



# Growth and Yield of Organically Grown Ashwagandha (*Withania somnifera* (L.) Dunal) under a Karanj (*Pongamia pinnata*) Based Agroforestry System

Princy Lakra <sup>a</sup>, Pratap Toppo <sup>a++</sup>, Sarita Bodalkar <sup>a</sup>,  
Rashmi Verma <sup>a</sup> and Shashank Baghel <sup>a\*</sup>

<sup>a</sup> College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.), 492012, India.

## Authors' contributions

This work was carried out in collaboration among all authors. Author PL conceived and conducted the experiment, collected and analyzed data, and drafted the manuscript. Author SB assisted with microbial and soil analysis and manuscript review. All authors read and approved the final manuscript.

## Article Information

DOI: <https://doi.org/10.9734/ijpss/2026/v38i116397>

## Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://pr.sdiarticle5.com/review-history/168315>

## Original Research Article

Received: 26/08/2026

Accepted: 18/10/2026

Published: 30/10/2026

## Abstract

An experiment was conducted during 2025-2026 at the Instructional-cum-Research Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur, India, to examine organic-input treatments for ashwagandha (*Withania somnifera* (L.) Dunal) grown beneath established Karanj (*Pongamia pinnata*) trees. Eight treatments were arranged in a randomized block design with three replications. Plant growth, root and seed production, selected soil properties, tree characteristics, and dry root based economic returns were evaluated. The largest numerical dry-root yield occurred with T<sub>7</sub> (farmyard manure 50% + vermicompost 25% + Jeevamrit 25%; 4.03 q ha<sup>-1</sup>), followed by T<sub>6</sub> (vermicompost 50% + Bijamrit 50%; 3.88 q ha<sup>-1</sup>) and T<sub>4</sub> (farmyard manure 50% + Bijamrit 50%; 3.53 q ha<sup>-1</sup>). These three yields were statistically indistinguishable under the reported critical difference of 0.70 q ha<sup>-1</sup>. T<sub>7</sub> provided the largest calculated gross return (₹90,675 ha<sup>-1</sup>), net return (₹52,675 ha<sup>-1</sup>), and gross return to cost ratio (2.39), based on a dry root selling price of ₹225 kg<sup>-1</sup>. Post harvest soil organic carbon was numerically highest under T<sub>7</sub> (0.73%), although its baseline value was also the highest. Descriptive tree measurements indicated an increase in mean height from 6.30 to 6.47 m during the study interval. The findings identify T<sub>7</sub> as a promising numerical performer among the treatments tested but do not establish its superiority over T<sub>6</sub> or

<sup>++</sup> Professor & Guide;

\*Corresponding author: E-mail: shashank281198@gmail.com;

T<sub>4</sub> for dry root yield. Interpretation is restricted by the single season design, baseline soil heterogeneity, and incomplete documentation of some input rates and measurements.

**Keywords:** *Ashwagandha*; *dry root yield*; *farmyard manure*; *Jeevamrit*; *medicinal agroforestry*; *Pongamia pinnata*; *vermicompost*.

## 1. Introduction

Ashwagandha (*Withania somnifera* (L.) Dunal), a member of the Solanaceae, is an important medicinal plant cultivated principally for its roots. Its phytochemical profile includes withanolides, a class of steroidal lactones studied in relation to pharmacological activity (Mirjalili *et al.*, 2009). Agronomic management that supports reliable root production is therefore relevant to medicinal-plant cultivation, although root yield alone does not establish phytochemical quality.

Organic manures may contribute nutrients and alter soil physical and biological properties. Vermicompost, in particular, has been associated with changes in soil porosity, moisture retention, and nutrient availability, but the magnitude and direction of responses depend on application rate and local conditions (Lim *et al.*, 2015). Plant growth promoting microorganisms can influence nutrient cycling by several mechanisms (Vessey, 2003). In ashwagandha, Jat *et al.* (2021) examined organic manures and biostimulant's over two field seasons and reported improvements in root production and selected soil indicators. Shrivastava *et al.* (2018) likewise evaluated nutrient-management responses of ashwagandha in central India.

Tree crop combinations add a further environmental dimension through possible modification of light, water, litter inputs, and nutrient cycling. Karanj (*Pongamia pinnata*), a multipurpose leguminous tree, is used in agroforestry and has been examined for its propagation and productive potential (Mukta & Sreevalli, 2010; Sangwan *et al.*, 2010). Nevertheless, tree canopies may also intensify competition for light and soil resources. In earlier ashwagandha agroforestry experiments, Thakur *et al.* (2014) investigated several tree crop combinations and nitrogen rates and found that plant responses depended on the trait being evaluated.

Evidence remains comparatively limited regarding combinations of solid organic amendments and liquid bio-inputs applied to ashwagandha within an existing Karanj stand under Chhattisgarh conditions. This study compared eight organic-input treatment designations for ashwagandha cultivated beneath Karanj, focusing on crop growth, root and seed yield, selected soil measurements, tree growth, and dry root economics. Because all plots were under Karanj, the experiment evaluates differences among inputs within that system rather than the effect of agroforestry relative to treeless cultivation.

## 2. Materials and Methods

### 2.1 Experimental Site and Design

The field experiment was conducted at the Instructional-cum-Research Farm, Department of Silviculture and Agroforestry, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India (approximately 21°14'01.3" N, 81°41'37.0" E; an elevation of about 295 m). The site is within the Chhattisgarh Plains agro climatic region, which has hot, dry summers and a predominantly monsoonal rainfall regime. The soil was described as a black, fine textured Vertisol with an angular blocky structure. Crop plots were established beneath an existing Karanj plantation.

Eight organic input treatments were allocated in a randomized block design with three replications, giving 24 crop plots. The ashwagandha cultivar was designated GAA and grown at a row by plant spacing of 60 × 30 cm. The treatment descriptions recorded for the experiment are provided in Table 1. The reported percentages are nominal treatment designations; they should not be interpreted as equal proportions of nutrient supply from materials of different compositions. Several input amounts, particularly for liquid bio-inputs and neem cake, were not quantified in the available treatment schedule.

