

# VERMICOMPOSTING AS A DETOXIFICATION AND NUTRIENT-RECOVERY STRATEGY FOR *PARTHENIUM HYSTEROPHORUS* L.

Dr. Mamta J. Patange<sup>1\*</sup>, Dr. Tushar U. Patel<sup>2</sup>, Dr. Shubhangi J. Dhage<sup>3</sup>, Dr. P. K. Waghmare<sup>4</sup>, Dr. N. K. Medhe<sup>5</sup>, Dr. Karuna M. Chaudhri<sup>6</sup>, Dr. Priya R. Chaudhari<sup>7</sup>, Dr. Sandeep G Shinde<sup>8</sup>

<sup>1\*</sup> Assistant Professor, Dept. of Agronomy, VNMKV, Parbhani, Maharashtra, India. Email: patangemj456@gmail.com

<sup>2</sup> Associate Professor, Dept. of Agronomy, NAU, Navsari, Gujarat, India

<sup>3</sup> Assistant Professor, dept. of SSAC, Dr. PDKV, Akola, Maharashtra, India

<sup>4</sup> Assistant Professor, Dept. of Agronomy, VNMKV, Parbhani, Maharashtra, India

<sup>5</sup> Cotton Agronomist, MPKV, Rahuri, Maharashtra, India

<sup>6</sup> Assistant Professor, Dept. of Agronomy, JAU, Junagadh, Gujarat, India

<sup>7</sup> Assistant Professor, Dept. of Agronomy, JAU, Junagadh, Gujarat, India

<sup>8</sup> Assistant Professor, GPB, VNMKV, Parbhani, Maharashtra, India

## ABSTRACT:

*Parthenium hysterophorus* L. is a noxious weed whose biomass contains phytotoxic compounds and should not be recycled into agriculture without stabilization. This study evaluated appropriate composting methods for converting *Parthenium* biomass into a mature, nutrient-rich, and crop-safe amendment. Eight treatments were tested in a completely randomized pot experiment with three replications: *Parthenium* combined with cow dung at 1:1 or 2:1 (w/w), the same mixtures with *Eisenia fetida* earthworms, and corresponding *Parthenium*:farm-waste:cow-dung mixtures at 1:1:1 or 2:1:1 (w/w), with and without earthworms. Each tub received 6 kg dry substrate, moisture was maintained at approximately 60–70%, and compost was harvested after 90–105 days. Maturity was assessed through pH, electrical conductivity, organic carbon, total N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, C:N ratio, and recovery. A green-gram bioassay tested residual phytotoxicity. Mature composts had near-neutral pH (7.236–7.621), EC of 1.300–1.463 dS m<sup>-1</sup>, C:N ratios of 9.550–16.287, total N of 1.720–2.420%, P<sub>2</sub>O<sub>5</sub> of 0.766–0.865%, and K<sub>2</sub>O of 1.250–1.500%. Earthworm treatments generally accelerated carbon loss, narrowed C:N ratio, increased recovery, and improved green-gram establishment. Treatment T<sub>7</sub>, *Parthenium* + farm waste + cow dung at 1:1:1 (w/w) with earthworms, gave 70.023% recovery, 13.057 C:N ratio, 0.865% P<sub>2</sub>O<sub>5</sub>, 100% green-gram germination by 5 days, 11.51 cm shoot length, 11.20 cm root length, and vigour index 2271. T<sub>4</sub>, *Parthenium* + cow dung at 2:1 with earthworms, produced the highest mature N and K concentrations and the lowest C:N ratio in the non-farm-waste group. The results show that balanced co-substrates with earthworms provide the most reliable combination of maturity, nutrient recovery, and crop safety, and that crop bioassay should accompany chemical compost testing before field use.

