employing nearly half of India's workforce and defining the landscape of states from Punjab to Uttar Pradesh, will inevitably be part of that journey.

But can a sector built on biology on ruminant digestion, flooded soils, and the basic chemistry of nitrogen ever truly reach zero net emissions? Or is 'net-zero agriculture' better understood as a direction of travel rather than a finish line: a bundle of practical, provable practices that cut emissions, lock carbon back into soils and trees, and, crucially, leave farmers better off? This article sets out to answer a single question that matters as much to a scientist in a laboratory as it does to a farmer standing in a scorched wheat field: is net-zero agriculture a myth, or is it a reality already within reach?

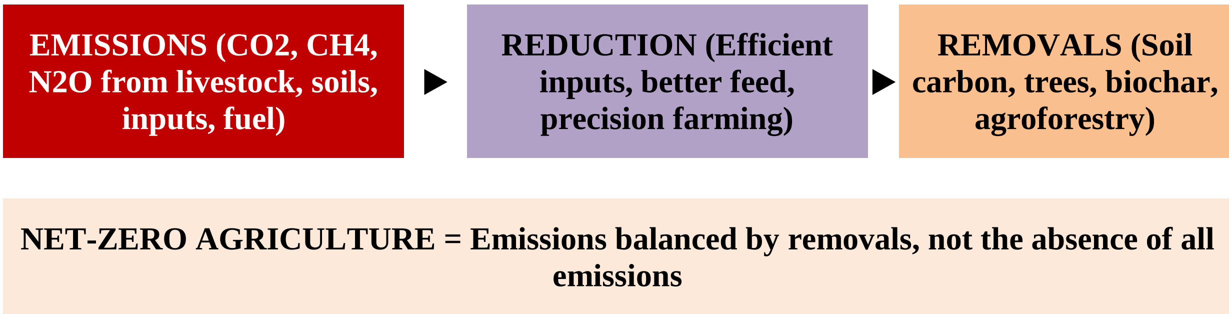

Figure 1. The concept of net-zero agriculture: balancing unavoidable emissions with deliberate reductions and carbon removals.

Understanding Net-Zero Agriculture

'Net-zero' is often used loosely, so it is worth being precise. A farm, a company, or a country reaches net-zero when the greenhouse gases it releases into the atmosphere are balanced by an equivalent amount removed, whether through natural sinks such as soils and forests or through technology. Net-zero is not the same as carbon neutrality, a related but narrower idea usually applied to carbon dioxide alone; a genuinely net-zero farming system must also account for methane (CH_4) and nitrous oxide (N_2O), the two gases that dominate agricultural emissions.

These three gases behave differently, and that difference matters for policy and for farmers alike. Carbon dioxide is released mainly from diesel-powered machinery, irrigation pumps, and the loss of soil organic carbon when land is tilled or converted. Methane, roughly 27 to 30 times more powerful than CO_2 as a warming agent over a century, comes chiefly from the digestive systems of cattle and buffalo and from flooded rice paddies, where waterlogged soil creates ideal conditions for methane-producing microbes. Nitrous oxide, which can be over 250 times more potent than CO_2, is released when nitrogen fertiliser is applied in excess of what a crop can use, particularly under wet soil conditions typical of the rice-wheat belt.

Understanding this chemistry explains why 'net-zero agriculture' cannot simply mean eliminating every emission. Cattle will continue to digest fibrous feed through microbial fermentation, and rice will continue to be grown in flooded fields across much of Asia. What net-zero agriculture asks for instead is a serious, measurable effort to shrink emissions per unit of food produced, while actively building up the carbon stored in soils, trees, and other biomass so that the books, over time, come close to balancing.

Agriculture's Carbon Footprint

Four sources dominate agriculture's contribution to climate change in North India. Livestock the region's vast population of dairy cattle and buffalo release methane through enteric fermentation, the microbial digestion of fibrous fodder in the rumen, and through stored manure. Rice cultivation, especially the continuously flooded paddies common across Punjab, Haryana, and eastern Uttar Pradesh, is one of the largest single agricultural sources of methane worldwide, since submerged soil starves decomposing organic matter of oxygen and favours methane-producing microbes. Synthetic nitrogen fertiliser, applied heavily to sustain the yields of the rice-wheat system, is the principal source of nitrous oxide. And diesel-powered tractors, threshers, and tube-well pumps add a steady stream of carbon dioxide, compounded in many districts by the practice of burning crop residue.

