Full Length Research Article

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Research Journal of Agricultural Sciences
Volume 17; Issue 04 (July–Aug 2026); pp 441–449

ISSN: 0976-1675 (P)
ISSN: 2249-4538 (E)

Influence of Integrated Micronutrient Nutrition through Soil Application on Fruiting Dynamics of Mango (*Mangifera indica* L.) cv. Langra

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Received: 27 May 2026; Revised accepted: 05 July 2026

Abstract

A field experiment was conducted during 2022-23 and 2023-24 to evaluate the influence of integrated micronutrient nutrition through soil application on fruiting dynamics of mango (*Mangifera indica* L.) cv. Langra at Matawala Bagh, School of Agricultural Sciences, Shri Guru Ram Rai University, Dehradun, Uttarakhand, India. The experiment was laid out in a Randomized Block Design with three replications comprising fifteen treatments. The treatment combinations included M_1: Control (RDF only); M_2: RDF + Boric acid @ 250 g tree^{-1}; M_3: RDF + Zinc sulphate @ 250 g tree^{-1}; M_4: RDF + Copper sulphate @ 250 g tree^{-1}; M_5: RDF + Ferrous sulphate @ 250 g tree^{-1}; M_6: RDF + Boric acid @ 250 g tree^{-1} + Zinc sulphate @ 250 g tree^{-1}; M_7: RDF + Boric acid @ 250 g tree^{-1} + Copper sulphate @ 250 g tree^{-1}; M_8: RDF + Boric acid @ 250 g tree^{-1} + Ferrous sulphate @ 250 g tree^{-1}; M_9: RDF + Zinc sulphate @ 250 g tree^{-1} + Copper sulphate @ 250 g tree^{-1}; M_{10}: RDF + Zinc sulphate @ 250 g tree^{-1} + Ferrous sulphate @ 250 g tree^{-1}; M_{11}: RDF + Copper sulphate @ 250 g tree^{-1} + Ferrous sulphate @ 250 g tree^{-1}; M_{12}: RDF + Boric acid @ 250 g tree^{-1} + Zinc sulphate @ 250 g tree^{-1} + Copper sulphate @ 250 g tree^{-1}; M_{13}: RDF + Boric acid @ 250 g tree^{-1} + Zinc sulphate @ 250 g tree^{-1} + Ferrous sulphate @ 250 g tree^{-1}; M_{14}: RDF + Boric acid @ 150 g tree^{-1} + Zinc sulphate @ 150 g tree^{-1} + Copper sulphate @ 150 g tree^{-1} + Ferrous sulphate @ 150 g tree^{-1}; and M_{15}: RDF + Boric acid @ 250 g tree^{-1} + Zinc sulphate @ 250 g tree^{-1} + Copper sulphate @ 250 g tree^{-1} + Ferrous sulphate @ 250 g tree^{-1}. The results revealed that soil application of micronutrients significantly influenced fruiting dynamics of mango cv. Langra. Among all the treatments, M_{15} consistently performed best and recorded the highest number of fruits per panicle (10.34), fruit set per panicle (18.20%), number of fruits at the initial stage (16.00), number of fruits at the marble stage (5.34) and number of fruits at the pre-harvest stage (2.33). The treatment also recorded the lowest fruit drop per panicle (75.90%) indicating superior fruit retention and reduced fruit abscission.

Key words: Mango, Langra, Micronutrients, Boric acid, Zinc sulphate, Copper sulphate, Ferrous sulphate, Fruit set, Fruit retention, Fruit drop, Fruiting dynamics

Mango (*Mangifera indica* L.), belonging to the family Anacardiaceae, is one of the most economically important fruit crops cultivated in tropical and subtropical regions throughout the world. Owing to its excellent flavour, attractive aroma, rich nutritional composition and high consumer preference, mango is popularly known as the "King of Fruits." The crop has been cultivated in the Indian subcontinent for more than 4,000 years and occupies a significant place in the horticultural economy of many countries. Mango fruits are consumed in fresh as well as processed forms and constitute an important source of carbohydrates, vitamins A and C, minerals, dietary fiber, phenolic compounds and antioxidants that contribute to human nutrition and health [1]. Globally, mango is cultivated in more than 100 countries across Asia, Africa, Latin America and Oceania. According to recent estimates, the global production of mangoes exceeded 62 million tonnes in 2024, indicating the increasing economic and nutritional importance of this fruit crop worldwide [2]. India is the leading producer of mango and contributes approximately 42-45 per cent of the total global production. During 2024-25, mango production in India was estimated at about 22.84 million tonnes from an area exceeding 2.3 million hectares, reflecting its dominant position in the horticultural sector [3-4]. Major mango-producing states include Uttar Pradesh, Andhra Pradesh, Karnataka, Telangana, Bihar, Gujarat, Maharashtra, West Bengal and Tamil Nadu. Uttar Pradesh ranks first in production, while Andhra Pradesh occupies the largest area under mango cultivation. Among the numerous commercial cultivars grown in India, 'Langra' is one of the most popular and economically important cultivars cultivated predominantly in Uttar Pradesh, Bihar, Uttarakhand and adjoining northern states. The cultivar is highly appreciated for its characteristic flavour, pleasant aroma, fibreless pulp,

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Citation: Tiwari M, Singh S. 2026. Influence of integrated micronutrient nutrition through soil application on fruiting dynamics of mango (*Mangifera indica* L.) cv. Langra. *Res. Jr. Agril. Sci.* 17(4): 441-449.

