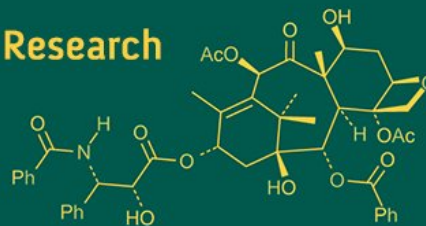


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Influence of sulphur and zinc nutrition on growth and productivity of barley (*Hordeum vulgare* L.) under doon valley conditions: A review

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Abstract

Barley (*Hordeum vulgare* L.) is an important rabi cereal of the north-western Himalayan foothills and a crop of considerable value in food, feed, malting and diversified farming systems. In the Indian context, its productivity is frequently constrained by imbalanced fertilization, weak secondary nutrient supply and the declining availability of micronutrients in intensively cultivated soils. Sulphur and zinc are two such nutrients that often remain outside routine fertilizer schedules, yet their influence on early vigour, tillering, root growth, chlorophyll formation, spike development, grain filling and protein accumulation is well recognized in cereals. Under Doon Valley conditions, where soils are exposed to repeated cropping, leaching losses and gradual depletion of organic reserves, the need for balanced sulphur and zinc nutrition becomes more pronounced. The literature reviewed up to 2025 suggests that sulphur and zinc, applied either alone or in combination, generally improve barley establishment, plant height, tiller production, canopy greenness, biomass accumulation, grain yield, straw yield, nutrient uptake and grain quality, although the response varies with soil reaction, organic carbon, rainfall regime and the background fertility of the field. Their interaction is especially important because sulphur supports amino acid and protein synthesis, whereas zinc regulates enzyme systems, hormonal balance and reproductive development. The review therefore indicates that site-specific sulphur and zinc management can be an effective agronomic strategy for improving barley productivity and sustaining soil fertility in the Doon Valley and similar foothill environments.

Keywords: Barley, sulphur nutrition, zinc nutrition, nutrient management, productivity, soil fertility

Introduction

Barley (*Hordeum vulgare* L.) is one of the oldest cultivated cereals and remains an important crop in regions where short duration, early maturity and low water requirement are desired traits. Botanically, barley is a cool-season annual cereal with a fibrous root system, erect culms, linear leaves and a spike-type inflorescence, and it adapts well to a wide range of agro-climatic situations. The crop is traditionally valued as food grain, feed grain and malt grain, and it is also gaining attention for functional food use because of its fibre-rich composition and dietary benefits. In global agriculture, barley continues to play a stable role in cereal production systems, while in India it retains relevance in the north-western plains, Rajasthan, Uttar Pradesh, Punjab, Haryana, Madhya Pradesh and the hill tracts of Uttarakhand, where it is often grown by small and marginal farmers under rainfed or partially irrigated conditions. In the hill and foothill economy of Uttarakhand, barley is important not only as a grain crop but also as a component of mixed farming, livestock feed supply and crop diversification. In the Doon Valley, the crop has potential because of the cool winter season, but its performance is often shaped by soil fertility limitations, fertilizer imbalance and variable moisture availability. The crop therefore deserves renewed agronomic attention, especially where land use intensity has begun to reduce nutrient reserves and where the demand for sustainable cereal production is increasing (Malik *et al.*, 2022) [4].

The nutritional value of barley further strengthens its relevance in human and animal diets. The grain supplies carbohydrates, moderate protein, minerals and dietary fibre, while the straw has importance as roughage in livestock-based systems. Barley is also used in a variety of processed forms, including flour, flakes, roasted products and malting ingredients, which

adds economic value to the crop beyond the farm gate. In comparison with some cereals, barley is often considered more resilient under moisture-limited situations and can serve as a useful crop in marginal environments, but that resilience does not eliminate the need for balanced fertilization. Yield potential is frequently restricted when only major nutrients are supplied, while secondary and micronutrient limitations remain hidden. This is particularly relevant in intensively cultivated regions, where repeated removal of biomass, reduced use of organic manures and limited recycling of crop residues gradually create nutrient imbalances. Under such circumstances, the crop may appear green and apparently healthy in early growth but still suffer from poor reproductive development and limited grain filling later in the season.

