

GREEN REVOLUTION, NATIONAL FOOD SECURITY AND THE CHALLENGE OF PESTICIDE DEPENDENCE IN INDIA: A CRITICAL REVIEW WITH AN APPRAISAL OF AGROHOMOEOPATHY AS A COMPLEMENTARY SUSTAINABLE APPROACH

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ABSTRACT

The Green Revolution, launched in India in the mid-1960s, converted a chronically food-deficient country into a producer of cereal surpluses and became closely tied to national-security thinking after the wars of 1962, 1965 and 1971 and the food-aid dependence of the mid-1960s. The same package of high-yielding varieties, synthetic fertilisers, irrigation and agrochemicals has, however, left a legacy of soil degradation, groundwater depletion, biodiversity loss, pest resistance and pesticide-related health risks. This narrative review traces the historical and strategic origins of the Green Revolution, summarises its achievements and ecological costs, and analyses the emergence of pesticide dependence in Indian agriculture. Established alternatives, namely integrated pest management, organic and natural farming and precision agriculture, are discussed, followed by a critical appraisal of AgroHomoeopathy, the use of potentised (ultra-diluted)

homeopathic preparations to modulate plant growth and stress responses. Published systematic reviews of plant-based bioassays report statistically significant effects in a subset of well-controlled experiments, and some phytopathological and field studies are encouraging. However, effect sizes are generally small, replication has been inconsistent (including reversal of effect direction), field-scale evidence is limited, and a mechanism compatible with established physical chemistry has not been demonstrated. AgroHomoeopathy is therefore best regarded as a low-input, low-risk candidate for rigorous, pre-registered, multi-site evaluation as an adjunct within integrated pest management, and not yet as a validated substitute for proven crop-protection measures. A staged research and policy agenda is proposed.

KEYWORDS: Green Revolution, Food Security, Pesticide Dependence, Integrated Pest Management, AgroHomoeopathy, Sustainable Agriculture, India.

1. INTRODUCTION

Agriculture has been central to India's economic development, food security and social stability. At independence in 1947 the country faced chronic food deficits, low yields, recurrent drought and dependence on imported grain, while rapid population growth steadily raised demand.^[1] By the mid-1960s it was evident that traditional production systems could not close the gap, and the government adopted a strategy built on high-yielding crop varieties, assured supplies of fertiliser and irrigation, and remunerative support prices that came to be known as the Green Revolution.^[1,2]

The outcome was a transformation of Indian cereal production. India moved from being a food-deficit nation reliant on imports and food aid to one of the world's largest producers of wheat and rice.^[1,2] Yet the input-intensive model that delivered these gains has also produced well-documented costs, including declining soil quality, falling water tables, loss of crop and associated biodiversity, and growing reliance on synthetic pesticides.^[3-5] India must now reconcile food production with environmental sustainability and public-health protection, a challenge that this review describes as the "second battle" of Indian agriculture.

Among the responses proposed to reduce chemical dependence is AgroHomoeopathy: the application of potentised (serially diluted and succussed) homeopathic preparations to seeds, soil, foliage or irrigation water in order to influence plant growth, stress tolerance and disease expression. Interest in the approach dates to the early twentieth century^[6,7], and studies are

now reported from several countries, including Italy, Brazil, Mexico, India and Germany.^[8] The approach is attractive to farmers and policy makers because the preparations are inexpensive and are presumed to impose a negligible ecological burden. It is also controversial, because the dilutions typically used exceed the point at which any molecule of the starting material is expected to remain, and because the clinical literature on homeopathy in humans remains contested.^[9,10]

The objectives of this review are (i) to trace the historical and strategic origins of the Green Revolution; (ii) to summarise its achievements and ecological consequences; (iii) to analyse the emergence of pesticide dependence and its environmental and health implications in India; (iv) to review established sustainable alternatives; and (v) to appraise critically the scientific evidence for AgroHomoeopathy and to define the conditions under which it could be responsibly evaluated as a complementary tool.

