PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp3): 18-24
https://doi.org/10.14719/pst.4852

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RESEARCH ARTICLE

Establishing optimal nutrient level of magnesium and boron in black pepper for optimization of productivity in Western Ghats of Kerala

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OPEN ACCESS

ARTICLE HISTORY
Received: 27 September 2024
Accepted: 02 November 2024
Available online
Version 1.0 : 25 December 2024

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
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Beena VI, Geetha P, Prabha Susan Philip, Sureshkumar P, Anusree T, Amrutha SA, Amrutha KK, Nihala Jabin PP, Reji AM, Sruthi K, Behera SK. Establishing optimal nutrient level of magnesium and boron in black pepper for optimization of productivity in Western Ghats of Kerala. Plant Science Today. 2024; 11(sp3): 18-24. https://doi.org/10.14719/pst.4852

Abstract

Critical nutrient level of magnesium and boron in soil and plant biomass of black pepper (*Piper nigrum*) have been estimated in Western Ghats of Kerala by conducting field experiments in three seasons (2018-2020) by magnesium and boron fertilization. Nutrient management in black pepper plantations wins important value due to its wider use as spice all over the world. As black pepper plants are easily prone to Mg and B deficiency, its response to Mg in the form of magnesium sulphate and B as borax was evaluated in terms of yield, plant nutrient content and nutrient status in soil. Effect of Mg as well as B application on the other available nutrients and leaf nutrient content were also determined in the study. Response curves were fitted by plotting relative yield of black pepper with Mg and B in soil and index leaf. The graphical method of Cate and Nelson was used to derive the optimal concentrations of nutrients. The critical levels of magnesium in soil and black pepper leaves were established as 140 mg kg^{-1} and 0.44 % respectively. Optimum dose of magnesium sulphate for getting highest yield of black pepper was found as 120 kg ha^{-1} followed by $MgSO_4$ at 80 kg ha^{-1}. Similarly critical limit of B in the soil and index leaf of black pepper were 0.58 and 21 mg kg^{-1} respectively. The maximum potential yield was obtained by applying boron as borax at 0.2 % via foliar application and at a higher dosage of 2 kg per hectare through soil application.

Keywords

black pepper; boron; critical nutrient level; magnesium; nutrient content; optimum dose

Introduction

Black pepper (*Piper nigrum* L.), indigenous to Western Ghats of South India, is mostly planted in states of Kerala, Tamil Nadu and Karnataka. Black pepper is popular as a spice as well as for its medicinal values. It is considered as the "King of spices" mainly due to its huge share of production and consumption among the spices globally (1). In the global market, India is the top producer, consumer and exporter of black pepper. In India, Kerala comes first in production of black pepper with an area of 82761 ha grown in various agro-ecological zones ranging from sea level to high ranges. In Kerala, Idukki and Wayanad are the two main black pepper growing districts (2).

Presently, the production status of black pepper plantations of Kerala is declining due to the unsuitable nutrient management and increased frequency of pest and diseases. So, proper management of the crop is very essential for economic crop production. Kerala receives a high average annual rainfall of 3107 mm as compared to national average rainfall of 1197 mm. Since Kerala receives high annual rainfall, its soils are often nutrient-deficient and acidic due to leaching. For profitable and quality crop production, nutrient deficiencies should be properly taken into consideration. Delineation and reassessment of secondary and micronutrients in Idukki district revealed that major parts of the district are deficient in magnesium (Mg) and boron (B) with an extent of 72 % and 71 % respectively.

Magnesium is an essential nutrient for the crop as the structural component of chlorophyll molecule and for many critical physiological processes. It shows a principal role in photosynthesis and energy balance of cell (3). The low CEC (Cation Exchange Capacity) of these highly weathered soils results in low exchangeable magnesium reserves in acid soils. Hence, bio-availability of Mg is a key factor in the acidic soils of Kerala (4). Symptoms of magnesium deficiency in black pepper include pale yellowing of the left margins and tips of leaves, with the main veins remaining green. Laterals subsequently turn yellow, leading to defoliation and necrosis (5). Due to low existing Mg supplying capacity of soils, external inputs are essential to maintain the levels required for plant availability. Lack of Mg at optimal level in soil causes interveinal chlorosis on mature leaves and decrease crop growth. According to Wang et al. (6), regardless of variety of the crop, soil environment, or additional conditions, the average yield improvement were 8.5 % and agronomic efficiency were 34.4 kg ha^{-1} after the application of Mg fertilizers.