Residue burning deserves particular attention because it concentrates so much environmental and human cost into a few weeks each year. An estimated 2.5 million farmers across northwest India burn some 23 million tonnes of rice straw after the kharif harvest to clear fields quickly for wheat sowing, a practice linked to significant air pollution across the Indo-Gangetic Plain and to tens of thousands of premature deaths annually from exposure to fine particulate matter (Keil et al., 2021). Beyond the smoke, burning destroys soil organic matter and the nutrients and microbial life it supports, undermining the very productivity farmers are trying to protect.

Table 1. Major sources of agricultural greenhouse gas emissions relevant to North India, their impact, and common mitigation approaches.

Source	Main Gas(es)	Impact	Mitigation Approach
Livestock (enteric fermentation & manure)	CH4, N2O	Largest single source of farm methane; affects air quality and warming on short timescales	Improved fodder quality, balanced feeding, manure management, biogas recovery
Flooded rice cultivation	CH4	Major regional methane source from waterlogged, low-oxygen soils	Alternate wetting and drying (AWD), direct seeded rice (DSR), mid-season drainage
Synthetic nitrogen fertilisers	N2O	Excess/unbalanced use raises emissions and input costs without raising yield	Soil-test based dosing, Soil Health Cards, biofertilisers, split application
Farm machinery & diesel irrigation pumps	CO2	Fossil-fuel combustion for tillage, harvesting, and groundwater pumping	Solar pumps (PM-KUSUM), laser land levelling, conservation tillage
Crop residue burning	CO2, CH4, N2O, particulate matter	Severe seasonal air pollution; loss of soil organic matter and nutrients	Happy Seeder/Super Seeder, in-situ incorporation, ex-situ residue use
Land-use change & soil degradation	CO2	Loss of stored soil and biomass carbon reduces the land's own carbon sink	Agroforestry, cover cropping, reduced/zero tillage

Taken together, these sources make agriculture, forestry, and other land use responsible for an estimated 13 to 21 percent of global anthropogenic greenhouse gas emissions between 2010 and 2019 (IPCC, 2022; UNFCCC, n.d.). The picture is shifting: agriculture's relative share of global emissions has actually declined over recent decades even as absolute emissions from energy and industry have grown faster (FAO, 2019). That is a reminder that farming is not the world's biggest climate problem but it is one of the most solvable, because so many of the fixes also make farms more resilient and more profitable.

Why Net-Zero Agriculture Matters

The case for pursuing net-zero agriculture rests on more than atmospheric chemistry. Food security in a country of over a billion people depends on the same soils, aquifers, and monsoon patterns that climate change is now disrupting. Heat stress during grain filling can quietly shave yield off a wheat crop long before a farmer notices; erratic rainfall can wash away a standing crop or delay sowing past the window that a variety needs. Every tonne of emissions avoided or carbon re-absorbed into soil is, indirectly, an investment in the stability of future harvests. Soil health and biodiversity are similarly bound up with the net-zero agenda. Practices that build soil organic carbon reduced tillage, residue retention, cover cropping, agroforestry also improve water infiltration, support soil microbial life, and provide habitat for pollinators and natural pest predators. Water resources, already under acute stress in Punjab and Haryana where groundwater tables have fallen sharply due to decades of rice cultivation and heavily subsidised electricity for pumping, stand to benefit directly from water-saving practices that also happen to cut emissions, such as direct seeded rice and alternate wetting and drying. These co-benefits connect North Indian farming decisions to global commitments. The Paris Agreement, adopted under the UNFCCC in 2015, commits signatory countries, including India, to pursue efforts to limit global warming and to strengthen the ability of food systems to adapt. The UN's Sustainable Development Goals reinforce the same logic: SDG 2 on ending hunger and SDG 13 on climate action are, in agriculture, effectively two sides of the same coin. A farming system that ignores climate risk cannot deliver food security for long; a climate strategy that ignores farmers' livelihoods will not be adopted at scale.

