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Amendment Modified Boron Dynamics in Sandy Loam Soil Cultivated with Cowpea

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ABSTRACT

A study was carried out in Instructional Farm II, College of Agriculture, Padannakkad, Kasaragod, Kerala to study short-term dynamics of boron in a sandy loam soil as modified by different amendments and its impact on growth and yield parameters of cowpea. The experimental field was established in randomized block design, comprising eight treatments and three replications using cowpea (Variety-Kanakamony) as the test crop. Different soil management practices using farm yard manure, lime, dolomite, inorganic fertilizers and borax were included in the treatments. In all the treatments residual boron fraction was dominant followed by oxide-bound boron, organically bound boron, specifically adsorbed boron and readily soluble boron. Among the different treatments, the highest content of boron fractions except organically bound boron was detected at the T7 treatment (Soil Test Based Fertilize + borax + lime) during various growth stages of cowpea. A consistent decline in the levels of boron fractions was noted as the crop grew. Treatments have a significant effect on the plant nutrient contents. The highest boron content in the plant was observed in the T7 treatment. The results obtained from field experiments show that there is a significant effect of treatments on the growth and yield of cowpea. The study revealed that the combined application of soil test-based fertilizer, borax and lime had a significant positive effect on soil boron fractions, growth and yield parameters of cowpea in sandy loam soil.

Keywords : Boron fractions, Boron dynamics, Sandy loam soil, Cowpea

COWPEA is a leguminous vegetable crop that has a high response to fertilizer application. It can improve soil quality on symbiotic association with *Rhizobium* and also by mobilizing insoluble soil nutrients with its deep root system. Boron is an essential micronutrient needed for the proper growth of plants, significantly contributing to improved growth, yield and nodulation in peas. Deficiency of boron is a major constraint in cowpea production. Its deficiency results in sterility in plants due to the malformation of reproductive tissues that impair pollen germination, leading to increased flower drop and decreased fruit set (Subasinghe *et al.,* 2003).

Boron has been identified as the second most deficient micronutrient in Indian soils after zinc (Chatterjee *et al.*, 2018). According to Gupta *et al*. (2008), about one-third of India's agricultural soils are deficient in boron. The deficiency levels ranged from 2 per cent in the alluvial soils of Gujarat to 68 percent in the red soils of Bihar. According to Jyolsna and Mathew (2008), boron has high mobility in the soil, which further contributes to the considerable leaching of the element caused by the high annual rainfall.

There are several forms of boron in the soil, which are in a state of dynamic equilibrium with one another.

These forms include readily soluble boron, specifically adsorbed boron, oxide-bound boron, organically bound boron and residual boron (Barman *et al.*, 2017). These fractions collectively contribute to the overall boron content in the soil. Readily soluble boron is the most assessable form for plant uptake, making up 1-2 per cent of total boron. Specifically adsorbed boron is also available for plant uptake, making up 0.01-0.61 per cent of the total boron. Residual boron is the most dominant form of boron in the soil which is unavailable for plant uptake (Kasture *et al.*, 2020). Fractionation of boron is essential for studying the dynamics of boron in the soil.

Hence present investigation was proposed to assess the dynamics of boron in sandy loam soils and to study the effect of organic and inorganic management practices on such dynamics which will help to evolve the best management practices for correcting nutrient deficiency and enhancing the fertility of these soils.

Material and Methods

Field Experiment

The field experiment for the present study was carried out during October to December 2022 at instructional farm II, College of Agriculture, Padannakkad, Kerala Agricultural University, Kerala. The experimental site is geographically located at 12°14'45" North latitude, 75°8'6" East longitude and 9 m above mean sea level. Soils in the region are sandy loam in texture. The field was laid out in a randomized block design with eight treatments and three replications. The cowpea variety Kanakamony was used as a test crop for the field experiment and planted with a spacing of 45 cm x 15 cm.

Treatment Details

T_1: Control

T_2: Kerala Agricultural University Package of Practices (KAU POP) based lime (250 kg ha^{-1}) and fertilizers (NPK 20:30:10 kg ha^{-1})

T_3: KAU organic POP based lime (250 kg ha^{-1}) and farm yard manure (20 t ha^{-1})

T_4: Soil test-based fertilizers excluding Ca, Mg and B

T_5: T_4 + dolomite @ 400 kg ha^{-1}

T_6: T_4 + lime @ 250 kg ha^{-1}

T_7: T_6 + borax @ 10 kg ha^{-1}

T_8: T_4 + *Rhizobium* seed inoculation

Soil and Plant Sampling

Soil samples collected before the experiment were analysed for standard soil parameters such as pH, EC, organic carbon (%), available N (kg/ha), available P (kg/ha), available K (kg/ha), available Ca, Mg, S, Fe, Cu, Zn, Mn (mg/kg) and B fractions (Readily soluble B, specifically adsorbed B, oxide bound B, organically bound B, residual B and total B) (mg/kg). Soil samples collected at flowering and at harvest stages were analysed for boron fractions. Biometric observation of the crop was taken which included leaf area (cm^2), plant height (cm), number of branches per plant, number of pods per plant, test weight (100 grain weight in g) and pod yield (kg ha^{-1}).

