



MINI REVIEW ARTICLE

# Nutrient impact on growth, yield and quality of oats: A review

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## Abstract

Oats (*Avena sativa* L.) represent a vital cereal crop extensively grown for both human and animal consumption. Effective nutrient management is crucial for influencing the growth, health and quality of crops. This review investigates the effect of both macro and macronutrients on oat production, focusing on their roles in biomass accumulation, grain yield and nutritional quality. Additionally, the review addresses sustainable nutrient management approaches to enhance oat productivity. It talks about the latest advancements in cutting-edge trend management strategies like precision agriculture, biofertiliser use and integrated nutrient management. Furthermore, the review examines how changing climatic conditions affect nutrient needs and oat production, underscoring the necessity of adaptive strategies to maximise yield across various agroclimatic environments.

**Keywords:** nutrient management; oats; quality; yield

## Introduction

Enhancing crop yield and nutritional quality is essential in contemporary agriculture (1). In India, the livestock population stands at 536.76 million (2). Improving yield and nutritional quality in animal production is vital for sustainable agricultural methods (3), particularly in light of the deficits of 35.6 %, 10.5 % and 44 % in green fodder, dry fodder and concentrates, respectively (4). Oats (*Avena sativa*), an annual plant, can be cultivated in the autumn for a late summer harvest or in spring for an early autumn yield. Classified under the grass family *Poaceae*, oats are represented by the species *Avena sativa*, commonly known as common oat, an allohexaploid with a total of 42 chromosomes ( $2n = 6x = 42$ ). They provide a valuable source of protein, fibre and essential minerals, although the global oat grain production experienced a downturn due to the rise of farm mechanisation between 1930 and 1950. Despite this, oats continue to be a significant crop for communities in marginal environments across the developing world as well as for specialised applications in developed nations. In various regions, oats are cultivated not only as grain but also for forage, fodder, straw, hay, haylage, silage and chaff.

Globally, oats are cultivated on an extensive 102.12 M/ha, producing a remarkable 223 Mt yearly. In India, however, the cultivation of oats is restricted to just 4.9 % of the total agricultural area. The area dedicated to cultivated fodders stands at 8.6 M/ha when considered crop-by-crop. Uttar Pradesh dominates oat cultivation, occupying 34 % of the area, followed by Punjab with 20 %, Bihar with 16 %, Haryana with 9 % and Madhya Pradesh with 6 %. Oats are ranked fifth in the world for cereal production. Cultivated fodder occupies only 4.9 % of the total cropped area in the country (5). To encourage farmers to engage in seed production for forage