Pathways Towards Net-Zero Agriculture

No single technology delivers net-zero agriculture. It emerges from a portfolio of approaches, each addressing a different part of the emissions and removals ledger. Climate-smart agriculture, a framework popularised by the FAO and the CGIAR research programme on Climate Change, Agriculture and Food Security, pursues three goals simultaneously: higher productivity, greater resilience to climate shocks, and lower emissions where possible. Regenerative agriculture emphasises rebuilding soil organic matter and biological activity through minimal disturbance, diverse rotations, and permanent soil cover. Precision agriculture uses data, sensors, and variable-rate technology to apply water, nutrients, and pesticides only where and when they are needed, cutting waste and emissions together. Agroforestry deliberately integrating trees with crops or livestock adds a long-lived carbon sink to the farm while diversifying income through timber, fruit, or fodder. Carbon farming and biochar (a stable, carbon-rich material made by heating biomass with limited oxygen) go a step further, actively drawing carbon out of the short-term cycle and locking it into soils for decades to centuries, with biochar shown in peer-reviewed research to durably sequester carbon while improving soil water-holding capacity (Woolf et al., 2010). Renewable energy solar-powered irrigation in particular replaces diesel combustion at the pump with sunlight. Conservation agriculture, efficient irrigation, and sustainable nutrient management round out the portfolio, each trimming a different slice of the farm's carbon footprint.

Table 2. Sustainable agricultural practices and their principal climate benefit.

Practice	Primary Climate Benefit
Climate-smart agriculture	Integrates productivity, resilience, and emission reduction as joint goals
Regenerative / conservation agriculture	Builds soil organic carbon; reduces fuel use from tillage
Precision agriculture	Cuts over-application of water, fertiliser, and pesticide
Agroforestry	Adds a long-term, on-farm carbon sink and diversified income
Carbon farming & biochar	Actively sequesters carbon in soil for the long term
Renewable energy (solar irrigation)	Displaces diesel and grid-electricity emissions at the pump
Efficient / micro-irrigation	Saves groundwater and the energy used to pump it
Sustainable nutrient management	Reduces N2O emissions from excess fertiliser

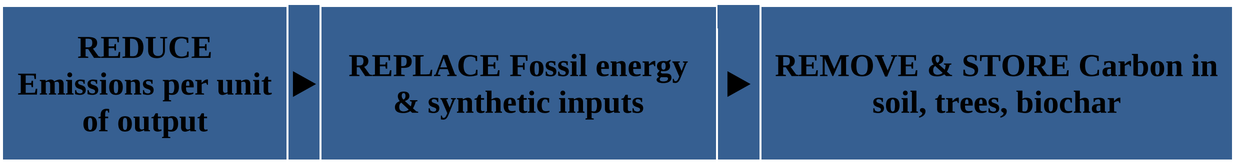

Figure 2. Pathways towards net-zero agriculture: reduce, replace, and remove.

Digital Technologies

If climate-smart practices are the 'what' of net-zero agriculture, digital technology is increasingly the 'how'. Artificial intelligence and machine learning are being used to convert satellite imagery and weather data into practical sowing and irrigation advice. The Internet of Things connects soil-moisture sensors in a field directly to a farmer's phone, ending the guesswork in deciding when to irrigate. Drones and remote sensing platforms can flag a nitrogen deficiency or a pest outbreak days before it is visible to the eye, allowing a targeted

spray rather than a blanket one. Geographic Information Systems and satellite monitoring, used at scale in countries such as the Netherlands, help track crop health, water stress, and even farm-level emissions with a precision that was unimaginable a generation ago.
Robotics and automated machinery extend the same logic to fieldwork itself, while decision-support systems stitch all of this together into a single recommendation a farmer can act on: what to plant, how much fertiliser to apply, and when to irrigate. None of this replaces agronomic knowledge; it sharpens it, turning generic advice into something specific to a single field on a single day.

AI / ML	**IoT Sensors**	**Drones & Remote Sensing**	**GIS & Satellites**	**Decision Support Systems**

Figure 3. The digital agriculture ecosystem: data-driven tools feeding into a single farm-level decision-support layer.

