

Review Article

Yohannes Gelaye*, Sewnet Getahun

Potential influence of nitrogen fertilizer rates on yield and yield components of carrot (*Daucus carota* L.) in Ethiopia: Systematic review

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Abstract: Carrot is a significant root crop in Ethiopia but its production faces challenges such as nutrient loss and unfavorable growth conditions, which hinder its productivity. The objective of this review was to evaluate the impact of nitrogen fertilizer rates on carrot yield in Ethiopia. A systematic review using databases like PubMed and Scopus focused on peer-reviewed, English-language studies with quantitative data on nitrogen fertilizer and carrot yield in Ethiopia, excluding non-peer-reviewed articles and those lacking quantitative data or in other languages. Globally, carrot yields are 30–100 tons per hectare, but only 5.5 tons in Ethiopia. Carrots are rich in vitamins A, C, and B, proteins, minerals, and fiber, with vitamin C boosting immunity and aiding in wound healing and allergy management. Meanwhile, vitamin A plays a crucial role in vision, bone growth, immune function, and reproduction. It is a rich source of carotenoids and anthocyanins. The application of nitrogen fertilizer significantly improved carrot yield (root length, fresh weight, and dry weight). In Ethiopia, the use of nitrogen fertilizer affects the marketability and total yield of carrots, with small-scale farmers employing diverse rates for cultivation. Current recommendations suggest 69 kg/ha of phosphorus (P_2O_5) and 46 kg/ha of nitrogen, but farmers often do not follow these guidelines. In conclusion, optimizing nitrogen fertilizer usage is crucial for enhancing carrot yields among small farmers, underscoring the need for government support to tailor recommendations to local soil conditions and boost productivity.

Keywords: carrot yield, carrot production, nitrogen fertilizer, nutrient management

* **Corresponding author: Yohannes Gelaye**, College of Agriculture and Natural Resources, Debre Markos University, Amhara, P.O. Box. 269, Ethiopia, e-mail: yohanes_gelaye@dmu.edu.et

Sewnet Getahun: College of Agriculture and Natural Resources, Debre Markos University, Amhara, P.O. Box. 269, Ethiopia
ORCID: Yohannes Gelaye 0000-0002-6772-0198

1 Introduction

Carrot, scientifically known as *Daucus carota* L., is a member of the Apiaceae family. It is classified as a biennial annual crop, indicating that it typically completes its life cycle over 2 years, but is cultivated annually [1]. Carrots, classified as moderately hardy plants, thrive in cool environments and can withstand frost without damage, germinating well even in chilly conditions [2]. Carrot growth slows down as temperature increases, implying that it develops more slowly under warmer conditions [3]. Carrot plants are mainly cultivated for their edible roots, valued for their high levels of carotene and anthocyanins, offering both nutritional value and potentially beneficial compounds [4]. It also contains abundant nutrients, such as proteins, carbohydrates, fiber, and sodium [5]. Carrots are versatile vegetables, and their fleshy roots are commonly used in various culinary applications. They can be eaten raw in salads, added to soups for flavor and nutrition, or steamed or boiled as a side dish in many vegetable-based recipes [6]. This vegetable is believed to have various medicinal benefits, including cooling the body, strengthening the heart and brain, preventing constipation, and acting as a diuretic [7]. Purple and black carrots are used to make a beverage known as Kanjal, valued for its excellent appetizing qualities [3]. Carrots, despite their extensive cultivation history, still possess untapped potential due to their low yield per acre, necessitating urgent improvements in production to meet demand and boost agricultural output [8]. Globally, carrot yields vary from 30 to over 100 tons per hectare due to diverse growing conditions, including climate, soil quality, and agricultural practices [9]. In Ethiopia, the Central Statistical Agency [10] reported in 2020/21 that 19648.7 tons of carrots were harvested from 3717.22 hectares of land, resulting in an average yield of 5.5 tons per hectare [10]. Various factors, including plant spacing, floral set, root health, size, and age, affect carrot yield and quality, with nitrogen fertilizer crucial for promoting growth and carbohydrate synthesis, especially when applied early for thicker roots [11]. In Ethiopia, the

standard suggested rates of phosphorus (P_2O_5) and nitrogen fertilizer for the growing of carrots are around 69 and 46 kg/ha, respectively [12].

