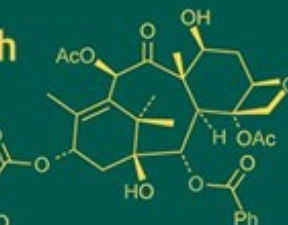
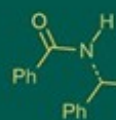


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## Synergistic effects of NPK levels and biofertilizers on the foliage and oil yield of patchouli (*Pogostemon cablin* Benth.)

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### ABSTRACT

An experiment entitled “Synergistic effects of NPK levels and biofertilizers on the foliage and oil yield of patchouli (*Pogostemon cablin* Benth.)” was carried out at Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Ratnagiri (M.S.) during two consecutive years 2023-24 and 2024-25. The experiment comprised nine treatments involving the recommended dose of fertilizer (RDF) and the biofertilizers *Azotobacter*, phosphate-solubilizing bacteria (PSB) and potassium-solubilizing bacteria (KSB), arranged in a randomized block design with three replications. Among the treatments, T9 i.e., 100% RDF + PSB + *Azotobacter* + KSB, recorded the highest essential oil content (3.06 % and 2.98 % at the first and second harvest, respectively) and the highest total essential oil yield (53.28 kg/ha), almost double that of the control (26.88 kg/ha). Treatment T8 (75% RDF + PSB + *Azotobacter* + KSB) recorded 45.85 kg/ha, more than any treatment combining 100% RDF with a single biofertilizer. The integrated application of biofertilizers with chemical fertilizers significantly enhanced both the concentration and the yield of patchouli oil.

**Keywords:** Patchouli, Essential oil content, Oil yield, Biofertilizers, *Azotobacter*, PSB, KSB

### 1. Introduction

Patchouli oil is a staple of the perfume industry. It is widely used as a fixative that slows the evaporation of lighter fragrance notes and it also finds use in soaps, lotions, detergents and at very low concentrations in flavoured foods and drinks (Angadi *et al.*, 1995) [1]. India needs far more of the oil than it produces and the shortfall is largely met through imports (Jadhav *et al.*, 2002) [2]. For a grower, however, the quantity of oil harvested from a unit of land is what matters in the end and this is the product of two components: the oil concentration of the herbage and the amount of herbage produced.

Both components respond to nutrition. Chemical fertilizers are an obvious input, but their cost and the large share lost from the soil make it desirable to reduce their use. Biofertilizers are one such option. Nitrogen-fixing and phosphate-solubilizing bacteria improve nutrient uptake, which can raise biomass and also influence essential oil content (Roshanpour *et al.*, 2014) [3]. Positive effects on oil have been reported in several aromatic crops, and the oil yield of patchouli has also been shown to respond to crop management practices such as soil cover (Vital *et al.*, 2024) [4]. However, information on patchouli grown in the lateritic soils of the Konkan is scarce.

Hence, the present investigation entitled “Synergistic effects of NPK levels and biofertilizers on the foliage and oil yield of patchouli (*Pogostemon cablin* Benth.)” was undertaken to study the effect of different levels of NPK in combination with *Azotobacter*, PSB and KSB, used alone or together, on the fresh and dry foliage yield and oil yield of patchouli at the first and second harvests.

### 2. Materials and Methods

The present investigation was conducted during 2023-24 and 2024-25 at the Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri, Maharashtra. Dapoli lies on the west coast of Maharashtra at an altitude of about 240 m above mean sea level and roughly 8 km from the Arabian Sea. The climate is tropical, with warm humid summers, a heavy monsoon from June to October (average annual rainfall about 4000 mm) and mild winters. The mean minimum and maximum temperatures are about 18.5 and 30.8 °C, respectively and the relative humidity averages around 78%. The soil was red lateritic, well drained and of uniform depth. Rooted cuttings of the ‘CIM-Samarth’ (Kalra *et al.*, 2006) [5] were planted at 60 × 60 cm spacing and the trial was repeated a fresh in each season. The experiment consisted of nine treatments (Table 1) laid out in a randomized block design (RBD) with three replications (27 plots of 3.6 × 3.0 m, with 30 plants per plot).