Similarly, boron is a fundamental micronutrient for plant growth and reproduction (7). It plays a key role in cell wall biosynthesis, cell division, cell wall lignification, membrane function, RNA and carbohydrate metabolism, sugar transport, nucleotide synthesis and respiration (8). Symptoms of boron deficiency in black pepper include dark, necrotic patches within the leaf area accompanied by chlorosis, reduced branching, short internodes and yellowing between the veins of young and newly mature leaves, especially in the central and distal segments. These signs are common in the black pepper growing regions of Kerala. It may be one of the reasons for yield reduction in black pepper plantations of Kerala.

Requirement of large amounts of nutrients and long duration of plants necessitate the nutrient recommendations based on results of soil and leaf analysis. The nutrient recommendations based on the nutrient status of soil only, characterizes the mineral makeup of the soil and there is further risk for inaccuracies (9) as the soil available nutrients may not be completely taken up by the plant. Hence, the nutrient requirements can be better decided by judging the nutrient levels in both soil and leaf (10).

For defining critical nutrient limits in soil and also in plant to get the maximum yield with optimized fertilizer use, field trials are directed with diverse quantity of nutrient supply and response curves are generated that help to identify the deficient conditions. Critical nutrient level approach by Cate and Nelson (11) is an approach to figure out the optimal scales and critical nutrient concentrations to provide a high level of production. In Kerala, the current research was performed for the establishment of critical nutrient norms and optimum dose of Mg and B in black pepper for the maximization of productivity in tropical acid soils of Western Ghats.

Materials and Methods

Location of the area and its properties

The study area was located at Rajakumari and Senapathi, the major black pepper growing regions of Idukki district in Kerala. Soil samples were initially collected to estimate the levels of available nutrients in the soil under study. The soil was sieved through 2 mm sieves for laboratory analysis. pH was measured using pH meter, EC using conductivity meter, available N was estimated by digestion and distillation as suggested by (12), available K, Ca and Mg using 1N NH_4OAc method, available P extracted using Bray method (13), available S was extracted using 0.15 % $CaCl_2$ and estimated using spectrophotometer and available micronutrients (Fe, Mn, Zn and Cu) were extracted by HCl (0.1 N) and estimated using atomic absorption spectrophotometer. These initial chemical properties (soil) are displayed in Table 1. The area under study was acidic with a pH of 4.85, EC of 0.23 dS m^{-1}, available N was 274 kg ha^{-1} (low), available P was 54 kg ha^{-1} (high) and S was 11.5 mg kg^{-1} (high) and available K was 215 kg ha^{-1} (medium). But the soils were deficient in available calcium, magnesium and boron (184, 64.89 and 0.39 mg kg^{-1}) respectively and high in available micronutrients.

Field experiment in black pepper plantation

The field experiments were laid out in three seasons during 2018-2020, in standing crop of black pepper variety *Karimunda* planted at 4 x 2 m spacing at Rajakkad and Senapathi. The study was conducted as two experiments with six treatments replicated thrice in RBD (Randomized Block Design). The treatments imposed in the Mg optimization experiment were different levels of Mg as $MgSO_4$ applied at the rates of 20, 40, 60, 80, 120 kg ha^{-1} and a control (T_1 toT_6 consecutively). Similarly, in the second