2. REVIEW APPROACH

This is a narrative review. Historical, agronomic and public-health literature was identified through PubMed, Scopus and Google Scholar and from Government of India statistical releases, with priority given to systematic reviews, replication studies and official data. For AgroHomoeopathy, the analysis is anchored in the published systematic reviews of plant-based homeopathic research and in the replication trials they identify, supplemented by recent primary studies and narrative reviews. Findings are reported as published. The strength of each body of evidence is judged by study design, the presence of adequate controls, replication, and the independence of the research groups involved.

3. HISTORICAL BACKGROUND AND STRATEGIC CONTEXT

3.1 Indian agriculture before the Green Revolution

Before the 1960s Indian agriculture was characterised by low-yielding traditional varieties, heavy dependence on monsoon rainfall, limited irrigation, traditional cultivation methods, frequent crop failures, and recurrent food-shortage and famine concerns.^[1] Productivity was constrained by limited access to improved seed, fertiliser, mechanisation and scientific advice. In drought years the shortfall was met by imported grain, which raised concerns about national sovereignty and economic stability.^[11]

3.2 Food security as strategic security

The 1960s and early 1970s were a period of acute geopolitical stress. The 1962 conflict with

China exposed weaknesses in national preparedness and drew attention to the economic and agricultural base of national strength. The 1965 war with Pakistan coincided with severe drought and heavy reliance on imported grain, which reinforced the argument for agricultural self-reliance.^[11,12] The 1971 war further strengthened the policy consensus that stable domestic food production was a condition of strategic autonomy. Food security consequently became closely linked with national-security policy, and planners increasingly regarded agricultural modernisation as essential for political stability.^[11,12]

Historians caution against a single-cause account. The adoption of the new strategy also reflected successive monsoon failures in 1965–66, balance-of-payments pressure, the availability of semi-dwarf wheat and rice germplasm developed at international research centres, the leadership of scientists and administrators such as M.S. Swaminathan and C. Subramaniam, and the wider Cold War context.^[1,11] The strategic framing is nevertheless a useful reminder that food systems are matters of national resilience, and that any successor transition must not compromise production.

4. THE GREEN REVOLUTION: COMPONENTS AND ACHIEVEMENTS

4.1 Technological components

The Green Revolution rested on a package of interdependent innovations. High-yielding varieties (HYVs), particularly semi-dwarf wheat and rice, converted additional fertiliser into grain rather than into lodging-prone straw and gave markedly higher yields under favourable conditions.^[1] Nitrogen, phosphorus and potassium fertilisers were introduced to raise nutrient supply. Irrigation expanded through canals, tube wells and groundwater extraction, allowing multiple cropping. Mechanisation, through tractors, pumps, threshers and harvesters, raised efficiency and reduced labour requirements. Chemical pesticides became an integral part of the package, protecting genetically uniform, densely planted and well-fertilised crops from insects, diseases and weeds.^[1,5]

4.2 Achievements

The most visible achievement was a sustained increase in cereal production, especially of wheat and rice, which allowed India to reduce its dependence on imported grain and to meet domestic demand.^[1,2] Large-scale famine was averted, and cheaper staple grain contributed to poverty reduction in many regions.^[2] Agricultural prosperity raised farm incomes in several regions and stimulated investment in irrigation, storage, transport, agricultural universities, research institutions and extension services.^[1] These achievements deserve recognition. The

argument of this review is not that the Green Revolution was a mistake, but that its second-generation consequences now require a second transition.

5. ECOLOGICAL COSTS OF AGRICULTURAL INTENSIFICATION

5.1 Soil degradation

Continuous cultivation of the same cereals under high chemical inputs has been associated with declining soil organic matter, compaction, nutrient imbalance, reduced microbial diversity and secondary salinisation in irrigated tracts.^[1,3] Soil health underpins long-term production, so its degradation threatens the very food security that the Green Revolution secured.

