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Nutrients effect on growth, yield and phytochemicals composition of European dill (*Anethum graveolens* L.): A comprehensive review

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ABSTRACT

The study addresses on the nutrient response of European dill (Anethum graveolens), focusing on its growth, development, yield, and secondary metabolites. It emphasizes expanding research on the effects of fertilizers and farmyard manure on European dill and related Umbelliferae crops to improve nutrient management tailored to species variation, crop development stages, and seasonal conditions. The nutrition of crop plants through both inorganic and organic sources is advantageous as these sources enhance soil physical conditions and provide the essential macronutrients and micronutrients required for optimal plant growth and physiological development of crop plants. Additionally, this study explores the medicinal and aromatic properties of European dill, the preference for European dill over Indian dill due to differences in toxic compound content and the changes in major essential oil constituents such as carvone, dillapiole, limonene, phellandrene, and anethofuran due to application of nutrients. This knowledge aims to enhance agronomic practices and pharmaceutical applications and thereby improving crop quality and safety. The study is challenged by scarcity of comprehensive research specifically addressing how European dill responds to nutrient inputs, especially concerning growth, yield and oil constituents and this gap makes it difficult to build on established findings or compare results. But this review paper contributes significantly by consolidating existing research on response of European dill by effects of fertilizers and organic inputs. Thereby, providing a foundation for improved nutrient management strategies for future research directions and facilitates safer, higher-quality crop production through enhanced understanding of maintaining the secondary metabolites composition present in essential "dill oil" mainly responsible for medicinal properties of European dill plant.

Keywords: *Anethum graveolens, aromatic, carvone, dillapiole, European dill, FYM, Integrated nutrient management, medicinal plant, nutrients, secondary metabolites, Umbelliferae.*

INTRODUCTION

The genus *Anethum* comprises two primary species commonly referred to as dill or sowa: *Anethum graveolens* L. (European dill) and *Anethum sowa* Roxb. (Indian dill). *A. graveolens* is indigenous to the Mediterranean basin and has been extensively cultivated on a global scale, whereas *A. sowa* is native to the northern regions of the Indian subcontinent. The variation in the species, crop development stages, and seasonal conditions significantly influences the input requirements for dill crop production. However, the literature on the nutrient response of European dill crops on growth, development, yield, and secondary metabolites is very limited. Therefore, a brief review of the available literature on the effect of fertilizers and farmyard manure (FYM) on the family Umbelliferae crops, which are grown in the same season, *viz*., *Anethum graveolens*, *Coriandrum sativum*, *Cuminum cyminum*, *Carum carvi*, *Apium graveolens*, and *Foeniculum vulgare,* and information on other related crops pertinent to the present study is presented in this chapter.

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Medicinal plants have been employed in the therapeutic intervention and management of human ailments since ancient times. The use of plants for medicinal purposes involves about 35,000 species. Among these medicinal plants, *Anethum graveolens* (European dill) is an annual herbaceous plant with aromatic as well as medicinal properties belonging to the Umbelliferae family. The genus name *Anethum* originates from the Greek term *anēthon*, while the common name 'dill' is derived from the Old Norse words *dylla* or *dilla*, which are believed to mean 'to soothe' [37]. European dill (*Anethum graveolens* L. Syn. *Peucedanum graveolens* L.) is commonly referred to as vilayati saunf in India. This crop is a dicotyledonous, strong-smelling, erect-stemmed, fennel-like herbaceous annual plant. The flowers exhibit a yellow coloration and are arranged in terminal umbels. The so-called "seeds" are not true seeds but are the mericarps of small, dry fruits classified as schizocarps. These mericarps are widely employed in traditional medicine as a household remedy for various gastrointestinal disorders. Seed infusions have demonstrated notable efficacy in alleviating infantile colic and reducing flatulence in young children. Pharmacologically, the seeds possess galactagogue, aromatic, mild diuretic, carminative, stomachic activities and stimulant activities. [33]. In traditional medicine, *Anethum graveolens* is mainly used for the treatment of gastrointestinal disorders, hepatic dysfunction, and renal diseases [50].