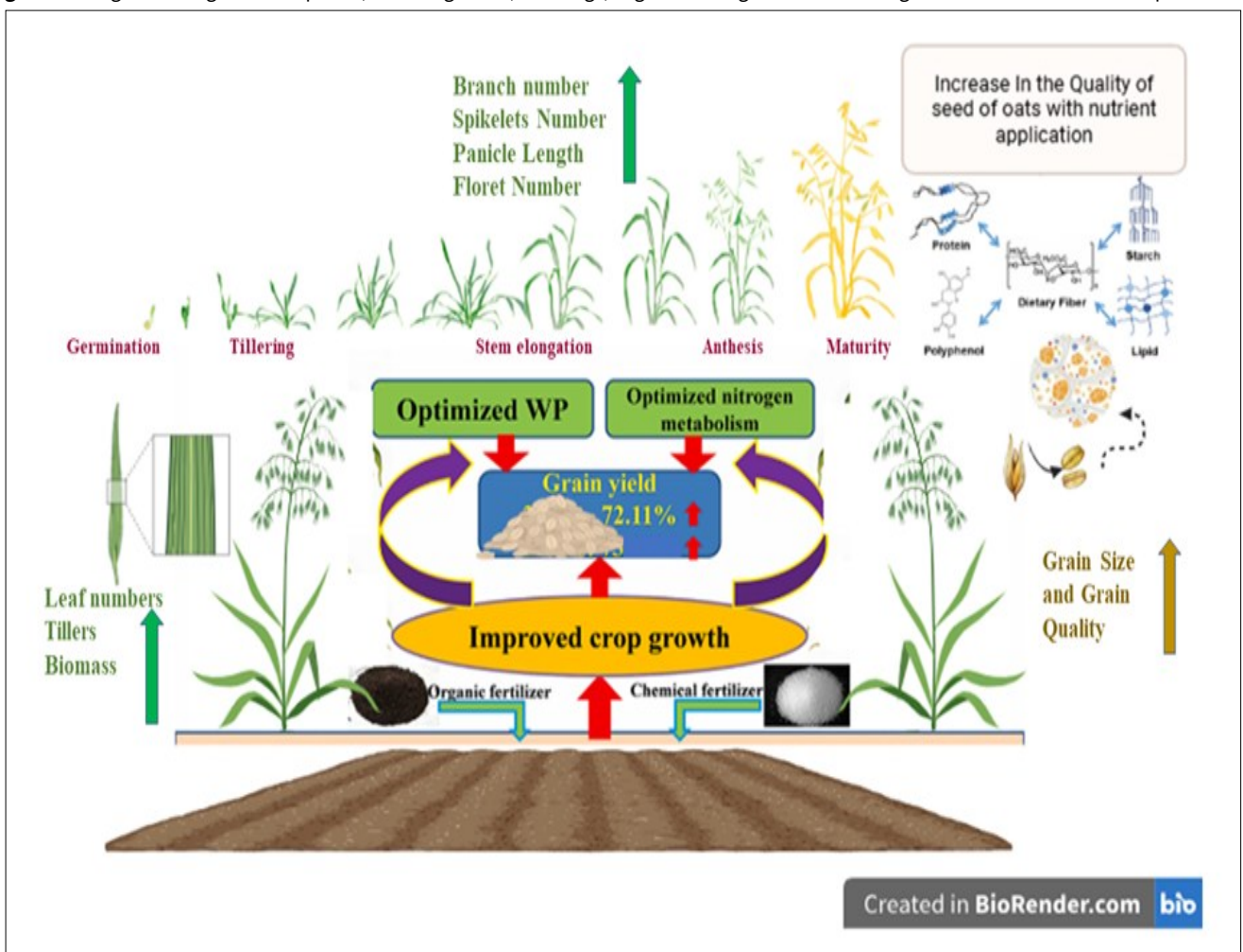
crops, especially oats, it is essential to introduce varieties that can yield higher seed outputs.

Oats are more adaptable to diverse soil types and tend to thrive on acidic soils more efficiently than other small-grain cereal crops. They are primarily cultivated in cool, moist climates but can be adversely affected by hot, dry conditions from the time of head emergence until maturity. The different growth stages are represented in Fig. 1. Most global oat production is derived from spring-sown varieties. Nevertheless, oat productivity faces several challenges. Numerous factors can impact the profitable production of oats and among these, soil fertility is crucial for producing high-quality seed and feed. A significant issue is inadequate soil fertility, which is often worsened by poor nutrient management practices. The main causes of our nation's low oat crop output are cultural practices, insufficient manuring and low soil fertility (6). Our soils have run out of both major and minor components, which is reducing agricultural productivity. For optimal growth and yield, oats need a well-balanced supply of macro and micronutrients (Fig. 2). Applying these nutrients in the correct ratios and growth stages can significantly boost productivity. However, excessive dependence on chemical fertilisers, inadequate nutrient management and the effects of climate change present considerable obstacles to sustainable oat production (7).

Incorporating numerous micronutrients, such as zinc, is integral in the production of tryptophan, which serves as a precursor to indole acetic acid (IAA). This compound is vital for plant development, nitrogen metabolism, starch and chlorophyll formation, ATPase activity and the movement of assimilates (8). The presence of boron in oat seed production not only enhances the quality of the seeds but also mitigates micronutrient deficiencies in



**Fig. 1.** Varied growth stages of oats plants, including seeds, seedlings, vegetative stage and mature stage of seed and for fodder crop.