**Table 1. Organic Input Treatments Applied to Ashwagandha Beneath Karanj**

| Treatment      | Composition as reported in the treatment schedule                                         |
|----------------|-------------------------------------------------------------------------------------------|
| T <sub>1</sub> | FYM 100%; 10 t ha <sup>-1</sup>                                                           |
| T <sub>2</sub> | Vermicompost 100%; 5 t ha <sup>-1</sup>                                                   |
| T <sub>3</sub> | Bijamrit 100%; 10 L (application area basis not documented)                               |
| T <sub>4</sub> | FYM 50%; 5 t ha <sup>-1</sup> + Bijamrit 50%                                              |
| T <sub>5</sub> | FYM 50% + neem cake 50%                                                                   |
| T <sub>6</sub> | Vermicompost 50%; 2.5 t ha <sup>-1</sup> + Bijamrit 50%; 4 L                              |
| T <sub>7</sub> | FYM 50%; 5 t ha <sup>-1</sup> + vermicompost 25%; 1.25 t ha <sup>-1</sup> + Jeevamrit 25% |
| T <sub>8</sub> | Jeevamrit 100%                                                                            |

*FYM, farmyard manure. Where an absolute rate is not given, the treatment fraction does not specify a reproducible mass or volume per unit land area*

### 2.2 Crop Management and Sampling

The soil was cultivated three times using a tractor drawn cultivator; weeds and residual crop material were removed before sowing. Organic inputs were applied once before sowing, according to the nominal treatment schedule. Seeds were sown on 23 December 2025 at approximately 10-12 kg ha<sup>-1</sup>. Irrigation was provided immediately after sowing, again at approximately 20 days after sowing (DAS), and subsequently according to crop requirements at intervals of about 15 days. Thinning and weeding were conducted manually, with thinning at approximately 60 DAS. Fallen Karanj litter and twigs were removed from the crop plots when considered necessary.

The reported harvest date was 8 June 2026. Plants were uprooted by hand following light irrigation; the roots were then separated, washed and sun dried before yield determination. Fresh root weights were recorded from net plots and expressed per hectare; dry root and seed yields were similarly scaled from net plot harvests. A fixed final moisture endpoint for dried roots was not specified in the available measurement description.

## 2.3 Crop Observations

Plant height was measured from ground level to the growing apex; leaf length was measured from the leaf base to the tip; and branches were counted. Five representative plants were sampled per plot, and plot averages were used as the observational units for treatment summaries. Measurements were labelled at nominal 30, 60, 90, 120, 150, and 180 DAS, depending on the variable. The nominal 180 DAS label is not chronologically consistent with the stated sowing and harvest dates and is therefore treated as a late stage recorded observation rather than independently validated calendar timing.

Leaf area index (LAI) was described as leaf area divided by the corresponding ground area. The instrument or technique used to measure leaf area and the exact ground area denominator were not recorded in the summary protocol. Root length was measured from the collar to the tip, and maximum root diameter was measured using a Vernier caliper on five plants per plot. Harvest index was intended to represent the ratio of economic dry root yield to total biological yield; however, the underlying biological yield measurements and a consistent scale for the published index values were not available for independent verification. Accordingly, harvest-index values are reported descriptively and not subjected to treatment inference.

## 2.4 Soil and Tree Measurements

Soil was sampled before input application and after crop harvest. Bulk density was determined by an oven dry core method; soil pH was assessed in a 1:2.5 soil to water suspension. Soil organic carbon was estimated by dichromate oxidation (Walkley & Black, 1934), available nitrogen by alkaline potassium permanganate distillation (Subbiah & Asija, 1956), and available phosphorus by sodium-bicarbonate extraction (Olsen *et al.*, 1954). Exchangeable potassium was extracted with neutral 1 N ammonium acetate and determined by flame photometry. Bulk-density values are presented uniformly in  $\text{g cm}^{-3}$ ; available nutrient values are expressed in  $\text{kg ha}^{-1}$ .

Selected Karanj trees were measured for height, diameter at breast height (DBH), branch count, and crown spread. Tree height was measured with a field height instrument, while DBH was measured at approximately 1.37 m. East-west and north-south crown diameters were averaged to describe crown spread. Individual stem volume estimates were tabulated using a geometric form factor relationship,  $V = \pi r^2 h f$ , where  $r$  is stem radius,  $h$  is height, and  $f$  is a form factor. The separately tabulated dimensions used for volume estimation differ from the paired DBH and height measurements, so those estimates are treated as approximate descriptive quantities. Twelve tree records were available; their identifiers denote trees, not crop nutrient treatments.

## 2.5 Economic and Statistical Calculations

Gross return was calculated as marketed dry root yield ( $\text{kg ha}^{-1}$ ) multiplied by an assumed sale price of ₹225  $\text{kg}^{-1}$ . Net return was gross return minus the cultivation cost, and the benefit cost (B:C) ratio was gross return divided by the cultivation cost. Returns exclude any revenue attributable to seeds or Karanj trees, and the reported cost totals do not resolve expenditures for individual input ingredients.

Treatment means and the reported standard error of a treatment mean (SEm) and critical difference at 5% (CD) were derived under the stated randomized block design. With eight treatments and three blocks, the treatment, block, and residual degrees of freedom are 7, 2, and 14, respectively. The two sided pairwise critical difference can be written as  $t_{0.025,14} \times \sqrt{(2\text{MSE}/3)}$ . The available dataset consists of reported means and error summaries rather than plot level observations; therefore, F statistics, exact p values, assumptions, and revised residual mean squares cannot be reconstructed. Statistical comparisons below use the supplied CDs without imputing missing replicate observations.



