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Forgotten Fertilizers: Repurposing India's Bio-Waste for Soil Superpowers

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ABSTRACT

Sustainable agriculture emerges as the one of the most important phenomena for the well-being of soil and environment in the 21st century. It addresses the challenges like food security and environmental degradation. With the help of sustainable agriculture, we determine the biodiversity maintenance, crop productivity and ecosystem resilience. Over past few decades since the Green Revolution (1960), farmers heavily depend on the use of chemical fertilizers for better crop yield and production but it causes very harmful effects on soil health, human health and the environment. It has been found that excessive use of chemical fertilizers, pesticides, intensive tillage and mono cropping have caused the decline of soil microbial diversity up to 38 per cent (FAO, 2020) and nearly 24 billion tonnes of fertile soil lost annually due to erosion. In contrast, the adoption of sustainable agriculture, which include use of bio-inputs, organic fertilizers, green manure, biofertilizers and compost has shown significant promise in restoring soil health. Researches conducted by Indian Council of Agricultural Research (ICAR) in which they found that use of biofertilizers can reduce the consumption of chemical fertilizers up to 25 to 30 per cent. The government of India, under Paramparagat Krishi Vikash Yojana (PKVY), has promoted organic clusters and bio-input use across over 10 lakh hectares to boost sustainable farming. However, vermicompost and compost-based farming adopted by small and marginal farmers to reduce costs and regenerate degraded soils. This article reviews the evidence supporting this transition and underscore the critical need to shift toward agroecological models that integrate traditional knowledge with modern science. Strengthening farmer awareness, investing in bio-inputs supply chain, and supportive policy frameworks are essential for ensuring soil health, long-term productivity and climate-resilient agriculture.

Keywords: *Sustainability, Bio-inputs, Soil-health, Biochar, Pressmud, Neem-cake, Subsidies*

Introduction

Agriculture plays an indispensable role in maintaining life balance on Earth. Globally, countless varieties of food crops, industrial plants and medicinal plants are cultivated to meet relentless demand. With rapidly increase in the world population, the demand for food is increasing by an estimated 3.8 per cent annually (Bauddh *et al.*, 2022). It has been estimated that by the year 2050, the world population will surge by 50 per cent placing immense pressure on the agriculture sector. Conversely, food production is reported to be growing by only 1.2 per cent annually (Bauddh *et al.*, 2022), which is a major concern for the developing and developed country to meet the food demand of the people. Various agriculture practices are followed such as intensive use of synthetic fertilizer, pesticides, energy, hybrid seeds, copious amounts of water and significant capital investment in the form of agriculture machinery to meet the demand and maximize the food production. These practices inflict negative impact on the environment, directly or indirectly leading to accelerated soil erosion, soil health degradation, loss of soil fertility, contamination of fresh water ecosystem, depletion of groundwater, loss of traditional crop verities. Since the green revolution (1960s), farmers shifted toward the modern approaches and techniques abandoning traditional methods of agriculture for better crop growth, development, yield, and economic benefits. Driven by the desire for maximum yield and economical benefits farmers adapted modern practices recklessly, which ultimately started deteriorating soil health and causing various forms of degradation including reduced microbial population, fertility decline, and chronic nutrient loss. In essence, these modern approaches have caused significant adverse effects on the agroecosystem (Taiwo, 2019).

Modern approaches are chemical-intensive and fundamentally unsustainable, requiring a critical re-

evaluation not just for better crop production but also for safeguarding human health. However, we cannot simply abandon these modern approaches, as they were the key to achieving high yields required after 1960s, but we must prioritize alternative strategies focused on restoring soil health. The recycling of organic waste is now emerging as one of the best sustainable strategies. It not only mitigates environmental pollution but also addresses the nutrient needs of agriculture crops. While these organic resources cannot entirely replace the chemical fertilizer, they are essential in significantly reducing our dependence on them. As knowledge of the harmful effect of modern approach on the environment, soil health and human health increases, farmers are increasingly turning toward agricultural by-products. The use of agriculture by-products is becoming the most suitable and sustainable approach to meet the demand of plant nutrition and there are many promising by-products like bio-gasses, pressmud, and molasses which are utilized as vital source of plant nutrients these by-products not only furnish essential nutrients to the plants but also improve the soil health and mitigate environmental toxins.