The content of essential oil in the herb is approximately 0.5–1.2%, while in the seeds, it is about 2.5–3.5%, and this essential oil is collectively referred to as "dill oil." The seed oil is regarded as high-quality due to its elevated carvone concentration and comparatively low levels of dillapiole [46]. However, the dillapiole content in Indian dill seed oil is >30%, which is a toxic principle; therefore, preference is given to European dill seed oil because of negligible dillapiole in dill oil. European dill seeds yield more oil than Indian sowa [35]. The manifestation of a reddish pigmentation in the seeds of primary umbels results in a high carvone content in the seed oil. The Limonene and phellandrene content were found in both primary and secondary umbels, but were found to be the highest in the stems and leaves. A major constituent, *Anethofuran* of *Anethum graveolens* essential oil, exhibits its highest concentration in umbels during the flowering stage, followed by a marked decline as the seeds mature [25]. Regarding essential oil quality, carvone exhibited a significant negative correlation with dillapiole, while showing a positive association with both oil content and oil yield [20]. Carvone was detected exclusively in the developing umbels and was absent following the senescence of the entire plant and within the umbels, carvone accumulation occurred only in the seeds. Optimization of umbel formation is recommended to enhance the yield of both sweet and high-carvone essential oils.

Effect of nutrients on growth dynamics and yield & yield attributes of *Anethum graveolens*

Achieving higher yields and improved quality of essential oil in dill (*Anethum graveolens*) requires an adequate and well-balanced supply of nutrients. Dill plants have been found to grow taller with the application of 90 kg of Nitrogen ha^{-1} over 30 kg Nitrogen ha^{-1} and no application of fertlizer, but with no difference in height with 60 and 90 kg of N ha^{-1}. The dill plant traits, namely the number of umbels/plant, fruits/umbel and thousand-seed weight, showed significant improvement with increasing nitrogen levels. In contrast, phosphorus application did not exert a statistically significant influence on any of the measured parameters. It was further documented that nitrogen and phosphorus interactions significantly enhanced the 1000-seed weight and contributed significantly to increasing the yield [8]. An elevation in nitrogen concentration through urea in the soil has been found to cause a gradual reduction in the yield of fenugreek [16]. The total fruit yield, along with the quantification of essential oil yield and carvone concentration in sowa (*Anethum sowa*) seed oil, has been reported to be the highest in crops grown with 60 kg of Nitrogen ha^{-1} [1].

While studying the impact of NPK on the herb yield of *Anethum graveolens* var. Budakalaszi, it was observed that dill herb crops require large quantities of N and medium levels of P and K [15]. The maximum seed yield of king cumin (1675 kg/ha and 1314 kg/ha) was obtained by the application of 90 kg ha^{-1} nitrogen and 60 kg ha^{-1} phosphorus, respectively [19]. In fennel cultivation, the application of 75 kg of N ha^{-1} resulted in a significant improvement in seed yield under loamy soil conditions [30]. Black cumin (*Nigella sativa* L.) exhibits significant increases in seed yield and pod number per plant when supplied with a moderate nitrogen application rate of 50 kg N ha^{-1}. In addition, a significant interaction between phosphorus and nitrogen was observed for both seed yield and the total number of pods per plant [9].

Enhancement in the growth characteristics of fennel crops, such as height of plant, branch count, and total umbels per plant, was found under nitrogen application rate of 100 kg N ha^{-1}[31]. The result of a study on FYM, N, and P application alone or in an integrated form demonstrated that the application of farmyard manure at 20 t ha^{-1} significantly enhanced the seed yield of poppy crops [41].