Plate 1. Site Of Field Experimental Plot Prepared for Sowing of Ashwagandha



**Plate 2. Seed Germination of Ashwagandha for Experiment**



**Plate 3. Measurement of Plant Height of Ashwagandha**



**Plate 4. Growth of Ashwagandha After 60 (DAT)**



**Plate 5. Collection of Soil Sample**

### 3. Results and Discussion

#### 3.1 Vegetative Growth

Plant height increased across successive observation stages in all eight treatments (Table 2). The final recorded mean was numerically largest under T<sub>7</sub> (87.04 cm), followed by T<sub>6</sub> (86.11 cm), T<sub>4</sub> (85.85 cm), and T<sub>5</sub> (85.09 cm); T<sub>8</sub> had the lowest final value (80.77 cm). The reported CD for the final height measurement was 0.47 cm, implying separation of T<sub>7</sub> from T<sub>6</sub> under the supplied error estimate. T<sub>7</sub> also had the greatest recorded final branch count (8.00 plant<sup>-1</sup>), followed by T<sub>6</sub> (7.67 plant<sup>-1</sup>), whereas T<sub>8</sub> had 5.00 plant<sup>-1</sup>. These differences are consistent with responses to contrasting organic inputs reported by Shrivastava *et al.* (2018), but variation in nutrient composition and tree shading cannot be separated in the available data.

Final leaf length was numerically largest under T<sub>5</sub> (10.33 cm), T<sub>7</sub> (10.27 cm), and T<sub>1</sub> (10.15 cm); their differences were below the reported final-stage CD of 0.85 cm. The supplied LAI series reached 35.52 under T<sub>7</sub> at its final labelled observation, markedly above the LAI of 0.97 reported in a different ashwagandha agroforestry experiment by Thakur *et al.* (2014). Given the absence of supporting leaf-area and ground-area records, the numerical LAI series is shown for completeness but should not be used as quantitative evidence of canopy area or photosynthetic capacity. Table 2 organizes the growth observations by trait and measurement stage.

**Table 2. Reported Growth Attributes of Ashwagandha Under Eight Organic Input Treatments**

| <b>A. Plant Height (cm)</b>                |               |               |                |                |                |                |
|--------------------------------------------|---------------|---------------|----------------|----------------|----------------|----------------|
| <b>Treatment</b>                           | <b>30 DAS</b> | <b>60 DAS</b> | <b>90 DAS</b>  | <b>120 DAS</b> | <b>150 DAS</b> | <b>180 DAS</b> |
| T <sub>1</sub>                             | 5.08          | 8.81          | 21.25          | 53.09          | 66.05          | 82.04          |
| T <sub>2</sub>                             | 4.57          | 9.23          | 22.52          | 58.67          | 68.59          | 83.40          |
| T <sub>3</sub>                             | 4.83          | 8.04          | 22.27          | 51.05          | 60.19          | 81.03          |
| T <sub>4</sub>                             | 4.83          | 11.94         | 24.13          | 57.40          | 73.93          | 85.85          |
| T <sub>5</sub>                             | 1.95          | 11.43         | 23.11          | 56.13          | 71.14          | 85.09          |
| T <sub>6</sub>                             | 5.33          | 12.19         | 25.65          | 58.67          | 75.67          | 86.11          |
| T <sub>7</sub>                             | 6.35          | 12.45         | 26.42          | 60.11          | 76.48          | 87.04          |
| T <sub>8</sub>                             | 3.81          | 8.13          | 20.07          | 50.12          | 60.93          | 80.77          |
| <b>SE m ±</b>                              | <b>0.06</b>   | <b>0.14</b>   | <b>0.16</b>    | <b>0.22</b>    | <b>1.17</b>    | <b>0.15</b>    |
| <b>CD (at 5%)</b>                          | <b>0.18</b>   | <b>0.43</b>   | <b>0.49</b>    | <b>0.66</b>    | <b>3.56</b>    | <b>0.47</b>    |
| <b>B. Leaf Length (cm)</b>                 |               |               |                |                |                |                |
| <b>Treatment</b>                           | <b>60 DAS</b> | <b>90 DAS</b> | <b>120 DAS</b> | <b>150 DAS</b> | <b>180 DAS</b> |                |
| T <sub>1</sub>                             | 4.68          | 8.25          | 8.20           | 8.97           | 10.15          |                |
| T <sub>2</sub>                             | 4.01          | 8.06          | 8.10           | 8.77           | 9.77           |                |
| T <sub>3</sub>                             | 4.69          | 8.20          | 7.83           | 8.59           | 9.60           |                |
| T <sub>4</sub>                             | 4.83          | 8.13          | 7.60           | 8.37           | 9.70           |                |
| T <sub>5</sub>                             | 5.28          | 9.00          | 8.50           | 9.31           | 10.33          |                |
| T <sub>6</sub>                             | 5.53          | 8.40          | 7.70           | 12.77          | 9.83           |                |
| T <sub>7</sub>                             | 5.47          | 8.13          | 8.10           | 9.27           | 10.27          |                |
| T <sub>8</sub>                             | 5.75          | 8.67          | 7.77           | 13.46          | 9.52           |                |
| <b>SE m ±</b>                              | <b>0.17</b>   | <b>0.28</b>   | <b>0.23</b>    | <b>2.23</b>    | <b>0.28</b>    |                |
| <b>CD (at 5%)</b>                          | <b>0.51</b>   | <b>0.86</b>   | <b>0.69</b>    | <b>6.75</b>    | <b>0.85</b>    |                |
| <b>C. Leaf Area Index (reported scale)</b> |               |               |                |                |                |                |
| <b>Treatment</b>                           | <b>60 DAS</b> | <b>90 DAS</b> | <b>120 DAS</b> | <b>150 DAS</b> | <b>180 DAS</b> |                |
| T <sub>1</sub>                             | 11.84         | 25.01         | 27.87          | 28.43          | 28.60          |                |
| T <sub>2</sub>                             | 10.25         | 23.47         | 27.54          | 28.51          | 28.85          |                |
| T <sub>3</sub>                             | 9.69          | 23.97         | 25.87          | 28.33          | 29.00          |                |
| T <sub>4</sub>                             | 11.63         | 36.79         | 23.65          | 30.33          | 31.00          |                |
| T <sub>5</sub>                             | 13.52         | 25.37         | 29.36          | 30.33          | 31.33          |                |
| T <sub>6</sub>                             | 11.08         | 23.08         | 26.25          | 31.33          | 31.33          |                |
| T <sub>7</sub>                             | 11.12         | 22.33         | 28.47          | 33.69          | 35.52          |                |
| T <sub>8</sub>                             | 9.57          | 24.79         | 24.35          | 25.04          | 26.33          |                |
| <b>SE m ±</b>                              | <b>1.83</b>   | <b>4.90</b>   | <b>1.62</b>    | <b>0.65</b>    | <b>0.60</b>    |                |
| <b>CD (at 5%)</b>                          | <b>5.56</b>   | <b>14.87</b>  | <b>4.90</b>    | <b>1.98</b>    | <b>1.82</b>    |                |
| <b>D. Branches Per Plant (count)</b>       |               |               |                |                |                |                |
| <b>Treatment</b>                           | <b>30 DAS</b> | <b>60 DAS</b> | <b>90 DAS</b>  | <b>120 DAS</b> | <b>150 DAS</b> | <b>180 DAS</b> |
| T <sub>1</sub>                             | 3.67          | 4.00          | 4.33           | 4.67           | 5.00           | 6.00           |
| T <sub>2</sub>                             | 4.00          | 4.33          | 4.67           | 5.00           | 5.33           | 5.67           |
| T <sub>3</sub>                             | 3.67          | 4.00          | 4.33           | 4.67           | 5.00           | 5.33           |
| T <sub>4</sub>                             | 5.33          | 5.67          | 6.00           | 6.33           | 6.67           | 6.67           |
| T <sub>5</sub>                             | 4.33          | 5.00          | 5.33           | 5.67           | 6.00           | 6.33           |
| T <sub>6</sub>                             | 6.00          | 6.33          | 6.67           | 7.00           | 7.33           | 7.67           |
| T <sub>7</sub>                             | 6.33          | 6.67          | 7.00           | 7.33           | 7.67           | 8.00           |
| T <sub>8</sub>                             | 3.33          | 3.67          | 4.00           | 4.33           | 4.67           | 5.00           |
| <b>SE m ±</b>                              | <b>0.43</b>   | <b>0.46</b>   | <b>0.55</b>    | <b>0.46</b>    | <b>0.46</b>    | <b>0.46</b>    |
| <b>CD (at 5%)</b>                          | <b>1.32</b>   | <b>1.40</b>   | <b>1.67</b>    | <b>1.40</b>    | <b>1.40</b>    | <b>1.38</b>    |