Table 1. Characteristics of experimental soil

Soil parameters	Value
pH	4.85
EC (ds m^{-1})	0.23
Available N (kg ha^{-1})	274
Available P (kg ha^{-1})	54
Available K (kg ha^{-1})	215
Available Ca (mg kg^{-1})	184
Available Mg (mg kg^{-1})	64.89
Available S (mg kg^{-1})	11.15
Available Fe (mg kg^{-1})	22.64
Available Zn (mg kg^{-1})	5.52
Available Mn (mg kg^{-1})	14.98
Available Cu (mg kg^{-1})	5.87
Available B (mg kg^{-1})	0.39

experiment, various doses of B applied at the rates of 0.5, 1, 1.5, 2.0 kg ha^{-1} as soil application, foliar application of borax at the rates of 0.2 % and control were the imposed treatments (T_1 to T_6). The nutrient applications were done in April-May and September-October in 2 split doses. All other nutrients especially nitrogen, phosphorus and potassium were supplied as per the soil test-based recommendations as per 'KAU POP' (2016). Liming of the experiment area was done to raise the soil pH to optimum range before starting the experiment.

Soil and plant sample analysis

After the harvests in 2018, 2019 and 2020, soil samples and index plant parts of black pepper were analyzed to check the soil nutrient availability and plant nutrient content respectively. Post harvest soil samples were studied for the nutrients like N, K, P, Ca, S, Mg, Fe, Mn, Zn, Cu and B as given in 2 and 3. Similarly, index leaf, youngest mature leaf from fruiting lateral all-round the black pepper was collected from every treatment and analyzed for their macro and micronutrients contents as per the standard analytical procedures (14). The plant samples collected were cleaned with water and kept for air drying and then for oven drying at 60±5 °C. The samples dried in oven were powdered. Index leaf N content was determined by micro Kjeldahl digestion with H_2SO_4 and then distillation. For the evaluation of nutrients except N in index leaf, samples (leaf) were digested with nitric-perchloric acid mixture (9:4) and P was calculated by vanado-molybdo method and K using the principle of flame photometry. Presence of S was studied by turbidimetry and Fe, Cu, Zn, Mn and B using ICP-OES (14).

Fresh berry yield

Average yield in terms of berry yield (kg /vine) was recorded from the plantations, treatment wise from each year. In addition, relative percent yield was calculated as detailed below.

Relative percent yield = (Threshold yield / Plateau yield) × 100

The highest recorded yield or maximum yield achieved from each experiments conducted was taken as the plateau yield and yield at each level of nutrient is referred as threshold yield.

Data analysis

The data obtained in three years were pooled and the mean values were statistically evaluated to ensure whether there are significant changes in the soil and plant nutrient contents and berry yield among the treatments.

Critical nutrient level estimation

Cate and Nelson method (11) was used for the analysis of critical level of nutrients like Mg and B in the soil and black pepper plants. As per this approach, scattered plot diagrams were drawn with relative percent yield (y axis) and available nutrient level in soil or nutrient content in plant (X axis). The scatter diagrams were plotted with the data generated for Mg and B in the field experiments conducted in Western Ghats. In this technique, the scatter plot was divided into two populations with two perpendicular lines in such a way that, maximum number of points fall in right upper corner quadrant and fewest points fall in left lower corner. The nutrient concentration at the point of intersection of dividing lines were estimated as critical limit of that nutrient.

Results

Impact of treatments on pH, EC and nutrient availability in the soil

Table 2 showed that pH significantly decreased with increasing $MgSO_4$ application rates, reaching a minimum of 5.33 in T_5 (120 kg $MgSO_4 ha^{-1}$). The plant available form of secondary and micronutrients such as Ca, Mg, S, Fe, Mn and Zn were significantly enhanced with the application of Mg at various doses. The increased concentration of Ca may be due to the solubility of applied lime; however, the decrease in pH, even after applying lime, may be due to the insufficient quantity of applied lime to neutralize the potential acidity. The highest values of Mg and S (123.35 and 46.56 mg kg^{-1}) were recorded in the treatment T_5 which received $MgSO_4$ at 120 kg ha^{-1}. Whereas in case of available Ca, T_5 ($MgSO_4$ at 120 kg ha^{-1}) and T_4 ($MgSO_4$ at 80 kg ha^{-1}) were on par with each other (Table 2). In case of micronutrients, there was statistically significant raise in Fe and Mn with the treatment of different doses of Mg. Both registered the highest value with the highest dose of Mg (T_5: 120 kg ha^{-1}).