India's Journey

India's climate commitments give the net-zero agriculture conversation a firm policy anchor. At COP26 in Glasgow in 2021, Prime Minister Narendra Modi pledged that India would reach net-zero emissions by 2070, alongside four other 2030 targets on renewable energy capacity and emissions intensity, together described as the 'Panchamrit' (Press Information Bureau, 2021). Agriculture-specific programmes have been building towards this goal for over a decade. The National Mission for Sustainable Agriculture and its National Innovations on Climate Resilient Agriculture (NICRA) initiative, run by the Indian Council of Agricultural Research, develop and demonstrate climate-resilient crop varieties and practices for vulnerable districts, including several in North India. On the energy side, the PM-KUSUM scheme supports farmers in installing solar-powered irrigation pumps and solarising existing grid-connected pumps, directly displacing diesel and reducing farmers' energy costs while advancing India's renewable energy goals (Ministry of New and Renewable Energy, n.d.; CEEW, 2026). The Soil Health Card scheme, launched in 2015, has issued crore of cards helping farmers apply fertiliser based on actual soil test results rather than habit, contributing to more judicious, lower-emission nutrient use (Press Information Bureau, 2015). More recently, the National Mission on Natural Farming, launched in 2024 with an outlay of over ₹2,481 crore, aims to extend chemical-free, low-input farming practices to a large number of farmers through model farms and bio-input resource centres (FAO, 2024). A Digital Agriculture Mission is similarly extending data infrastructure farmer registries, digital crop surveys, and advisory platforms to the village level.

Table 3. Selected Government of India policies supporting net-zero and climate-resilient agriculture.

Policy / Programme	Focus Area
Panchamrit / Net-Zero by 2070 pledge (COP26, 2021)	National economy-wide climate commitment
National Mission for Sustainable Agriculture (NMSA) & NICRA	Climate-resilient crops, practices, and research (ICAR)
PM-KUSUM	Solar irrigation pumps; diesel displacement
Soil Health Card Scheme	Soil-test based, judicious fertiliser use
National Mission on Natural Farming (2024)	Chemical-free, low-input farming at scale
Digital Agriculture Mission	Farmer registries, digital advisories, data infrastructure

Global Success Stories

North India is not alone in this effort, and there is value in looking at how other farming systems are responding. The Netherlands, despite its small size, is one of the world's most productive and closely monitored agricultural economies; research benchmarking its environmental performance shows that while Dutch farming remains intensive, sustained policy and farm-level measures have improved its eco-efficiency relative to the rest of the European Union, even as nutrient and emissions pressures remain a live policy challenge (van Grinsven et al., 2019). Widespread adoption of precision sensors, satellite monitoring, and controlled-environment greenhouses illustrates how data-driven farming can raise output per unit of emissions. Denmark and other members of the European Union have set explicit targets to cut agricultural methane and nitrogen losses as part of the EU's Farm to Fork strategy, combining regulation with financial support for farmers who adopt lower-emission livestock and manure management practices. Australia, notably, was where the Happy Seeder now central to North India's own residue-management efforts was first developed and field-tested, an example of agricultural research crossing borders to solve a shared problem of straw disposal after mechanised harvesting. In the United States, government-backed 'climate-smart commodities' initiatives have funded farmer-level trials of cover cropping, reduced tillage, and nutrient management, generating the kind of on-farm evidence that policymakers elsewhere, including in India, can draw upon.

Practical Net-Zero Farming Practices for North Indian Farmers

This is where the abstract idea of net-zero agriculture becomes a set of decisions a farmer in Punjab, Haryana, Uttar Pradesh, or Uttarakhand can actually make this season. The practices below are organised from field establishment through to nutrient and water management, energy, and advisory support, each with a note on suitability across farm sizes.

Tillage and Residue Management

Zero tillage sowing the next crop directly into unploughed soil is now well established in the rice-wheat system of the Indo-Gangetic Plain. It cuts diesel use for land preparation, preserves soil structure, and, when combined with residue retention, steadily builds soil organic carbon. The Happy Seeder takes this a step further by sowing wheat directly into standing rice stubble without prior burning; independent economic evaluation across more than 1,000 farm households in Punjab found the Happy Seeder saved farmers meaningful production costs compared with burning-and-tilling, without any yield penalty, while also saving irrigation water (Keil et al., 2021). The Super Seeder, a related machine that also incorporates chopped straw into the soil, offers similar benefits with the added advantage of returning residue nutrients to the field rather than removing them.

Water and Nutrient Management

Drip and sprinkler irrigation deliver water directly to the root zone or in a fine, controlled spray, cutting the substantial losses that occur with flood irrigation, particularly valuable for vegetables, orchards, and sugarcane. Precision nutrient management, guided by Soil Health Card data, matches fertiliser dose to what a field and crop actually require rather than a flat, habitual application, directly reducing nitrous oxide emissions from excess urea. Biofertilisers and composting, including vermicomposting using earthworms to convert farm and kitchen waste into nutrient-rich manure, reduce dependence on synthetic fertiliser while improving soil biology.