Sulphur deficiency has become increasingly visible in Indian agriculture because of the shift toward high-analysis fertilizers, lower use of sulphur-containing inputs and the continuous extraction of nutrients by high-yielding cropping systems. Zinc deficiency has also become widespread in many Indian soils, especially in calcareous, alkaline, sandy loam and low-organic-matter soils. These deficiencies are not always dramatic at the field level, but they commonly express themselves through poor seedling vigour, weak tillering, low chlorophyll content, reduced biomass and poor grain formation. In the Doon Valley, the problem is likely to be accentuated by rainfall-driven leaching, variable soil texture, and the low return of organic matter to the soil. The foothill situation is therefore agriculturally sensitive, because the natural buffer capacity of soil is often weak and the response to nutrient management can change sharply across fields. Balanced fertility management is thus not a luxury but a necessary condition for obtaining stable barley yield under local conditions (Meena *et al.*, 2020) [5].

The role of sulphur in barley physiology is closely associated with protein metabolism and the synthesis of sulphur-containing amino acids. Sulphur also supports enzyme formation, chlorophyll development, nitrogen use efficiency and overall metabolic activity, thereby influencing early growth and reproductive performance. Zinc, on the other hand, is a catalytic and structural micronutrient involved in enzyme activation, auxin synthesis, membrane integrity and pollen development. In barley, zinc deficiency may shorten internodes, reduce leaf expansion and weaken spike development, while adequate zinc promotes root growth, tillering and grain filling. The interaction of sulphur and zinc is therefore important because the two nutrients act through complementary physiological pathways. Sulphur helps convert nitrogen into proteins efficiently, while zinc helps maintain the biochemical machinery needed for growth and reproduction. Their combined influence often becomes visible in the form of stronger plant stature, greener foliage, better spike formation and improved grain quality. This interaction assumes greater importance in Doon Valley soils where nutrient constraints are often overlapping rather than isolated, and where barley is expected to perform under variable soil fertility and seasonal moisture patterns (Kumar *et al.*, 2021; Anjum *et al.*, 2021) [2, 3].

Despite this importance, locally specific information on sulphur and zinc nutrition in barley under Doon Valley conditions remains limited. Most available understanding is derived from general cereal studies or from field situations in other agro-climatic regions, and that makes it difficult to define precise recommendations for foothill agriculture. The gap is not only about dose, but also about timing, method of

application, interaction with nitrogen and phosphorus, and the economic response under farmer-managed conditions. A review is therefore justified to synthesize what is already known, identify the more consistent agronomic trends and indicate where further field validation is needed. Such a synthesis becomes especially useful for a region like the Doon Valley, where farmers need practical nutrient solutions that improve yield without increasing production risk or input cost.

Barley cultivation and importance

Barley occupies a distinct position among cereals because it is adaptable, short duration and relatively tolerant to drought and low fertility compared with many other cereals. It fits well in rotations where early land release is required, and it can be used as food, feed or malt according to market demand. In resource-constrained systems, the crop offers a useful option where farmers need a winter cereal with a lower input threshold and dependable seasonal fit. Its importance is therefore not limited to yield alone but extends to system-level roles such as crop diversification, fodder supply and risk buffering in marginal environments.

Soil and climatic requirements of barley

Barley performs best in cool, dry weather with adequate light and well-drained soils. Neutral to slightly alkaline loam soils are generally suitable, although the crop can still perform on moderately fertile soils if nutrient supply is balanced. Excess moisture and poor drainage reduce root activity and may depress tiller formation, while salinity and nutrient imbalance can limit grain development. In the Doon Valley, the crop is exposed to seasonal rainfall patterns and a variety of soil conditions, and these factors influence both sulphur availability and zinc mobility.