**KEYWORDS:** compost maturity; *Eisenia fetida*; invasive weed; nutrient recovery; *Parthenium hysterophorus*; phytotoxicity; vermicomposting

## INTRODUCTION

*Parthenium hysterophorus* L. is an aggressive annual weed that colonizes disturbed habitats and cultivated landscapes. Its rapid growth, high seed production, and environmental adaptability make it difficult to suppress once established [1–3]. The weed also produces allelochemicals that can inhibit neighboring vegetation and reduce crop establishment [4–7]. These properties create a disposal dilemma: biomass removed from non-cropped areas must be handled in ways that prevent seed dispersal and avoid transferring phytotoxic compounds into crop soil. Composting is a controlled biological process in which organic residues are decomposed and stabilized into a humus-like material. Co-substrates such as cow dung and farm waste can improve the feedstock balance, moisture retention, aeration, and microbial environment. Vermicomposting adds the activity of earthworms, which fragment organic matter, stimulate microbial transformation, and contribute nutrient-rich casts [8–12]. Several reports suggest that *Parthenium* can be recycled through composting or vermicomposting, but the appropriate method should be judged by more than final nutrient concentration. A mature compost should also have a stable C:N ratio, acceptable pH and EC, adequate recovery, and low residual phytotoxicity.

The present investigation addressed the objective of finding an appropriate composting method for *Parthenium* by combining these criteria. It compared *Parthenium*–cow-dung mixtures with and without earthworms, diversified mixtures containing farm waste, and their earthworm-assisted counterparts. Green gram was used as a sensitive crop bioassay to determine whether the products supported rapid germination and early seedling growth.

## 2. MATERIALS AND METHODS

### 2.1 Composting site, feedstock, and design

The experiment was conducted during 2023–2024 at the College Farm of N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat, India. *Parthenium* was collected before flowering from fallow areas, washed,

shade dried, and chopped into 2–3 cm pieces. Cow dung, farm waste, and *Eisenia fetida* were obtained from the university livestock research facility. The experiment was laid out in a completely randomized design with three replications and eight treatments. Each 60-cm-diameter × 22-cm-height plastic tub received 6 kg dry substrate. In earthworm treatments, 50 g earthworms were added per tub after the substrate had cooled.

**Table 1. Composting treatments and management**

| Code           | Substrate                                                          | Earthworms | Initial substrate | Harvest period |
|----------------|--------------------------------------------------------------------|------------|-------------------|----------------|
| T <sub>1</sub> | <i>Parthenium</i> + cow dung (1:1 w/w)                             | None       | 6 kg              | 90–105 days    |
| T <sub>2</sub> | <i>Parthenium</i> + cow dung (2:1 w/w)                             | None       | 6 kg              | 90–105 days    |
| T <sub>3</sub> | <i>Parthenium</i> + cow dung (1:1 w/w) + earthworms                | 50 g/tub   | 6 kg              | 90–105 days    |
| T <sub>4</sub> | <i>Parthenium</i> + cow dung (2:1 w/w) + earthworms                | 50 g/tub   | 6 kg              | 90–105 days    |
| T <sub>5</sub> | <i>Parthenium</i> + farm waste + cow dung (1:1:1 w/w)              | None       | 6 kg              | 90–105 days    |
| T <sub>6</sub> | <i>Parthenium</i> + farm waste + cow dung (2:1:1 w/w)              | None       | 6 kg              | 90–105 days    |
| T <sub>7</sub> | <i>Parthenium</i> + farm waste + cow dung (1:1:1 w/w) + earthworms | 50 g/tub   | 6 kg              | 90–105 days    |
| T <sub>8</sub> | <i>Parthenium</i> + farm waste + cow dung (2:1:1 w/w) + earthworms | 50 g/tub   | 6 kg              | 90–105 days    |

## 2.2 Compost management and analysis

Moisture was maintained at approximately 60–70% by periodic watering under a farm shed. The materials were turned after 20 days and subsequently as required. Watering was stopped approximately 10 days before harvest. Mature compost was identified by appearance, odour, and colour, then harvested, sieved, and stored under shade. pH and EC were measured in 1:5 compost: water extracts. Organic carbon, total nitrogen, total phosphorus as P<sub>2</sub>O<sub>5</sub>, and total potash as K<sub>2</sub>O were determined using the methods described in the thesis. The C:N ratio was calculated from total carbon and total nitrogen. Recovery (%) = final dry compost weight / initial dry substrate weight × 100.