The LAI measurements are presented at their recorded scale; the sampling denominator and unusually large values preclude independent validation. Growth observations labelled 180 DAS correspond to the recorded last sampling label; the harvest calendar does not independently establish that date.

### 3.2 Root Traits, Root Yield and Seed Yield

Root length ranged from 21.00 cm in T<sub>8</sub> to 25.53 cm in T<sub>7</sub>, while root diameter ranged from 1.24 to 2.00 cm (Table 3). The T<sub>7</sub>-T<sub>6</sub> difference in root length (0.53 cm) was below the reported CD (1.16 cm), whereas the diameter difference (0.12 cm) exceeded the reported CD (0.09 cm). Thus, not all root traits exhibit the same pattern of statistical separation among the higher-performing treatments.

Fresh-root yield was numerically highest under T<sub>7</sub> (1,522.67 kg ha<sup>-1</sup>), followed by T<sub>6</sub> (1,483.33 kg ha<sup>-1</sup>), and lowest under T<sub>8</sub> (1,107.33 kg ha<sup>-1</sup>). The reported SEM of 0.93 kg ha<sup>-1</sup> and CD of 2.83 kg ha<sup>-1</sup> are unusually small relative to the observed yield magnitudes and cannot be validated from treatment means alone; consequently, the fresh-yield rankings are emphasized descriptively rather than as precise evidence of treatment effects.

T<sub>7</sub> produced the greatest recorded dry-root yield (4.03 q ha<sup>-1</sup>), compared with 3.88 q ha<sup>-1</sup> for T<sub>6</sub>, 3.53 q ha<sup>-1</sup> for T<sub>4</sub>, and 2.48 q ha<sup>-1</sup> for T<sub>8</sub>. The reported dry-root-yield CD is 0.70 q ha<sup>-1</sup>; the differences T<sub>7</sub>-T<sub>6</sub> (0.15 q ha<sup>-1</sup>) and T<sub>7</sub>-T<sub>4</sub> (0.50 q ha<sup>-1</sup>) are below this threshold. Accordingly, T<sub>7</sub>, T<sub>6</sub>, and T<sub>4</sub> are not statistically distinguishable for dry-root yield using the reported CD. The numerical pattern is compatible with the importance of organic amendment combinations described by Jat *et al.* (2021), although their separate experiment involved different formulations and measured quality attributes not quantified here.

Seed yield ranged from 100.55 kg ha<sup>-1</sup> in T<sub>8</sub> to 170.64 kg ha<sup>-1</sup> in T<sub>7</sub>. T<sub>7</sub>, T<sub>6</sub> (163.58 kg ha<sup>-1</sup>), and T<sub>4</sub> (161.91 kg ha<sup>-1</sup>) were not statistically distinguishable under the stated CD of 52.62 kg ha<sup>-1</sup>. The tabulated harvest-index entries span 0.032-0.035, but their scale cannot be reconciled with the stated SEM (0.08) and CD (0.23), and biological-yield data were not included. No statistical harvest-index conclusion is therefore drawn. Table 3 shows the measured yield series and distinguishes unavailable harvest-index precision estimates from the recorded index entries.

