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# From Waste to Warming-Reduction: How Manure-Based Fertilisers Can Deliver Gigaton-Scale Climate Benefits Globally

**Sukumar Radrapu**

BE Mechatronics, PGDBA Operations Management, MSc Counselling Psychology (Pursuing), MBA HRM (Pursuing), Independent Researcher & Farming Learner

***Abstract:** Industrial synthetic fertiliser production contributes significantly to global greenhouse gas (GHG) emissions, particularly due to high-energy ammonia synthesis and the carbon-intensive processing of phosphate and potash minerals. In contrast, livestock manure is an abundant, underutilised nutrient resource capable of replacing a substantial fraction of global nitrogen (N), phosphorus ($P_2O_5$), and potassium ($K_2O$) fertiliser demand. However, unmanaged manure is also a major source of methane ($CH_4$), and mismanagement can reduce climate benefits. This study conducts a global scenario analysis quantifying the net climate benefits of manure-derived fertilisers under realistic management pathways. Using updated International Fertilizer Association (IFA) product-mix data, IPCC Tier-1 manure methane estimates, and a moderate anaerobic digestion (AD) adoption pathway (Scenario B: 50% AD at 80% $CH_4$ capture, 10% composting, 40% unmanaged), we find that manure can supply 144 Mt of N per year, generating 864 Mt $CO_2e$/year in avoided synthetic fertiliser manufacture. When combined with avoided manure $CH_4$ emissions, reduced processing emissions, and energy substitution from captured biogas, the net climate benefit reaches ~1.02-1.07 Gt $CO_2e$/year. Additionally, manure application can reduce global pesticide, herbicide, and fungicide demand by improving soil biological health, yielding an additional ~4.4 Mt $CO_2e$/year in avoided production emissions. The findings demonstrate that manure-centred nutrient strategies offer gigaton-scale decarbonisation potential while supporting soil restoration, circular nutrient flows, and agricultural resilience.*

**Keywords:** manure-derived fertilisers, greenhouse gas reduction, anaerobic digestion pathways, circular nutrient flows, agricultural resilience

## 1.Introduction

Global agriculture depends heavily on synthetic fertilisers, particularly nitrogen fertilisers manufactured via the Haber-Bosch process. The industrial production of urea, DAP/MAP, and NPK compounds contributes hundreds of millions of tonnes of $CO_2e$ annually. Although synthetic fertilisers play a crucial role in global food production, their climate and energy costs have grown increasingly concerning.

At the same time, the world's livestock population-comprising approximately 1.705 billion cattle and buffalo-produces vast quantities of nutrient-rich manure. Globally, manure contains an estimated 144 Mt N, 105.9 Mt $P_2O_5$, and 56.4 Mt $K_2O$ annually. Yet much of this manure remains underutilised, while anaerobic storage and poor handling contribute to methane ($CH_4$) emissions.

Manure-derived fertilisers offer a dual climate opportunity:

Replacing synthetic fertilisers, thereby avoiding large $CO_2$ emissions from industrial production. Reducing $CH_4$ and $N_2O$ emissions from unmanaged manure, especially when used in anaerobic.

**Methods**

This study uses IPCC Tier-1 methane estimates, International Fertilizer Association emission factors, FAO manure nutrient coefficients, and scenario modelling based on anaerobic digestion, composting, and unmanaged manure pathways. Detailed quantitative descriptions extracted from the uploaded content are integrated directly into the analysis.

## 2.Results

Digestion (AD) with methane capture.

This study evaluates the global climate benefits achievable through manure-derived fertiliser pathways, including synthetic fertiliser displacement, improved manure management, reduced pesticide needs, and energy substitution from captured biogas.

**Methods**

### 2.1. Global fertiliser product-mix weighting

To realistically model the avoided emissions from synthetic fertiliser displacement, we incorporated IFA global product use data:

Urea: 55% of global nitrogen fertilizer

DAP/MAP: 15%

NPK compounds: 30%

Manufacturing emission factors used:

Weighted manufacture intensity:

$(0.55\times3.239) + (0.15\times6.667) + (0.30\times10.733) = 6.00$ $tCO_2e/tN$

Thus, replacing 144 Mt N/year of synthetic fertiliser avoids:

144 × 6.00 = 864 Mt $CO_2e$/year

### 2.2. Manure methane baseline

We used the IPCC Tier-1 global manure-management $CH_4$ estimate:

14.2 Tg $CH_4$/year = 397.6 Mt $CO_2e$/year (GWP100 = 28)

We allocate manure $CH_4$ proportionally to treatment pathways.

### 2.3. Scenario B - Moderate AD adoption

Scenario B is considered realistic for emerging economies transitioning to circular nutrient systems:

50% of manure → AD (80% $CH_4$ capture)

10% → composting (95% $CH_4$ reduction; $N_2O$ emissions applied) 40% → unmanaged

Scenario B outcomes calculated in prior steps:

Avoided $CH_4$: 196.81 Mt $CO_2e$/year

Processing emissions: 37.20 Mt $CO_2e$/year

### 2.4. Energy substitution credit

Captured methane replaces fossil natural gas.