**Fig. 2.** Effect of nutrient application on growth, yield and quality of oats.

animals. Without these nutrients, animals may experience malnutrition and various health issues, as boron is vital for cell wall formation and lignification, thus alleviating micronutrient deficiencies. Yields can still be obtained regardless of whether crops are planted in soils deficient in micronutrients. Likewise, from an agronomic standpoint, this method lowers seed rates, which results in considerable input cost savings. Grain concentrates and high-micronutrient feed are beneficial for raising animals. These crops are gaining popularity again because of strong scientific proof of their benefits as food, feed and fodder. High photosynthetic activity, robust growth, high yield and dark green feed are all indicators of an appropriate macro and micro nutrient supply, which is also known to aid in the utilisation of carbohydrates and boost the feed's succulence. This review delves into the significance of both macro and micronutrients in the growth and quality of oats. It explores the existing understanding of oats' nutrient management and presents strategies to enhance nutrient availability for sustainable oat cultivation.

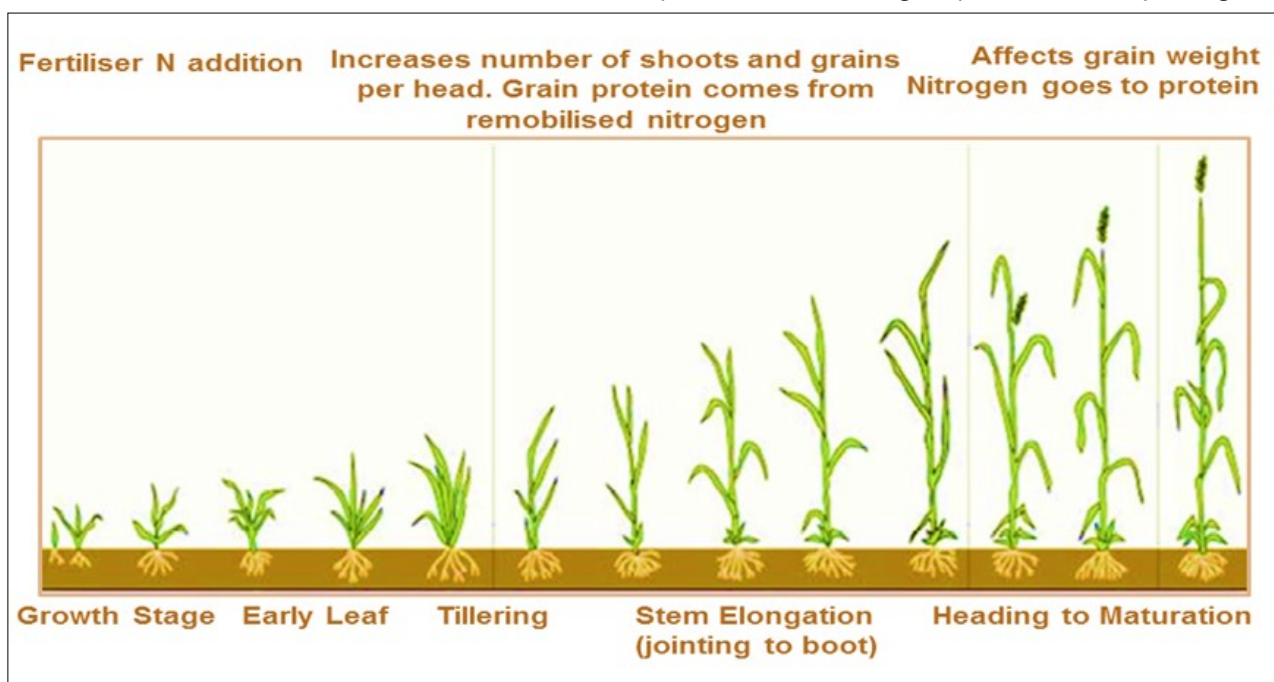
### Role of macronutrients in oat growth, yield and quality