**Table 2. Compost maturity and recovery measurements**

| Indicator                     | Method                                      | Timing                 |
|-------------------------------|---------------------------------------------|------------------------|
| pH                            | Potentiometric method                       | Initial and maturity   |
| EC                            | Conductometry                               | Initial and maturity   |
| Organic carbon                | Ignition method                             | Initial and maturity   |
| Total N                       | Kjeldahl method                             | Initial and maturity   |
| P <sub>2</sub> O <sub>5</sub> | Vanadomolybdophosphoric acid method         | Initial and maturity   |
| K <sub>2</sub> O              | Flame photometry                            | Initial and maturity   |
| C:N                           | Total carbon ÷ total nitrogen               | Maturity and reduction |
| Recovery                      | Final dry weight ÷ initial dry weight × 100 | Harvest                |

## 2.3 Green-gram bioassay

The eight matured composts were evaluated in a separate completely randomized pot experiment with three replications. Green gram cultivar GM-7 was sown at ten seeds per 20-kg soil pot receiving the corresponding compost treatment. Germination was recorded at 3 and 5 days after sowing, the time to 100% germination was noted, and seedlings were harvested at 10 days for shoot and root length, dry weight, and vigour index. Vigour index was calculated as germination percentage × (shoot length + root length).

## 2.4 Statistical and interpretive approach

The source thesis used analysis of variance under a completely randomized design and reported standard error, critical difference at P=0.05, and coefficient of variation. In this article, treatment means are reported directly from the source tables. The multi-criteria figures are descriptive normalizations for interpretation and do not replace the original statistical comparisons. The recommendation is based on an integrated reading of chemical maturity, recovery, and crop-bioassay response.

# 3. RESULTS

## 3.1 pH, EC, organic carbon, and C:N ratio

All treatments produced near-neutral compost. Mature pH ranged from 7.236 in T<sub>8</sub> to 7.621 in T<sub>5</sub>. The greatest pH reduction occurred in T<sub>8</sub> (6.515%), followed by T<sub>7</sub> (6.074%) and T<sub>6</sub> (5.962%), showing the combined influence of diversified feedstock and earthworms. EC increased in all treatments from 0.880–1.103 to 1.300–1.463 dS m<sup>-1</sup>. T<sub>5</sub> had the largest relative EC increase (53%), while T<sub>8</sub> had the smallest (33%). The increase is consistent with mineralization and release of soluble ions during decomposition, while the lower increase in several earthworm treatments suggests incorporation of soluble products into more stable organic fractions.

**Table 3. Compost maturity indicators**

| Treatment      | Mature pH | pH reduction (%) | Mature EC | EC increase (%) | Mature OC (%) | OC reduction (%) | Mature C:N | C: N reduction (%) |
|----------------|-----------|------------------|-----------|-----------------|---------------|------------------|------------|--------------------|
| T <sub>1</sub> | 7.571     | 3.9              | 1.300     | 48              | 30.102        | 26.1             | 13.260     | 54                 |

|                |       |     |       |    |        |      |        |    |
|----------------|-------|-----|-------|----|--------|------|--------|----|
| T <sub>2</sub> | 7.391 | 4.3 | 1.341 | 49 | 31.502 | 30.5 | 13.348 | 53 |
| T <sub>3</sub> | 7.421 | 5.1 | 1.320 | 38 | 22.151 | 44.7 | 9.550  | 64 |
| T <sub>4</sub> | 7.274 | 5.3 | 1.368 | 34 | 23.341 | 44.8 | 9.649  | 61 |
| T <sub>5</sub> | 7.621 | 4.9 | 1.404 | 53 | 28.011 | 33.3 | 16.287 | 55 |
| T <sub>6</sub> | 7.486 | 6.0 | 1.421 | 45 | 29.132 | 33.8 | 14.707 | 56 |
| T <sub>7</sub> | 7.421 | 6.1 | 1.441 | 36 | 23.641 | 41.3 | 13.057 | 60 |
| T <sub>8</sub> | 7.236 | 6.5 | 1.463 | 33 | 24.900 | 41.0 | 12.028 | 59 |

Organic carbon decreased from 40.042–45.323% initially to 22.151–31.502% at maturity. The greatest reductions occurred in T<sub>4</sub> (44.836%) and T<sub>3</sub> (44.681%), both earthworm-assisted treatments. The mature C:N ratio was lowest in T<sub>3</sub> (9.550) and T<sub>4</sub> (9.649), whereas the highest was T<sub>5</sub> (16.287). All treatments were below 20:1, indicating stabilization within the commonly used maturity range. The results show that earthworms enhanced carbon turnover, but the magnitude also depended on substrate composition.