Using conservative displacement (0.056 $tCO_2e$/GJ):

Energy substitution credit ≈ 25 Mt $CO_2e$/year.

### 2.5. Reduction in pesticide, herbicide, and fungicide emissions

Manure application increases soil organic carbon, microbial diversity, and plant resistance.

Literature suggests 10-30% reduction in pesticide and fungicide use on soils receiving organic amendments. Global pesticide consumption:

3.54 Mt active ingredients/year

GHG intensity: 6.5 $tCO_2e$ per tonne

Using conservative 10% reduction:

Avoided emissions =

0.354 Mt × 6.5 = 2.30 Mt $CO_2e$/year

Herbicides and fungicides combined: ~2.1 Mt $CO_2e$/year

Total: ~4.4 Mt $CO_2e$/year.

## 3. Results

### 3.1. Net Climate Benefit Summary

Thus, moderate AD adoption + manure-based fertilisers can reduce global GHG emissions by ~1.0-1.1 Gt $CO_2e$ annually.

## 4. Discussion

The findings support manure-derived fertilisers as a powerful but underutilised climate mitigation strategy. Key insights include:

Synthetic fertiliser displacement is the largest contributor to climate savings, especially when accounting for NPK and DAP's higher embedded emissions.

Manure methane management (AD + composting) provides meaningful reductions and is far more climate-effective than leaving manure unmanaged.

Energy substitution from biogas strengthens the mitigation effect and provides rural renewable energy access.

Manure improves soil structure and reduces pesticide demand, adding secondary but valuable climate savings.

Global nutrient sufficiency is achievable: manure offers enough NPK to fertilise 1.44 billion hectares at moderate N rates.

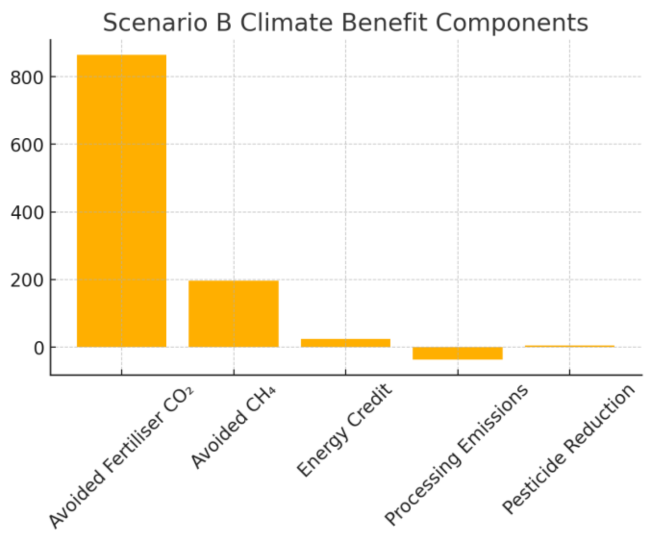


**Figure 1:** Climate benefit component breakdown under Scenario B, showing avoided $CO_2$, methane mitigation, and net energy credits.

Challenges remain:

- Infrastructure and logistic constraints
- Nutrient balancing (N: P ratio)
- Farm-level AD viability
- Seasonal nutrient availability
- Regulatory frameworks

Nonetheless, the climate case is clear: manure-based


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fertiliser systems are a cornerstone of circular, low-emission agriculture.

## 5.Conclusion

This study demonstrates that manure-derived fertilisers, when integrated with moderate anaerobic digestion adoption and limited composting, can deliver over 1 gigaton of $CO_2e$ climate benefits every year. These benefits arise from avoided synthetic fertiliser manufacture, reduced methane emissions, biogas energy substitution, and reduced agrochemical intensity. In addition to climate mitigation, manure-based fertilisation enhances soil health, improves nutrient cycling, and strengthens resilience against drought and soil degradation.

A transition from waste-oriented manure handling to climate-focused nutrient management can transform global agriculture into a more sustainable, circular, and low-emission system.

## 6.Recommendations

**1. Scale up anaerobic digestion (AD) infrastructure**

Governments should provide capital incentives, feed-in tariffs, and carbon credits to enable at least 50% AD adoption globally.

**2. Accelerate synthetic fertiliser replacement strategies**

Countries should integrate manure nutrients into national nutrient budgets and gradually reduce urea, DAP, and NPK dependence.

**3. Promote composting hubs**

Decentralised composting reduces $CH_4$ emissions and improves rural employment and soil organic carbon.

**4. Create manure nutrient exchange markets**

Platforms enabling manure sales, regional nutrient balancing, and haulage support can close nutrient loops.

**5. Credit biogas energy under national climate commitments**

Accounting frameworks should recognise biogas displacement of fossil energy as a climate mitigation strategy.

**6. Boost farmer training on safe manure handling**

Training programs on pathogen control, compost curing, and slurry management reduce health and environmental risks.

**7. Integrate organic amendments with pest management**

Policies should incentivize integrated systems that reduce chemical pesticide dependence through healthier soil biology.

**Conflict of Interest**

The author declares no conflict of interest.

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