5.2 Groundwater depletion

Reliance on tube-well irrigation has drawn heavily on aquifers. Satellite gravimetry indicated groundwater loss in north-western India (Rajasthan, Punjab and Haryana) of the order of 18 km³ per year during 2002–2008, attributable mainly to irrigation withdrawals.^[13] Falling water tables raise pumping energy costs and reduce water availability, and many productive regions now experience critical groundwater stress.

5.3 Biodiversity loss

Monocultures displaced diversified traditional systems, contributing to loss of indigenous crop varieties, beneficial insects and pollinators, and to simplification of agro-ecosystems. Reduced biodiversity makes production systems more vulnerable to pests, diseases and climatic uncertainty.^[3,4]

6. PESTICIDES: BENEFITS, DEPENDENCY AND RISKS

6.1 Role of pesticides in modern agriculture

Pesticides were introduced primarily to reduce crop losses caused by insects, fungi, weeds and other pests. Their benefits include higher and more stable yields, reduced pest-related losses, better quality of produce, improved economic returns and greater stability of food supply. Pests remain a major cause of pre-harvest loss in India, and without effective crop protection a substantial portion of production may be lost before harvest.^[14]

6.2 Emergence of pesticide dependency

Over time, Indian agriculture became increasingly dependent on chemical pest control. Four drivers are commonly identified. Monocropping over large areas created favourable

conditions for pest outbreaks. Repeated use of the same active ingredients selected for resistance. Market pressures led farmers to seek immediate, visible pest control to protect economic returns. Finally, limited training in safe and integrated pest management encouraged excessive or inappropriate use.^[5,14]

Official statistics show that chemical pesticide use is concentrated in a few large agricultural states. In 2023–24, Uttar Pradesh, Maharashtra and Punjab reported the highest consumption, with Uttar Pradesh and Maharashtra reporting roughly 11,800 t and 8,700 t of technical-grade material, respectively.^[15] India's average use per hectare has been low compared with many intensively farmed countries, but use is uneven across regions and crops, and unsafe handling practices are common.^[5,16]

6.3 Environmental consequences of excessive use

Persistent residues may accumulate in agricultural soils, with potential effects on microbial activity, nutrient cycling and fertility.^[17] Pesticides can reach rivers, canals, lakes and groundwater through runoff and leaching, contaminating drinking water and harming aquatic ecosystems.^[5,17] Many insecticides also affect non-target beneficial insects: neonicotinoids, for example, pose recognised risks to pollinators^[18], and a 27-year study in German protected areas recorded a decline of more than 75% in flying insect biomass, although the causes are multifactorial and the finding is not specific to India.^[19] Broad-spectrum products may eliminate natural enemies of pests, leading to secondary pest outbreaks, pest resurgence and still greater dependence on chemical applications.^[20,21]

6.4 Human health concerns

Farmers and agricultural workers face the highest exposure through spraying, mixing, improper storage and inadequate protective equipment. A systematic review estimated that some 385 million cases of unintentional acute pesticide poisoning occur worldwide each year, with a disproportionate burden among agricultural workers in low- and middle-income regions.^[22] Dietary exposure depends on the type of pesticide, residue level, frequency of consumption and regulatory compliance, while community exposure arises through spray drift, contaminated water and environmental residues.^[16,17] These concerns have prompted increased scientific investigation and regulatory oversight. Table 1 summarises the principal consequences of input-intensive agriculture.

Table 1: Principal consequences of input-intensive agriculture.