### 3.2 Nutrient enrichment and compost recovery

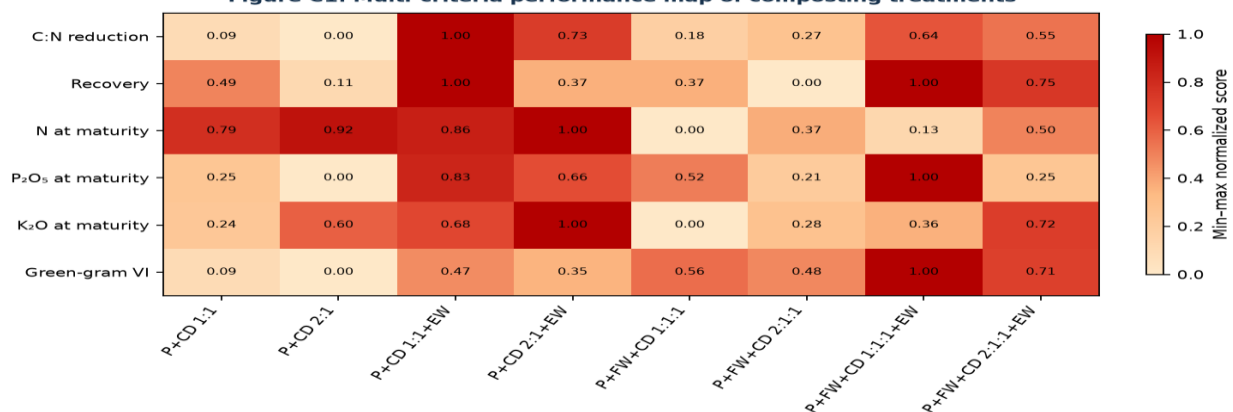
Total nitrogen increased in every treatment. T<sub>4</sub> had the highest mature nitrogen (2.420%), followed by T<sub>2</sub> (2.361%) and T<sub>3</sub> (2.321%). Mature P<sub>2</sub>O<sub>5</sub> ranged from 0.766% in T<sub>2</sub> to 0.865% in T<sub>7</sub>, and mature K<sub>2</sub>O ranged from 1.250% in T<sub>5</sub> to 1.500% in T<sub>4</sub>. Earthworm treatments generally produced high nutrient values, although the highest value depended on the element and feedstock combination.

**Table 4. Nutrient enrichment and recovery**

| Treatment      | N maturity (%) | N increase (%) | P <sub>2</sub> O <sub>5</sub> maturity (%) | P increase (%) | K <sub>2</sub> O maturity (%) | K increase (%) | Recovery (%) |
|----------------|----------------|----------------|--------------------------------------------|----------------|-------------------------------|----------------|--------------|
| T <sub>1</sub> | 2.270          | 60             | 0.791                                      | 88             | 1.310                         | 28             | 66.037       |
| T <sub>2</sub> | 2.361          | 47             | 0.766                                      | 102            | 1.400                         | 27             | 63.027       |
| T <sub>3</sub> | 2.321          | 52             | 0.848                                      | 136            | 1.420                         | 49             | 70.023       |
| T <sub>4</sub> | 2.420          | 43             | 0.831                                      | 149            | 1.500                         | 39             | 65.022       |
| T <sub>5</sub> | 1.720          | 47             | 0.817                                      | 86             | 1.250                         | 29             | 65.033       |
| T <sub>6</sub> | 1.981          | 50             | 0.787                                      | 97             | 1.320                         | 27             | 62.142       |
| T <sub>7</sub> | 1.810          | 46             | 0.865                                      | 111            | 1.340                         | 34             | 70.023       |
| T <sub>8</sub> | 2.070          | 43             | 0.791                                      | 88             | 1.430                         | 35             | 68.023       |