In second experiment (different doses of B), the post-harvest soil analysis revealed that the availability of nutrients such as S, Fe, Mn and B were significantly higher in treatments which received borax than control (Table 3). The highest value of B and S was observed in the treatment received borax at 2.0 kg ha^{-1} (T_4) recording the values of 14.11 and 0.6 mg kg^{-1} respectively. It was recorded that the available boron in soil was also enhanced from sub optimal to the sufficiency range by the treatment of borax through soil application.

Effect of treatments on concentration of nutrients in black pepper plant

In the experiment conducted with different doses of Mg, the highest nutrient content in index leaf was with the treatment T_5 having $MgSO_4$ at 120 kg ha^{-1} (Table 4) and it was statistically on par with the treatment having $MgSO_4$ at 80 kg ha^{-1} (T_4). As there is a Mg stress in soil owing to low content, an external application of Mg is needed for ameliorating the deficiency to enhance the crop uptake. Concentration of K, Ca, Mg, S and micronutrients were significantly higher in the treatments with different doses of Mg as compared to control. The contents of Mg and S showed higher and statistically on par values of 0.6, 0.58 mg kg^{-1} and 0.48 and 0.46 mg kg^{-1} respectively with the supply of $MgSO_4$ at 120 and 80 kg ha^{-1}.

In the experiment with different doses of B, the highest B content in the index leaf of black pepper was seen in the treatment with foliar application of borax at 0.2 per cent (T_5) (Table 5) and it was significantly on par with the treatment T_4 which received soil application of borax at a higher concentration of 2 kg ha^{-1}. It was observed that the leaf N, Ca, Mg and S content at harvest was enhanced with the addition of different doses of B. The highest P (0.28 %) and K (2.8 %) content were observed in T_5. Fe, Mn, Zn and Cu also showed significantly higher values in B applied treatments as compared to control. While the B deficiency was corrected by the foliar application, uptake of other nutrients also increased as compared to other treatments.

Effect of treatments on black pepper berry yield

The highest berry yield was observed with treatment receiving $MgSO_4$ at 120 and which was on par with the treatment receiving $MgSO_4$ 80 kg ha^{-1} (T_5 and T_4 respectively). Here, in treatment T_5 black pepper yield increased 1.97 times greater than that of control and in treatment T_4 black pepper yield increased 1.89 times greater than that of control (Table 4). Similarly, in the second experiment, the treatment T_5, which received borax at 0.2 % (foliar method) and the treatment T_4, which received borax at 2.0 kg ha^{-1} (direct application to soil) were significantly on par and were higher than all other treatments in the case of berry yield (Table 5).

Table 2. Effect of different levels of Mg on pH, EC and available nutrient status in soil (Means of 2017, 2018 and 2019)

Treatments	pH	EC	Av. Ca	Av. Mg	Av. S	Av. Fe	Av. Mn	Av. Zn	Av. Cu	Av. B
		(dS m^{-1})	mg kg^{-1}							
T_1- Soil application $MgSO_4$ at 20 kg ha^{-1}	5.98	0.41	224.45	112.77	38.90	24.24	11.31	5.47	4.85	2.11
T_2- Soil application $MgSO_4$ at 40 kg ha^{-1}	5.89	0.45	228.29	113.41	32.91	24.66	11.85	5.48	4.88	2.21
T_3- Soil application $MgSO_4$ at 60 kg ha^{-1}	5.79	0.54	232.35	104.42	36.00	27.12	13.30	5.22	4.88	2.23
T_4- Soil application $MgSO_4$ at 80 kg ha^{-1}	5.37	0.61	246.24	104.81	42.49	29.67	14.16	5.05	4.94	2.32
T_5- Soil application $MgSO_4$ at 120 kg ha^{-1}	5.33	0.79	246.56	123.35	46.56	31.70	14.38	5.50	4.97	2.35
T_6- Control	6.06	0.21	190.71	98.97	23.01	22.83	10.70	4.96	4.76	2.02
CD (0.05)	0.12	0.14	18.25	0.25	4.06	2.56	1.24	0.40	NS	NS