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The recommended dose of fertilizer (RDF) was 5 t/ha vermicompost plus 150:50:50 kg N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O /ha, supplied through urea, single super phosphate and muriate of potash. Vermicompost was applied before planting. The entire phosphorus and potash and one-fourth of the nitrogen were applied as a basal dose, and the remaining nitrogen was top-dressed in three equal splits. *Azotobacter* (*Azotobacter chroococcum*), phosphate-solubilizing bacteria (PSB; *Bacillus megaterium*) and potassium-solubilizing bacteria (KSB; *Bacillus mucilaginosus*) were applied in solid form at 10 kg/ha, 15 days after the chemical fertilizers. irrigation, hand weeding and need-based plant protection measures were common to all plots.

The crop was harvested twice, at 120 and 210 days after transplanting (DAT). At each harvest, the herbage was shade-dried for 4-7 days, spread in thin layers and turned from time to time for uniform drying of patchouli leaves. A 250 g sample of dried herbage, chopped into small pieces was hydro-distilled for 4 hours in a Clevenger's apparatus (Clevenger, 1928) [6]. The oil was collected in glass vials and dried over anhydrous sodium sulphate. Essential oil content was expressed as a percentage of dry herbage (oil yield relative to dry herbage yield × 100), and essential oil yield was expressed in kg/ha for each harvest and cumulatively over the two harvests. The data of each year and the pooled data were analysed by analysis of variance for RBD as described by Panse *et al.* (1995) [7] using SAS and treatment means were compared at the 5% level of significance (critical difference, CD).

### 3. Results

The data on foliage yield (t ha<sup>-1</sup>), essential oil content (%) and essential oil yield (kg ha<sup>-1</sup>) showed significant variation across the different NPK levels and biofertilizer treatments at both harvests (120 and 210 DAT) during both years of the experiment (2023-24 and 2024-25) and the pooled data were then worked out.

#### 3.1 Fresh foliage yield (t ha<sup>-1</sup>)

The data concerning the fresh herb yield (t ha<sup>-1</sup>) was recorded twice during 1<sup>st</sup> harvest (120 DAT) and 2<sup>nd</sup> harvest (210 DAT). The total fresh herb yield (t ha<sup>-1</sup>) was calculated by combining the yields obtained from both harvests during the research period (2023-25), as indicated in Table 1. The application of various NPK levels and biofertilizers significantly influenced fresh herb yield (t ha<sup>-1</sup>) of patchouli. Data reveals that, in first and second harvest among the various treatments studied, treatment T<sub>9</sub> *i.e.*, 100% RDF + PSB + *Azotobacter* + KSB recorded the maximum fresh foliage yield (tonnes per ha) (4.94 t and 3.72 t). Meanwhile, treatment T<sub>1</sub> *i.e.*, 100% RDF noted the minimum fresh foliage (tonnes per ha) (3.42 t and 2.41 t). Also, treatment T<sub>9</sub> recorded the maximum cumulative (8.65 t) fresh foliage yield, while treatment T<sub>1</sub> observed the minimum (5.84 t) cumulative fresh foliage yield, respectively.

#### 3.2 Dry foliage yield (t ha<sup>-1</sup>)

The pooled of two-year data reveals that, in first and second harvest treatment T<sub>9</sub> *i.e.*, 100% RDF + PSB + *Azotobacter* + KSB recorded the maximum dry foliage yield tonnes per ha) (0.99 t and 0.74 t). Meanwhile, treatment T<sub>1</sub> *i.e.*, 100% RDF noted the minimum dry foliage (tonnes per ha) (0.68 t and 0.48 t). Besides, the treatment T<sub>9</sub> also reported maximum (1.73 t) cumulative dry foliage yield and treatment T<sub>1</sub> recorded the lowest (1.17 t) dry yield, respectively.

#### 3.3 Essential oil yield (kg ha<sup>-1</sup>)

The essential oil yield (kg ha<sup>-1</sup>) was determined following the two consecutive harvests *viz.*, 1<sup>st</sup> harvest (120 DAT) and 2<sup>nd</sup> harvest (210 DAT) through hydro-distillation using Clevenger's apparatus from the shade dried leaves of patchouli. The total essential oil (kg ha<sup>-1</sup>) was estimated by combining the essential oil yields from both harvests (1<sup>st</sup> and 2<sup>nd</sup>) during the study period 2023-24 and 2024-25, as presented in Table 3.