Plants rely heavily on macronutrients, which are vital nutrients needed in large quantities. These nutrients are critical for photosynthesis, root formation and energy distribution. When it comes to growing oats, the four primary macronutrients necessary are nitrogen (N), phosphorus (P), potassium (K) and sulfur (S). The lucrative cultivation of oats can be influenced by various factors, with soil fertility essential for producing high-quality fodder and seeds. Our country's subpar yields of oats are mainly due to low soil fertility, inadequate fertilisation and poor agricultural practices. Our soils have become depleted of major and minor essential nutrients, which restricts crop yields. New oat varieties require increased nutrient levels to reach their maximum yield potential. Proper and balanced fertiliser application not only enhances yields but also positively impacts the quality of the produce. All crops, particularly non-legumes, have a high demand for nitrogen. Beyond its various roles, nitrogen is a fundamental component of proteins and chlorophyll in green plants. Fig. 3 depicts the effect of nitrogenous fertiliser on the oats plant's vegetative stage to maturity.

Phosphorus is vital for energy transfer, root growth and flower development. It is vital for the successful establishment of seedlings and the development of root systems, which significantly affects the overall growth of oats (9). Additionally, phosphorus is essential for producing key enzymes that facilitate photosynthesis and energy movement within the plant. Insufficient phosphorus in the soil can lead to stunted root growth, fragile plant structures and lower yields. On the other hand, an adequate supply of phosphorus promotes robust seedling health, stronger roots and improved grain quality. Research in Madhya Pradesh demonstrated that applying 60 kg  $P_2O_5$ /ha markedly increased oat yields (7). It was observed that the blanket recommended fertiliser dose of 150% (61.5 kg N + 30 kg P/ha) increased the grain yield performance of oat varieties and farm profitability (10, 11).

### Impact of fertilisation with macronutrients on oat growth

Oat plants respond remarkably well to nitrogen fertilisation. The use of nitrogen resulted in a substantial increase in plant height, with shorter varieties benefiting more from the application than many taller ones. For cereal crops, nitrogen (N) is a vital nutrient; the total yield of these crops is closely associated with nitrogen absorption. Synthetic nitrogen fertilisers are required to be employed on the soil, whilst the natural rate of nitrogen mineralisation there frequently falls short of the nutritional requirements of the crops. By encouraging more leaf area, extending leaf area duration and boosting grain site production—all of which collectively improve yield—nitrogen fertilisers help to maximise grain yield. Irish cereal growers have increasingly embraced the technique of separating nitrogen applications; this helps to extend leaf area duration, lower the risk of nitrogen leaching and consequently optimise grain yield (12). Research indicates a clear and satisfactory link between the nitrogen application rate to grain yield in oat production (13, 14). Usually showing a declining returns pattern, this link reflects the nature of cereal crops. In the case of oats, however, the higher probability of crop lodging at high nitrogen levels can exceed the expected yield increases. Farmers thus usually choose to apply nitrogen below the recommended level to lower the risk of lodging (15). In these investigations, nitrogen fertiliser was applied during the early growth phase to enhance nitrogen uptake and recovery throughout the



**Fig. 3.** Effect of nitrogenous fertiliser on oats vegetative growth to the maturation phase.

growing season (15). Oat grain yield is characterised by a high number of grains but a low weight per individual grain, with a common negative correlation between these two factors.

The application of nitrogen at 120 kg/ha led to a remarkable increase in oat plant height, rising from 89.9 cm to 126.8 cm and the tiller row length/m also grew from 68.6 cm to 88.1 cm, in comparison to the lower nitrogen applications of 40.0 and 80 kg/ha (16). Nitrogen addition of 110 kg/ha significantly enhanced both the growth rate and the dry fodder yield of oats. It was noted that all growth parameters were significantly affected by nitrogen levels between 40 and 120 kg/ha. At the same time, the leaf-to-stem ratio and the number of tillers/m row length increased up to 80 kg N/ha (17). Furthermore, it was reported that the number of tillers per meter row length was significantly impacted by nitrogen levels from 40 to 120 kg/ha. However, plant height only saw an increase of up to 80 kg N/ha (18). Research indicates that while plant height increased up to 80 kg N/ha only, the number of tillers/m row length was considerably impacted by increases in nitrogen levels from 40 to 120 kg/ha (18).