Table 3. Effect of different levels of B on chemical properties and available nutrient status in soil (Means of 2018, 2019 and 2020)

Treatments	pH	EC	Av. Ca	Av. Mg	Av. S	Av. Fe	Av. Mn	Av. Zn	Av. Cu	Av. B
		(dS m^{-1})	mg kg^{-1}							
T_1- Soil application Borax at 0.5 kg ha^{-1}	5.84	0.35	224.45	112.77	13.32	47.26	12.22	3.83	4.09	0.45
T_2- Soil application Borax at 1.0 kg ha^{-1}	5.80	0.36	228.29	113.41	13.87	48.82	12.89	3.83	4.01	0.49
T_3- Soil application Borax at 1.5 kg ha^{-1}	5.85	0.40	232.35	104.42	13.41	39.31	14.42	3.87	4.18	0.55
T_4- Soil application Borax at 2.0 kg ha^{-1}	5.89	0.42	236.24	104.81	14.11	30.97	14.89	4.11	4.28	0.60
T_5- Foliar application Borax at 0.2 %	5.91	0.45	237.56	113.35	13.55	29.98	15.79	4.21	4.30	0.35
T_6- Control	5.92	0.32	222.71	112.97	13.11	24.16	10.54	3.82	3.99	0.30
CD (0.05)	NS	NS	NS	NS	0.043	4.45	2.84	NS	NS	0.80

Table 4. Effect of different levels of Mg on concentration of nutrients in pepper (Means of 2018, 2019 and 2020)

Treatments	Nutrient content in index leaf											Berry yield (kg $plant^{-1}$)
	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B	
	%						mg kg^{-1}					
T_1- Soil application $MgSO_4$ at 20 kg ha^{-1}	2.15	0.25	3.51	0.74	0.35	0.32	179.11	23.35	10.54	6.38	10.64	3.25
T_2- Soil application $MgSO_4$ at 40 kg ha^{-1}	2.18	0.26	3.52	0.75	0.45	0.34	186.42	24.03	11.96	6.69	10.80	3.55
T_3- Soil application $MgSO_4$ at 60 kg ha^{-1}	2.25	0.26	3.61	0.79	0.49	0.38	189.64	25.82	13.05	7.11	10.93	3.89
T_4- Soil application $MgSO_4$ at 80 kg ha^{-1}	2.56	0.27	3.67	0.84	0.58	0.46	214.45	29.15	13.99	7.45	12.07	4.56
T_5- Soil application $MgSO_4$ at 120 kg ha^{-1}	2.58	0.28	3.82	0.94	0.60	0.48	221.82	31.20	14.87	8.11	14.34	4.75
T_6- Control	2.01	0.24	2.99	0.68	0.16	0.25	165.19	18.63	9.25	5.69	9.13	2.41
CD (0.05)	NS	NS	0.36	0.09	0.07	0.04	12.15	3.98	2.31	0.89	0.76	0.38

Table 5. Effect of different levels of B on concentration of nutrients in pepper (Means of 2018, 2019 and 2020)

Treatments	Nutrient content in index leaf											Berry yield (kg $plant^{-1}$)
	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B	
	%						mg kg^{-1}					
T_1- Soil application Borax at 0.5 kg ha^{-1}	2.21	0.13	2.44	0.64	0.25	0.18	130.11	33.15	11.13	3.28	21.64	3.38
T_2- Soil application Borax at 1.0 kg ha^{-1}	2.31	0.14	2.46	0.64	0.25	0.21	130.42	41.03	12.16	3.49	23.39	3.56
T_3- Soil application Borax at 1.5 kg ha^{-1}	2.35	0.16	2.49	0.69	0.26	0.24	139.64	45.82	12.75	3.76	26.93	3.83
T_4- Soil application Borax at 2.0 kg ha^{-1}	2.41	0.17	2.52	0.77	0.26	0.31	141.45	49.15	12.98	4.11	32.07	4.43
T_5- Foliar application Borax at 0.2 %	2.51	0.28	2.80	0.82	0.29	0.33	143.82	57.00	13.87	4.32	34.04	4.69
T_6- Control	2.09	0.10	2.26	0.59	0.19	0.15	108.19	28.63	8.29	3.09	6.68	2.13
CD (0.05)	0.13	0.02	0.16	0.09	0.07	0.09	6.35	4.48	0.73	0.96	0.92	0.55