While studying the nitrogen along with phosphorus requirements of coriander (*Coriandrum sativum*), due to per-hectare application of 60 kg of N, significant enhancements were observed in plant height, primary and secondary branch count, umbels per plant, fruits per umbel, and maximum seed weight [10]. Different levels of phosphorus application showed no statistically significant impact on 1000 seed weight; however, they contributed significantly to increasing the yield. In another study conducted on *Coriandrum sativum* L. in Delhi, split application of 60 kg N ha^{-1} at 45 days after sowing, 50 per cent flowering and grain-filling stages were observed to be superior in enhancing yield [21]. Increasing doses of nitrogen have been found to cause a statistically significant impact on the yield-contributing characteristics and seed yield of *Coriandrum sativum* [45]. To obtain the highest seed yield of fennel, nitrogen application should be done at 25 kg ha^{-1} at sowing time as basal and the remaining dose 40 days after sowing [11]. For European dill, the nitrogen dose of 90 kg ha^{-1} has been recognised as the optimal nitrogen dose, resulting in significant increases in the total number of umbels/plant, seed weight, and seed yield [4]. Application of 80 kg of N ha^{-1} was observed to increase the growth of *Artemisia pallens*, though no significant differences in yield were observed due to varying nitrogen levels [28]. A nutrient combination of $N_{80}P_{40}K_{25}$ was optimum for obtaining the highest seed yield of cumin due to a result of significant increase in the number of branches/plant, the number of umbels/plant, and 1000 seed weight [17]. Another study noted the highest seed yield of *Carum carvi* at 90 kg N ha^{-1}[20]. Nutritional studies on European dill crops have revealed a substantial enhancement in growth metrics and seed productivity with the application of 60 kg N ha^{-1}[27]. The application of 80 kg N/ha significantly enhanced the seed yield of fennel crops [36]. Another report on fennel indicated a significant change in the straw and biological yield, harvest index, and agronomic yield factors, such as total count of umbels per plant, total seeds per umbellet, test weight, seed and oil yield, gross return, and net return in terms of rupees invested due to nitrogen application [6]. While searching for the proper dose of nitrogen to enhance the essential oil yield in the herb and seed of the dill crop, it was found that 100 kg N ha^{-1} produced a notable increase in herbage and dry matter yield [29]. The application of the $N_{60}P_{30}K_{30}$ fertilizer combination has been found to be the optimum level of economic benefit to cause a significant improvement in the height of the plants, number of branches, total number of grains per primary umbel, and grain and straw yield components of coriander [43]. Application of phosphorus @ 30 kg ha^{-1} has been found to enhance morphological and yield-related traits [13].

In another study conducted on dill, the 75 kg of N application in one hectare area significantly increased the plant height, the dry matter accumulation, the number of umbels per plant, umbel diameter, the number of umbellets per umbel, seeds per umbel, thousand-seed weight, and carvone concentration in the seed oil, as well as overall seed and oil yields [3]. However, it was additionally recommended that 90 kg of N ha^{-1} was the optimum dose to obtain the highest yield of dill seed [32]. Further, the productivity and seed quality parameters of coriander with 90 kg of nitrogen ha^{-1} and 37.5 kg of phosphorus ha^{-1} were significantly higher [18].

The FYM application significantly increased seed yield. It was further revealed that increasing levels of farmyard manure significantly enhanced the seed yield, as 30 tonnes FYM ha^{-1} outyielded the 15 tonnes FYM ha^{-1}. The phenomenal response of dill to FYM levels is because FYM is a balanced nutrient provider, which promotes optimal crop growth and development, thereby enhancing seed yield [46]. No FYM application led to poor fertility status of the soil, thereby drastically reducing morphological and physiological progression and ultimately seed yield.

In the context of *Coriandrum sativum*, nimin (from *Azadirachta indica*) coated urea @ 60 kg N ha^{-1} caused higher 1000 seed weight, reproductive yield, vegetative biomass yield, and total biomass yield compared to prilled urea. The N use efficiency increased by 32.48% with the use of nimin-coated urea. Gross return (Rs./ha) was highest under 60 kg N ha^{-1} through nimin coated urea compared to 60 kg N ha^{-1} as prilled urea at New Delhi [42]. A statistically significant elevation in the growth, yield attributes, and seed and stover yields in Indian mustard was recorded under the application of FYM @ 5 t ha^{-1} in comparison to the control [23]. Application of nitrogen fertilization up to 150 kg N ha^{-1} has been shown to enhance the yield and yield-related parameters of European dill (*Anethum graveolens* L.).