attractive fruit quality and superior processing attributes. Despite its commercial significance and consumer preference, the productivity of mango cv. Langra often remains below its genetic potential due to several physiological, environmental and nutritional constraints. Excessive fruit drop, poor fruit retention, low fruit set, nutrient deficiencies and imbalanced orchard nutrition are among the major factors responsible for reduced productivity in many mango-growing regions [5]. Fruiting dynamics constitute one of the most critical determinants of mango productivity and encompass a sequence of reproductive events including flowering, fruit set, fruit retention, fruit growth, fruit drop and final fruit yield. Successful fruit production depends on the coordinated functioning of these processes. However, mango is characterized by a high degree of fruit abscission, with only a small proportion of initially formed fruits reaching maturity. In many commercial orchards, fruit drop may exceed 90-95 per cent of the initial fruit set, resulting in substantial yield losses [6]. Fruiting behaviour is influenced by a complex interaction of genetic factors, climatic conditions, hormonal regulation and nutritional status of the tree. Therefore, optimization of nutrient management practices has emerged as an important strategy for improving fruit set, fruit retention and overall productivity in mango orchards. Plant nutrition plays a pivotal role in regulating vegetative growth, reproductive development and fruit production. While macronutrients are required in relatively large quantities, micronutrients are equally indispensable because of their involvement in numerous physiological and biochemical processes. Micronutrients function as activators and constituents of enzymes, participate in photosynthesis and respiration, regulate hormone biosynthesis, facilitate carbohydrate metabolism and contribute to reproductive development [7]. Deficiencies of micronutrients adversely affect flowering, fruit set, fruit retention, nutrient translocation and fruit quality, ultimately leading to reduced yield and profitability. Among the essential micronutrients, zinc, boron, iron and copper are particularly important for reproductive growth and fruiting in mango. Zinc is involved in auxin biosynthesis, enzyme activation, chlorophyll formation and carbohydrate metabolism. Adequate zinc nutrition promotes flower bud differentiation, pollen viability, fruit set and fruit development, whereas zinc deficiency results in poor flowering, reduced fruit retention and lower yields [5], [8]. Boron plays a critical role in cell division, cell wall formation, sugar transport, pollen germination and pollen tube elongation. Its deficiency impairs fertilization processes, resulting in poor fruit set and increased fruit drop [9-10]. Several studies have demonstrated that boron application significantly improves fruit retention, fruit size and overall yield in mango and other fruit crops [7], [11]. Iron is an essential component of various enzyme systems and is involved in chlorophyll synthesis, photosynthetic electron transport and respiratory metabolism. Iron deficiency reduces photosynthetic efficiency, restricts carbohydrate production and adversely affects fruit development [12]. Copper plays an important role in oxidation-reduction reactions, lignin synthesis, reproductive growth and enzyme activity. Adequate copper nutrition enhances plant vigour, reproductive efficiency and fruit development [6]. Collectively, these micronutrients contribute to improved physiological functioning and reproductive success in mango orchards. Micronutrient deficiencies have become increasingly widespread in mango growing soils due to intensive cultivation, continuous nutrient removal, low organic matter content, soil alkalinity and imbalanced fertilizer use. In many subtropical regions of India, deficiencies of zinc, boron and iron have emerged as major nutritional constraints limiting mango productivity [13]. Such deficiencies negatively influence fruiting dynamics by reducing flower quality, fruit set, fruit retention and fruit growth. Consequently, correction of micronutrient deficiencies has become an essential component of sustainable orchard management. Integrated application of micronutrients often produces superior results compared to individual nutrient application due to synergistic effects on nutrient utilization efficiency and plant metabolism [11]. Nevertheless, information regarding the specific influence of soil applied micronutrients on fruiting dynamics of mango cv. Langra under the subtropical conditions of Uttarakhand remains limited. Therefore, the present investigation entitled "Influence of integrated micronutrient nutrition through soil application on fruiting dynamics of mango (*Mangifera indica* L.) cv. Langra" was undertaken to evaluate the effect of soil-applied micronutrients on fruiting behaviour and to identify suitable micronutrient combinations for improving fruit set and fruit of mango under the subtropical conditions of Uttarakhand.

MATERIALS AND METHODS

The present investigation was carried out during 2022-23 and 2023-24 at the mango orchard of Matawala Bagh, School of Agricultural Sciences, Shri Guru Ram Rai University, Dehradun, Uttarakhand, India. Geographically, Dehradun is situated at 30.3165° N latitude and 78.0322° E longitude with an altitude of approximately 640 m above mean sea level. The region experiences a humid subtropical climate characterized by hot summers, a distinct monsoon season and cool winters. The maximum temperature during summer varies from 35°C to 38°C, whereas the minimum temperature during winter may fall to about 3°C. The area receives an average annual rainfall of nearly 2073 mm, most of which is concentrated during the southwest monsoon period. Such climatic conditions are considered highly suitable for mango cultivation and fruit production. The experiment was conducted on healthy, vigorous and uniformly maintained 35 year old mango trees of cv. Langra planted at a spacing of 10 m × 10 m. The soil of the experimental orchard was alluvial in origin, sandy loam in texture, well-drained and moderately fertile with a pH ranging from 6.35 to 6.42. Prior to commencement of the experiment, representative soil samples were collected from the active root zone of the experimental trees and analyzed for various physico-chemical properties using standard laboratory procedures. The experiment was laid out in a Randomized Block Design comprising fifteen treatments with three replications. The treatments consisted of different combinations of soil-applied micronutrients along with the recommended dose of fertilizers (RDF). The treatment details were: M_1: Control (RDF only); M_2: RDF + Boric acid @ 250 g tree^{-1}; M_3: RDF + Zinc sulphate @ 250 g tree^{-1}; M_4: RDF + Copper sulphate @ 250 g tree^{-1}; M_5: RDF + Ferrous sulphate @ 250 g tree^{-1}; M_6: RDF + Boric acid @ 250 g tree^{-1} + Zinc sulphate @ 250 g tree^{-1}; M_7: RDF + Boric acid @ 250 g tree^{-1} + Copper sulphate @ 250 g tree^{-1}; M_8: RDF + Boric acid @ 250 g tree^{-1} + Ferrous sulphate @ 250 g tree^{-1}; M_9: RDF + Zinc sulphate @ 250 g tree^{-1} + Copper sulphate @ 250 g tree^{-1}; M_{10}: RDF + Zinc sulphate @ 250 g tree^{-1} + Ferrous sulphate @ 250 g tree^{-1}; M_{11}: RDF + Copper sulphate @ 250 g tree^{-1} + Ferrous sulphate @ 250 g tree^{-1}; M_{12}: RDF + Boric acid @ 250 g tree^{-1} + Zinc sulphate @ 250 g tree^{-1} + Copper sulphate @ 250 g tree^{-1}; M_{13}: RDF + Boric acid @ 250 g tree^{-1} + Zinc sulphate @ 250 g tree^{-1} + Ferrous sulphate @ 250 g tree^{-1}; M_{14}: RDF + Boric acid @ 150 g tree^{-1} + Zinc sulphate @ 150 g tree^{-1} + Copper sulphate @ 150 g tree^{-1} + Ferrous sulphate @ 150 g tree^{-1}; and M_{15}: RDF + Boric acid @ 250 g tree^{-1} + Zinc sulphate @ 250 g tree^{-1} +