Ethiopia has significant potential for large-scale carrot cultivation, but low production is hindered by a lack of localized nitrogen fertilizer research, poor soil fertility, limited access to quality fertilizers, and inadequate irrigation infrastructure. Irregular rainfall, pests, diseases like root-knot nematodes, inadequate post-harvest practices, and limited access to advanced agricultural technologies collectively harm crop yields and quality. Consequently, farmers often do not adhere to fertilizer guidelines, leading to the application of either insufficient or excessive amounts, which negatively impacts carrot yields. The hurdles in carrot production in Ethiopia encompass the lack of improved carrot varieties, subpar farming techniques, pest and disease problems, and inadequate postharvest infrastructure. Additionally, the nitrogen-deficient soil in Ethiopia's tropical climate poses further challenges for cultivation. Thus, this review was aimed to evaluate the potential influence of nitrogen fertilizer rates on carrot yield and its components in Ethiopia.

2 Review methodology

In the course of the literature review, various strategies were employed to ensure a comprehensive and systematic approach. Reputable journals from the Scopus, Web of Science, and PubMed databases were used for the compilation of this review, along with the Cochrane Library and Google Scholar, to broaden the scope of the search. A systematic review approach was employed to identify relevant studies. Initially, a comprehensive search strategy was developed using specific keywords and terms related to the review topic, such as “nitrogen fertilizer,” “carrot yield,” “Ethiopia,” and related terms. The search focused on articles published after 2019, with the exception of older but relevant facts and books. The inclusion criteria were defined to ensure the relevance and quality of the studies included in the review: articles published in peer-reviewed journals, written in English, providing quantitative data and employing research designs including randomized controlled trials, cohort studies, and case-control studies (Figure 1). Non-peer-reviewed articles, such as editorials, opinion pieces, and conference abstracts, were excluded, as well as studies not available in English, articles lacking quantitative data, case reports, and studies with small sample sizes. The screening process involved several steps: duplicate records were removed to avoid redundancy, titles, and abstracts

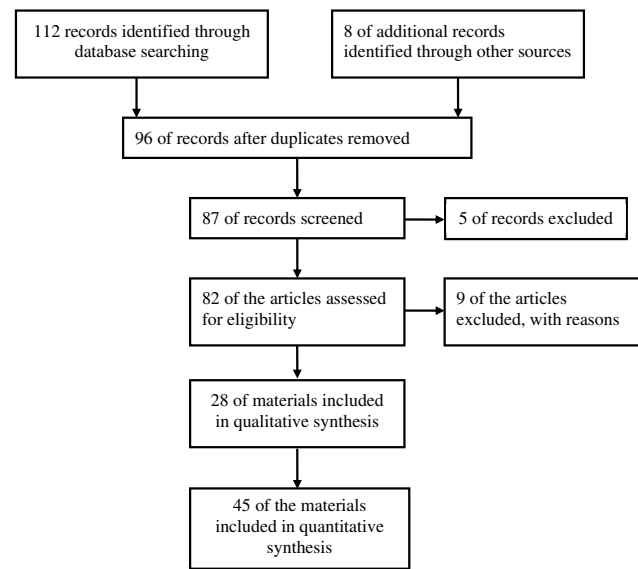


Figure 1: PRISMA flow diagram.

of the remaining records were screened for relevance, and full-text articles of potentially eligible studies were then assessed for inclusion based on the predefined criteria (Figure 1). Relevant data from the included studies were extracted systematically and synthesized to evaluate the potential influence of nitrogen fertilizer rates on carrot yield and its components in Ethiopia.