**Table 3. Root Growth and Yield Attributes of Ashwagandha**

| Treatment      | Root Length (cm) | Root Diameter (cm) | Fresh Root (kg ha <sup>-1</sup> ) | Dry Root (q ha <sup>-1</sup> ) | Seed (kg ha <sup>-1</sup> ) | Harvest Index* |
|----------------|------------------|--------------------|-----------------------------------|--------------------------------|-----------------------------|----------------|
| T <sub>1</sub> | 23.09            | 1.58               | 1313.63                           | 2.91                           | 138.30                      | 0.032          |
| T <sub>2</sub> | 23.63            | 1.68               | 1360.67                           | 3.03                           | 152.53                      | 0.033          |
| T <sub>3</sub> | 22.02            | 1.39               | 1206.00                           | 2.60                           | 118.89                      | 0.034          |
| T <sub>4</sub> | 24.33            | 1.84               | 1421.33                           | 3.53                           | 161.91                      | 0.034          |
| T <sub>5</sub> | 24.07            | 1.79               | 1404.00                           | 3.18                           | 157.62                      | 0.034          |
| T <sub>6</sub> | 25.00            | 1.88               | 1483.33                           | 3.88                           | 163.58                      | 0.032          |
| T <sub>7</sub> | 25.53            | 2.00               | 1522.67                           | 4.03                           | 170.64                      | 0.035          |
| T <sub>8</sub> | 21.00            | 1.24               | 1107.33                           | 2.48                           | 100.55                      | 0.032          |
| SEm (±)        | 0.38             | 0.03               | 0.93                              | 0.23                           | 17.35                       | —              |
| CD (5%)        | 1.16             | 0.09               | 2.83                              | 0.70                           | 52.62                       | —              |

\*Index values are shown on the recorded numerical scale. Their percentage/fraction interpretation and uncertainty could not be established from biological-yield data; no inferential interpretation is made

### 3.3 Selected Soil Properties

Soil bulk density was lower after harvest than at baseline in every treatment (Table 4). For example, T<sub>6</sub> declined from 1.370 to 1.220 g cm<sup>-3</sup>, T<sub>2</sub> from 1.410 to 1.270 g cm<sup>-3</sup>, and T<sub>7</sub> from 1.420 to 1.330 g cm<sup>-3</sup>. These observations are directionally consistent with changes in soil physical properties documented for organic amendments (Lim *et al.*, 2015). However, without paired-plot change analyses and information on other field operations, the magnitude of change cannot be attributed exclusively to the applied amendments.

Post-harvest pH varied from 6.62 (T<sub>2</sub>) to 7.83 (T<sub>4</sub>), spanning mildly acidic to mildly alkaline conditions. T<sub>7</sub> showed the largest post-harvest soil organic carbon value (0.73%), but this treatment also had the largest initial value (0.63%); its observed change was +0.10 percentage points. T<sub>1</sub> increased from 0.44% to 0.47%, and T<sub>8</sub> from 0.43% to 0.50%. The baseline differences limit a direct comparison of final soil organic carbon as a treatment effect.

Post-harvest available N was largest in T<sub>2</sub> (271.8 kg ha<sup>-1</sup>), followed by T<sub>6</sub> (269.5 kg ha<sup>-1</sup>) and T<sub>7</sub> (268.3 kg ha<sup>-1</sup>). Most treatment rows showed an increase relative to their corresponding baseline, but T<sub>4</sub> decreased from 274.4 to 256.5 kg ha<sup>-1</sup>. Available P increased from 19.2 to 25.6 kg ha<sup>-1</sup> in T<sub>2</sub>, from 19.4 to 24.8 kg ha<sup>-1</sup> in T<sub>6</sub>, and from 19.1 to 24.5 kg ha<sup>-1</sup> in T<sub>7</sub>. Available K was also numerically largest after harvest in T<sub>2</sub> (348.5 kg ha<sup>-1</sup>). The range of baseline nutrient levels, particularly the available N value for T<sub>4</sub>, discourages a simple causal ranking from post-harvest means. Organic amendments and microbial bio-inputs can affect nutrient dynamics through multiple processes (Jat *et al.*, 2021; Ram *et al.*, 2018; Vessey, 2003), but microbial activity was not measured here. Table 4 presents initial and final soil properties in common units.

**Table 4. Soil Physical and Chemical Properties Before Input Application and After Harvest****A. Bulk Density, Ph, and Soil Organic Carbon**

| Treatment      | BD initial (g cm <sup>-3</sup> ) | BD final (g cm <sup>-3</sup> ) | pH initial | pH final | SOC initial (%) | SOC final (%) |
|----------------|----------------------------------|--------------------------------|------------|----------|-----------------|---------------|
| T <sub>1</sub> | 1.390                            | 1.300                          | 7.39       | 7.39     | 0.44            | 0.47          |
| T <sub>2</sub> | 1.410                            | 1.270                          | 6.62       | 6.62     | 0.52            | 0.57          |
| T <sub>3</sub> | 1.430                            | 1.340                          | 7.60       | 7.60     | 0.53            | 0.57          |
| T <sub>4</sub> | 1.400                            | 1.320                          | 7.73       | 7.83     | 0.52            | 0.55          |
| T <sub>5</sub> | 1.380                            | 1.250                          | 7.75       | 7.77     | 0.53            | 0.56          |
| T <sub>6</sub> | 1.370                            | 1.220                          | 7.58       | 7.54     | 0.54            | 0.56          |
| T <sub>7</sub> | 1.420                            | 1.330                          | 7.70       | 7.70     | 0.63            | 0.73          |
| T <sub>8</sub> | 1.440                            | 1.390                          | 7.39       | 7.40     | 0.43            | 0.50          |
| SEm (±)        | 0.005                            | 0.006                          | 0.34       | 0.34     | 0.02            | 0.01          |
| CD (5%)        | 0.016                            | 0.019                          | 1.03       | 1.02     | 0.05            | 0.04          |