Copper sulphate @ 250 g tree^{-1} + Ferrous sulphate @ 250 g tree^{-1}. The required quantities of micronutrients were applied to the soil during the second fortnight of September in both years of experimentation. Circular trenches measuring approximately 20-25 cm in depth and 25-30 cm in width were prepared around the drip line of each experimental tree. The calculated quantity of each micronutrient according to treatment specifications was accurately weighed and uniformly applied in the trenches. In combined treatments, the respective micronutrients were thoroughly mixed before application to ensure uniform distribution within the root zone. After application, the micronutrients were incorporated into the soil and the trenches were refilled with excavated soil. Light irrigation was provided immediately after application to facilitate nutrient dissolution and movement within the active root zone. All experimental trees received a common recommended dose of 100 kg farmyard manure along with 750 g nitrogen, 160 g phosphorus and 750 g potassium per tree. Farmyard manure and fertilizers were applied through the band placement method following standard orchard management practices. Observations pertaining to fruiting dynamics were recorded at different stages of fruit development. Five representative panicles were randomly selected and tagged on each experimental tree for recording observations. The number of fruits per panicle was determined by counting all fruits retained on the tagged panicles after fruit set and calculating the average value. Fruit set percentage was computed by relating the number of fruits set to the total number of hermaphrodite flowers present on the selected panicles and expressing the value as percentage. Fruit drop percentage was determined by recording the number of fruits shed during the fruit development period and expressing it as a percentage of the initial fruit set. The number of fruits retained at the initial stage, marble stage and pre-harvest stage were counted manually on tagged panicles and the average values were calculated. These observations were used to assess the influence of different micronutrient treatments on fruit retention, fruit development and overall fruiting behaviour of mango cv. Langra. The data generated from various fruiting parameters were statistically analyzed according to the procedure described by Panse and Sukhatme [14] for randomized block design. Analysis of variance was performed to determine the significance of treatment effects, and the significance of differences among treatment means was tested at the 5 per cent level of probability. Critical difference values were calculated wherever treatment effects were found significant.

Table 1 Treatment details with their concentrations

Treatment	Treatment doses
M_1	Control (as RDF)
M_2	RDF + Boric acid @ 250 g per tree
M_3	RDF + Zinc sulphate @ 250 g per tree
M_4	RDF + Copper sulphate @ 250 g per tree
M_5	RDF + Ferrous sulphate @ 250 g per tree
M_6	RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree
M_7	RDF + Boric acid @ 250 g per tree + Copper sulphate @ 250 g per tree
M_8	RDF + Boric acid @ 250 g per tree + Ferrous sulphate @ 250 g per tree
M_9	RDF + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree
M_{10}	RDF + Zinc sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree
M_{11}	RDF + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree
M_{12}	RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree
M_{13}	RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree
M_{14}	RDF + Boric acid @ 150 g per tree + Zinc sulphate @ 150 g per tree + Copper sulphate @ 150 g per tree + Ferrous sulphate @ 150 g per tree
M_{15}	RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree

RESULTS AND DISCUSSION

Number of fruits per panicle

The data pertaining to the number of fruits per panicle as influenced by different soil-applied micronutrient treatments have been presented in (Table 2) and graphically illustrated in (Fig 1). The data revealed that the application of different micronutrients significantly influenced the number of fruits per panicle during both years of investigation (2022-23 and 2023-24). During the year 2022-23, the maximum number of fruits per panicle (11.00) was recorded under treatment M_{15} (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), which was statistically at par with treatment M_{14} (10.33). These treatments were found significantly superior to all other treatments. The next best treatment was M_{13} (8.67), followed by M_{12} (7.67), M_{11} (7.33), M_{10} (6.67), M_8 (6.33) and M_9 (6.33). The treatments M_6 and M_7 each recorded 5.67 fruits per panicle, while M_4 produced 5.00 fruits per panicle. The minimum number of fruits per panicle (4.00) was observed under treatment M_1 (control). During the second year (2023-24), a similar trend was observed with significant differences among the treatments. Treatment M_{14} recorded the highest number of fruits per panicle (10.33), which remained statistically at par with treatment M_{15} (9.67). These treatments were significantly superior to the remaining treatments. Treatment M_{13} produced 8.67 fruits per panicle, followed by M_{12} (8.33), M_{11} (7.67), M_9 (6.67), M_{10} (6.33) and M_8 (6.00). Treatments M_4, M_6 and M_7 recorded 5.33 fruits per panicle, whereas M_3 recorded 4.67 fruits per panicle. The lowest number of fruits per panicle (4.33) was observed under treatments M_2 and M_5, while the control treatment M_1 recorded only 5.00 fruits per panicle. On the basis of pooled performance over both years, treatment M_{14} recorded the highest mean number of fruits per panicle (10.33), followed by M_{15} (10.34), M_{13} (8.67) and M_{12} (8.00). The treatments M_{11} (7.50), M_9 (6.50), M_{10} (6.50) and M_8 (6.17) also exhibited comparatively higher fruit retention per panicle. The minimum pooled number of fruits per panicle (4.50) was recorded under treatment M_1 (control). The results of the present investigation are in close agreement with those reported by Dutta [15], who observed that foliar application of boron significantly improved panicle growth, fruit retention and fruit development in mango cv. Himsagar. Similar findings were reported by Bhowmick *et al*. [16], who observed that combined application of zinc and boron significantly increased fruit retention, number of fruits per panicle and fruit yield in mango cv. Amrapali. Yadav *et al*. [17], also reported that integrated nutrient management involving micronutrients significantly improved flowering, fruit set, fruit retention and yield of mango under high-density planting. Likewise, Ahmad *et al*. [9] reported that combined soil and foliar application of zinc and boron enhanced fruit set, fruit retention, fruit yield and fruit quality by improving reproductive efficiency and nutrient utilization in mango. Similar observations were also reported by Shukla *et al*. [18], who demonstrated that adequate boron nutrition significantly enhanced fruit yield, nutrient uptake and biochemical constituents of mango by improving reproductive processes and assimilate translocation. Earlier, Singh and Dhillon [19] also reported that boron application significantly improved panicle development, fruit retention and yield in mango cv. Dusehri. Furthermore, Kumar *et al*. [20] observed that integrated application of micronutrients, particularly zinc, boron and copper, significantly enhanced flowering intensity, fruit number and yield of mango cv. Dashehari owing to improved physiological efficiency and nutrient availability.