3 Origin, domestication, and botanical characteristics of carrot

Carrots, the most cultivated in the Apiaceae family, encompass other vegetables like parsnip, fennel, celery, root parsley, celeriac, arracacha, herbs, and spices [13]. Carrot seeds are known for their aromatic properties, which makes them useful in spices and herbal medicines. Modern cultivated carrots trace their origins back to the wild carrot, *Daucus carota* L., which is native to Europe, Asia, and Africa [6]. The primary source of carrots, particularly in Central Asia, notably Afghanistan, is supplemented by Turkey as a secondary origin [6]. Carrot cultivars are classified by maturity, root traits, and foliage to aid growers in selecting suitable varieties for their needs [14]. Carrots are categorized into types like short-horn, Nantes, Amsterdam, forcing, Chantenay, Autumn King, and St. Valery, each with unique attributes in size, shape, and suitability for specific growing conditions or culinary purposes [15]. Carrot is considered a cool-season vegetable crop, and most breeding efforts aim to improve production in temperate regions. In

these areas, where temperatures below approximately 10°C can induce early flowering or bolting, the focus is on developing varieties that are more resilient to these conditions [16]. Efforts have been directed toward expanding carrot cultivation to warmer subtropical regions. Carrots are typically grown annually and are upright plants that complete their life cycle over 2 years [17]. Carrot plants, ranging from 20 to 100 cm in height, develop a primary taproot system that swells and thickens, showcasing diverse shapes and sizes [18]. The plant displays a swollen, orange or red root with solid stems near the base, while its leaves are arranged alternately in a segmented pinnate pattern with long, broad petioles [19]. The inflorescence is white or pink, compound, and umbrella-shaped, with a diameter ranging from 3 to 7 cm. It consists of branched stalks with five petals and five hairy ovaries [20]. The vegetable is described as having hooked spines and ridges, while the seed is oval and contains valuable oils. Additionally, the flowers typically consist of a few sterile dark purple flowers found in the center of the umbel [21].

4 Climatic and growth requirements of carrot

Carrots are a significant root crop grown at high altitudes, specifically between 2,500 and 3,000 m above sea level, in Ethiopia [22]. Carrots thrive best in loamy or sandy loam soils enriched with humus, offering a balanced texture, effective drainage, and ample organic matter for optimal growth (Figure 2). To attain high yields, the optimal soil pH

range for carrot cultivation is between 5.5 and 6.5; however, soils with a pH of 7.0 are usable, and extremes in acidity or alkalinity are deemed unsuitable [23]. Carrots thrive in both cold and warmer climates, with an optimal temperature range of 16–18°C for ideal green foliage growth [24] (Figure 2). Temperature critically influences plant growth, with temperatures above 28°C harming top growth and producing shorter, thicker roots, while those below 16°C cause poor coloration and elongated roots [25]. Temperatures between 15 and 20°C produce appealing roots and improve the color and quality of carrots [26]. The seeding process includes drilling or broadcasting small seeds (about 800 seeds per gram) in the field, with up to 85% typically germinating successfully, and they can maintain viability for nearly 3 years [27]. Accurate seed requirement calculation relies on determining germination percentage, usually taking 7–21 days, crucial for effective seed allocation and planning for optimal growth [28]. Carrots can be cultivated throughout the year, provided temperatures remain above 3.9°C, with an optimal germination temperature range of 20–30°C [29]. Successful carrot planting depends on the local climate and thorough soil preparation, including deep ploughing, harrowing, leveling, and clearing, to create an ideal environment for seed germination and growth [30]. For ideal seed bed conditions, thorough removal of debris is crucial, followed by fine preparation, and sowing methods like broadcasting, drilling, or hand-sanding mixed with sand, ash, or fine soil, with carrots usually seeded in ridges or flat beds, utilizing shallow furrows (30–45 cm) [31]. Dibbling carrot seeds with 7.5–10 cm spacing ensures optimal growth and development by providing proper spacing [32]. For optimal conditions, 4–6 kg of seeds per hectare should be gently covered with soil or sand after sowing, with