Domain	Principal consequences	Key sources
Soil	Decline in organic matter; compaction; nutrient imbalance; reduced microbial diversity; secondary salinisation	[1,3]
Groundwater	Falling water tables; higher energy demand for pumping; regional groundwater stress	[13]
Biodiversity	Loss of indigenous varieties; decline of beneficial insects and pollinators; simplified agro-ecosystems	[4,19]
Pest dynamics	Monocropping-associated outbreaks; resistance; resurgence and secondary pests	[5,20]
Soil and water contamination	Residues in soil; runoff and leaching to surface water and groundwater; harm to aquatic life	[17]
Human health	Occupational poisoning; dietary residue exposure; community exposure through drift and water	[16,22]

7. THE "SECOND BATTLE" AND ESTABLISHED SUSTAINABLE ALTERNATIVES

If the first great challenge of independent India was overcoming hunger, the current challenge is ensuring sustainability. Modern agriculture must simultaneously deliver food security, farmer livelihoods, environmental protection, public health and climate resilience.^[23] This transition can be regarded as India's second agricultural transformation. Several established approaches are available.

7.1 Integrated pest management

Integrated pest management (IPM) combines biological control agents, pest monitoring, crop rotation, resistant varieties and targeted, threshold-based pesticide application. It seeks to keep pest populations below economically damaging levels rather than to eliminate them completely.^[20] IPM is the natural framework within which any new crop-protection input, including those discussed later in this review, should be evaluated.

7.2 Organic agriculture

Organic farming emphasises natural nutrient management, biological pest control, reduced chemical dependence and ecological sustainability. Meta-analyses indicate that organic yields are on average roughly 20–25% lower than conventional yields, with large variation by crop and management, and that the gap narrows when diversification practices such as crop rotation and polyculture are used.^[24,25] Productivity and scalability therefore remain real challenges, but organic systems offer important lessons for sustainable agriculture.

7.3 Precision agriculture

Emerging technologies, including drones, sensors, geographic information systems and artificial-intelligence-based decision support, enable more efficient use of inputs. Precision agriculture has the potential to reduce unnecessary pesticide applications while maintaining productivity, although adoption by smallholders depends on cost, connectivity and extension support.

7.4 Natural farming approaches

Natural farming systems promote minimal external inputs, soil biological activity, local resource use and ecological resilience. Zero Budget Natural Farming in Andhra Pradesh, for example, has progressed from a farmer movement to a state-supported programme.^[26] Such approaches are increasingly evaluated as complementary strategies for sustainable agricultural development, and continued independent assessment of their agronomic and economic performance is warranted.

8. AGROHOMOEOPATHY: CONCEPT, EVIDENCE AND CRITICAL APPRAISAL

8.1 Concept and preparations

Homeopathic preparations are produced by serial dilution and vigorous agitation (succussion) of a mother substance of mineral, plant, animal or pathogen (nosode) origin in water–ethanol, or by trituration with lactose. Potencies are written on the decimal (x or D; 1:10 per step) or centesimal (C or CH; 1:100 per step) scale. Beyond about 12C (24x) the expected number of molecules of the starting material per dose falls below one, and such preparations are termed ultramolecular.^[27,28] In agriculture, preparations are applied by seed soaking or pelleting, soil drench, foliar spray or addition to irrigation water. Remedies are selected on the basis of the stressor (for example, a potentised form of arsenic applied to arsenic-stressed plants, an "isopathic" approach), of symptom similarity, or of empirical screening.^[29,30]

8.2 Historical development and Indian context

Experimental work on dilute preparations and plants dates to the early twentieth century^[6], and the first critical review of homeopathy in agriculture was published in 1984.^[7] Research has since expanded in Europe, Latin America and India.^[8,29] Indian groups have examined potentised drugs against plant viruses, fungal pathogens, nematodes and aflatoxin production by *Aspergillus parasiticus* since the 1970s; these reports are summarised in the review by Betti *et al.*^[29] That review identified 44 publications on phytopathological models, of which only 19 included statistical analysis, which illustrates the limited quality of much of the early

literature.^[29]