Table 2 Effect of soil application of micronutrients on number of fruits per panicle, fruit set per panicle (%) and fruit drop per panicle (%) of mango

Treatment symbol	Number of fruits per panicle		Fruit set per panicle (%)		Fruit drop per panicle (%)	
	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
M_1	4.00	5.00	12.97	13.33	99.05	99.04
M_2	4.33	4.33	16.56	16.43	84.88	84.60
M_3	4.67	4.67	16.87	16.76	84.93	84.73
M_4	5.00	5.33	16.69	16.77	82.70	83.94
M_5	4.67	4.33	16.90	16.87	82.93	82.57
M_6	5.67	5.33	17.14	17.11	83.40	81.53
M_7	5.67	5.33	17.24	17.17	82.70	82.23
M_8	6.33	6.00	17.15	17.23	80.73	80.97
M_9	6.33	6.67	17.34	17.28	81.63	82.10
M_{10}	6.67	6.33	17.46	17.37	79.33	81.70
M_{11}	7.33	7.67	17.47	17.43	80.30	80.87
M_{12}	7.67	8.33	17.62	17.30	78.80	76.13
M_{13}	8.67	8.67	17.88	18.52	76.30	76.15
M_{14}	10.33	10.33	17.73	17.93	77.06	76.43
M_{15}	11.00	9.67	18.07	18.33	75.07	76.72
$C.D._{(p=0.05)}$	1.42	1.23	0.36	0.56	1.83	2.14
S.Em. ±	0.49	0.42	0.12	0.19	0.63	0.73

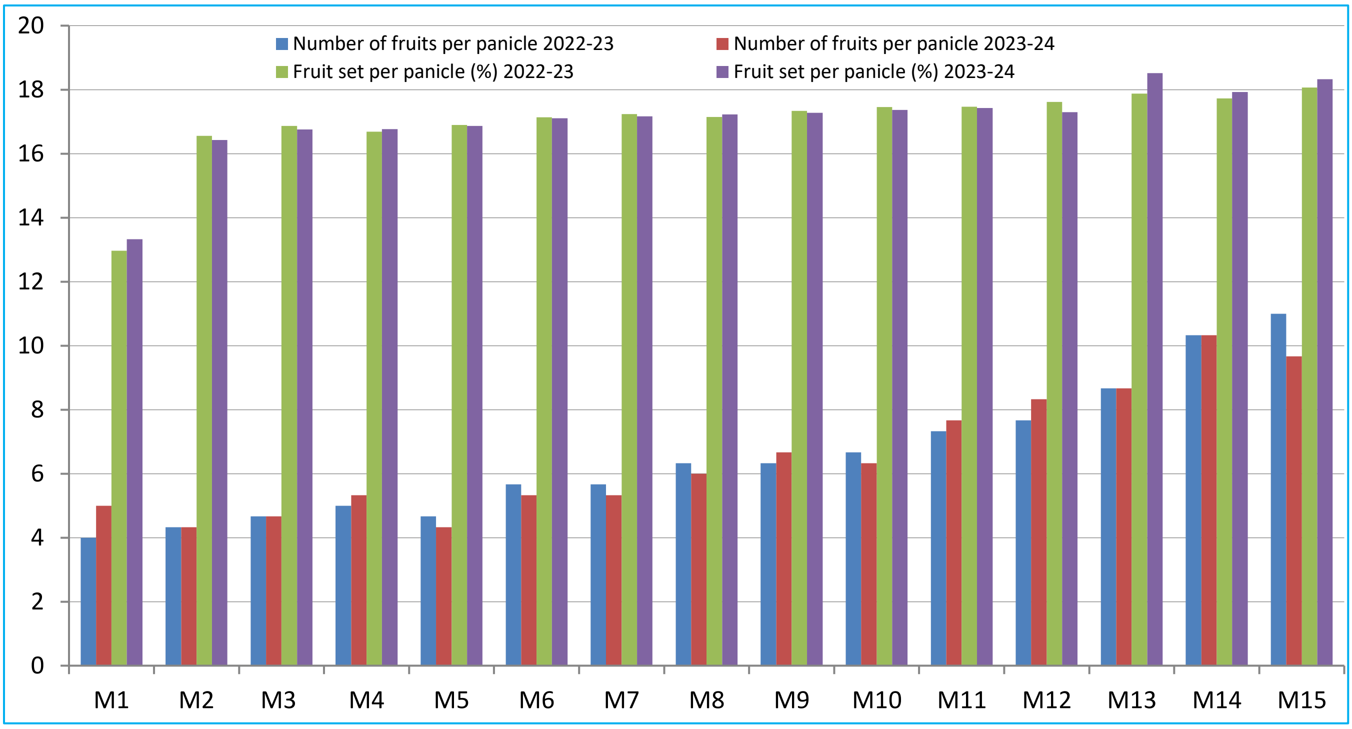

Fig 1 Impact of soil application of micronutrients on number of fruits per panicle and fruit set per panicle (%) of mango

Fruit set per panicle (%)

The data related to fruit set per panicle (%) as influenced by different soil-applied micronutrient treatments have been presented in (Table 2) and graphically illustrated in (Fig 1). The data revealed that the application of micronutrients significantly influenced fruit set per panicle during both the years of investigation (2022-23 and 2023-24). During the year 2022-23, the maximum fruit set per panicle (18.07%) was recorded under treatment M_{15} (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree