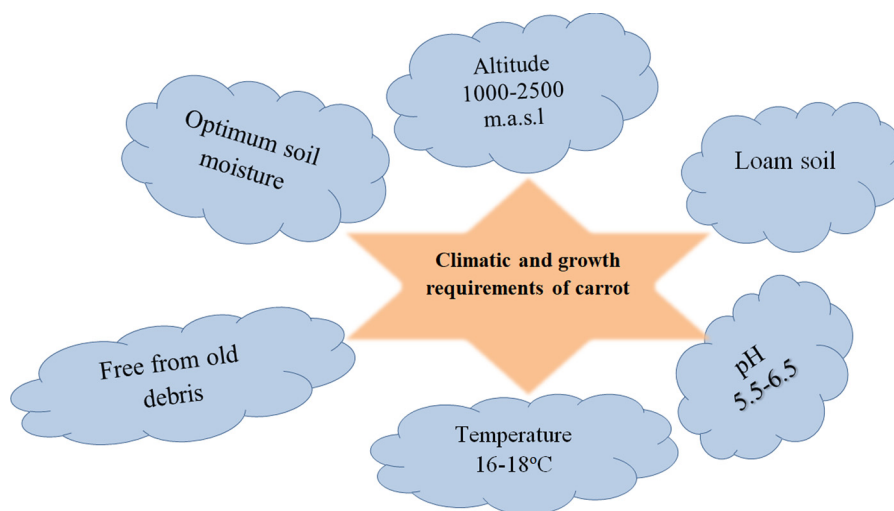


Figure 2: A summary of climate and growth requirements for carrot cultivation in Ethiopia.

optional pre-sowing irrigation for moisture, germination in 10–15 days, light post-germination irrigation, and thinning to 7.5–10 cm spacing [33]. Irrigation frequency varies depending on factors like soil type, season, and crop variety, which dictate the watering needs for plant thriving [34]. For crop irrigation, irrigation every 4–5 days during summer and every 10–15 days during winter is generally considered sufficient to maintain adequate moisture levels for the crop's needs [32]. Adequate water supply during root development is crucial to prevent cracking, while grounding, especially for long-rooted varieties, supports healthy plant growth [35]. During storage, carrots undergo chemical changes in which polysaccharides, complex carbohydrates, break down into simpler sugars, and sucrose is converted into reducing sugars [36]. Rapidly cooling harvested carrots to 5°C or below is essential for extending storage duration, preserving quality, freshness, flavor, and nutritional value while preventing spoilage [37]. Roots that did not have adequate precooled experienced faster decay [38]. Mature carrots can be stored for 7–9 months when kept at temperatures between 0 and 1°C, along with a very high relative humidity ranging from 95 to 100% [39]. Carrots have a freezing point of −12°C and if they freeze, severe tissue damage occurs, causing cracking and blistering along the length due to the formation of ice crystal formation beneath the surface [35].

5 Importance of carrots

In the early stages of human evolution, roots and tubers were essential components of the diet, providing crucial sustenance for our ancestors [40]. Root and tuber crops like carrots are agriculturally significant for their long shelf life, serving culinary, economic, ornamental, and social purposes, providing essential nutrients, and featuring prominently in diverse dishes from mains to desserts [41]. Highly nutritious carrot crops provide essential minerals and vitamins A, C, and B, crucial for overall health and well-being [7]. Vitamin C boosts immunity, aids wound healing, manages allergies, and fights respiratory diseases, while vitamin A supports vision, bone health, immunity, and reproduction, with carrots aiding digestion by promoting intestinal movement, preventing constipation, and reducing appetite [42]. Consuming carrots can help reduce the risk of various health problems, including gallstones, diabetes, heart-related diseases, and colon cancer [7].