Soil and Plant Analysis

The pH and electrical conductivity of soil samples were measured on soil water suspension made at 1:2.5 ratio. Organic carbon content in the soil was estimated by using Walkley (1934) chromic acid wet oxidation method. Available N was estimated using alkaline permanganate method (Subbaiah and Asija, 1956) and phosphorus by bray extraction with colorimetry (Bray and Kurtz, 1945). Available K is measured by flame photometry (Jackson, 1973) and sulphur by photoelectric colorimetry (Massoumi and Cornfiled, 1963). Titration with EDTA was used for the estimation of available calcium and magnesium (Hesse, 1971). Available Fe, Mn (Sims and Jhonson, 1991) Cu and Zn (Emmel *et al.*, 1977) were estimated by atomic absorption spectroscopy. For the plant boron, estimation azomethine H colorimetric method described by Jackson (1958) was followed.

Fractionation of Boron

Different B fractions in soil samples were determined according to the fractionation scheme proposed by

Hou *et al*., (1996), as modified by Datta *et al*., (2002). Readily soluble B was extracted by 0.01 M $CaCl_2$, specifically adsorbed B with 0.05 M KH_2PO_4, oxide bound B with 0.175 M ammonium oxalate (pH 3.25), organically bound B with 0.5 M NaOH and residual fraction by tri acid digestion (H_2SO_4, HF and $HClO_4$). Azomethine-H was used for the detection of readily soluble boron (John *et al*., 1975) and specifically adsorbed boron whereas carmine dye is used for the detection of oxide bound, organically bound and residual boron fractions (Hatcher and Wilcox, 1950). The intensity of the colour development was measured using a spectrophotometer. Total boron content was then calculated as the sum of all the above boron fractions.

Results and Discussion

The initial physico-chemical properties of the experimental site are given in Table 1. From the initial soil analysis, it is identified that the soil is strongly acidic and deficient in and boron.

Boron Fractions in Soil

Boron fractions in the sandy loam soil during pre-sowing, flowering and after harvest are presented in Tables 2, 3 and 4 respectively.

Table 1

Initial soil analysis

Parameter	Value
pH	5.34
EC (dS/m)	0.012
Organic carbon (%)	0.655
Available N (kg ha-1)	313.6
Available P (kg ha-1)	341.73
Available K (kg ha-1)	213.36
Available Ca (mg kg-1)	320.89
Available Mg (mg kg-1)	44.6
Available S (mg kg-1)	22.875
Available Fe (mg kg-1)	25
Available Mn (mg kg-1)	1.54
Available Zn (mg kg-1)	2.87
Available Cu (mg g-1)	1.65
Available B (mg kg-1)	0.183

Readily Soluble Boron

Readily soluble boron in soil did not change significantly across the treatments at pre-sowing

Table 2

Boron fractions in soil at pre sowing (mg/kg)

Treatment	Pre sowing (mg/kg)					
	RSB	SAB	OxB	OrgB	RB	T-B
T1	0.095	0.117	2.884	1.167	76.083	80.346
T2	0.090	0.118	2.955	1.137	78.333	82.633
T3	0.090	0.108	2.867	1.159	75.167	79.390
T4	0.092	0.115	2.795	1.123	75.667	79.792
T5	0.094	0.117	2.875	1.141	76.500	80.727
T6	0.094	0.110	2.857	1.161	77.583	81.804
T7	0.093	0.117	2.821	1.133	77.833	81.998
T8	0.091	0.112	2.763	1.170	75.858	79.995
C.D. (0.05)	NS	NS	NS	NS	NS	NS
SE (m)	0.002	0.004	0.066	0.015	1.381	1.371

Note : RSB - readily solyble boron, SAB - specifically adsorbed boron, OXB - oxide bound boron, OrgB - organically bound boron, RB - residual boron, T - B total boron

TABLE 3

Effect amendments on boron fractions in soil at flowering (mg/kg)