8.3 Evidence from systematic reviews

Between 2009 and 2018 a group of researchers systematically reviewed the plant literature in successive steps covering healthy plants, abiotically stressed plants and phytopathological models with field trials. The reviews applied a Study Methods Evaluation Procedure and a Manuscript Information Score (MIS) to identify publications with adequate reporting, and then identified the subset with adequate controls to detect specific effects.^[29–31] In the compilation of 157 publications describing 167 experimental studies, 29 studies had adequate controls to identify specific effects and reported significant effects of decimal and centesimal potencies, including dilutions beyond Avogadro's number; ten used systematic negative control (SNC) experiments to demonstrate the stability of the test system.^[28] The reviews repeatedly noted the scarcity of independent replications and recommended routine use of SNC experiments to exclude false-positive results.^[30,31] An update covering 2008–2017 identified 74 further publications, five describing novel test systems; among replication trials, one reproduced the original findings while three failed to confirm them, although possible external influencing factors were identified.^[32] Table 2 summarises these reviews.

Table 2: Systematic reviews of plant-based homeopathic basic research.

Review	Scope	Main findings reported
Majewsky et al., 2009 ^[31]	Healthy plants, 1920–2009	86 studies in 79 publications; 43 with statistics; 29 with MIS $\geq$ 5; 15 investigated specificity. Very few reproduction trials.
Betti et al., 2009 ^[29]	Phytopathological models and field trials, 1969–2009	44 publications on models (19 with statistics; 6 with MIS $\geq$ 5); 9 field publications (6 with MIS $\geq$ 5). Prospects judged promising, but much more experimentation needed, especially at field level.
Jäger et al., 2011 ^[30]	Abiotically stressed plants, 1920–2010	34 publications (1965–2010), 37 studies. More experimentation and independent replication trials needed.
Jäger et al., 2015 ^[28]	Compilation of the three reviews	157 publications, 167 studies; 29 studies with adequate controls reported significant effects, including beyond Avogadro's number; 10 studies used SNC experiments.
Ücker et al., 2018 ^[32]	Update, 2008–2017	74 publications; 5 novel test systems. Replication trials: one concordant with the original, three not confirming it.

8.4 Replication: the arsenic–wheat and arsenic–duckweed systems

The most extensively replicated systems illustrate both the promise and the fragility of the

evidence (Table 3). In a wheat germination model, an Italian group reported stimulating effects of potentised arsenic trioxide (As_2O_3), notably the 45x potency, on germination and seedling growth of arsenic-poisoned seed.^[33–35] An independent Swiss reproduction trial found a significant effect of the same preparation, but in the opposite direction, with reduced shoot growth.^[36] Further Swiss experiments did not reproduce the original growth increase, and a meta-analysis of all 17 experiments performed to that point yielded a small but statistically significant growth decrease of 3.2% ($p = 0.017$) with the 45x preparation; the authors concluded that the preparation produced specific effects as investigated by two independent working groups, but the direction was not consistent.^[37]

In a second system, arsenic-stressed duckweed (*Lemna gibba*), potentised As_2O_3 increased the relative growth rate by about 1.2% in the original series.^[38] An internal replication by the same group, using a different laboratory, experimenter and light regime, found an effect in the same direction but of smaller size (+0.64% and +0.89% in two series, +0.77% pooled, $p < 0.01$ for the pooled data; the first series was individually non-significant). SNC experiments indicated a stable test system.^[39]

Table 3: Selected replication histories in arsenic-based plant bioassays.

System	Original report	Replication follow-up /	Outcome
Wheat germination and seedling growth; As_2O_3 45x	Italian group: stimulating effects on germination and seedling growth of arsenic-poisoned seed ^[33–35]	Independent Swiss reproduction trial ^[36] ; further trials and meta-analysis of 17 experiments ^[37]	Specific effect detected, but direction reversed (shoot growth -3.2% , $p = 0.017$ in meta-analysis); original increase not reproduced
Arsenic-stressed duckweed (<i>Lemna gibba</i>); As_2O_3 17x–33x	Relative growth rate $+1.21\%$ (late period, $p < 0.001$) ^[38]	Internal replication, different laboratory, experimenter and light cycle: $+0.64\%$ ($p = 0.097$) and $+0.89\%$ ($p = 0.04$); pooled $+0.77\%$ ($p < 0.01$) ^[39]	Same direction, smaller effect; first series individually non-significant; stable system by SNC experiments

Two points merit emphasis. First, effects of around 1% on a laboratory growth rate are small relative to the variability that field agronomy must tolerate, so it is unclear whether such

effects would translate into agronomically meaningful benefits. Second, the reversal of effect direction in the wheat system shows that, even where specific effects are detected, their direction can depend on uncontrolled factors, which limits their predictive use.