Scholars have documented differences among oat varieties in the parameters measured. Furthermore, the application of fertiliser significantly affected nearly all parameters, except days to forage harvest (DFH), leaf-to-stem ratio (LSR) and phosphorus-nitrogen balance (PNB) in oats. This finding underscores the considerable influence of fertiliser on the parameters studied. Other research has also confirmed the impact of fertiliser on various aspects of oat growth (19). The interaction between variety and fertiliser was particularly significant for total dry weight (TDW), LSR, forage phosphorus concentration (FPC) and forage nitrogen concentration (FNC). This suggests that the varying responses of different oat varieties, along with the distinct effects of fertiliser, played a role in the observed changes in FPC and FNC. In contrast, the interaction between TDW and LSR was attributed to the specific effects of fertiliser on TDW and the differing responses of the varieties concerning LSR (10).

Studies indicate that fertiliser application and the choice of varieties notably affect the number of leaves at forage harvest (NLFH) in oats. The increase in leaves per plant is likely due to the stimulating effect of fertilisers on vegetative growth, which raises plant height, increases the number of nodes and elongates internodes, resulting in more leaves. This finding is in agreement with the research conducted in the previous study (19). A higher NLFH is essential for enhancing fodder yield and quality. Typically, NLFH is influenced by plant height, the number of nodes and internode length, as well as by variety, soil conditions, climate, management practices and their interactions.

### Forage and seed yield

It was pointed out that the strategy aimed at maximising yield by increasing grain quantity may lead to a higher number of inadequately filled grains (20). Exploring alternative nitrogen application methods could optimise these essential processes and improve grain yield in winter and spring sown oats. The concept known as the plasticity of yield components significantly influences yield stability (21). The plasticity of yield components and cereal crops is organised hierarchically with the following order: number of tillers > number of inflorescences > grains per inflorescence > seed size. However, in oats, this hierarchy is inverted as plasticity is more pronounced in the grain's perpendicular direction compared to the number of inflorescences (12, 22). Researches indicate that the application of nitrogen fertiliser during the early stages of growth

correlates with increased final yield and ear density in cereal cultivation. However, it was also observed that the number of grains/panicle decreased as the nitrogen application rate increased during later application timings. In a more recent study, it was found that the number of grains/panicle remained consistent across growth stages GS 21, GS 30 and GS 32 but experienced a significant decline when nitrogen application was postponed until GS 39 in winter-sown oats (12). The application of nitrogen fertiliser beyond growth stage 39 is unlikely to result in increased growth, although it may lead to higher brain protein levels. Not able to panicle is distinct in its ability to provide more photosynthates than the last leaf during the grain filling period. Research has shown that the timing of nitrogen application can significantly affect the factors determining grain number in various cereal crops, highlighting the need for oat-specific strategies to optimise nitrogen application.

The timing of nitrogen application and the impact of application rates on the development of critical yield-related characteristics, such as the number of panicles per metre, spikelets per panicle and grains/m<sup>2</sup>, are vital as they influence the pre-anthesis yield potential of the crop. Oat spikelet poses are distinctive, keeping the ability to generate primary, secondary and tertiary grains, each exhibiting significant variations in grain quality characteristics. When sufficient photosynthate is available during the grain filling stage, the plant will start to fill tertiary grains after the primary and secondary grains in each spikelet have been filled. A deficiency in photosynthates can lead to the abortion of florets and spikelets, which helps to ensure that grain fill remains consistent across each spikelet in the panicle. While research indicates that agronomic factors are relatively less critical compared to climatic influences during the grain fill stage, examining the effects of nitrogen application rates and timing on sink and source capacities before this stage and their relationship with oat Grain fill patterns is of significant agronomic interest (15).