Carrots are valued for their nutritional value and aesthetic appeal, enhancing landscapes with lush green foliage in Ethiopia and contributing to the economy by providing

income for local farmers and exporters [22]. Carrots serve as animal feed worldwide and are a staple in Ethiopia, commonly featured as the main dish or traditional side, prepared through steaming, boiling, baking, or frying [43].

Despite its underutilization, the carrot crop holds promise for enhancing food security, income generation, and resource conservation, particularly in Ethiopia, where it is a traditional food supporting family self-sufficiency, income, and soil conservation [44].

Carrot crops in Ethiopia act as vital security measures during crop failures and food shortages, cultivated alongside other root and tuber crops across diverse agricultural landscapes to mitigate food scarcity.

6 Challenges of carrot production in Ethiopia

In Ethiopia, carrot cultivation holds significant promise, but it faces several challenges that hinder its production and overall productivity [45]. Various aspects within the agricultural sector require research attention, including production methods, post-harvest practices, processing techniques, transportation systems, utilization of products, marketing strategies, and methods for protecting crops (Figure 3).

Carrot production in Ethiopia is hindered by limited high-yield varieties, poor seed access, soil and water issues, underused indigenous crops, and inadequate pest control [46]. Consequently, poor storage, packaging, and processing facilities, information and awareness problems in appropriate processing equipment, and poor transportation and logistics facilities are some of the limitations of carrot agriculture in the country (Figure 3). Carrot production faces hurdles such as insufficient startup funds, ineffective marketing methods, and weak connections between growers and buyers.

7 Role of nitrogen in carrot growth

Carrot fertilizer recommendations, based on soil type, carrot variety, and season, commonly include nitrogen, P_2O_5 , potassium (NPK), and farm manure, with the entire manure amount mixed into the soil to a depth of 20–25 cm during land preparation [47]. The recommendation suggests splitting nitrogen application, half before sowing and the rest after germination, as nitrogen is crucial for plant physiology, especially in photosynthesis [48]. The

concentration of nutrients in the soil surrounding carrot roots strongly correlates with their absorption rate, directly impacting how much nutrients the carrots can uptake [49]. The concentration of ions near the roots of a plant is influenced by two factors: the speed at which ions move from the surrounding soil to the root and the ability to absorb these ions [50]. Nitrogen fertilizers, containing ions like ammonium, nitrate, and urea, are vital for plant growth, with ammonium providing stability, nitrate offering rapid uptake, and urea forming both, while nitrogen is crucial in the structure and function of organic molecules such as amino acids, nucleic acids, and hormones [51]. Nitrogen significantly influences carrot growth, development, and yield formation, with approximately 85–90% absorbed during growth stages, while only 10–15% is taken up in the first and last quarters of growth [52]. Furthermore, it stimulates root growth and development, as well as the uptake of other nutrients [48]. Nitrogen deficiency in carrots slows growth, limits cell division and expansion, reduces chloroplast development and chlorophyll concentration, and decreases enzyme activity [53].

8 Effect of nitrogen on the yield and quality of carrots

The nitrogen released from urea fertilizer is linked to the height of mature carrot plants, indicating its influence on growth and development, potentially affecting their final height [54]. Varying nitrogen levels significantly affect carrot growth and yield, impacting factors like leaf number, root length, fresh and dry shoot weight, and overall root yield [55]. The

experiment conducted in Debiganj, Bangladesh, from November 2009 to February 2010 aimed to evaluate nitrogen's impact on carrot growth and yield, with 100 kg N/ha resulting in the highest values across parameters, including plant height (47.36 cm), root length (16.17 cm), leaf fresh weight (145.1 g), leaf dry matter (11.66 g), root fresh weight (68.33 g), root dry matter (15.90%), gross yield (22.55 tons/ha), and marketable yield (20.67 tons/ha) [52].