Press-Mud

As the world's second largest producer of sugarcane after Brazil, India generates a massive volume of by-products (Gunja and Gunjal, 2021). Press mud is the fibrous by-product of sugarcane industry and for every tonne of sugarcane processed, approximately 30-33 kg of pressmud is generated (Poria *et al.,* 2022). Annually, 3.6-3.9 million tonnes of material are produced as a by-product of sugarcane which is a rich source of nutrients, typically containing 1-1.5 per cent Nitrogen, 4-5 per cent phosphorous and 2-7 per cent potassium (Poria *et al.,* 2022). Yet, the majority of this valuable resource is frequently burned in the brick kins for fuel, resulting in loss of millions of tonnes of vital nutrients and causing significant environmental pollution.

The fibrous by-product is dark brown, amorphous, and spongy primarily composed of sugar, fibre, and coagulated colloids, such as soil particles. Press mud is far more than just a source of N-P-K; it acts as a holistic builder. Its superior values lie in its high organic fraction and rich source of secondary nutrient content which include 1-4 per of calcium oxide, 0.5-1.5 per cent of magnesium oxide, 5-15 per cent sugar, 15-30 per cent of fibre, 5-15 per cent crude protein, 4-10 per cent of silica oxide, and 9-10 per cent of ash (Gupta *et al.*,2011). This unique composition helps fundamentally improve soil structure, increase water infiltration and water holding capacity which make soil more resilient to drought and reduce irrigation needs.

Neem Cake

While Press mud offers crucial improvements to soil structure and secondary nutrient supply, the single most expensive and polluting problem in Indian agriculture remains the staggering waste of Nitrogen(N). This led us to our next powerhouse resource: Neem cake. This organic resource acts as a nature manure, possessing no adverse impact on plant, soil or human health. It is used in the soil as a direct nutrient source or can be blended with urea or other organic manures for optimal results. Coating chemical fertilizer with Neem cake helps in preventing the nutrient loss, and also enrich the nutrient profile of other organic manures like FYM, vermicompost and compost. As a by-product of Neem seed, Neem cake is completely organic and contain 100 per cent natural NPK and other micro nutrients essential for plant growth and development. It contains about 2-5 per cent of nitrogen, 0.5-1 per cent of phosphorous, 1-2 per cent of potassium, 0.3-1 per cent of magnesium, 0.5-3 per of calcium, and 0.2-3 per cent of sulphur. It is also a significant source of micronutrients, including 15-60 ppm of zinc, 4-20 ppm of copper, 500-1200 ppm of iron, and 20-60 ppm of manganese (Gupta, 2022). Beyond its nutrient profile, it is highly valued as a soil conditioner, and a potential biopesticide helping protected stored grains from pests. Neem based product are eco-friendly and superior in quality compared to chemical pesticides. The use of this product helps reduce ecological and health threats posed by chemical fertilizers and pesticides. Ultimately, Neem cake is a boon for organic agriculture, crucial for maintaining environmental sustainability.

Biochar

As an agriculture dominant country, India produces more than 500 million tonnes of crop residues annually, including residues from rice, wheat, maize, millet, cotton, sugarcane, jute, rapeseed-mustard, and groundnut. The majority of this crop residue is often burnt in the field, primarily to clear left-over straw and stubble after harvest. The reason behind burning this huge volume of crop residue include non-availability of the labour, high cost of mechanical remove, and the increasing reliance on combine harvesters. Burning the residue directly cause severe environmental pollution; it produces greenhouse gases, contributes significantly to global warming, and is hazardous to human health. It is also responsible for decreasing in the population of beneficial microbes in the soil and depleting essential nutrients like N,P, and K. It has been estimated that by burning 1 tonne of paddy straw it releases about 3 kg of particulate matter, 60 kg of CO, 1460 kg CO_2, 199 kg ash and 2 kg of SO_2. One tonne of paddy straw contains approximately 5.5 kg nitrogen, 2.3 kg phosphorous, 25 kg of potassium, 1.2 kg of sulphur, 50-70 per cent of micronutrients absorbed by rice and 400 kg of carbon which are lost due to burning of paddy straw (Ministry of Agriculture and farmer Welfare, 2022).