Critical concentration of Mg and B in soil and plant

By plotting the different concentrations of soil and plant Mg and B against the relative yield of black pepper in the experiment, the critical level of Mg in the index leaf of black pepper was found as 0.44 per cent (Fig. 1) and the critical limit of available Mg in soil was determined as 140 mg kg^{-1} (Fig. 2). Similarly, critical level of B in the index leaf of black pepper was discovered to 21 mg kg^{-1} (Fig. 3) and critical level in the soil was 0.58 mg kg^{-1} (Fig. 4). So, the nutrients must be given at a quantity to continue their intensity above the critical level in soil and plant.

Discussion

The treatments imposed on the black pepper plants had significantly influenced the soil available secondary and micronutrients, the amount of nutrients in the index leaf and the berry yield.

Effect of treatments on pH, EC and nutrient availability in the soil

Applying $MgSO_4$ to soil results in a decrease in soil pH, with the most significant reduction seen in the treatment with the highest $MgSO_4$ dose (T_5), where the pH reached 5.33. This effect is attributed to the slightly acidic nature of $MgSO_4$ and the dissolution of sulfate ions (SO_4^{2-}) into the soil solution, as supported by (15, 16). It showed that increase in dose of $MgSO_4$ had increased the Mg and S level in soil. It was confirmed by the highest electrical conductivity recorded by T_5 owing to the highest release of Mg and SO_4 to the soil. A notable rise in Mn and Fe levels with the application of various doses of Mg was also recorded. Both Fe and Mn reached their highest concentrations with the maximum Mg dose (T_5 120 kg ha^{-1}). The lowered soil pH might have improved the solubility of Fe and Mn in the soil. According to Disch et al. (17) there was a significant positive change in concentration of the element Fe in soil after the application of Mg in the form of $MgSO_4$. Goss et al. (18) showed that a synergistic relation among the Mg and Mn content in the soil, which defends the present discoveries.

Effect of treatments on concentration of nutrients in black pepper plant

The aggregated data on the nutrient status of black pepper revealed that applying magnesium sulfate positively influenced the major and micronutrient levels in the plants (Table 4). The highest nutrient levels in the black pepper were observed with $MgSO_4$ at 120 kg ha^{-1} for the essential nutrients studied. This suggests that balanced fertilization and nutrient availability are crucial for the proper growth and yield of black pepper. According to (19) an increase in plant nutrient content was noted with higher rates of Mg application. (20) reported that $MgSO_4$ promotes the nutrient content and uptake of Ca, K, Mg and S.

In the second set of experiment (B optimisation), the treatment, T_5 having foliar application of borax at 0.2 %, recorded the highest content of B (34.04 mg kg^{-1}) in black pepper. This confirms that the application of B by foliar method is more efficient method than its direct application to soil as the recovery percentage of B might be more in foliar application than soil application (21, 22). The higher availability of B in soil would have led to higher intake and content of B in leaves (23). It was observed that the leaf N, Ca, Mg and S content at harvest was enhanced with the application of different doses of B. According to Fuertes-Mendizábal et al. (24), B is an essential player to improve the