Recovery ranged from 62.142% in T<sub>6</sub> to 70.023% in T<sub>3</sub> and T<sub>7</sub>. Earthworm treatments generally exceeded their non-earthworm counterparts. T<sub>7</sub> combined 70.023% recovery with the highest mature P<sub>2</sub>O<sub>5</sub> concentration, while T<sub>4</sub> combined the highest mature N and K concentrations with the lowest C:N ratio among the high-*Parthenium* cow-dung treatments. These results indicate a trade-off: high nitrogen and potassium concentration, maximum recovery, and highest crop-bioassay performance were not all expressed by the same treatment.

**Figure C1. Multi-criteria performance map of composting treatments**



**Figure C1. Min–max normalized multi-criteria performance of the eight composting treatments. Values are descriptive scores derived from reported treatment means.**

### 3.3 Green-gram crop safety and early growth

The green-gram bioassay separated the products more clearly than pH alone. T<sub>1</sub> and T<sub>2</sub>, which lacked earthworms and contained only *Parthenium* and cow dung, reached 100% germination at 7 and 8 days, respectively. T<sub>3</sub> and T<sub>5</sub>–T<sub>8</sub> reached 100% by 5 days. T<sub>7</sub> produced the highest 3-day germination (82.55%), 11.51 cm shoot length, 11.20 cm root length, 0.057 g plant<sup>-1</sup> dry weight, and vigour index 2271. T<sub>8</sub> ranked second in early growth with 9.81 cm shoot length, 8.90 cm root length, 0.043 g plant<sup>-1</sup> dry weight, and vigour index 1871.

**Table 5. Green-gram bioassay of matured *Parthenium* compost**

| Treatment      | Germination 3 DAS (%) | Germination 5 DAS (%) | Days to 100% | Shoot (cm) | Root (cm) | Dry wt. (g plant <sup>-1</sup> ) | Vigour index |
|----------------|-----------------------|-----------------------|--------------|------------|-----------|----------------------------------|--------------|
| T <sub>1</sub> | 47.30                 | 95.10                 | 7            | 5.46       | 5.22      | 0.028                            | 1016         |

|                |       |        |   |       |       |       |      |
|----------------|-------|--------|---|-------|-------|-------|------|
| T <sub>2</sub> | 40.00 | 90.00  | 8 | 5.04  | 4.87  | 0.025 | 892  |
| T <sub>3</sub> | 55.23 | 100.00 | 5 | 7.80  | 7.63  | 0.032 | 1543 |
| T <sub>4</sub> | 50.32 | 96.95  | 6 | 7.20  | 7.00  | 0.030 | 1377 |
| T <sub>5</sub> | 73.01 | 100.00 | 5 | 8.70  | 7.92  | 0.037 | 1663 |
| T <sub>6</sub> | 65.00 | 100.00 | 5 | 7.89  | 7.70  | 0.033 | 1559 |
| T <sub>7</sub> | 82.55 | 100.00 | 5 | 11.51 | 11.20 | 0.057 | 2271 |
| T <sub>8</sub> | 75.00 | 100.00 | 5 | 9.81  | 8.90  | 0.043 | 1871 |

The bioassay indicates that the composting process reduced the residual phytotoxicity associated with *Parthenium*, but the degree of detoxification depended on method. Earthworms improved both the speed of germination and subsequent seedling growth, and the addition of farm waste strengthened performance when combined with earthworms. T<sub>7</sub> therefore provided the most balanced biological response. T<sub>4</sub> was chemically strong but produced lower green-gram vigour than T<sub>7</sub>, demonstrating why crop-safety testing should accompany nutrient analysis.