Carrot plant growth initially progresses slowly during the vegetative stage but notably accelerates after the formation of 7–8 leaves, with nitrogen fertilizers significantly influencing the growth dynamics of carrot leaves [56]. The application of nitrogen influences the fresh root weight per plant in carrot crops, with studies revealing a positive correlation between higher nitrogen levels and increased fresh root weight, demonstrating nitrogen's impact on carrot crop yield [57]. Nitrogen is vital for crucial biological compounds like chlorophyll, amino acids, and nucleic acids, profoundly influencing carrot growth and yield [48]. The most productive carrot yield has been achieved with the application of 150 kg per hectare [58].

The experiment in Canada from 2002 to 2004 aimed to assess carrot yield response to nitrogen fertilization in mineral and organic soils, differentiating between pre-plant and residual soil nitrogen effects, concluding that a universal nitrogen recommendation is not viable due to variations in soil type and nitrogen levels, impacting carrot yield differently annually [59]. Assessing soil nitrogen availability is crucial to mitigate loss risks from nitrogen application, necessitating comprehension of soil nitrogen levels before determining application rates to prevent potential crop yield losses.

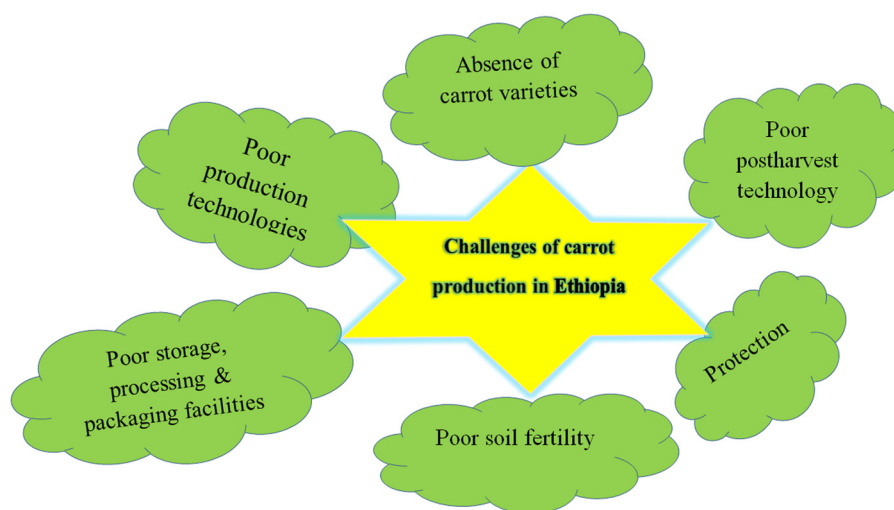


Figure 3: The spectrum of challenges for carrot production in Ethiopia.

Table 1: A summary of major findings on carrot production related to nitrogen fertilization

S/N	Major findings (short summary)	Reference
1	Appropriate nitrogen fertilization significantly enhances the yield and quality of carrot crops	[66]
2	Nitrogen influences both the vegetative and reproductive phases of carrot development, ultimately affecting the yield	[67]
3	Carrots grown with increased nitrogen levels exhibited substantial improvements in root size, weight, and overall yield	[68]
4	Nitrogen fertilization influences several yield components, such as root length, diameter, and biomass	[69]
5	Excessive nitrogen negatively impacts root morphology, resulting in issues like forking and reduced marketability	[70]
6	Optimal nitrogen application not only maximizes yield but also improves economic returns for farmers	[71]
7	Continuous nitrogen application affects soil properties, microbial activity, and overall soil fertility over multiple growing seasons	[72]
8	Further research could include more comprehensive environmental assessments, such as measuring nitrate leaching, greenhouse gas emissions, and potential contamination of water sources	[73]

The Bangladesh study from 2019 to 2020 analyzed nitrogen and sulfur's effects on carrot growth and yield, revealing the highest yield (22.21 tons/ha) with the application of 120 kg/ha nitrogen and 10 kg/ha sulfur [60]. Similarly, in a study in Serbia during the 2005 and 2006 growing seasons, higher nitrogen fertilization rates were examined for their effects on nitrate accumulation, vitamin C, and β -carotene levels in two carrot varieties, showing that increasing nitrogen from 60 to 120 kg N/ha reduced vitamin C levels but increased β -carotene content [11].