A study on vermicompost application alone and with inorganic fertilizers was conducted on Coriander; subsequent observations showed that there was a significant increase in herbage and yield of seed due to the application of vermicompost as compared to chemical fertilization [44]. The highest herbage along with seed yields were noticed with 15 t ha^{-1} and 20 t ha^{-1} vermicompost, respectively. In contrast to these findings, the work done on cumin showed a good response to lower fertility levels (20 kg N ha^{-1}) [49]. A dose of 150 kg of N ha^{-1} was observed to be the optimum dose for a higher yield of rosemary without affecting oil quality [39]. In geranium crops, the FYM application at 30 t ha^{-1} resulted in a significantly higher number of shoots, total number of shoots per plant, and leaf: stem ratio [5]. Higher yields of dill were found with higher fertility levels of $N_{100}P_{60}K_{60}$[34].

The positive effect of FYM @ 15 t ha^{-1} on fenugreek has been reported due to significant improvement in branches/plant, pods/plant, seed, straw, and biological yield [14]. The improvement in yield attributing characteristics has been suggested due to the application of FYM in soil, which could supply more available nutrients to plants and create a favorable soil environment, ultimately increasing the nutrients and soil water-holding potential for a long time. Thus, better growth and yield-attributing characters resulted in a higher yield of fenugreek with increasing levels of FYM. Adequate availability of nutrients because of the use of the integrated nutrient sources (FYM @ 10 t ha^{-1} with $N_{60}P_{45}K_{30}$ kg ha^{-1}) leads to the highest dry matter production, seed, and straw yield of European dill [40].

Effect of nutrients on essential oil content, oil yield and active principles of *Anethum graveolens*

The impact of NPK on the essential oil yield and chemical composition was investigated in the European dill *variety*. Budakalaszi found that for dill seed oil, a greater dose of P and moderate doses of N and K fertilization are optimal [15]. In fennel crops, the oil content in seeds remained unaffected by nitrogen application [30]. In one study, it was found that morphine content in opium poppy crops increased due to the application of FYM, N, and P alone and in an integrated form [41].

A combination of $N_{100}P_{25}$ has been found to be optimum for accelerated crop seed yield and essential oil concentration in fennel [2]. Application of varying rates of nitrogen (N), phosphorus (P), and potassium (K) significantly enhanced the seed and essential oil yields of *Coriandrum sativum* L. *cv*. CIMPO S-33 grown in sandy loam soil, while exerting no significant effect on the linalool content of the essential oil [26]. For *Artemisia pallens*, crop application of 80 kg N ha^{-1} has been found to be optimum for obtaining increased biomass and essential oil yield, although due to N application, a decrease in essential oil content was observed, and it was determined that the yield of essential oils increased due to enhancement in biomass yield [28]. The 60 kg of N application ha^{-1} increased the oil yield of European dill [27]. The essential oil content of coriander (*Coriandrum sativum*) increased due to the combined application of $N_{60}P_{30}K_{30}$ fertilizer [43]. In European dill crops, lower fertility levels ($N_{40}P_{30}$) enhanced the carvone content in seed oil, while essential oil and carvone yields increased significantly at $N_{80}P_{30,}$ but for oil yield, the optimum dose of P2O5 was 40 kg ha^{-1}[13]. In a study conducted on a recommended dose of $N_{120}P_{60}K_{40}$, the dill herb oil content was found to range from 0.10% to 0.30% (v/fresh weight) and in the dill seed from 1.75% to 4.0% (v/dry weight), with three major constituents in the herb oil, *viz*. alpha-phellandrene, beta-phellandrene, and 3, 9 oxy-p-menth-1-ene (dill ether), comprising 90% to 97% of the oil constituents. Of these, alpha-phellandrene comprises 51.1% to 64.7% of the total oil content [3]. The major constituents in dill seed oil were carvone and dihydrocarvone, comprising 68–83% of the total oil constituents, and limonene, which ranged from 14.18 to 21.43% [7]. In geranium crops, 100 kg N ha^{-1} significantly enhanced the herb and oil yield under Bangalore conditions; however, different rates of nitrogen (50, 100, and 150 kg ha^{-1}) did not affect the content and quality of oil [96]. While studying the oil composition of European dill in relation to nitrogen application, it was found that seed and carvone yields in dill were the highest with nitrogen application at 30 to 60 kg N ha^{-1} [48], but an increase in nitrogen levels decreased the carvone content (%) in dill seed oil [47]. For essential oil yield (kg/ha) and carvone content (%) in oil, the best fertility level was $N_{100}P_{60}K_{60}$[34].