BD, bulk density; SOC, soil organic carbon. Initial bulk-density values were converted from kg m<sup>-3</sup> to g cm<sup>-3</sup>; the recorded SEm/CD values are expressed in g cm<sup>-3</sup>

**B. Available Soil Nutrients**

| Treatment      | N initial | N final | P initial | P final | K initial | K final |
|----------------|-----------|---------|-----------|---------|-----------|---------|
| T <sub>1</sub> | 248.5     | 261.4   | 18.6      | 22.8    | 318.5     | 336.8   |
| T <sub>2</sub> | 250.3     | 271.8   | 19.2      | 25.6    | 320.4     | 348.5   |
| T <sub>3</sub> | 246.8     | 252.7   | 18.3      | 20.7    | 317.2     | 325.6   |
| T <sub>4</sub> | 274.4     | 256.5   | 18.8      | 21.9    | 319.1     | 332.4   |
| T <sub>5</sub> | 249.1     | 266.2   | 19.0      | 24.1    | 321.0     | 340.7   |
| T <sub>6</sub> | 250.0     | 269.5   | 19.4      | 24.8    | 322.1     | 345.2   |
| T <sub>7</sub> | 249.7     | 268.3   | 19.1      | 24.5    | 321.6     | 343.8   |
| T <sub>8</sub> | 247.8     | 254.8   | 18.5      | 21.2    | 318.0     | 328.9   |
| SEm (±)        | 1.26      | 1.48    | 0.32      | 0.45    | 1.85      | 2.42    |
| CD (5%)        | 3.82      | 4.49    | 0.97      | 1.36    | 5.61      | 7.34    |

N, P, and K values are expressed in kg ha<sup>-1</sup>. Baseline differences were not adjusted by an analysis of covariance; SEm and CD values refer to the source summaries at each sampling time

**3.4 Karanj Tree Component**

The 12 sampled Karanj trees showed increases in recorded size measurements over the experimental interval (Table 5). Mean measured height was 6.30 m before sowing and 6.47 m after harvest, a mean increment of approximately 0.17 m. Mean DBH increased from 13.22 to 14.49 cm, and mean branch count from 6.20 to 7.08. These are descriptive tree level changes without a corresponding no crop stand or a tree level treatment assignment.

Estimated tree-stem volumes ranged from 0.043 to 0.105 m<sup>3</sup> per tree (mean 0.070 m<sup>3</sup>). Mean crown spread across the two horizontal axes ranged from 3.80 to 5.70 m; the average was approximately 4.74 m. The two tabulated perpendicular crown diameters for Tree 8 give a mean of 4.00 m. Because the stem-volume input dimensions differ from the direct DBH/height measurements and the exact form-factor value was not specified, volume estimates should be considered approximate. Table 5 separates direct pre/post tree measurements from the dimensions associated with volume estimation.

**Table 5. Characteristics of the Twelve Sampled Karanj Trees****A. Paired Height, Diameter, And Branch Measurements**

| Tree    | Height Initial (m) | Height Final (m) | Increment (m) | DBH Initial (cm) | DBH Final (cm) | Branches Initial | Branches Final |
|---------|--------------------|------------------|---------------|------------------|----------------|------------------|----------------|
| Tree 1  | 8.00               | 8.10             | 0.10          | 16.73            | 18.11          | 7.33             | 8.11           |
| Tree 2  | 8.83               | 9.10             | 0.27          | 18.17            | 19.55          | 9.67             | 10.15          |
| Tree 3  | 4.83               | 4.90             | 0.07          | 11.87            | 12.15          | 5.33             | 5.55           |
| Tree 4  | 6.67               | 6.75             | 0.08          | 13.80            | 15.22          | 6.67             | 7.33           |
| Tree 5  | 5.50               | 5.68             | 0.18          | 11.50            | 13.25          | 5.00             | 6.22           |
| Tree 6  | 5.83               | 5.93             | 0.10          | 12.27            | 13.11          | 5.33             | 6.25           |
| Tree 7  | 6.33               | 6.55             | 0.22          | 12.60            | 14.45          | 6.33             | 7.35           |
| Tree 8  | 5.00               | 5.12             | 0.12          | 10.80            | 10.90          | 4.33             | 5.50           |
| Tree 9  | 5.30               | 5.50             | 0.20          | 12.22            | 13.55          | 5.44             | 5.65           |
| Tree 10 | 6.33               | 6.66             | 0.33          | 11.25            | 13.10          | 6.12             | 7.45           |
| Tree 11 | 5.55               | 5.70             | 0.15          | 12.77            | 14.15          | 7.25             | 8.12           |
| Tree 12 | 7.44               | 7.65             | 0.21          | 14.65            | 16.33          | 5.56             | 7.25           |
| Mean    | 6.30               | 6.47             | 0.17          | 13.22            | 14.49          | 6.20             | 7.08           |

Averages are arithmetic means of the twelve displayed tree records. Tree identifiers are independent of the crop-input treatment labels

**B. Stem Volume Inputs and Crown Dimensions**

| Tree        | Volume-Input Diameter (cm) | Volume-Input Height (m) | Stem Volume (m <sup>3</sup> ) | Crown E-W (m) | Crown N-S (m) | Crown Mean (m) |
|-------------|----------------------------|-------------------------|-------------------------------|---------------|---------------|----------------|
| Tree 1      | 18.5                       | 6.20                    | 0.047                         | 4.20          | 4.00          | 4.10           |
| Tree 2      | 20.2                       | 6.45                    | 0.059                         | 4.60          | 4.30          | 4.45           |
| Tree 3      | 17.8                       | 6.10                    | 0.043                         | 3.90          | 3.70          | 3.80           |
| Tree 4      | 22.4                       | 6.80                    | 0.075                         | 5.10          | 4.80          | 4.95           |
| Tree 5      | 19.6                       | 6.35                    | 0.055                         | 4.40          | 4.20          | 4.30           |
| Tree 6      | 23.1                       | 7.10                    | 0.084                         | 5.40          | 5.10          | 5.25           |
| Tree 7      | 21.5                       | 6.70                    | 0.069                         | 4.80          | 4.60          | 4.70           |
| Tree 8      | 18.9                       | 6.25                    | 0.050                         | 4.10          | 3.90          | 4.00           |
| Tree 9      | 24.0                       | 7.20                    | 0.093                         | 5.60          | 5.30          | 5.45           |
| Tree 10     | 25.3                       | 7.35                    | 0.105                         | 5.90          | 5.50          | 5.70           |
| Tree 11     | 21.8                       | 6.90                    | 0.074                         | 5.00          | 4.70          | 4.85           |
| Tree 12     | 23.7                       | 7.15                    | 0.091                         | 5.50          | 5.20          | 5.35           |
| <b>Mean</b> | <b>21.40</b>               | <b>6.71</b>             | <b>0.070</b>                  | <b>4.88</b>   | <b>4.61</b>   | <b>4.74</b>    |