8.5 Phytopathological and field evidence

For disease control, Betti *et al.* identified 44 publications on phytopathological models and nine on field trials (six of which had adequate reporting), and concluded that prospects for homeopathic treatments in agriculture are promising but that considerably more experimentation is needed, particularly at field scale and on potentiation techniques, effective potency levels and conditions for reproducibility.^[29] Representative reports include altered resistance to tobacco mosaic virus in tobacco treated with potentised arsenic^[40] and in-vitro antifungal and anti-aflatoxin effects of selected remedies.^[29] Recent narrative syntheses describe improvements in germination, growth, secondary metabolites and stress tolerance in several crops.^[8] In the absence of independent replication and field-scale randomised trials, these reports are best regarded as hypothesis-generating.

8.6 Plausibility and methodological considerations

The proposition that ultramolecular preparations exert specific biological effects conflicts with established principles of physical chemistry and pharmacology, and proposed mechanisms have not been shown to be physically coherent.^[27] Proponents counter that plant bioassays are placebo-free systems that can be blinded and randomised, and that reproducible effects, if confirmed, would require a new mechanistic explanation.^[28,39] The two positions are not reconciled by current data.

Several methodological issues limit confidence. Reported effects are small and sensitive to season, light regime, seed lot, experimenter and laboratory.^[37,39] Systematic negative control experiments and rigorous randomisation and blinding are needed to detect false positives arising from environmental gradients^[41], and uniform reporting standards such as the REHBaR guideline are only slowly being adopted.^[42] Much of the replication literature originates from a small number of closely connected research groups, and several studies were funded by homeopathy-affiliated foundations^[39]; independent confirmation is therefore particularly valuable.

Evidence from other biological models and from human clinical research is relevant context. A systematic review of in-vitro studies found effects of high potencies in a large share of

experiments, but no model was reproduced consistently by all independent investigators^[43], and a later bibliometric update documented continued replication efforts.^[44] In humans, a comparative analysis found the clinical effects of homeopathy compatible with placebo effects^[9], and a national evidence review concluded that there were no health conditions for which homeopathy had been shown reliably effective.^[10] Plant bioassays are not clinical trials, but these findings caution against extrapolating from isolated positive results.

8.7 Safety, ecological and regulatory considerations

Because preparations beyond 12C contain no measurable residue of the starting material and are applied in small volumes, direct toxicological and environmental risks are presumed to be low. This presumption should be demonstrated rather than assumed. Low-potency preparations of toxic substances such as arsenic do contain the substance, and vehicles such as ethanol and lactose should be accounted for in phytotoxicity and ecotoxicity testing. Regulatory classification also needs clarification: efficacy claims for crop-protection products in India are normally assessed under the framework of the Insecticides Act, 1968, and it should be established how homeopathic preparations intended for crop use are to be treated within that framework. Claims that AgroHomoeopathy is "residue-free" or a "complete replacement" for conventional protection are not supported by current evidence.

9. TOWARD EVIDENCE-BASED INTEGRATION WITHIN IPM

In view of the evidence, a staged approach is proposed. In Stage 1, effects are re-examined in blinded, randomised, controlled bioassays with SNC experiments in at least two independent laboratories. In Stage 2, greenhouse and pot trials are conducted on crops of Indian priority (for example rice, wheat, cotton and vegetables) with defined abiotic stressors or pathogens. In Stage 3, multi-location field randomised trials in farmers' fields compare homeopathic preparations with an untreated control, standard IPM and an approved biopesticide, using agronomic and economic outcomes (disease incidence and severity, pest counts, yield, input cost and net return) over at least two seasons. In Stage 4, ecotoxicological, residue, economic and regulatory evaluations are completed. Until Stage 3 trials are supportive, AgroHomoeopathy should not replace proven crop-protection measures, and farmers who participate in trials should retain access to standard protection as a rescue option. Table 4 lists the proposed design standards.