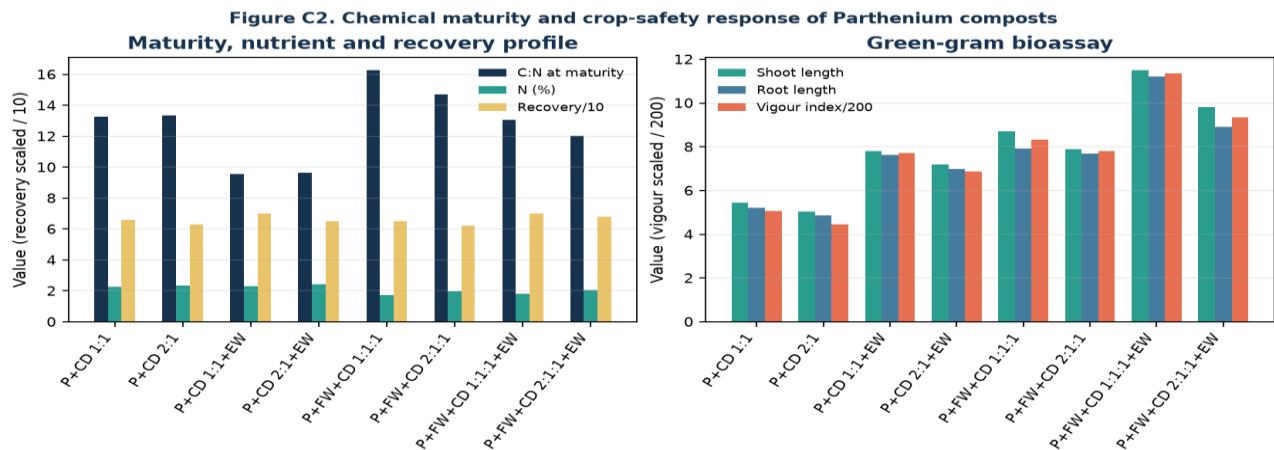


Figure C2. Mature compost chemistry, maturity, recovery, and green-gram response. Vigour index and recovery are scaled only for visual comparison.

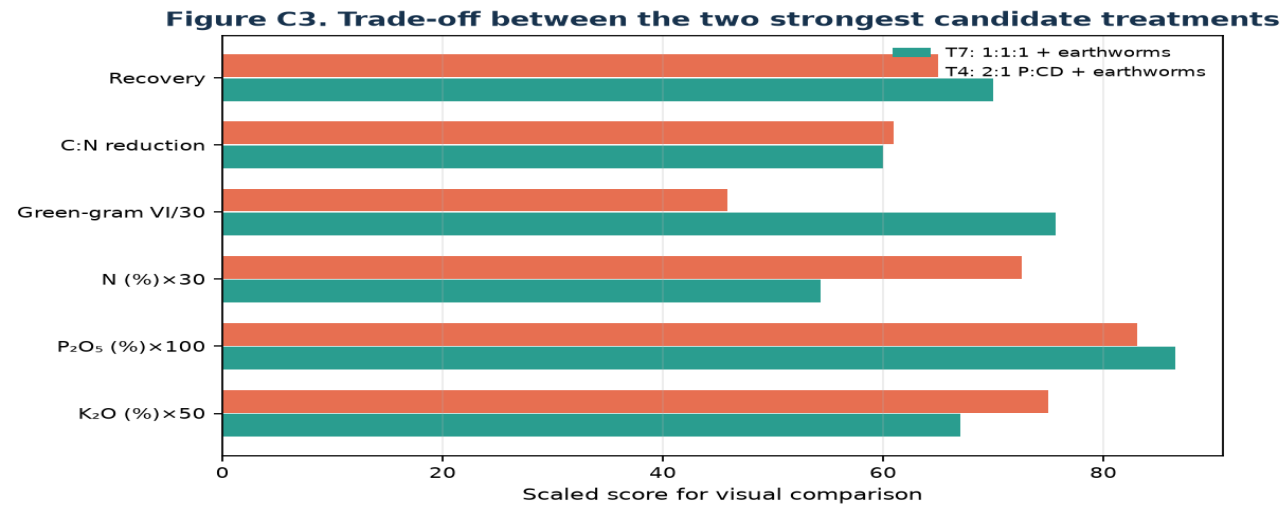


Figure C3. Descriptive comparison of T7 and T4, the two strongest candidate treatments under different decision criteria.

