

Synergistic effects of nano urea and PSB on oil quality, production and crop productivity of *Monarda citriodora* in Jammu region

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Limited quantitative information is available on the integrated use of Nano Urea and phosphate-solubilizing bacteria (PSB) for improving essential oil yield and composition in aromatic crops under subtropical conditions. This study aimed to generate statistically robust, stage-specific evidence on the effects of Nano Urea-PSB integration on growth, biomass, essential oil yield and thymol content of *Monarda citriodora*. A two-year field experiment (Rabi 2022–23 and 2023–24) was conducted at CSIR-IIIM, Jammu, using a randomized block design with five treatments and three replications. Data were analyzed at $P \leq 0.05$ and oil composition was determined by GC–MS at pre-flowering (75 Days After Transplanting) and full bloom (90 Days After Transplanting). Integrated Nano Urea and PSB application significantly improved vegetative growth, biomass accumulation, and oil recovery over conventional fertilization. At 90 DAT, thymol, the principal oil constituent ranged from 80.08–83.74% during the first year and 70.98–76.59% during the second year, confirming sustained thymol dominance under integrated nutrient management. Enhanced levels of *P*-cymene and carvacrol further indicated improved oil compositional diversity. This study provides quantified, stage-specific GC–MS evidence linking Nano Urea-PSB integration to thymol-rich essential oil production in *Monarda citriodora*, suggesting a sustainable nutrient strategy to enhance productivity and oil quality in aromatic crops in subtropical climates.

Keywords: Essential oil, Fertilizer, Lemon bee balm, PSB culture, Recommended dose of Fertilizer