+ Ferrous sulphate @ 250 g per tree), which was statistically at par with treatment M_{13} (17.88%) and M_{14} (17.73%). These treatments were found significantly superior to all other treatments. The next best treatment was M_{12} (17.62%), followed by M_{11} (17.47%), M_{10} (17.46%), M_9 (17.34%), M_7 (17.24%), M_8 (17.15%) and M_6 (17.14%). Among the individual micronutrient treatments, M_5 (16.90%) recorded higher fruit set than M_3 (16.87%), M_4 (16.69%) and M_2 (16.56%). The minimum fruit set per panicle (12.97%) was observed under treatment M_1 (control). During the second year (2023-24), a similar trend was observed. Treatment M_{13} recorded the highest fruit set per panicle (18.52%), which was statistically at par with treatment M_{15} (18.33%) and M_{14} (17.93%). These treatments remained significantly superior over the remaining treatments. Treatment M_{11} recorded 17.43% fruit set per panicle, followed by M_{10} (17.37%), M_{12} (17.30%), M_9 (17.28%), M_8 (17.23%), M_7 (17.17%) and M_6 (17.11%). Among the individual micronutrient applications, M_5 recorded 16.87% fruit set, followed by M_4 (16.77%), M_3 (16.76%) and M_2 (16.43%). The lowest fruit set per panicle (13.33%) was recorded under treatment M_1 (control). On the basis of pooled performance over both years, treatment M_{13} recorded the highest mean fruit set per panicle (18.20%), followed closely by M_{15} (18.20%) and M_{14} (17.83%). These were followed by M_{12} (17.46%), M_{11} (17.45%), M_{10} (17.42%) and M_9 (17.31%). The lowest pooled fruit set per panicle (13.15%) was observed under treatment M_1 (control). The findings of the present investigation are in close conformity with those reported by Dutta [15] who observed that foliar application of boron significantly improved panicle development, fruit set and fruit retention in mango cv. Himsagar. Similar results were reported by Bhowmick *et al*. [16], who observed that combined application of boron and zinc significantly increased fruit set, fruit retention and fruit yield in mango cv. Amrapali. Ahmad *et al*. [9] also reported that combined soil and foliar application of zinc and boron markedly enhanced fruit set, fruit retention, yield and fruit quality by improving reproductive efficiency, nutrient uptake and physiological activity in mango. Earlier, Singh and Dhillon [19] demonstrated that boron application significantly improved flowering, sex expression, fruit set and fruit retention in mango cv. Dusehri. Likewise, Shukla *et al*. [18] reported that adequate boron nutrition enhanced fruit yield and reproductive performance through improved nutrient uptake and translocation in mango. Similar observations were also recorded by Kumar [20], who found that integrated micronutrient application involving zinc, boron and copper significantly improved flowering behaviour, fruit set and yield of mango cv. Dashehari. These findings are further supported by Brdar-Jokanović [10], who reviewed the physiological role of boron in reproductive development and concluded that adequate boron nutrition is essential for pollen viability, fertilization and successful fruit set in horticultural crops.

Fruit drop per panicle (%)

The data pertaining to fruit drop per panicle (%) as influenced by different soil-applied micronutrient treatments have been presented in (Table 2) and graphically illustrated in (Fig 2). The data reported that the application of micronutrients significantly influenced fruit drop per panicle during both years of investigation (2022-23 and 2023-24). During the year 2022-23, the minimum fruit drop per panicle (75.07%) was recorded under treatment M_{15} (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), which was statistically at par with treatment M_{13} (76.30%) and M_{14} (77.06%). These treatments proved significantly superior to all other treatments in reducing fruit drop. The next best treatment was M_{12} (78.80%), followed by M_{10} (79.33%), M_{11} (80.30%), M_8 (80.73%), M_9 (81.63%), M_4 (82.70%), M_7 (82.70%) and M_5 (82.93%). Treatments M_6, M_2 and M_3 recorded fruit drop values of 83.40%, 84.88% and 84.93%, respectively. The maximum fruit drop per panicle (99.05%) was observed under treatment M_1 (control). During the second year (2023-24), a similar trend was observed among the treatments. The minimum fruit drop per panicle (76.13%) was recorded under treatment M_{12} (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree), which was statistically at par with M_{13} (76.15%), M14 (76.43%) and M_{15} (76.72%). These treatments were significantly superior to the remaining treatments. Treatment M_8 recorded 80.97% fruit drop, followed by M_{11} (80.87%), M_6 (81.53%), M_{10} (81.70%), M_9 (82.10%) and M_7 (82.23%). Among the individual micronutrient treatments, M_5 recorded 82.57% fruit drop, followed by M_4 (83.94%), M_2 (84.60%) and M_3 (84.73%). The highest fruit drop per panicle (99.04%) was again recorded under treatment M_1 (control). On the basis of pooled performance over both years, treatment M_{15} recorded the lowest mean fruit drop per panicle (75.90%), closely followed by M_{13} (76.23%), M_{14} (76.75%) and M_{12} (77.47%). The highest pooled fruit drop per panicle (99.05%) was observed under M_1 (control). The present findings are in close agreement with those of Singh and Dhillon [19], who reported that foliar application of boron significantly reduced fruit drop and enhanced fruit retention in mango cv. Dashehari by improving reproductive development and fruit retention. Dutta [15] also observed that boron application significantly reduced premature fruit drop and improved fruit retention in mango cv. Himsagar through enhanced panicle development and better fertilization. Similar findings were reported by Bhowmick *et al*. [16], who demonstrated that combined application of zinc and boron significantly reduced fruit drop while improving fruit retention and yield in mango cv. Amrapali. Likewise, Ahmad *et al*. [9] reported that combined soil and foliar application of zinc and boron enhanced nutrient uptake, reproductive efficiency, fruit retention and yield while reducing fruit abscission in mango. Shukla *et al*. [18] further demonstrated that maintaining adequate boron nutrition improved reproductive performance, nutrient translocation and fruit yield by reducing physiological disorders associated with boron deficiency. Similar observations were also reported by Kumar [20], who found that integrated application of zinc, boron and copper significantly minimized fruit drop and increased fruit retention and yield in mango cv. Dashehari through improved photosynthetic efficiency, nutrient mobility and overall physiological activity of the trees.