### Quality

Oats have long been recognised for their high soluble fibre content, particularly  $\beta$ -glucan, which is important in reducing cholesterol levels and enhancing cardiovascular health. Their increasing popularity can be observed through the growing demand for oats, particularly in urban parts of countries like India, where individuals are health-conscious and incorporating oats into their diet. The increasing demand has required improved oat yields and quality oats, which can be achieved only through good nutrient management practices. One of the key factors influencing the nutritional quality of fodder crops is their protein content. The findings revealed that different fertilisers significantly affected the crude protein levels.

The application of nitrogen leads to a notable rise in crude protein yields, reaching 7.37 q/ha with the application of 100 kg N/ha (23). Similarly, nitrogen levels profoundly affected the nitrogen content in fodder, grain and straw, in conjunction with the soil after harvesting oats (24). Nitrogen also enhanced the protein content in fodder, grain and straw over both years of study. Furthermore, Nitrogen application up to 120 kg N/ha significantly boosted crude protein content and yield (18). It was asserted that a fertility level of 150:70:40 (N: P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O kg/ha) resulted in the augmentation of crude protein content compared to the lower levels of 125:60:30 and 100:50:20 (N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O kg/ha) (25). However, they also noted a substantial decline in crude fibre content as the fertility level rose. Application of nitrogen at a rate of 120.0 kg/ha resulted in a

substantial increase in protein content, rising from 11.9 to 13.6 % (16). It boosted protein yield from 6.3 to 12.1 q/ha when compared to the lower nitrogen applications of 40.0 and 80 kg/ha. Similarly, it was also noticed that the crude protein content and its yield showed an upward trend with higher nitrogen levels, peaking at 120 kg N/ha (17). Furthermore, it was noted that applying 110 kg N/ha significantly enhanced quality metrics, including crude protein at 1937.13 kg/ha, crude fibre at 5061.22 kg/ha, ether extract at 303.25 kg/ha, mineral matter at 1277.18 kg/ha, nitrogen-free extract at 8877.58 kg/ha and total digestible nutrients at 12595.7 kg/ha (25). Crude protein content and yield increased with higher nitrogen applications, with the highest yield occurring at 120 kg N/ha (18). The enhancement in quality could be attributed to phosphorus, a vital element in DNA and different types of RNA essential for protein synthesis. Consequently, sufficient phosphorus availability boosts protein synthesis, leading to an increase in both the content and yield of crude protein.

#### **Uptake of NPK in fodder, grain and straw**

Among the various climatic factors, a well-distributed rainfall pattern significantly enhanced the absorption of nitrogen, phosphorus and potassium. This improvement was due to increased moisture levels in the soil, which elevated the concentrations of these nutrients in the labile pool, facilitating better uptake by crop plants. Furthermore, the application of nitrogen had a notable impact on the uptake of N, P and K. Specifically, applying 125 kg of nitrogen/ha led to a marked increase in the uptake of N (96.80 kg/ha), P (16.86 kg/ha) and K (82.11 kg/ha) compared to 100 kg N/ha. The highest uptake levels of N, P and K can be attributed to the positive effects of nitrogen availability in the soil solution and increased dry matter yields, which enhanced nutrient absorption to optimal levels (26, 27). Nitrogen level significantly influenced the nitrogen content in fodder, grain and straw, as well as in the soil post-oat harvest (24). Furthermore, research indicates that nitrogen and phosphorus substantially boosted the uptake of copper, manganese and iron in oat fodder, grain and straw, with the  $N_{120} + P_{60}$  treatment yielding the best results among all tested treatments (28).