Table 4: Proposed design and reporting standards for evaluating AgroHomoeopathy.

Design element	Recommended standard	Rationale
Allocation and blinding	Randomised allocation; coded preparations; analysis blind to treatment	Excludes allocation and observer bias ^[41]
Controls	Untreated control; vehicle controls (unsuccussed and succussed solvent); conventional or approved bio-input comparator	Separates specific from non-specific effects and benchmarks against proven options ^[28]
System stability	Systematic negative control experiments alongside every treatment series	Detects false positives from environmental gradients ^[39,41]
Replication	Pre-registered protocols; at least two independent laboratories or sites; adequate statistical power	Addresses non-replication and reversal of effect direction ^[32,37]
Reporting	REHBaR checklist for basic research; CONSORT-type reporting for field trials	Transparency and reproducibility ^[42]
Field outcomes	Disease incidence and severity, pest counts, yield, input cost and net return over at least two seasons	Agronomic and economic relevance ^[29]
Safety and residues	Phytotoxicity, ecotoxicity and vehicle analysis; exclusion of low-potency forms of toxic substances	Verifies, rather than assumes, environmental safety
Governance	Independent funding or oversight; open data; farmer informed consent	Limits conflict of interest and protects livelihoods

10. POLICY IMPLICATIONS

Future agricultural policy should emphasise the following measures, which apply irrespective of the outcome of AgroHomoeopathy research:

- Balanced and soil-test-based use of fertilisers and pesticides.
- Scientific monitoring of environmental impacts, including continuous surveillance of pesticide residues in food, soil and water.
- Farmer education and training, and strengthened agricultural extension services.
- Promotion and incentives for integrated pest management.
- Investment in sustainable technologies, including precision agriculture and biological inputs.
- Protection of groundwater resources and conservation of agricultural biodiversity.
- Promotion of climate-resilient agricultural practices.
- Public funding of independent, pre-registered, multi-site trials of emerging low-input approaches such as AgroHomoeopathy, with clear regulatory pathways and truthful claims to farmers.

11. LIMITATIONS OF THIS REVIEW

This is a narrative rather than a systematic review. For AgroHomoeopathy, it relies principally on published systematic reviews and on replication trials identified through them, and may therefore under-represent recent or non-English primary studies, including regional Indian literature. The underlying studies are heterogeneous, often small and subject to potential publication bias. The conclusions drawn here should be revisited as independent replication and field-scale trials become available.

12. CONCLUSION

The Green Revolution secured India's food supply and remains one of the most consequential agricultural transformations of the twentieth century, but the input-intensive model that delivered it has generated significant ecological and public-health costs, among which pesticide dependence is prominent. India's second agricultural transformation must sustain production while restoring soils, water and biodiversity and reducing chemical exposure. Established approaches, namely integrated pest management, diversified and natural farming systems and precision technologies, have the strongest evidence base and should form the core of this transition.

AgroHomoeopathy offers an inexpensive, low-input option that has generated intriguing but inconsistent results in controlled plant bioassays, with small effect sizes, partial replication including effect reversal, scant field-scale evidence and no accepted mechanism. It is therefore appropriate to evaluate it as a candidate adjunct within integrated pest management through rigorous, independent, multi-site trials, and inappropriate at present to promote it as a validated solution or as a substitute for proven crop protection. If subsequent trials confirm agronomically meaningful and reproducible benefits, AgroHomoeopathy could earn a place in a diversified sustainable-agriculture toolkit; if they do not, the research will still have clarified where limited public resources should be invested.

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