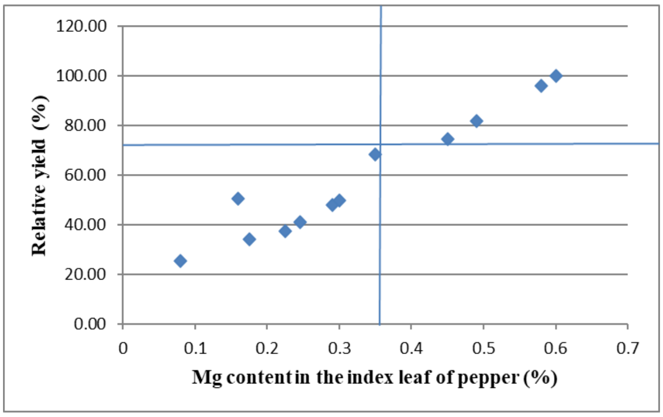

Fig 1. Critical limit of Mg in index leaf of Black pepper

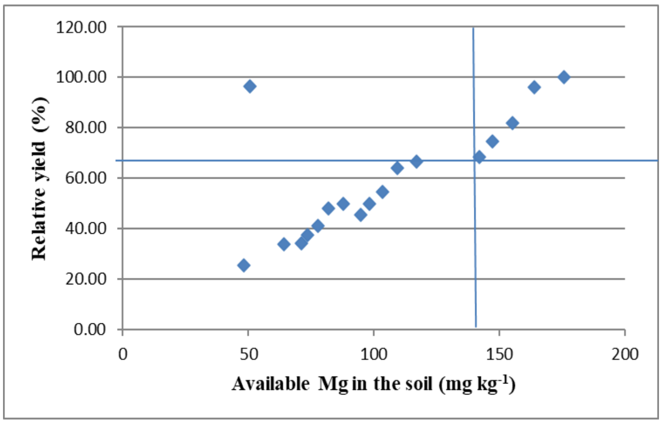

Fig 2. Critical limit of available Mg in soils of Black pepper plantation

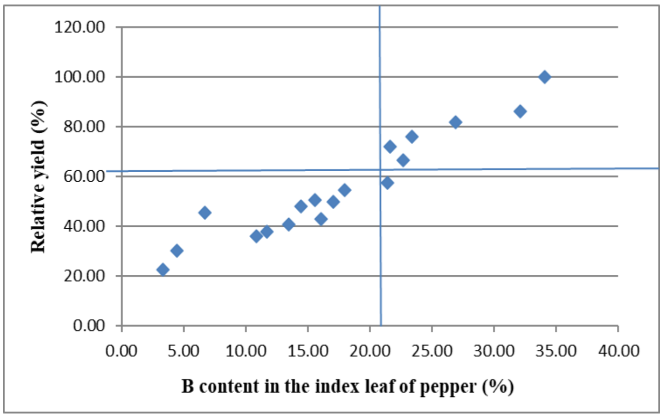

Fig 3. Delineation of critical limit of B in index leaf of Black pepper

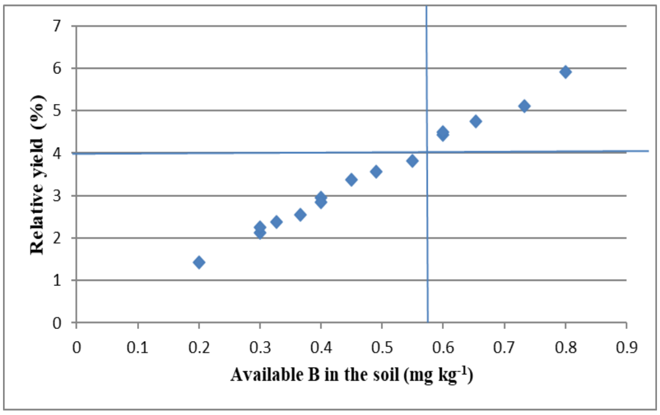

Fig. 4. Delineation of critical limit of B in soil

N uptake by boosting the N availability in soil. The highest P and K content were observed in T_5 with the values of 0.28 and 2.8 % respectively. Das et al. (25) reported that correlation of B with P was positive, owing to the involvement of anionic forms of P and B in anion exchange phenomena. Similarly, the synergistic effect of available boron and exchangeable potassium that might cause the increased K content (26). All the micronutrients like Fe, Mn, Zn and Cu also showed significantly higher values in B applied treatments as compared to control. The foliar application corrected the deficiency of B and led to an increased uptake of other nutrients compared to all other treatments.