Nutrient use efficiency refers to the optimal economic yield achieved per unit of nutrients either applied or absorbed by plants. The concentration of nutrients within plant tissues can differ based on several factors, including the type of tissue examined (such as leaves, shoots or the entire plant), the age of the plant, the level of dry matter or grain yield, the species or genotypes of the crop, management practices and environmental conditions (29). The application of nitrogen (N) fertiliser has been shown to enhance both the nitrogen concentration and its uptake in oat forage yields (30). Research indicated that the total nitrogen uptake in oat fodder peaked with the application of 80 kg N/ha. Furthermore, the highest nitrogen levels and uptake in oats were observed with a 120 kg N/ha application. Nitrogen application led to an increase in phosphorus (P) content within the forage (31). Additionally, it was found that applying phosphorus fertilisers raised both the concentration and uptake of phosphorus. The total phosphorus uptake in forage was maximised with the application of 80 kg N/ha, while it was reported that gradually increasing phosphorus levels up to 60 kg/ha resulted in higher phosphorus content in the forage (7, 32, 33).

#### **Micronutrients**

Micronutrients, though required in smaller doses than macronutrients, play an indispensable role in the growth and quality

of oats. Elements such as zinc (Zn), iron (Fe), manganese (Mn) and boron (B) are integral to various physiological processes that impact plant development, bolster disease resistance and enhance the nutritional value of the grains. Zinc is essential for the activity of enzymes, the synthesis of proteins and the formation of DNA. It significantly contributes to the vigour of seedlings, the growth of roots and the overall health of plants. Oats deficient in zinc may experience stunted growth, weak root systems and diminished yields. Foliar applications of zinc have demonstrated effectiveness in improving the nutrient composition of grains and boosting oat yields. A study in Maharashtra found that applying 5 kg Zn/ha resulted in a 12 % increase in oat yield, along with substantial improvements in the protein and mineral content of the grains (31). Furthermore, zinc is integral to protein synthesis, which directly impacts the grain's nutritional quality. Incorporating numerous micronutrients, including zinc, is integral to synthesising tryptophan, a precursor to indole acetic acid (IAA). This mechanism is critical for promoting plant development, facilitating nitrogen metabolism, aiding in the synthesis of starch and chlorophyll production, as well as ATPase activity and transport of assimilate (24). Furthermore, using boron in oat seed production improves seed quality and reduces nutritional shortages in animals. Animals may suffer from malnutrition and other illnesses if these minerals are deficient, as boron is crucial for cell wall synthesis and lignification (8).

Reviews have depicted that utilising 100 % NPK along with FYM in conjunction with specific amounts of  $ZnSO_4$  and Borax, promotes a greater tiller count per plant than using either  $ZnSO_4$  or Borax on their own with the same NPK and FYM application. Although the application of larger quantities of  $ZnSO_4$  and Borax resulted in more tillers, the differences were not statistically significant compared to their lower doses. This trend was also observed in dry matter ( $g/m^2$ ). Adding boron and zinc results in improved growth of oats, though it alters the nutritional characteristics of the forage. Utilising higher doses of these nutrients can enhance the absorption and accumulation of essential elements in plant tissues, thereby affecting different aspects of plant growth. Field experiments conducted in Gujarat revealed that applying manganese at a rate of 3 kg/ha led to a 10 % boost in oat yield. This highlights manganese's crucial role in enhancing oats' quantity and quality (7). Additionally, manganese contributes to better grain filling and strengthens disease resistance, underscoring its significance as a vital nutrient for sustainable oat farming.

#### **Conclusion**

Nutrient management practices heavily influence the effectiveness and quality of oat production. Appropriately applying both macronutrients and micronutrients is crucial to enhancing growth, yield and nutritional value. As research advances in developing new nutrient management techniques, ongoing efforts are necessary to refine nutrient delivery systems for oat cultivation, particularly in areas dealing with soil fertility issues and climate fluctuations.

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## Authors' contributions

R contributed to conceptualisation, supervision, editing and final drafting of the manuscript. RKG contributed to conceptualisation, supervision, editing and final drafting of the manuscript. AK contributed to conceptualisation, experimentation and manuscript writing. A contributed to conceptualisation, experimentation and manuscript writing. DK contributed to conceptualisation, experimentation, manuscript writing and data recording. SS contributed to data recording. All authors reviewed and approved the final version of the manuscript.

## Compliance with ethical standards

**Conflict of interest:** Authors declare that there is no conflict of interest.

**Ethical issues:** None

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