#### 4. DISCUSSION

The composting treatments demonstrate that *Parthenium* is not inherently unusable as an organic feedstock; rather, its use depends on biological stabilization. The decline in organic carbon and C:N ratio indicates active decomposition and mineralization, while the increase in apparent nutrient concentration reflects carbon loss and nutrient retention in the mature product. The mature pH values close to neutrality are compatible with soil application, and the EC values were sufficiently moderate in the source bioassay to support green-gram establishment.

Earthworms enhanced the integrated outcome through multiple mechanisms. Fragmentation increases surface area for microorganisms, burrowing improves aeration, and gut passage transforms organic substrates into casts with altered nutrient availability. The lower mature C:N ratios in T<sub>3</sub> and T<sub>4</sub> and the high recovery in T<sub>3</sub> and T<sub>7</sub> are consistent with accelerated stabilization. The highest phosphorus in T<sub>7</sub> likely reflects the combination of diversified feedstock and earthworm-mediated mineral transformation. Similar mechanisms have been reported for vermicomposting of toxic weeds and mixed organic substrates [8–14].

The green-gram bioassay is central to the interpretation. Chemical maturity alone cannot prove that allelochemicals have been neutralized. T<sub>1</sub> and T<sub>2</sub> had acceptable-looking products but delayed germination and lower vigour than the

earthworm and farm-waste treatments. The improvement in T<sub>3</sub> and T<sub>7</sub> suggests that earthworm activity was associated with greater detoxification, while the superior response of T<sub>7</sub> indicates that a balanced 1:1:1 substrate moderated the high phytotoxic and fibrous load of *Parthenium* without sacrificing recovery.

T<sub>7</sub> is recommended as the best overall method under the tested conditions because it achieved the strongest combined result: high recovery, strong C: N reduction, highest mature P<sub>2</sub>O<sub>5</sub>, full germination by 5 days, and the highest seedling vigour. T<sub>4</sub> is a reasonable alternative when the priority is mature N and K concentration or the lowest C:N ratio. T<sub>8</sub> is also promising but contains a higher *Parthenium* proportion than T<sub>7</sub> and produced lower crop-bioassay values. The recommendation should therefore be stated as a multi-criteria decision rather than as a claim that one treatment maximizes every individual variable.

The experiment has practical and scientific limitations. It used one location, one composting cycle, and one earthworm species, and the bioassay measured only early green-gram responses. The source study did not quantify parthenin or phenolic residues after composting, nor did it evaluate field application rates, long-term soil effects, weed-seed viability in large-scale batches, or pathogen indicators. Future work should validate T<sub>7</sub> across seasons and soils, quantify chemical detoxification, measure microbial communities and temperature trajectories, and compare agronomic performance with farmyard manure and a standard vermicompost.

## 5. Recommended composting protocol

**Table 6. Operational protocol corresponding to the strongest integrated treatment, T<sub>7</sub>**

| Step | Recommended practice                                                                                  |
|------|-------------------------------------------------------------------------------------------------------|
| 1    | Collect pre-flowering <i>Parthenium</i> and prevent seed-bearing biomass from entering the feedstock. |
| 2    | Wash or clean the biomass and chop it to 2–3 cm pieces.                                               |
| 3    | Prepare a 1:1:1 (w/w) mixture of <i>Parthenium</i> , farm waste, and cow dung.                        |
| 4    | Add approximately 50 g <i>Eisenia fetida</i> per 6 kg dry substrate per tub or scale proportionally.  |
| 5    | Maintain 60–70% moisture under shade and turn after approximately 20 days and as needed.              |
| 6    | Harvest after approximately 90–105 days when the material is dark, odourless, and stable.             |
| 7    | Confirm pH, EC, C:N ratio, nutrient content, recovery, and a crop bioassay before field use.          |