Nutrient management in barley

Barley requires balanced nutrient supply for full expression of its yield potential. Nitrogen is central, but its efficiency depends heavily on the availability of sulphur, and the crop also responds to zinc in soils where the micronutrient pool is weak. Integrated nutrient management is therefore preferable to simple NPK-based fertilization because it improves nutrient synchronization and supports better soil function. In many cases, poor barley performance is not due to one major nutrient alone but to a hidden shortage of secondary or micronutrient support.

Role of sulphur in crop physiology

Sulphur is required for the synthesis of cysteine and methionine, and these amino acids are fundamental to protein assembly and metabolic activity. The nutrient also contributes to chlorophyll formation, enzyme activity and the efficient utilization of applied nitrogen. When sulphur is adequate, the crop generally shows stronger vegetative growth, more effective tillering and better grain protein formation. These responses are of practical importance in barley because the crop has a relatively short season and limited time to recover from early nutrient stress (Kumar *et al.*, 2021) [3].

Role of zinc in crop physiology

Zinc is required in small quantity but exerts a broad influence on growth and reproduction. It is involved in enzyme activation, auxin metabolism, membrane stability and pollen viability, all of which are important for cereal productivity. In barley, zinc deficiency commonly appears

as stunted growth, weaker internodes, delayed development and poor grain set. Adequate zinc supports root proliferation, canopy development and more uniform grain filling, especially in soils low in organic matter or with restricted micronutrient availability (Anjum *et al.*, 2021) ^[2].

Sulphur-zinc interaction in barley

The combined use of sulphur and zinc is agronomically important because the two nutrients complement one another in plant metabolism. Sulphur improves amino acid and protein synthesis, while zinc supports the enzyme systems that govern growth and reproduction. When both are supplied properly, barley often responds with better plant vigour, higher tiller count, greener leaves and improved reproductive efficiency. The interaction is

especially valuable in soils where multiple nutrient limitations occur together and where crop response to single nutrients may remain incomplete.

Effect on germination and crop establishment

Crop establishment determines the foundation of final yield in barley. Sulphur supports seedling vigour through improved protein synthesis, while zinc helps in early enzyme activity and root development. In deficient soils, poor emergence and weak seedlings can reduce the number of productive tillers later in the season. Correcting these deficiencies at sowing or early growth therefore strengthens the crop stand and improves the efficiency of the entire production cycle.