Effect of treatments on black pepper berry yield

Magnesium is vital for phloem-loading and the transport of photo-assimilates to sink organs, particularly during the berry forming stage, which is critical for black pepper yield (27). Additionally, Mg is essential for maintaining crop productivity (28). In the current study, compared to the control, Mg fertilization increased the berry yield. According to many researchers, fertilization of crops with Mg improves the crop yield in the field under Mg deficiency (29, 30). Similar results were reported by Wang et al. (6), compared the effects of Mg fertilisation on crop growth and consistent agronomic-efficiencies in various methods of production under different types of soil by a meta-analysis. Not considering the crop variety, status of soil, or other conditions, the agronomic-efficiency and average yield improvement resulting from addition of reasonable amount of Mg were 34.4 kg kg^{-1} and 8.5 %, respectively.

Similarly, in the experiment with borax, foliar application of borax at 0.2 % resulted in the highest mean value for berry yield, and which was significantly higher with the treatment, borax at 2.0 kg ha^{-1}. Absorption efficiency of plant available nutrients is more in foliar fertilization and shows higher yield in comparison to the soil applied higher dose of borax. Since the quantity of B needed for foliar method is far less than that for soil application, it appears to be the better treatment. (31) reported an increased tomato yield with soil or foliar applied B than the plants receiving no boron. Similarly, (32) reported that both soil and foliar applications of B resulted in a significantly higher fruit yield over a three-year period, along with an increase in the absorption of N, P and K. The fact is that the requirement of B is more for reproductive growth than vegetative growth.

The spike and berry yield of black pepper were significantly increased by the addition of Mg and B in laterite soil with the highest value in the treatment with 40 g $MgSO_4$ and 4 g borax per vine (23). It is proposed that maintaining an optimal balance of soil nutrients and their absorption by crop plants leads to a successive increase in yield (33). Hence, the concept of optimum nutrient level in soil and plant is very much essential while considering the crop yield.

Critical concentration of Mg and B in soil and plant

Critical value of Mg content in the index leaf of black pepper was found as 0.44 % and that of available Mg in soil was determined as 140 mg kg^{-1}. As the concentrations of soil Mg fluctuate greatly, in most of the soil, more than 120 mg kg^{-1} is mostly thought as adequate for best possible crop yield (6, 34). Similarly, critical level of the micronutrient B in the index leaf of black pepper and in the soil was found to 21 and 0.58 mg kg^{-1} respectively. Therefore, nutrients must be supplied at a dosage that keeps their concentration above the critical threshold in both the soil and plant tissue. Sadanandan et al. (35) defined the DRIS (Diagnosis and Recommendation Integrated System) rules for optimum leaf nutrient concentration range in black pepper as 0.40-0.69% for Mg and 16-120 mg kg^{-1} for B.

Conclusion

In black pepper plantations of the Western Ghats, where Mg and B deficiencies are present, these deficiencies can be corrected and maximum yield can be achieved by applying 120 kg ha^{-1} of Mg as $MgSO_4$ and 0.2 % borax as a foliar spray for B. At these rates, nutrient levels remain above their critical concentration in both soil and plant tissue.

Acknowledgements

The authors gratefully acknowledge the financial support provided by AICRP-MSPE for research work. We express our sincere thanks to Kerala Agricultural University for providing infrastructure facilities to conduct the research work.

Authors' contributions

Every author has contributed actively to this work. AT, ASA, AKK, RAM, SK and NJP worked in both the lab and in the field. The experiment was conceived and overseen by BVI, GP, PSP and SP. The manuscript was prepared and edited by NJP, AT, BVI, GP and PSP. BSK contributed to the result's interpretation and offered criticism.

Compliance with ethical standards

Conflict of interest: The authors declare that there is no conflict of interest.

Ethical issues: None.

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