Faced with the massive volume of economically defunct crop residue, which simultaneously degrades the soil and pollutes the environment, the major sustainable solution lies in the conversion of this biomass into biochar. Biochar offers the twin benefits of climate mitigation and use as an

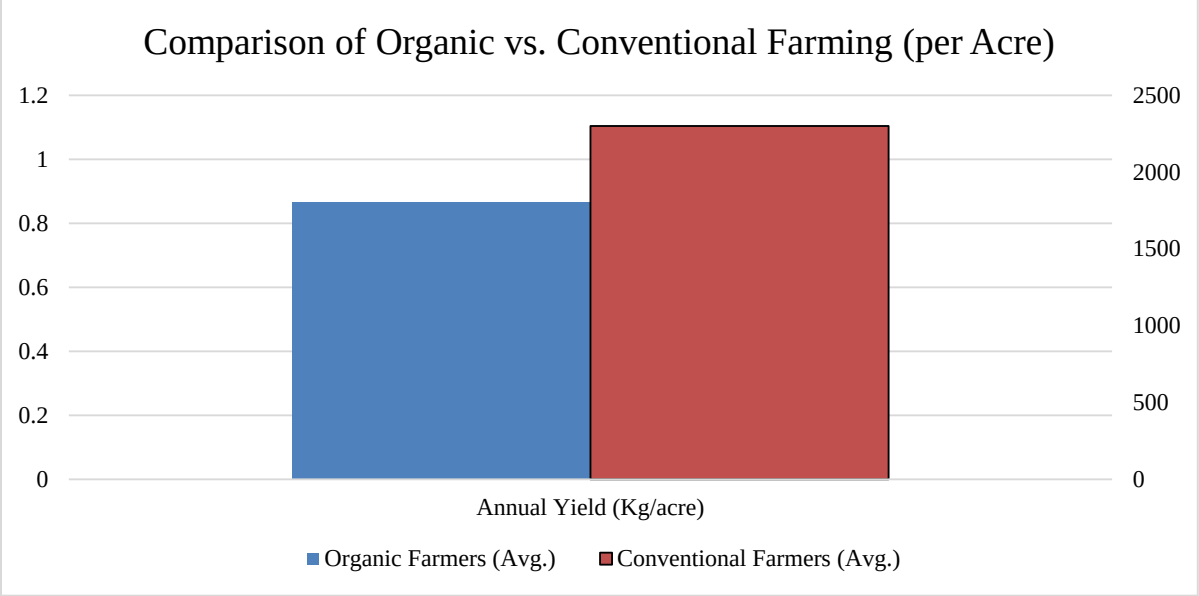
amendment to enhance the soil quality. The unique physical and chemical properties of biochar make it an effective adsorption material to remove pollutant. Beyond its physical benefits, the integrated application of biochar with a sustainable amount of nitrogen and a legume based cropping system has been shown to return greater profits to farmers. The application of Biochar increases the total porosity of the soil, reduces the bulk density, increase the soil aggregation, and improve moisture content.