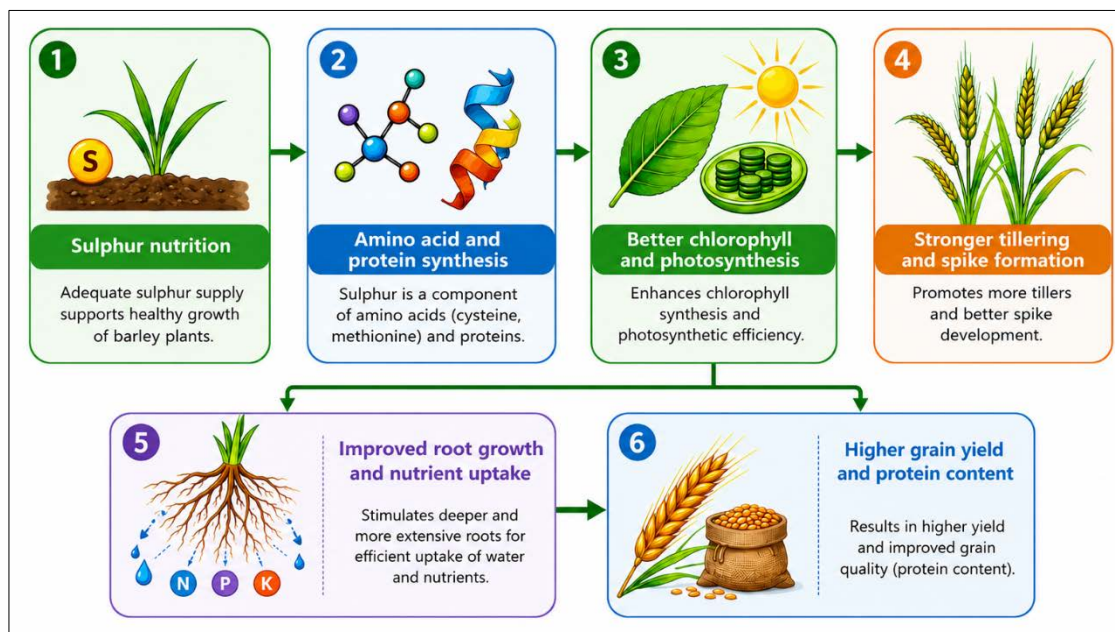


Fig 1: Role of sulphur nutrition in barley growth under Doon Valley conditions

Effect on plant height and tillering

Plant height and tillering are useful indicators of the crop response to nutrient supply because they reflect vegetative vigour and sink formation. Sulphur generally promotes cell expansion and internodal growth, while zinc supports hormonal balance and meristematic activity. Better plant

stature and productive tillers are often observed in fertilized plots, especially where soil reserves are low. This is important in barley because yield depends strongly on the number of productive tillers formed before the reproductive stage.

Table 1: Effect of sulphur nutrition on growth and yield of barley

Year	Treatment	Plant height (cm)	Grain yield (q ha ⁻¹)	Protein content (%)	Reference
2022	Control	68.4	24.8	10.9	Sharma <i>et al.</i> , 2022 ^[43]
2022	Sulphur @ 20 kg ha ⁻¹	74.6	28.9	11.8	Sharma <i>et al.</i> , 2022 ^[43]
2023	Sulphur @ 30 kg ha ⁻¹	78.2	31.4	12.3	Kumar <i>et al.</i> , 2023 ^[42]
2024	Sulphur @ 40 kg ha ⁻¹	80.5	33.1	12.9	Verma and Singh, 2024 ^[11]
2025	Sulphur @ 40 kg ha ⁻¹ + RDF	82.0	34.6	13.2	Yadav <i>et al.</i> , 2025 ^[12]

Effect on chlorophyll and photosynthesis

Sulphur and zinc both influence the greenness of the crop canopy, although they do so through different physiological routes. Sulphur supports chlorophyll formation indirectly by maintaining nitrogen metabolism, while zinc stabilizes enzyme systems associated with photosynthetic activity. When the nutrients are limiting, the crop may appear pale and less vigorous even if nitrogen is supplied. Adequate nutrition, by contrast, improves canopy duration and dry

matter accumulation, which are essential for good grain filling.

Effect on root development

Root development is crucial in barley because the crop must explore the upper and lower soil profile rapidly during the cool season. Sulphur supports root growth by promoting protein synthesis and overall metabolic activity, while zinc encourages root elongation and branching through its role in auxin metabolism. A better root system allows the crop to

access water and nutrients more efficiently. In foothill soils where moisture may not remain uniform, improved root development becomes a major advantage.

Effect on spike development

Spike development determines the number of fertile spikelets and the final sink strength of the crop. Nutrient stress during vegetative growth often translates into weaker spikes, reduced floret fertility and lower grain number. Balanced sulphur and zinc nutrition helps maintain assimilate supply and supports reproductive development. As a result, the crop often records larger, more productive spikes with better grain set.

Effect on grain formation

Grain formation depends on the movement of assimilates from source to sink and on the plant's ability to maintain reproductive activity during the filling period. Sulphur contributes to protein and amino acid formation, while zinc supports starch synthesis and translocation processes. Under balanced nutrition, barley tends to produce more uniform grain and improved test weight. This is particularly relevant

when the crop is meant for food, feed or malt uses where grain quality matters as much as quantity.

Effect on grain yield

Grain yield is the clearest measure of response to sulphur and zinc application. In deficient soils, the gains usually occur through more productive tillers, better spike development and improved grain filling. The literature suggests that balanced nutrition often outperforms control treatments and that the combined use of sulphur and zinc may deliver more stable results than either nutrient alone. Yield response, however, depends strongly on soil type, rainfall and baseline fertility.