Crown mean = (E-W diameter + N-S diameter)/2. Stem-volume inputs are reported separately because they do not equal the paired DBH and tree-height measurements in Panel A; individual volume estimates are descriptive

**3.5 Economics of Dry-root Production**

Crop returns were calculated from the reported dry-root yields using a uniform market price of ₹225 kg<sup>-1</sup> (Table 6). Total cost was ₹35,000 ha<sup>-1</sup> for T<sub>1</sub>, T<sub>2</sub>, T<sub>3</sub>, and T<sub>8</sub> and ₹38,000 ha<sup>-1</sup> for T<sub>4</sub>-T<sub>7</sub>. Numerically, T<sub>7</sub> generated the largest gross return (₹90,675 ha<sup>-1</sup>), net return (₹52,675 ha<sup>-1</sup>), and B:C ratio (2.39), followed by T<sub>6</sub> (₹87,300 ha<sup>-1</sup>; ₹49,300 ha<sup>-1</sup>; 2.30). T<sub>8</sub> gave the lowest corresponding estimates (₹55,800 ha<sup>-1</sup>; ₹20,800 ha<sup>-1</sup>; 1.59). Across the eight treatment summaries, the mean cultivation cost was ₹36,500 ha<sup>-1</sup> and the mean net return was ₹35,612.50 ha<sup>-1</sup>.

These estimates describe receipts from dry roots only. They do not quantify price volatility, incremental value from seeds, trees, land occupancy, or external ecosystem services. Because the cost schedules were summarized as totals rather than by component, profitability comparisons reflect the recorded accounting assumptions and are not a substitute for a complete enterprise level economic assessment. Moreover, the top dry root yields were not statistically separable under the supplied CD; numerical income rankings need not imply reliably distinct economic performance across seasons.

**Table 6. Dry Root Based Economic Returns from Ashwagandha Cultivated Beneath Karanj**

| Treatment      | Fixed Cost (₹ ha <sup>-1</sup> ) | Variable cost (₹ ha <sup>-1</sup> ) | Total Cost (₹ ha <sup>-1</sup> ) | Dry Root (kg ha <sup>-1</sup> ) | Gross Return (₹ ha <sup>-1</sup> ) | Net Return (₹ ha <sup>-1</sup> ) | B:C Ratio   |
|----------------|----------------------------------|-------------------------------------|----------------------------------|---------------------------------|------------------------------------|----------------------------------|-------------|
| T <sub>1</sub> | 8000                             | 27000                               | 35,000                           | 291                             | 65,475                             | 30,475                           | 1.87        |
| T <sub>2</sub> | 8000                             | 27000                               | 35,000                           | 303                             | 68,175                             | 33,175                           | 1.95        |
| T <sub>3</sub> | 8000                             | 27000                               | 35,000                           | 260                             | 58,500                             | 23,500                           | 1.67        |
| T <sub>4</sub> | 8000                             | 30,000                              | 38,000                           | 353                             | 79,425                             | 41,425                           | 2.09        |
| T <sub>5</sub> | 8000                             | 30000                               | 38,000                           | 318                             | 71,550                             | 33,550                           | 1.88        |
| T <sub>6</sub> | 8000                             | 30000                               | 38,000                           | 388                             | 87,300                             | 49,300                           | 2.30        |
| T <sub>7</sub> | 8000                             | 30000                               | 38,000                           | 403                             | 90,675                             | 52,675                           | 2.39        |
| T <sub>8</sub> | 8000                             | 27000                               | 35,000                           | 248                             | 55,800                             | 20,800                           | 1.59        |
| <b>Mean</b>    | <b>8,000</b>                     | <b>28,500</b>                       | <b>36,500</b>                    | <b>320.5</b>                    | <b>72,112.50</b>                   | <b>35,612.50</b>                 | <b>1.97</b> |

Market price was ₹225 kg<sup>-1</sup> for all treatments. B:C = gross return/total cost. The final B:C entry is the arithmetic mean of the eight treatment ratios (rounded to two decimals), not the ratio of mean returns to mean costs. Mean monetary values are arithmetic means of the treatment values



**Plate 6. Measurement of Tree DBH**



**Plate 7. Seed Germination of Ashwagandha for Experiment**



**Plate 8. Preparation of Jeevamrit**



**Plate 9. Tagging of Crops**



**Plate 10. Irrigation of Field**



**Plate 11. Application of Vermicompost**



**Plate 12. Field Preparation**



**Plate 13. Observation Taking from Field**



**Plate 14. Root Yield Measurement of Ashwagandha**



**Plate 15. Seed Yield Measurement of Ashwagandha**



**Plate 16. Test Weight Measurement of Ashwagandha**



**Plate 17. Root Length Measurement of Ashwagandha**



**Plate 18. Measurement of Biological Yield of Ashwagandha**



**Plate 19. Dry Weight of Ashwagandha**



**Plate 20. Drying of Ashwagandha Roots in Hot Air Oven**



**Plate 21. Analysis of Soil Sample of Experimental Site**

#### 4. Scope and Limitations

The observations were drawn from one experimental season at one site under an established Karanj stand; the design did not include a treeless ashwagandha comparator or a mineral-fertilizer control. Consequently, neither an agroforestry advantage nor broader nutrient-management superiority can be inferred. Plot areas, tree spacing and age, canopy irradiance, root competition, and detailed amendments for several treatment fractions were not available, limiting mechanistic and reproducibility assessments. The nominal 180 DAS growth stage is also inconsistent with the 167-day interval between the recorded sowing and harvest dates, reducing confidence in the timing of late-stage growth comparisons.