The Canadian study from 2002 to 2004 examined nitrogen dynamics in carrots, its influence on yield, and susceptibility to leaf blights, demonstrating that pre-plant nitrogen application had a greater impact on both yield and disease vulnerability compared to later applications or foliar application, attributed to deep nitrogen uptake and early leaf allocation during the early growth stages [56]. A Bangladesh study from 2003 to 2004 explored nitrogen's impact on yield and characteristics across three carrot varieties, revealing significant interactions between nitrogen levels and variety, notably affecting various parameters, including yield components [61].

In a 2013 experiment in Brazil, researchers assessed nitrogen, P_2O_5 , and potassium fertilizers' effectiveness in enhancing carrot recovery but found low nutrient recovery efficiency under the tested conditions [62].

Similarly, field trials conducted over three dry seasons at the Federal College of Horticulture Research Farm in Nigeria examined the influence of irrigation frequency, nitrogen levels, and intra-row spacing on carrot growth and yield, revealing that watering every 5 days and applying 150 kg N/ha with 15 cm intra-row spacing produced the highest yield [63].

In Morogoro, Tanzania, a study assessed the impact of varying irrigation and soil-based NPK fertilizer levels on carrot growth, yield, and sugar content under drip irrigation, concluding that applying 2 g of fertilizer per plant yielded the best growth, quality, and yield across both

seasons [9]. In Ethiopia, a 2-year field trial sought optimal carrot spacing in irrigation ridge-furrow systems, finding that 10 cm between rows and 4 cm within rows yielded the best results for irrigated carrot production in both 2015 and 2016 [64]. During the 2019 cropping season in Ethiopia's Sodo Zuria Woreda, a study investigated the response of the Nantes carrot variety to varied rates of blended NPS and KCl fertilizer, revealing the highest total root yield at 30.5 tons/ha and the highest marketable root yield at 24.6 tons/ha with the combined application of 150 kg/ha of NPS and 213 kg/ha of KCl fertilizers [65]. Nitrogen fertilization significantly enhances carrot production by improving root growth, yield, and quality, but excessive application can lead to environmental issues and diminishing returns (Table 1).

9 Research gaps and future perspectives

In Ethiopia, carrot yields fall significantly below their potential, revealing a gap between potential and actual yields across production stages. Research on carrot fertilization, particularly nitrogen application, remains scarce, compounded by the challenge of importing all agricultural inputs due to a lack of domestic agrochemical manufacturing. This reliance on imports extends to generalized fertilizer recommendations, overlooking location-specific needs for nitrogen application. Soil nutrient assessment and experimentation are irregular, with minimal exploration of soil acidity and alkalinity impacts on nutrient depletion. Climate change's influence on nutrient availability, notably nitrogen, P_2O_5 , and potassium, remains understudied. Integrated nutrient management research is insufficient, highlighting the need for further investigation.

Adopting systematic and predictive agronomic methods in carrot crop modeling is crucial to enhance nutrient management and optimize yield outcomes.

10 Conclusion and recommendations

In conclusion, the review study on nitrogen fertilizer rates' potential influence on carrot yield in Ethiopia underscores the critical need to tailor nutrient management practices to the country's diverse agro-ecological zones. Future reviews should prioritize comprehensive assessments across regions, considering factors such as soil fertility, irrigation practices, and crop rotation systems to develop context-specific recommendations. Additionally, exploring integrated nutrient management approaches that combine organic and inorganic fertilizers can enhance nutrient efficiency and minimize environmental impacts. By fostering collaboration and knowledge exchange, Ethiopia can strengthen its agricultural sector and improve food security.

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