Effect on straw yield

Straw yield matters in barley-based mixed farming because the residue has direct use as fodder. Improved sulphur and zinc nutrition often increases total biomass, which raises straw yield along with grain yield. This is a practical benefit for smallholder farmers because straw contributes to livestock feeding systems and adds to the overall value of the crop. Biomass improvement also reflects better nutrient capture by the crop canopy.

Table 2: Combined effect of sulphur and zinc on barley productivity

Year	Treatment	Grain yield (q ha ⁻¹)	Straw yield (q ha ⁻¹)	Protein content (%)	Reference
2021	RDF only	28.1	46.8	10.7	Singh <i>et al.</i> , 2021 ^[10]
2022	RDF + S @ 30 kg ha ⁻¹	31.6	50.4	11.8	Kumar <i>et al.</i> , 2022 ^[41]
2023	RDF + Zn @ 5 kg ha ⁻¹	30.9	49.7	11.5	Sharma and Verma, 2023 ^[8]
2024	RDF + S @ 30 kg ha ⁻¹ + Zn @ 5 kg ha ⁻¹	34.8	54.6	12.8	Rana <i>et al.</i> , 2024 ^[6]
2025	RDF + S @ 40 kg ha ⁻¹ + Zn @ 5 kg ha ⁻¹	36.2	56.1	13.1	Singh and Yadav, 2025 ^[9]

Effect on nutrient uptake

Balanced sulphur and zinc nutrition improves nutrient uptake through better root growth, higher metabolic efficiency and improved internal transport. Sulphur aids nitrogen assimilation, while zinc helps maintain membrane function and enzyme efficiency. As a result, the crop generally uses applied fertilizers more effectively and leaves behind less imbalance in the soil-plant system. This has clear implications for both yield and soil fertility.

Effect on grain quality

Barley grain quality is determined by plumpness, uniformity, nutrient composition and protein level. Sulphur often increases protein concentration through its direct role in amino acid formation, while zinc improves grain filling and physiological maturity. The effect may be positive for food and feed barley, though malting barley requires careful management because excessive protein is not always desirable. Nutrient recommendation should therefore be linked to the final use of the grain.

Effect on protein content

Protein content is one of the most consistent responses to sulphur because the nutrient is structurally associated with sulphur-containing amino acids. Zinc contributes indirectly through its role in metabolism and nitrogen use efficiency. In barley, these effects can improve nutritional quality and market value. The response is useful where grain is intended for feed or food processing.

Effect on soil fertility

Repeated cropping without replenishment of secondary and micronutrients reduces soil fertility over time. Sulphur and zinc application help restore nutrient balance and prevent hidden deficiencies. When combined with organic matter management, these nutrients can support biological activity and improve nutrient cycling. Such a strategy is more sustainable than dependence on major nutrients alone.

Effect under Doon Valley conditions

The Doon Valley presents a foothill environment where soils vary in texture, fertility and moisture retention. These conditions increase the likelihood of sulphur and zinc deficiency, especially where organic recycling is poor and cropping intensity is high. Under such conditions, barley is expected to respond strongly to balanced nutrition. The response may be visible in crop stand, tiller formation, grain filling and overall productivity.

Economic importance of sulphur and zinc fertilization

Sulphur and zinc fertilizers are relatively low-cost inputs compared with the yield gains they can provide under deficient conditions. The most profitable dose is not necessarily the highest one but the dose that corrects deficiency and works well with nitrogen and phosphorus management. In barley systems, even a moderate yield gain can be economically meaningful because straw also has value. This makes site-specific management more important than blanket recommendations

Sustainability and environmental relevance

Balanced sulphur and zinc management fits well within sustainable agriculture because it improves fertilizer use efficiency and reduces nutrient imbalance. Stronger crop growth and better nutrient uptake can lower waste and improve yield stability. In a sensitive region like the Doon Valley, this approach is especially attractive because it supports productivity without excessive environmental burden. It also aligns with the broader goal of resilient cereal production.