Number of fruits at initial stage

The data pertaining to the number of fruits at initial stage as influenced by different soil-applied micronutrient treatments have been presented in (Table 3) and graphically illustrated in (Fig 2). The data indicated that the application of micronutrients significantly influenced the number of fruits at the initial stage during both years of investigation (2022-23 and 2023-24). During the year 2022-23, the maximum number of fruits at the initial stage (16.33) was recorded under treatment M_{15}, which was statistically at par with treatment M_{14} (14.00). These treatments were significantly superior to all other treatments. The next best treatment was M_{13} (12.67), followed by M_{12} (12.33), M_{11} (12.00), M_{10} (10.67), M_8 (10.33) and M_9 (10.33). Treatments M_6 and M_7 each recorded 9.00 fruits at the initial stage, whereas M_5 recorded 8.67 fruits. The minimum number of fruits at the initial stage (7.33) was observed under treatment M_2, while the control treatment M_1 recorded 7.67 fruits. During the second year (2023-24), a similar trend was observed. Treatment M_{15} recorded the highest number of fruits at the initial stage (15.67), which was statistically at par with treatment M_{14} (13.67) and M_{13} (13.33). These treatments remained significantly superior over the remaining treatments. However, treatments M_{11} and M_{12} each recorded 12.33 fruits, followed by M_{10} (11.00), M_9 (10.00), M_8 (9.67), M_6 (9.33) and M_7 (9.00). Among the individual micronutrient treatments, M_5 recorded 8.67 fruits, followed by M_4 (8.00), M_3 (7.67), M_2 (7.33) and M_1 (7.00). Whereas, the lowest number of fruits at the initial stage was recorded under treatment M_1 (control). On the basis of pooled performance over both years, treatment M_{15} recorded the highest mean number of fruits at the initial stage (16.00), followed by M_{14} (13.84), M_{13} (13.00), M_{12} (12.33) and M_{11} (12.17). The treatments M_{10} (10.84), M_9 (10.17) and M_8 (10.00) also exhibited comparatively higher fruit retention at the initial stage. The lowest pooled value (7.34) was recorded under treatment M_1 (control). The findings of the present investigation are in close agreement with those reported by Bhowmick *et al*. [16], who observed that combined application of zinc and boron significantly improved fruit set, fruit retention and yield in mango cv. Amrapali through enhanced reproductive efficiency and improved nutrient utilization. Ahmad *et al*. [9] also reported that combined soil and foliar application of zinc and boron markedly increased fruit retention, fruit yield and fruit quality by improving nutrient uptake, reproductive performance and assimilate partitioning in mango. Similar findings were reported by Kumar *et al*. [20], who demonstrated that integrated application of zinc, copper and boron significantly enhanced flowering intensity, fruit number, fruit retention and yield of mango cv. Dashehari through improved physiological efficiency and nutrient availability. Earlier, Bains *et al*. [21] observed that adequate micronutrient nutrition, particularly boron and zinc, played an important role in improving fruit retention by regulating carbohydrate translocation and reducing premature fruit drop in mango. Further support is provided by Shukla *et al*. [18], who demonstrated that adequate boron nutrition significantly improved fruit yield and nutrient status by enhancing reproductive development and nutrient translocation in mango cv. Mallika. Singh and Dhillon [19] also found that foliar application of boron significantly increased fruit retention and reduced fruit abscission in mango cv. Dashehari by improving pollen viability, fertilization and early fruit development.

Table 3 Effect of soil application of micronutrients on number of fruits at initial stage**,** number of fruits at marble stage and number of fruits at pre-harvest stage of mango

Treatment symbol	Number of fruits at initial stage		Number of fruits at marble stage		Number of fruits at pre-harvest stage	
	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
M_1	7.67	7.00	2.67	2.67	0.33	0.33
M_2	7.33	7.33	2.67	2.00	1.00	0.67
M_3	7.67	7.67	3.33	2.33	1.33	1.33
M_4	7.67	8.00	3.00	3.00	0.67	1.00
M_5	8.67	8.67	3.33	3.67	1.00	1.33
M_6	9.00	9.33	3.67	2.67	1.33	1.33
M_7	9.00	9.00	2.33	2.67	1.00	2.00
M_8	10.33	9.67	2.67	2.67	1.67	2.00
M_9	10.33	10.00	3.33	3.33	2.00	2.00
M_{10}	10.67	11.00	3.00	3.667	2.33	1.67
M_{11}	12.00	12.33	3.00	3.33	2.00	2.67
M_{12}	12.33	12.33	3.00	3.00	2.00	2.33
M_{13}	12.67	13.33	3.00	2.67	2.00	1.67
M_{14}	14.00	13.67	3.00	3.00	2.33	2.00
M_{15}	16.33	15.67	5.67	5.00	2.33	2.33
C.D.$_{(p=0.05)}$	1.13	1.01	1.52	1.41	1.48	1.53
S.Em. ±	0.39	0.35	0.58	0.48	0.48	0.54