Numerous studies comparing bio-inputs and chemical fertilizer show that while organic methods may initially result in slightly lower yields, the input cost are significantly reduced and the resulting crops command a significantly higher market value than those from chemical fertilizer. A specific study (Kumar, 2025) focusing on the impact of organic agriculture in India found that, despite facing higher initial input costs compared to conventional farmers, organic practitioners consistently achieved greater market price, gross income, net profit and overall satisfaction. These contrasting results, where higher net profit outweighs lower gross yield, is further detailed in the accompanying Table 1:

Table 1: The comparative economic performance of organic and conventional farmers

Parameter	Organic Farmers (Avg.)	Conventional Farmers (Avg.)
Annual Yield (Kg/acre)	1800	2300
Input Cost (INR/acre)	5000	9000
Market Price (INR/acre)	30	18
Gross Income (INR/acre)	54000	41400
Net Profit (INR/acre)	49000	32400
Satisfaction Level (% farmers)	88%	63%

(Kumar, 2025)



(Kumar, 2025)

Fig 1.1: Graph: Bar Chart-Comparison of Economic Indicators (Per Acre)

A separate study (Salma and Hossain, 2021) compared Neem Cake, Biochar, Pressmud, and chemical Urea across several key parameter. The research concluded that neem Cake was the best overall amendment for crop growth, yield, nutrient uptake, and soil fertility improvement. Vermicompost ranked second in performance. It also noted that Biochar while excellent for long -term soil improvement, was slows acting for immediate crop response, and animal manure only improved growth moderately. Chemical Urea performed poorly, exhibiting low growth response and low Nutrient Use Efficiency (NUE).

Table 2: Comparison between organic by-product and chemical fertilizer

Parameter	Neem Cake	Biochar	Press-Mud	Chemical Fertilizer
Nutrient release speed	Fast	Slow and steady	Moderate	Fast
Soil health improvement	High	Very High	Moderate	None
Yield response	Highest	Moderate	Moderate	Low
Nutrient Use Efficiency	Medium	Medium-High	Low-medium	Low
Environmental Impact	Low	Very Low	Moderate	High (Leaching, runoff)

(Salma and Hossain, 2021)

The political Paradox and Lack of Support

Despite the proven efficacy and numerous benefits of these by-products, their adoption in agriculture remain severely limited. This limitation stems not from a lack of scientific potential, but from fundamental policy failure and lack of awareness. Lack of knowledge and training is a primary social barrier: Farmer often do not know about the preparation, correct application rate and long-term benefits of these amendments. Farmer are logically wary of the yield reduction during the transition period- the unavoidable initial drop in crop yield that occurs while the soil's biological activity and fertility naturally heal after decades of chemical use. The economic risk of this temporary dip is too high without strong government support or price assurance.

The Logistical Barriers: Supply and Access

"There is often a severe shortage and unavailability of raw organic biomass;" material like cow dung, crop residue, are frequently diverted for other vital household uses such as fuel, fodder, etc which limits the supply available for composting or Biochar production. This scarcity is compounded by a weak distribution network; unlike chemical fertilizers, which are easily accessible, bio-products are not readily available to farmer. The preparation and application of these materials are often highly labour and time intensive, requiring significant manual effort that modern chemical farming has largely reduced.

The Policy Barrier: The root Problem

Ultimately, these barriers are symptoms of a policy failure. The most critical limiting factor is the absence of clear, strong, supportive policy and financial backing from the government. This lack of foundational state support- specifically the absence of targeted subsidies for bio-inputs and the failure to regulate chemical fertilizer use- causes a lack of interest among farmers. Without policy intervention to correct market distortions and guarantee quality, the transition to sustainable farming will stall, regardless of how good the research results may be.

To overcome these barriers, the government launches various schemes to promote the use of organic by-products in the agriculture fields and to increase the fertility of the soil. Mission like National Mission on Sustainable Agriculture (NMSA) which focuses on the less use of fossil fuels, National Policy on Biofuels (NPB), which promotes the productions of Biochar for sustainable agriculture. Initiative like National Biochar Initiative, launched by Indian Ministry of Environment, Forests and Climate Change (MoEFCC) as a part of Government effort to support the soil health enrichment, carbon sequestration and sustainable agriculture. Indian Biochar and Bioresource Network (NBBN) is a committed platform focused on reducing the effect of greenhouse gases, increase carbon sequestration and improve various farm related problem in India. This organization aims to innovate across the value chain of biochar and bioresources in India.