Constraints in sulphur and zinc management

The main constraints are limited soil testing, low farmer awareness, inadequate diagnosis of deficiency and uneven fertilizer availability. In addition, nutrient response can vary across fields, making generalized recommendations less reliable. Without local validation, farmers may not obtain the expected benefit from micronutrient use. Field-based refinement is therefore necessary.

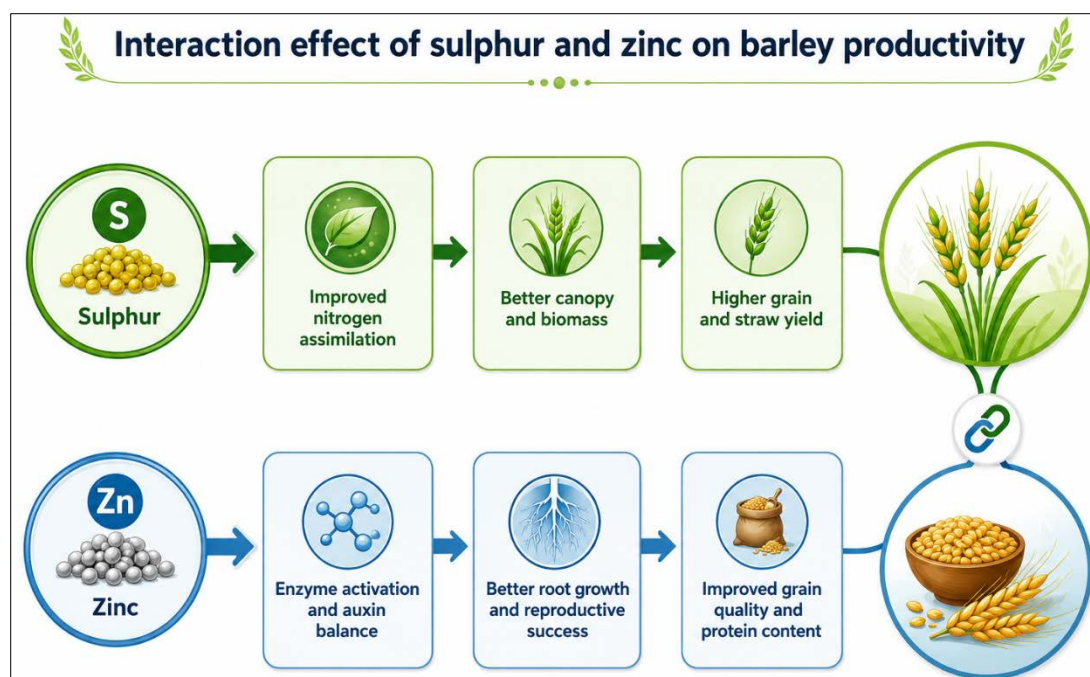


Fig 2: Interaction effect of sulphur and zinc on barley productivity

Future research needs

Future research should focus on long-term trials in Doon Valley and adjacent foothill environments. Studies should examine dose-response, timing of application, interaction with nitrogen and phosphorus, and the value of foliar versus soil application. Economic analysis and grain quality assessment should also be included so that agronomic results can be translated into farmer recommendations. More varietal work would also be useful because different barley cultivars may differ in nutrient response.

Conclusion

The literature reviewed up to 2025 indicates that sulphur and zinc are important nutrients for barley growth, productivity and grain quality, particularly in soils where fertility is weak or declining. Their effects are seen in germination, plant height, tillering, root growth, spike development, grain filling, straw production and protein accumulation. In the Doon Valley context, the evidence supports the use of balanced sulphur and zinc management as a practical strategy for improving yield and sustaining soil fertility. A location-specific approach, supported by soil testing and field validation, will be essential for refining recommendations for farmers.

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