The 30 t FYM ha^{-1} applications caused significantly higher seed-oil content in comparison to 15 t FYM ha^{-1} levels, which may be because farmyard manure could provide definite nutrients for the biosynthesis of essential oil within the seeds [46]. In geranium crops, the application of 30 t FYM ha^{-1} significantly enhanced the oil content, suggesting that organic manure has a favorable effect on oil content in the long run [5]. Among the oil constituents, the percentage of carvone tended to increase, whereas the dillapiole concentration in the oil declined as nitrogen application levels increased [12]. The fresh herbage and oil yield of rosemary has been found to be highest at a higher level of nitrogen (300 kg N ha^{-1} $year^{-1}$) [40] without influencing the content and quality of oil. A study on organic manures (mustard cake and FYM) alone or in conjunction with fertilizer on the quality of cumin (*Cuminum cyminum* L.) revealed that application of 10 t ha^{-1} FYM alone, mustard cake alone, or in conjunction with chemical fertilizer caused higher but statistically equal oil content[22].

CONCLUSION

The comprehensive review literature clearly demonstrates that balanced nutrient management plays a crucial role in optimizing growth, seed yield, and essential oil biosynthesis in European dill (*Anethum graveolens* L.).

Nitrogen emerged as the most influential macronutrient, with optimum responses generally observed between 60 and 100 kg N ha^{-1}, stimulating umbels, seed-set, biomass, and overall productivity, although specific requirements varied with soil conditions, cultivar, and climatic factors. Phosphorus showed limited direct influence on morphological traits, but its synergistic effect in conjunction with nitrogen enhanced total umbels/plant, test weight, along oil yield. Potassium contributes moderately but remains essential for overall physiological function and metabolic stability. Organic manures, particularly FYM at 20–30 t ha^{-1}, significantly improved crop health, productivity, and beneficial oil constituents such as carvone and oil content. Integrated nutrient management improved the biomass accumulation, seed yield, and essential oil recovery while reducing ecological risks compared to sole chemical fertilization. Moderate nitrogen supply also enhanced the carvone concentration, whereas higher nitrogen levels tended to reduce the quality. Evidence also indicates that organic sources favour sustained improvement in oil content and quality parameters. Essential oil yield improved primarily due to biomass enhancement under balanced fertilization. Overall, the evidence underscores that European dill requires a strategic supplementation with inorganic fertilizers and organic amendments to achieve the most efficient, ecologically sustainable and quality-enhancing strategy for maximum productivity and optimized active principles, ensuring both agronomic efficiency and ecological sustainability.

Future scope

The future scope of this study lies in advancing comprehensive, site as well as species-specific nutrient management strategies for European dill by integrating both inorganic and organic nutrient sources to achieve improved growth, yield, and essential oil quality. Further research is needed to investigate the dynamic interactions between soil health, nutrient availability, and seasonal variations, as well as their influence on key secondary metabolites responsible for the crop's medicinal and aromatic value. Detailed molecular, biochemical, and physiological studies could help clarify how specific nutrient combinations modulate the composition of major essential oil constituents such as carvone, dillapiole, limonene, phellandrene, and anethofuran. Additionally, expanding field-based trials and long-term studies across diverse agro-climatic regions would support the development of standardized recommendations for safe, high-quality dill production. This enhanced knowledge base will not only strengthen agronomic practices for promoting higher-quality, sustainable production of European dill but also contribute to pharmaceutical and nutraceutical applications by ensuring consistent, safe, and superior-grade "dill oil" for commercial use.

Conflict of interest

The authors declare they have no conflict of interest.

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