There are various factors that prevent farmers from adopting bio-inputs, despite their numerous benefits. The most significant barrier is the economic distortion created by Chemical Fertilizer Subsidy Regime. One of the major reasons for non-adoption is the economic distortion created by the highly subsidized chemical fertilizer market. Government provide subsidy on the chemical fertilizer due to which they become more available to the farmers on cheaper prices. For instance, the government provides nearly 1.4 lakh crore rupees in subsidy on chemical fertilizer, while offering very limited finical support for bui-inputs. The huge price difference between the chemical fertilizer and organic by-product make the farmer more discourage on the adoption of organic by-products. Furthermore, schemes like the Pradhan Mantri Krishi Vikash Yojana (PKVY) often provide support for only limited period (typically up to three years), after which financial assistance ceases, causing farmer to revert back to chemical alternative.

Another set of barriers are institutional and market failures, which include limited extension networks, fragmented network supply chains, and lack of proper certification mechanisms for organically produced goods. Organic crops produced by the farmers by using organic by-products often lack access to the premium markets and ends up selling at conventional prices. This failure to realize higher returns causes them to lose interest in the adoption of sustainable practices. Finally, there are clear regional disparities in the adoption of organic practices. Some states like Sikkim, Andhra Pradesh, Uttarakhand, and Himachal Pradesh promote the use of organic farming and natural products. In sharp contrast, agriculture intensive states such as Punjab, Haryana, and Uttar Pradesh remain highly dependent on chemical fertilizers due their entrenched high-input farming system. This regional imbalance reflects both policy difference and farmer awareness gap.

Table 3: Key Challenges in Bio-input adoption in India

Challenge Area	Description	Data/Impact	Source
Quality Control	Poor microbial counts in products	30 per cent biofertilizers sub-standard	ICAR, 2019
Awareness and Training	Farmers lack knowledge of bio-input use	85 per cent small/marginal farmers less exposed	GoI, 2021
Subsidy Imbalance	Fertilizer subsidies vs low support for bio-inputs	1.4 lakh crore subsidy for fertilizer	FAI, 2022
Shelf-life and Storage	Short viability period (4-6 months)	Poor storage reduces microbial activity	Singh Varma, 2017
Market Access	Organic crops sold at conventional prices	Certification costly and time consuming	FAO, 2020
Regional Disparities	Uneven adoption across states	High in Sikkim, AP; low in Punjab, UP	ICAR, 2019

Suggestion and Recommendations

Policy-Level Recommendations

Reform Fertilizer Subsidies: The government must rationalize the current chemical fertilizer subsidies budgets and reallocate these funds to promote bio-input specifically targeting support for biofertilizer, vermicomposting units, and Organic input enterprises (FAI, 2022)

Strengthen Quality control and Certification: Regulatory bodies must enhance and strictly enforce the quality control and certification system for bio-inputs to address reported issue of nearly 30 per cent of bio-fertilizers fails the quality norms.

Scale up Organic Clusters: Schemes like Paramparagat Krishi Vikash Yojana (PKVJ) must be scaled up significantly beyond existing targets (e.g.10 lakh hectares) and integrate with Soil Health Card Scheme for localized, targeted soil improvement.

Farmer-Level recommendations:

Enhance Training and Awareness: Implement village level workshops, establish Farmer Filed School, and fund

robust on-farm demonstration programs to build correct use of organic products.

Promote Sustainable Residue Management: Educate farmer about detrimental effects of residue burning and incentivize the utilization of biomass for mulching, composting, and Biochar preparation to enhance soil organic carbon (SCO) level.

Empower farmer Producer Organization (FPOs): Farmer produce organisation (FAO) and cooperatives need to empower to facilitate collective production, procurement, and marketing of certified organic produce, ensuring access to premium markets.

Research and Institutional Recommendation:

Strengthen Research and Development (R and D): Increase investment to support the development of next generation bio-inputs including microbial consortia, nanotechnology-based biofertilizers, and climate-resilient microbial strains.

Integrated Soil Health Monitoring: Enhance soil testing facilities and integrate soil Health Card Scheme with mobile advisory application to provide farmer with real time, actionable advice.