Interpretation of leaf area indices, harvest indices, fresh root yield precision, and tree stem volume requires particular caution because key primary measurements and calculations were unavailable for verification. Soil baseline values differed among treatments and were not analyzed as paired changes or adjusted for initial conditions. Root moisture at sale, withanolides content, and other quality parameters were not measured in the accessible summaries. The mean-based data permit arithmetic checks and comparisons against tabulated CDs but not an independent assessment of analysis of variance residuals or detailed error structure. The economic results depend on a fixed dry root price and on the recorded cost totals, and should not be extrapolated without sensitivity analysis.

#### 5. Conclusion

Among the eight organic-input treatment designations evaluated for ashwagandha under an existing Karanj stand, the mixture comprising FYM 50%, vermicompost 25%, and Jeevamrit 25% (T<sub>7</sub>) produced the greatest numerical dry root yield (4.03 q ha<sup>-1</sup>) and the largest calculated dry root gross and net returns. However, its dry root yield did not differ significantly from T<sub>6</sub> or T<sub>4</sub> under the reported critical difference, and its final soil organic carbon value was accompanied by a comparatively high baseline value. These results support further evaluation of integrated organic input treatments for ashwagandha grown beneath Karanj, particularly in multi-season trials with fully quantified application rates, consistent crop development dates, replicated soil change analyses, and measurements of root quality and canopy conditions.

#### Acknowledgement

The authors sincerely acknowledge the Department of Silviculture and Agroforestry, and Department of Agricultural Microbiology, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, for providing the necessary facilities and support to conduct the field experiment. The authors are grateful to the authorities, faculty members, technical staff and field workers for their valuable assistance during the execution of the experiment, data collection and laboratory analysis. The authors also sincerely acknowledge the support and guidance received from the Advisory Committee during the course of the study.

#### Declaration of AI Use

AI-assisted tools were used to support language editing, text organization, and bibliographic formatting. The authors are responsible for the experimental records, data integrity, interpretation, source verification, and final scientific content.

#### Competing Interests

Authors have declared that no competing interests exist.

#### References

- Jat, R. S., Basak, B. B., & Gajbhiye, N. A. (2021). Organic manures and biostimulant's fostered soil health and increased the harvest quality of the medicinal herb ashwagandha. *Agronomy Journal*, 113(1), 504-514. <https://doi.org/10.1002/agj2.20457>
- Lim, S. L., Wu, T. Y., Lim, P. N., & Shak, K. P. Y. (2015). The use of vermicompost in organic farming: Overview, effects on soil and economics. *Journal of the Science of Food and Agriculture*, 95(6), 1143-1156. <https://doi.org/10.1002/jsfa.6849>
- Mirjalili, M. H., Moyano, E., Bonfill, M., Cusido, R. M., & Palazón, J. (2009). Steroidal lactones from *Withania somnifera*, an ancient plant for novel medicine. *Molecules*, 14(7), 2373-2393. <https://doi.org/10.3390/molecules14072373>
- Mukta, N., & Sreevalli, Y. (2010). Propagation techniques, evaluation and improvement of the biodiesel plant, *Pongamia pinnata* (L.) Pierre-A review. *Industrial Crops and Products*, 31(1), 1-12. <https://doi.org/10.1016/j.indcrop.2009.09.004>
- Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). *Estimation of available phosphorus in soils by extraction with sodium bicarbonate* (Circular No. 939). U.S. Department of Agriculture. <https://archive.org/details/estimationofavai939olse>
- Ram, R. A., Singha, A., & Vaish, S. (2018). Microbial characterization of on-farm produced bio-enhancers used in organic farming. *The Indian Journal of Agricultural Sciences*, 88(1), 35-40. <https://doi.org/10.56093/ijas.v88i1.79550>
- Sangwan, S., Rao, D. V., & Sharma, R. A. (2010). A review on *Pongamia pinnata* (L.) Pierre: A great versatile leguminous plant. *Nature and Science*, 8(11), 130-139. [https://www.sciencepub.net/nature/ns0811/19\\_3880ns0811\\_130\\_139.pdf](https://www.sciencepub.net/nature/ns0811/19_3880ns0811_130_139.pdf)
- Shrivastava, A. K., Upadhyay, V. B., Gautam, D. S., Sarvade, S., & Sahu, R. K. (2018). Effect of integrated nutrient management on growth and productivity of *Withania somnifera* (L.) Dunal in Kymore Plateau and Satpura hills of Madhya Pradesh, India. *Archives of Agriculture and Environmental Science*, 3(2), 202-208. <https://doi.org/10.26832/24566632.2018.0302015>
- Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science*, 25, 259-260.
- Thakur, N. S., Verma, K. S., & Rana, R. C. (2014). Growth and yield performance of ashwagandha (*Withania somnifera*) under agroforestry. *The Indian Journal of Agricultural Sciences*, 84(8), 937-941. <https://doi.org/10.56093/ijas.v84i8.43068>

- Vessey, J. K. (2003). Plant growth promoting rhizobacteria as biofertilizers. *Plant and Soil*, 255, 571-586. <https://doi.org/10.1023/A:1026037216893>
- Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, 37(1), 29-38. <https://doi.org/10.1097/00010694-193401000-00003>

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

---

© Copyright (2026): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

**Peer-review history:**

The peer review history for this paper can be accessed here: <https://pr.sdiarticle5.com/review-history/168315>