Treatment	At flowering (mg/kg)					
	RSB	SAB	OxB	OrgB	RB	Total-B
T1	0.092 h	0.118 e	3.029 e	0.812 a	76.780 e	80.831 e
T2	0.100 f	0.132d	3.296 d	1.467 e	86.569 c	91.565 c
T3	0.107 e	0.133 d	3.638 c	1.817 a	89.122 b	94.816 b
T4	0.098 g	0.121 e	3.354 d	1.381 f	82.211 d	87.166 d
T5	0.119 c	0.150 c	4.157 a	1.544 cd	86.776 b	92.746 bc
T6	0.111 d	0.141 cd	4.092 a	1.515 de	87.884 b	93.744 bc
T7	0.193 a	0.308 a	4.077 a	1.604 b	94.505 a	100.686 a
T8	0.138 b	0.213 b	3.880 b	1.585 bc	88.872 bc	94.689 b
C.D. (0.05)	0.001	0.01	0.136	0.056	2.455	2.441
SE (m)	0	0.003	0.045	0.018	0.81	0.805

TABLE 4

Effect of amendments on boron fractions in soil after harvest (mg/kg)

Treatment	After harvest (mg/kg)					
	RSB	SAB	OxB	OrgB	RB	Total B
T1	0.084 h	0.096 d	2.709 h	0.542 f	61.550 e	64.982 e
T2	0.104 e	0.103 d	3.009 f	1.241 d	76.942 d	81.399 cd
T3	0.100 f	0.145 c	3.078 e	1.705 a	82.640 b	87.668 b
T4	0.090 g	0.111 d	2.926 g	1.104 e	75.633 d	79.863 d
T5	0.113 c	0.156 c	3.562 c	1.329 c	77.858 cd	83.019 c
T6	0.109 d	0.160 c	3.686 b	1.275 d	80.467 bc	85.696 b
T7	0.168 a	0.27 a	3.975 a	1.585 b	91.350 a	97.336 a
T8	0.121 b	0.184 b	3.209 d	1.352 c	81.267 b	86.133 b
C.D. (0.05)	0.003	0.008	0.56	0.013	2.666	0.866
SE (m)	0.001	0.023	0.018	0.039	0.879	2.626

(Table 2). However, it differs significantly among the treatments at flowering (Table 3) and after harvest (Table 4). Readily soluble boron (Rs-B), which accounts for approximately 1-2% of the total boron (T-B) in soil, is crucial for plant absorption (Padbhushan & Kumar, 2017). The field experiment was conducted in soil that was deficient in available boron, which resulted in readily soluble boron levels being less than 1% of the total boron. The highest value (0.193 mg kg^{-1}) of readily soluble boron was obtained in treatment T7 at flowering and after the harvest stage of analysis. The lowest value (0.092 mg

kg^{-1}) was registered in the control treatment (T1). This could be attributed to the borax application in T7 treatment. Readily soluble boron varies from 0.084 to 0.169 mg kg^{-1} with T1 treatment (control) and T7 treatments giving higher and lower values respectively. The readily soluble boron content decreased as crop growth progressed in the control treatment. In all other treatments, there was an increase of Rs-B up to flowering and thereafter decreased. Similar results were reported by Sathya *et al*., (2013). Organic or inorganic amendments if applied after lime application can increase the Rs-B content in soil. Increased uptake and other losses during different growth stages may cause a reduction in Rs-B content if amendments are not applied. The content of Rs-B was low in T4 treatment as lime application was not included. Conjoint application of lime with inorganic fertilizers can enhance boron fractions in the soil (Dey *et al*., 2015).

Specifically Adsorbed Boron

At flowering (Table 3) specifically adsorbed boron ranged from 0.118 to 0.308 mg kg^{-1}. Maximum content was observed in T7 treatment and minimum content was in control (T1 treatment) which was on par with T4. Similarly, in soil samples collected after the harvest stage of analysis (Table 4), T7 treatment showed the highest value (0.271 mg kg^{-1}) and T1 (control) recorded lowest value (0.0959 mg kg^{-1}) which was on par with T2 and T4 treatments. Bhupenchandra *et al.* (2020) reported similar results based on their study. This fraction is adsorbed onto clay surfaces in the soil and represents another form that is accessible for plant uptake (Jin *et al*., 1987). As crop growth advances, plants absorb boron directly from the readily soluble and specifically adsorbed fractions, leading to a noticeable decrease in their content after the harvest stage.