Data reveals that, in first and second harvest the maximum essential oil yield (30.39 kg and 22.90 kg) were observed in treatment T<sub>9</sub> *i.e.*, 100% RDF + PSB + *Azotobacter* + KSB. In contrast minimum essential oil yield (15.76 kg and 11.12 kg) was recorded in treatment T<sub>1</sub> *i.e.*, 100% RDF. However, the maximum essential oil yield (53.28 kg) was noted in treatment T<sub>9</sub> against the lowermost in T<sub>1</sub> (26.88 kg) respectively.

### 4. Discussion

Fresh foliage yield in patchouli reflects plant vigour and total biomass production and also demonstrates the effectiveness of treatments applied in the experiment. In the present study, the effectiveness of inorganic fertilizers was greatly improved when used along with biofertilizers. This integrated nutrient management approach likely enhanced soil fertility and overall soil biological activity by promoting nitrogen fixation, phosphate solubilization and better availability of essential nutrients. The combined application also improved the efficiency of applied NPK by stimulating microbial activity in the rhizosphere and releasing growth-promoting substances, which collectively supported better plant growth and development (Nevase, 2024) [8] (Venugopal, 2006) [9].

Improved phosphorus and potassium nutrition also plays an important role in dry matter production. Phosphorus supports energy transfer and root growth, while potassium regulates enzymatic activities and photosynthetic efficiency. These nutrients together improve the synthesis and movement of assimilates, resulting in better conversion of photosynthates into structural dry matter in foliage. (Nevase, 2024) [8], (Venugopal, 2006) [9]

Essential oil is the most economically important product of patchouli. In the present investigation, the maximum essential oil yield was recorded in treatment T<sub>9</sub> *i.e.*, 100% RDF + PSB + *Azotobacter* + KSB. The higher essential oil yield may be associated with improved plant growth and enhanced synthesis of secondary metabolites under balanced nutrient supply. Adequate availability of essential nutrients, particularly nitrogen, phosphorus and potassium, promotes vigorous vegetative growth, increased leaf area and higher biomass production. Since essential oils are mainly synthesized and stored in leaf tissues, greater foliage development directly contributes to increased oil yield. Similar results were obtained by Manjunath *et al.* (2002) [10] in patchouli resulted ranging from 26.64 kg ha<sup>-1</sup> to 36.53 kg ha<sup>-1</sup> by the use of biofertilizer like *Azotobacter*, PSB and VAM.

The present results are in agreement with those obtained by, Nevase (2024) [8], Mali *et al.* (2023) [11] Hammam *et al.* (2014) [12] in vetiver, Arafa *et al.* (2017) [13] in mentha, Asadian *et al.* (2017) [14] in basil, Mohamed *et al.* (2016) [15] in *Viola odorata* L plant, Venugopal, (2006) [9] in patchouli, Maheshwari *et al.* (1991) [16] in palmarosa, , Sirohi *et al.* (1983) [17] in the case of peppermint who reported increase in oil content with the use of biofertilizers.

Table 1. Treatment details.

| Code           | Treatment                     |
|----------------|-------------------------------|
| T <sub>1</sub> | 100% RDF (control)            |
| T <sub>2</sub> | 75% RDF + PSB                 |
| T <sub>3</sub> | 100% RDF + PSB                |
| T <sub>4</sub> | 75% RDF + <i>Azotobacter</i>  |
| T <sub>5</sub> | 100% RDF + <i>Azotobacter</i> |

(continued on next page)

| Code           | Treatment                                 |
|----------------|-------------------------------------------|
| T <sub>6</sub> | 75% RDF + KSB                             |
| T <sub>7</sub> | 100% RDF + KSB                            |
| T <sub>8</sub> | 75% RDF + PSB + <i>Azotobacter</i> + KSB  |
| T <sub>9</sub> | 100% RDF + PSB + <i>Azotobacter</i> + KSB |

**Table 2.** Effect of NPK levels and biofertilizers on fresh and dry foliage yield of patchouli – pooled data from 2023-24 and 2024-25