Diversification and Long-Term Carbon Storage

Agroforestry planting poplar, eucalyptus, or fruit trees along field boundaries or in rotation with crops is already practised across parts of Punjab and western Uttar Pradesh and offers farmers a second income stream from timber or fruit alongside a genuine, long-lived carbon sink. Cover crops and green manuring, growing a fast-cycling legume such as dhaincha or sunhemp and ploughing it back into the soil, add organic matter and biologically fixed nitrogen between main crop seasons. Crop diversification away from the water- and energy-intensive rice-wheat rotation, towards maize, pulses, or horticulture where agro-climatically suitable, eases pressure on groundwater and generally lowers the farm's overall emissions intensity. Biochar, produced by pyrolysing crop residue or agricultural waste, offers smallholders a way to convert what would otherwise be burnt into a soil amendment that locks carbon away for decades while improving water retention (Woolf et al., 2010).

Energy and Digital Advisory

Solar-powered irrigation pumps, supported under PM-KUSUM, let farmers replace diesel or costly grid electricity with sunlight, cutting both emissions and running costs over the pump's working life (Ministry of New and Renewable Energy, n.d.). AI-based advisory systems, delivered increasingly through mobile apps and Krishi Vigyan Kendras, translate satellite and weather data into simple, field-specific recommendations on sowing dates, irrigation scheduling, and pest alerts, extending expert-level agronomy to farmers who may never have set foot in a research station.

Table 4. Practical net-zero farming practices for North Indian farmers, by suitability and benefit.

Practice	Suitable Crops	Environmental Benefit	Economic Benefit	Recommendation
Zero tillage / Happy Seeder	Wheat after rice	Cuts residue burning, builds soil carbon	Lower fuel & labour cost; no yield penalty	Access via Custom Hiring Centres; suitable for all farm sizes
Super Seeder	Wheat after rice/cotton	Incorporates residue, adds soil organic matter	Saves nutrient input over time	Best where straw load is very heavy
Direct Seeded Rice (DSR)	Rice	Lower methane; saves irrigation water	Reduced labour & pumping cost	Requires laser-levelled, well-drained fields; strong weed control needed
Laser land levelling	All irrigated crops	Improves water-use efficiency	Higher input-use efficiency	One-time service via hire centres; benefits scale with plot size
Drip / sprinkler irrigation	Vegetables, orchards, sugarcane	Major water savings	Higher yield per unit water; subsidy support available	Best for medium/large horticultural plots; scalable to small plots with subsidy
Biofertilisers & vermicompost	All crops	Cuts synthetic fertiliser need; improves soil biology	Lower input cost over time	Suitable for all farm sizes; low capital needed
Agroforestry (poplar/fruit trees)	Field bunds, rotation blocks	Long-term carbon sink; biodiversity	Additional timber/fruit income	Best on medium/large holdings with longer investment horizon

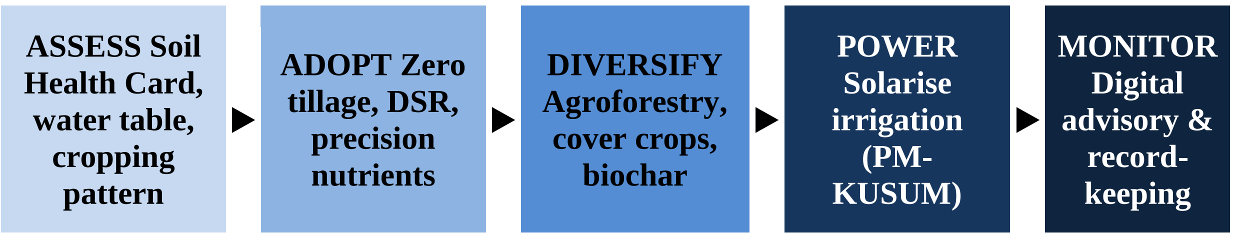

Figure 4. A practical roadmap for North Indian farmers moving towards net-zero agriculture.

Challenges

None of this is straightforward. The economics of new machinery and solar pumps still require an upfront investment that many small and marginal farmers, who make up the majority of landholders in North India, cannot easily absorb without subsidy or credit support. Technology access is uneven: a Custom Hiring Centre may be a short drive away in one block and effectively out of reach in another. Policy execution can lag policy announcement, and awareness of schemes like Soil Health Cards or PM-KUSUM does not always translate into uptake, especially where extension services are stretched thin.