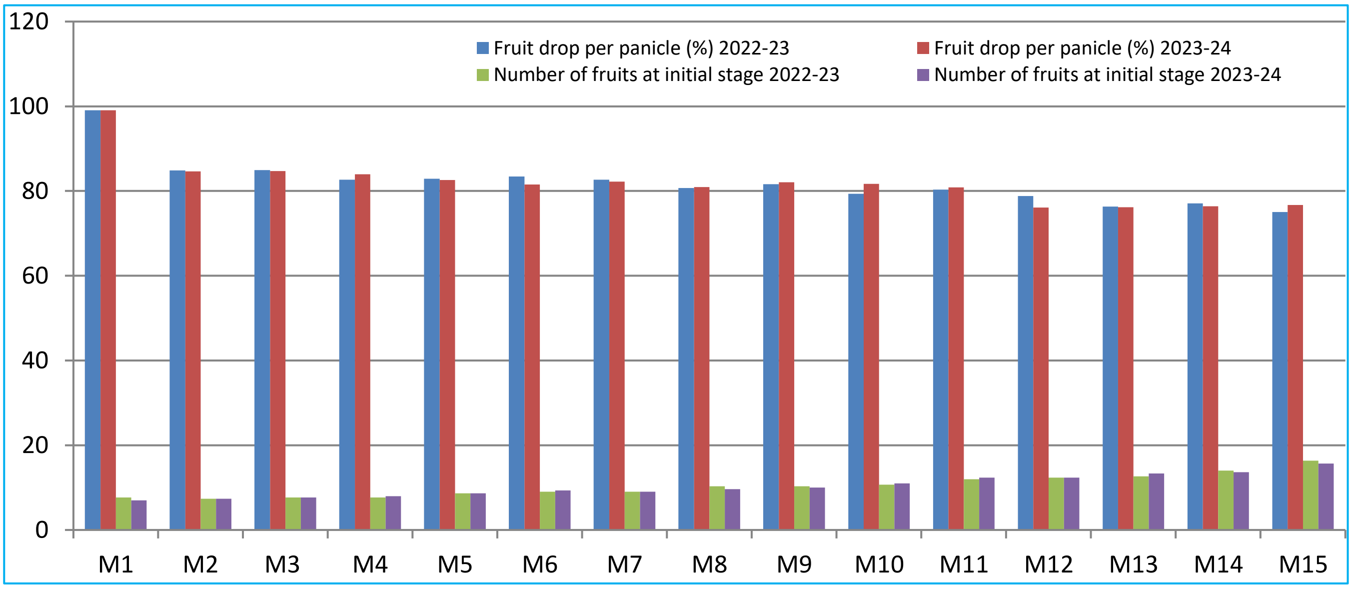

Fig 2 Impact of soil application of micronutrients on fruit drop per panicle (%) and number of fruits at initial stage in mango

Number of fruits at marble stage

The data pertaining to the number of fruits at marble stage as influenced by different soil-applied micronutrient treatments have been presented in (Table 3) and graphically illustrated in (Fig 3). The data revealed that the application of micronutrients significantly influenced the number of fruits retained at marble stage during both years of investigation (2022-23 and 2023-24). During the year 2022-23, the maximum number of fruits at marble stage (5.67) was recorded under treatment M_{15} (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), which was significantly superior to all other treatments. The next best treatment was M_6 (3.67), followed by M_3 (3.33), M_5 (3.33) and M_9 (3.33). Treatments M_4, M_{10}, M_{11}, M_{12}, M_{13} and M_{14} each recorded 3.00 fruits at marble stage. The treatments M_1, M_2 and M_8 recorded 2.67 fruits, whereas the minimum number of fruits at marble stage (2.33) was observed under treatment M_7 (RDF + Boric acid @ 250 g per tree + Copper sulphate @ 250 g per tree). During the second year (2023-24), a similar trend was observed among the treatments. Treatment M_{15} recorded the highest number of fruits at marble stage (5.00), which was significantly superior to all other treatments. The next best treatments were M_5 and M_{10}, each recording 3.67 fruits at marble stage, followed by M_9 and M_{11} with 3.33 fruits. Treatments M_4, M_{12} and M_{14} each recorded 3.00 fruits, whereas M_1, M_6, M_7, M_8 and M_{13} recorded 2.67 fruits. Treatment M_3 recorded 2.33 fruits, while the minimum number of fruits at marble stage (2.00) was observed under treatment M_2 (RDF + Boric acid @ 250 g per tree). On the basis of pooled performance over both years, treatment M_{15} recorded the highest mean number of fruits at marble stage (5.34), followed by M_{10} (3.33), M5 (3.50), M_9 (3.33) and M_{11} (3.17). Treatments M_4, M_{12} and M_{14} each maintained a pooled mean of 3.00 fruits at marble stage. The lowest pooled value (2.34) was observed under treatment M_2, followed by M_7 (2.50). The control treatment M_1 recorded a pooled mean of 2.67 fruits at marble stage. The findings of the present study are in close conformity with those reported by Rajput *et al.* [22], who observed that boron application significantly enhanced flowering, fruit set and fruit retention in mango cv. Langra by improving reproductive development and successful fertilization. Similar observations were reported by Banik *et al.* [23], who demonstrated that combined application of zinc and boron significantly increased fruit retention and fruit yield in mango through improved pollen viability and nutrient utilization. Abd-Allah [24] also reported that micronutrient application markedly improved fruit retention, fruit development and fruit quality by enhancing photosynthetic efficiency, assimilate translocation and nutrient uptake in fruit crops. Likewise, Yadav *et al.* [17] observed that integrated nutrient management involving micronutrients significantly enhanced flowering, fruit set, fruit retention and fruit yield of mango cv. Amrapali under high-density planting. Similar findings were reported by Sharma *et al.* [25], who concluded that integrated micronutrient nutrition improved reproductive development, carbohydrate metabolism and fruit retention by maintaining better physiological activity and nutrient balance in mango orchards. Further support is provided by Barman *et al.* [26], who reported that balanced micronutrient nutrition significantly enhanced flowering behaviour, reproductive efficiency and fruit retention in tropical fruit crops through improved metabolic activity and assimilate partitioning.