| Treatment                                                  | Foliage yield (t ha <sup>-1</sup> )       |                |             |                                         |                |             |
|------------------------------------------------------------|-------------------------------------------|----------------|-------------|-----------------------------------------|----------------|-------------|
|                                                            | Fresh foliage yield (t ha <sup>-1</sup> ) |                |             | Dry foliage yield (t ha <sup>-1</sup> ) |                |             |
|                                                            | First harvest                             | Second harvest | Total yield | First harvest                           | Second harvest | Total yield |
| T <sub>1</sub> : 100% RDF (control)                        | 3.42                                      | 2.41           | 5.84        | 0.68                                    | 0.48           | 1.17        |
| T <sub>2</sub> : 75% RDF + PSB                             | 3.56                                      | 2.50           | 6.06        | 0.71                                    | 0.50           | 1.21        |
| T <sub>3</sub> : 100% RDF + PSB                            | 3.92                                      | 2.76           | 6.68        | 0.78                                    | 0.55           | 1.34        |
| T <sub>4</sub> : 75% RDF + <i>Azotobacter</i>              | 4.07                                      | 2.90           | 6.97        | 0.81                                    | 0.58           | 1.39        |
| T <sub>5</sub> : 100% RDF + <i>Azotobacter</i>             | 4.40                                      | 3.26           | 7.65        | 0.88                                    | 0.65           | 1.53        |
| T <sub>6</sub> : 75% RDF + KSB                             | 3.68                                      | 2.58           | 6.26        | 0.74                                    | 0.52           | 1.25        |
| T <sub>7</sub> : 100% RDF + KSB                            | 3.76                                      | 2.66           | 6.42        | 0.75                                    | 0.53           | 1.28        |
| T <sub>8</sub> : 75% RDF + PSB + <i>Azotobacter</i> + KSB  | 4.56                                      | 3.39           | 7.95        | 0.91                                    | 0.68           | 1.59        |
| T <sub>9</sub> : 100% RDF + PSB + <i>Azotobacter</i> + KSB | 4.94                                      | 3.72           | 8.65        | 0.99                                    | 0.74           | 1.73        |
| <b>Mean</b>                                                | <b>4.03</b>                               | <b>2.91</b>    | <b>6.94</b> | <b>0.81</b>                             | <b>0.58</b>    | <b>1.39</b> |
| SEm ±                                                      | 0.06                                      | 0.07           | 0.13        | 0.01                                    | 0.01           | 0.03        |
| CD at 5%                                                   | 0.19                                      | 0.20           | 0.38        | 0.04                                    | 0.04           | 0.08        |

**Table 3.** Effect of NPK levels and biofertilizers on Essential oil yield of patchouli – pooled data from 2023-24 and 2024-25

| Treatments                                                 | Essential oil yield (kg ha <sup>-1</sup> ) |                |              |
|------------------------------------------------------------|--------------------------------------------|----------------|--------------|
|                                                            | First harvest                              | Second harvest | Total yield  |
| T <sub>1</sub> : 100% RDF (control)                        | 15.76                                      | 11.12          | 26.88        |
| T <sub>2</sub> : 75% RDF + PSB                             | 16.48                                      | 11.57          | 28.05        |
| T <sub>3</sub> : 100% RDF + PSB                            | 19.58                                      | 13.78          | 33.36        |
| T <sub>4</sub> : 75% RDF + <i>Azotobacter</i>              | 20.78                                      | 14.78          | 35.56        |
| T <sub>5</sub> : 100% RDF + <i>Azotobacter</i>             | 23.28                                      | 17.24          | 40.52        |
| T <sub>6</sub> : 75% RDF + KSB                             | 17.28                                      | 12.14          | 29.42        |
| T <sub>7</sub> : 100% RDF + KSB                            | 18.02                                      | 12.76          | 30.78        |
| T <sub>8</sub> : 75% RDF + PSB + <i>Azotobacter</i> + KSB  | 26.30                                      | 19.55          | 45.85        |
| T <sub>9</sub> : 100% RDF + PSB + <i>Azotobacter</i> + KSB | 30.39                                      | 22.90          | 53.28        |
| <b>Mean</b>                                                | <b>20.87</b>                               | <b>15.09</b>   | <b>35.97</b> |
| SEm ±                                                      | 1.06                                       | 0.80           | 1.44         |
| CD at 5%                                                   | 3.18                                       | 2.41           | 4.30         |

## 5. Conclusion

The study concluded that the integrated application of NPK levels and biofertilizers significantly enhanced the yield performance of patchouli. Among the different treatments, T<sub>9</sub> consisting of 100 % RDF + PSB + *Azotobacter* + KSB was found to be the most effective in improving fresh and dry herb yield as well as essential oil production of patchouli. Thus, the integrated use of NPK levels and biofertilizers enhanced plant growth-promoting activities.

Thus, the integrated use of biofertilizers and inorganic fertilizers can improve overall soil fertility and productivity of patchouli in fertility in lateritic soils of Konkan.

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