Infrastructure gaps from unreliable electricity for solarised feeder lines to inconsistent last-mile advisory delivery slow the pace of adoption. Smallholder farming itself is a structural challenge: fragmented, small plots make it harder to justify some investments and complicate any effort to verify or ‘account’ for the carbon a given practice actually sequesters, a problem known in policy circles as measurement, reporting, and verification (MRV). Building a credible, farm-level carbon accounting system across millions of small holdings remains, honestly, one of the hardest unsolved pieces of the net-zero puzzle anywhere in the world, not only in India.

Table 5. Key challenges to net-zero agriculture adoption in North India and emerging solutions.

Challenge	Emerging Solution
High upfront cost of machinery/solar pumps	Custom Hiring Centres, cooperative ownership, PM-KUSUM subsidy
Uneven technology & extension access	Krishi Vigyan Kendras, mobile advisory apps, FPO-led diffusion
Policy-to-practice gap	Village-level awareness campaigns, Soil Health Card follow-up support
Fragmented smallholder land	FPO aggregation for input purchase, machinery sharing, and market access
Carbon accounting & MRV complexity	Simplified, practice-based crediting; digital farm records; remote sensing
Infrastructure gaps (power, water)	Feeder-level solarisation, groundwater regulation, watershed development

Myth or Reality?

The case for calling net-zero agriculture a myth is not a frivolous one. Ruminant digestion and flooded rice cultivation are biological processes with hard emission floors that no amount of good management can reduce to zero; a hectare of paddy will release some methane as long as it is flooded. Carbon markets and MRV systems capable of fairly rewarding millions of small farmers for sequestering soil carbon remain immature almost everywhere. Costs of transition machinery, solar infrastructure, training are real, and public budgets are finite. Sceptics reasonably ask whether ‘net-zero agriculture’ risks becoming a slogan that promises more than any single farm, or even any single country, can currently deliver. The case for reality rests on a different observation: nearly every technology and practice this article has described is already proven, not experimental. Zero tillage and the Happy Seeder are documented, in peer-reviewed research, to cut costs and residue burning without sacrificing yield (Keil et al., 2021). Direct seeded rice measurably reduces methane and water use. Solar irrigation pumps are being installed under a functioning national programme today. Biochar’s carbon-locking properties are established in the scientific literature (Woolf et al., 2010). What is missing is not proof of concept but scale, financing, and consistent execution a different, more solvable problem than a scientific impossibility. The honest answer, then, sits between the two poles. Net-zero agriculture as a literal, universal, zero-emission farm is not realistic within the next few decades, and pretending otherwise does farmers no favours. But net-zero agriculture as a serious, science-based direction of travel cutting emissions intensity practice by practice, rebuilding soil carbon, and closing the gap year on year is not only possible; parts of it are already happening in the fields of Punjab, Haryana, and beyond.

Table 6. Conventional farming versus net-zero-oriented agriculture, practice by practice.

Aspect	Conventional Farming	Net-Zero-Oriented Agriculture
Tillage	Multiple ploughing passes	Zero / reduced tillage with residue retention

Rice establishment	Transplanting into flooded fields	Direct Seeded Rice with controlled irrigation
Residue management	Open field burning	Happy Seeder / Super Seeder incorporation
Nutrient use	Flat, habitual fertiliser dose	Soil-test based, precision dosing
Irrigation energy	Diesel / unsubsidised grid pumping	Solarised pumping (PM-KUSUM)
Farm income	Single dominant crop, weather-exposed	Diversified crops, agroforestry, and by-products

Conclusion

Net-zero agriculture is not about switching off every emission from a living, working farm; no such farm exists, and no such promise should be made to the people who grow India's food. It is about something more grounded and more achievable: steadily reducing emissions where they can be reduced, rebuilding the carbon that soils and trees can hold, using water and energy more carefully, and doing all of this in a way that leaves a farmer's income, not just the planet's atmosphere, better off. For the farmers of Punjab, Haryana, Uttar Pradesh, Uttarakhand, Rajasthan, Delhi, Himachal Pradesh, and Jammu & Kashmir, that journey already has a starting point in tools most have heard of, and some have used: the Happy Seeder, the Soil Health Card, a solar pump, a strip of poplar trees along a field bund. None of these, alone, adds up to net-zero. Together, adopted widely and supported consistently by policy, research, and extension, they represent something rarer than a slogan a realistic, region-specific path towards agriculture that feeds the nation while asking a little less of the climate it depends on.

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