## 6. CONCLUSIONS

*Parthenium* biomass can be converted into a mature and crop-safe organic amendment through co-composting and vermicomposting. All eight treatments reduced C:N ratio to below 20:1 and produced near-neutral compost, but earthworm-assisted treatments generally improved maturity, recovery, and green-gram performance. Treatment T<sub>7</sub>—*Parthenium* + farm waste + cow dung at 1:1:1 (w/w) with *Eisenia fetida*—was the most appropriate overall method, producing 70.023% recovery, mature C: N 13.057, N 1.810%, P<sub>2</sub>O<sub>5</sub> 0.865%, K<sub>2</sub>O 1.340%, and green-gram vigour index 2271. T<sub>4</sub> may be selected where nutrient concentration and narrow C:N ratio are prioritized. Fresh or incompletely decomposed *Parthenium* should not be applied near germinating crops. A validated composting process and a crop bioassay are essential safeguards for sustainable recycling.

## REFERENCES

- Adkins, S. W. and Shabbir, A. (2014). Biology, ecology and management of the invasive *Parthenium* weed (*Parthenium hysterophorus* L.). *Pest Management Science*, 70(7), 1023–1029.
- Tanveer, A., Khaliq, A., Ali, H. H., Mahajan, G. and Chauhan, B. S. (2015). Interference and management of *Parthenium*: the world's most important invasive weed. *Crop Protection*, 68, 49–59.
- Bashar, H. K., Juraimi, A. S., Ahmad-Hamdani, M. S., Uddin, M. K., Asib, N., Anwar, M. P. and Hossain, A. (2021). A mystic weed, *Parthenium hysterophorus*: threats, potentials and management. *Agronomy*, 11(8), 1514.
- Batish, D. R., Singh, H. P., Pandher, J. K. and Kohli, R. K. (2005). Allelopathic interference of *Parthenium hysterophorus* residues in soil. *Allelopathy Journal*, 15(2), 267–274.
- Chauhan, H. K. and Joshi, R. (2010). Composting of some toxic weeds using *Eisenia foetida*. *Ecotoxicology and Environmental Safety*, 73(3), 588–592.
- Yadav, A. and Garg, V. K. (2011). Vermicomposting—an effective tool for the management of invasive weed *Parthenium hysterophorus*. *Bioresource Technology*, 102(10), 5891–5895.
- Anbalagan, M., Manivannan, S. and Arul Prakasm, B. (2012). Biomangement of *Parthenium hysterophorus* using an earthworm, *Eisenia fetida*, for recycling nutrients. *Advances in Applied Science Research*, 3, 3025–3031.
- Ameta, K., Satish, R. A., Dave, D. and Ameta, S. C. (2016). Carbon to nitrogen ratio of combinations of feedstocks prepared for composting of *Parthenium hysterophorus* weed. *International Journal of Chemical Sciences*, 14(2), 949–954.
- Das, A., Mondal, S. and Bhattacharyya, P. (2017). Changes in carbon-to-nitrogen ratio during composting and its effect on maturity of compost. *International Journal of Recycling of Organic Waste in Agriculture*, 6(4), 343–349.
- Ndegwa, P. M. and Thompson, S. A. (2000). Effects of C-to-N ratio on vermicomposting of biosolids. *Bioresource Technology*, 75(1), 7–12.
- Suthar, S. (2009). Vermicomposting of vegetable-market solid waste using *Eisenia fetida*: impact on waste biodegradation and soil quality. *Bioresource Technology*, 100(21), 5914–5920.
- Aslam, R., Qureshi, T. M. and Naeem, M. (2021). Role of vermicomposting in improving organic waste management and soil fertility: a review. *International Journal of Environmental Sciences & Natural Resources*, 28(2), 001–007.

13. Maturi, K. C., Haq, I. and Kalamdhad, A. S. (2022). Biodegradation of the intrusive weed *Parthenium hysterophorus* through in-vessel composting: toxicity assessment and spectroscopic study. *Environmental Science and Pollution Research*, 29(56), 84600–84615.
14. Vyankatrao, N. P. (2017). Conversion of *Parthenium hysterophorus* L. weed to compost and vermicompost. *Bioscience Discovery*, 8(3), 619–627.
15. Abdul-Baki, A. A. and Anderson, J. D. (1973). Vigour determination in soybean by multiple criteria. *Crop Science*, 13, 630–633.