Foster Public-Private-Farmer Partnerships: Establish stronger linkage between agriculture university, ICAR institute, and NGOs to promote participatory, farmer-centric research and effective technology transfer.

Case Studies from India

Sikkim: The Organic State Model

After banning chemical fertilizer and pesticide from the state the Sikkim became the first state in the world which is fully organic through the mission Sikkim Organic Mission it promotes the use of bio-inputs and their adoption in the state. Under this mission, over 76,000 hectares of land was converted to organic, and all the farmers were trained in the use of compos, vermicompost, biopesticides and green manure (FAO, 2018). The state established the organic certification system and also promote the value chains for the products like ginger, cardamom, and vegetables. According to the data from FAO (2018), the transition not only improved soil fertility but also reduced environmental degradation, boosted eco-tourism, and created premium markets for organic produce, which made it a global model for sustainable agriculture.

Punjab and Haryana: Vermicompost and Residue Management

Following the Green Revolution (1960), the states like Punjab and Haryana became heavily depend upon chemical fertilizer, which led to a loss in soil organic matter (SOM) and chronic nutrient imbalance. Initiatives, supported by ICAR and state agriculture university have encouraged farmer to adapt vermicompost and crop residue management. In districts like Ludhiana and Patiala, farmer clusters using vermicompost reported improvement in the Soil Organic Carbon (SOC) by 0.2 per cent and reduction in the nitrogen fertilizer use by 20-25 per cent (ICAR, 2019). In Haryana, farmers using the Happy Seeder machine for residue management, combined with organic amendments, have reduced stubble burning while improving porosity and moisture retention.

Uttarakhand: Organic Clusters and Traditional Practices

The state promotes cluster-based farming through both the Pradhan Mantri Krishi Vikas Yojana (PKVY) and state -ed initiatives. Traditional organic practices, combined with bio-input like Farm Yard Manure (FYM), compost and indigenous microbial inoculants, have helped to converse soil fertility in hilly terrains. By 2020, over 100,000 farmers in Uttarakhand were engaged in organic farming clusters, reporting improved soil fertility and reduced chemical input dependency (GoI, 2021).

Table 4: Case Studies of Bio-input Adoption in India

State/Region	Initiative/Practice	Area Covered	Farmer Benefitted	Key Outcomes	Source
Sikkim	Organic State Model	76,000 ha	All state farmers	First fully organic state, improved soil health and tourism	FAO, 2018
Punjab and Haryana	Vermicompost and Residue Management	Cluster-based	Several farmer group	SOC ↑ 0.2% annually, 20-25 % less N fertilizer	ICAR, 2019
Uttarakhand	Organic Clusters (PKVY- supported)	100,000+ ha	100,000+ farmers	Enhanced soil fertility, reduced chemical dependency	GoI, 2021

Conclusion

With the increasing degradation of soil health and fertility status, sustainable agriculture become necessity in India. Soil health is the centre pillar of sustainability, and bio-inputs play a transformative role in restoring soil ecosystem. Evidence showed that organic by-products like Biofertilizer, Neem Cake, Biochar, Biopesticide and Vermicompost not only reduce the dependency on synthetic chemicals but also significantly improve Soil Organic Carbon (SOM), soil microbial density, and strengthen resilience to drought and pests (Singh and Verma, 2017).

Government initiatives like PKVY, NMSA and Soil Health Card schemes created a strong momentum toward sustainable agriculture, supported by various state-level programs such as the Sikkim Organic Model, Uttarakhand Organic Clusters Model. This transition, however, is severely hampered by institutional, economic, and infrastructural bottlenecks, particularly lack of awareness, weak certification system, and market distortions caused by heavy fertilizer subsidies.

To secure the health of the soil and environment, long term plans require decisive policy shifts: the rationalization of chemical fertilizer subsidies, increased financial backing for bio-inputs, and strategic investment in the decentralized production and farmer-centric adoption of its powerful, yet currently neglected, bio-wastes.

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