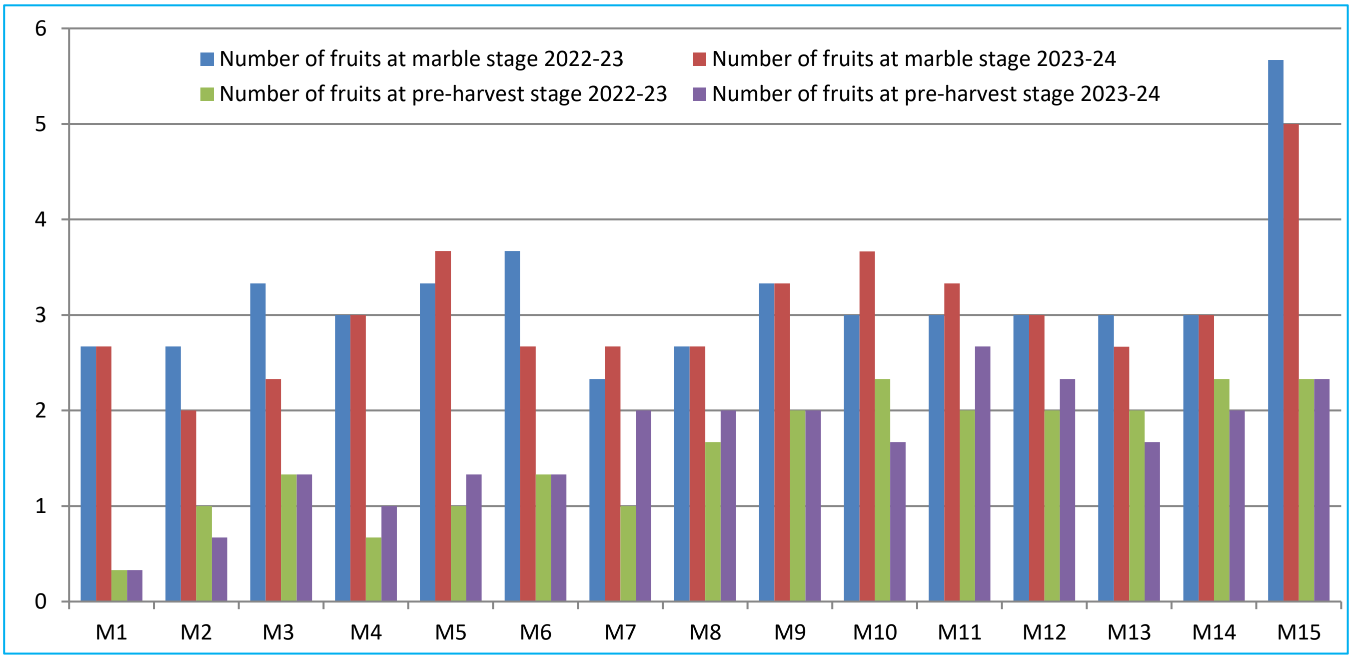

Fig 3 Impact of soil application of micronutrients on number of fruits at marble stage and number of fruits at pre-harvest stage in mango

Number of fruits at pre-harvest stage

The data pertaining to the number of fruits at pre-harvest stage as influenced by different soil-applied micronutrient treatments have been presented in (Table 3) and graphically illustrated in (Fig 3). The data revealed that the application of micronutrients significantly influenced the number of fruits retained at pre-harvest stage during both years of investigation (2022-23 and 2023-24). During the year 2022-23, the maximum number of fruits at pre-harvest stage (2.33) was recorded under treatment M_{10} (RDF + Zinc sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), M_{14} (RDF + Boric acid @ 150 g per tree + Zinc sulphate @ 150 g per tree + Copper sulphate @ 150 g per tree + Ferrous sulphate @ 150 g per tree) and M_{15} (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), which were statistically at par with each other. These treatments were significantly superior to the remaining treatments. The next best treatments were M_9, M_{11}, M_{12} and M_{13}, each recording 2.00 fruits at pre-harvest stage. Treatment M_8 recorded 1.67 fruits, while M_3 and M_6 each retained 1.33

fruits. Treatments M_2, M_5 and M_7 recorded 1.00 fruit per panicle, whereas treatment M_4 retained 0.67 fruit. The minimum number of fruits at pre-harvest stage (0.33) was observed under treatment M_1 (control). During the second year (2023-24), a somewhat similar trend was observed. Treatment M_{11} (RDF + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree) recorded the highest number of fruits at pre-harvest stage (2.67), which was statistically at par with treatment M_{12} (2.33) and M_{15} (2.33). These treatments were found significantly superior to the remaining treatments. Treatments M_7, M_8, M_9 and M_{14} each retained 2.00 fruits at pre-harvest stage, whereas M_{10} and M_{13} recorded 1.67 fruits. Treatments M_3, M_5 and M_6 each recorded 1.33 fruits, followed by M_4 with 1.00 fruit. Treatment M_2 retained only 0.67 fruit per panicle, while the minimum value (0.33) was recorded under treatment M_1 (control). On the basis of pooled performance over both years, treatment M_{15} recorded the highest mean number of fruits at pre-harvest stage (2.33), followed by M_{11} (2.34), M_{14} (2.17), M_{12} (2.17) and M_9 (2.00). Treatments M_7 and M_8 also maintained higher fruit retention with pooled means of 1.50 and 1.84 fruits, respectively. The lowest pooled value (0.33) was recorded under treatment M_1 (control). The present findings are in agreement with those reported by Bains *et al.* [21], who observed that adequate micronutrient nutrition, particularly boron and zinc, significantly improved fruit retention and reduced premature fruit drop in mango by enhancing carbohydrate translocation and reproductive efficiency. Similar findings were reported by Rajput *et al.* [22], who demonstrated that boron application increased fruit retention and improved fruit development in mango cv. Langra through enhanced fertilization and fruit growth. Yadav *et al.* [17] also reported that integrated nutrient management involving micronutrients significantly enhanced fruit retention, fruit yield and productivity of mango cv. Amrapali under high density planting by improving nutrient utilization and physiological efficiency. Likewise, Ahmad *et al.* [12] reported that combined soil and foliar application of zinc and boron significantly improved fruit retention, yield and fruit quality by increasing nutrient uptake, assimilate translocation and photosynthetic efficiency in mango. Similar observations were recorded by Shukla *et al.* [18], who demonstrated that adequate boron nutrition enhanced fruit retention and yield through improved nutrient status, carbohydrate metabolism and reproductive development in mango cv. Mallika. Furthermore, Kumar *et al.* [20] reported that integrated application of zinc, boron and copper significantly reduced fruit drop and enhanced fruit retention until harvest by improving photosynthetic activity, nutrient mobility and overall physiological performance of mango cv. Dashehari.

CONCLUSION

The present investigation clearly demonstrated that integrated soil application of micronutrients significantly influenced the fruiting dynamics of mango (*Mangifera indica* L.) cv. Langra under the subtropical conditions of Uttarakhand. Among all the treatments, the combined application of boric acid @ 250 g tree^{-1}, zinc sulphate @ 250 g tree^{-1}, copper sulphate @ 250 g tree^{-1} and ferrous sulphate @ 250 g tree^{-1} along with the recommended dose of fertilizers (M_{15}) proved to be the most effective treatment. This treatment recorded the highest number of fruits per panicle (10.34), fruit set per panicle (18.20%), number of fruits at the initial stage (16.00), number of fruits at the marble stage (5.34) and number of fruits retained at the pre-harvest stage (2.33). It also resulted in the minimum fruit drop per panicle (75.90%), indicating superior fruit retention and reduced fruit abscission throughout the fruit development period. The enhanced fruiting performance observed under this treatment may be attributed to the synergistic effects of boron, zinc, copper and iron in improving pollen viability, fertilization, assimilate translocation, hormonal balance and overall reproductive efficiency. Therefore, the integrated soil application of these micronutrients along with RDF can be recommended for improving fruit set, fruit retention and overall fruiting behaviour of mango cv. Langra under subtropical agro-climatic conditions.

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