Oxide Bound Boron

Oxide-bound boron fraction is a less labile pool of boron that is bound to oxides and hydroxides of Fe and Al (Jin *et al*., 1988). This pool contributes less than 3 per cent of total boron (Hou *et al*., 1994). However from the results of the field experiment, it was revealed that oxide-bound boron constitutes 3.72 to 4.05 per cent of the total boron. The increased value is attributed to the presence of iron and aluminium oxides and hydroxides in the acidic sandy loam soil. At the flowering stage (Table 3) highest value was obtained in T5, which was on par with T6 and T7. Dolomite, lime and borax were applied in T5, T6 and T7 treatments, respectively. The addition of boron had a positive impact on the oxide-bound boron fraction in the soil. It appears that a substantial amount of the applied boron is integrated into the oxide-bound fraction due to liming (Barman *et al*., 2014). There was a slight reduction of Ox-B at harvest time, with T7 treatment having maximum and T1 having minimum values. Crop uptake from readily soluble and specifically adsorbed boron pools resulted in transformations that replenish the available fraction from less labile pools (Xu *et al*., 2001). Hence these losses of labile pools are significant in ensuring boron supply to plants as the crop growth progresses.

Organically Bound Boron

At flowering (Table 3) and harvest stages (Table 4), the content of boron fraction associated with the organic matter was highest in T3 and the least value was noted in T1. The increased organically bound boron may be attributed to the farmyard manure application in T3. Native boron in the soil is adsorbed to organic matter present in farm yard manure resulting in a rise in organic bound boron in T3. Organically bound boron also provides available boron to crops through mineralization by microbes. Similar findings were reported by Ranjbar and Jalali (2013). The highest content was observed at the flowering stage and it was slightly reduced at the harvest stage. This could be a result of crop uptake and the transformation of boron into various forms within the soil solution equilibrium.

Residual Boron

The residual fraction represents the largest contributor among all forms of boron in the pool and is irrelevant to plant-available boron (Tsalidas *et a*l., 1994). Significant variation was observed in RB content among the treatments at the flowering (Table 3) and harvest stages (Table 4). The highest value was recorded in T7 and the lowest value was found in T1. The residual effect of boron fertilization in T7 could enhance the content of residual boron in the soil. Residual boron ranged from 61.55 to 94.505 mg kg^{-1} (93.86% to 94.72% of total boron) across the treatment in various crop stages. Datta *et al*., (2002) have reported similar findings from their study. After the harvest, the highest residual boron content was observed in T7 treatment, attributed to the elevated boron content in borax, which helped in maintaining a boron reserve after reaching equilibrium with the various fractions of boron in the soil. This conforms with the findings of Ajayan and Thampatti (2020).

Total Boron

The total boron content was highest in T7 treatment during the flowering (Table 3) and harvest stages (Table 4), owing to the borax application in addition to other inorganic fertilizers. Total boron was minimum in control T1 (treatment). It was found decreased at harvest stage due to conversion to other fractions from this pool to maintain equilibrium. Similar results were reported by Bhupenchandra *et al*., (2020). Availability of boron in the sandy loam soil is low irrespective of the high total boron content. This discrepancy may be attributed to the low levels of labile boron pools in the area.

Table 5

Effect of amendments on Boron content in the plant

Treatment	Boron content (ppm)
T1	22.167 e
T2	23.733 cd
T3	24.567 c
T4	22.467 de
T5	23.867 cd
T6	24.700 c
T7	30.067 a
T8	26.200 b
CD (0.05)	1.405
SD (m)	0.463

Plant Boron Content

The effect of treatments on plant boron content as depicted in table 5 shows that significant variation occurs among the treatments. It ranged from 22.167 to 30.067 ppm with the highest boron content in T7 treatment. The lowest value of plant boron content was noted in control T1 (22.167 ppm) which was on par with T4 (22.467 ppm). Application borax enhances boron content in the plant compared to control, as reported in the study conducted by Yadav *et al*., (2021). Boron is an essential micronutrient that plays an important role in legumes for its growth and yield.

Growth Parameters of Cowpea

The growth parameters of cowpea are presented in Table 6. There was a significant effect of treatments on the growth and yield parameters of cowpea. Treatment T7 which received borax fertilization recorded the highest plant height (181.667 cm) which was comparable to T6 treatment (166 cm) and the lowest value was reported in T1 (136.667 cm). The results are following the findings of Banasode and Channakeshava (2021). Boron is vital for plant physiological processes, including carbohydrate metabolism, sugar transport, cell wall structure, protein metabolism and root growth. Additionally, boron facilitates N fixation, ensuring adequate N

Table 6

Effect of amendments on growth parameters of cowpea

Treatment	Plant height (cm)	No. of branches per plant	Leaf area (cm2)
T1	136.667 d	4	37.647 e
T2	148.333 cd	4	41.615 d
T3	153.333b cd	5	44.492 c
T4	144.000 d	4	44.724 c
T5	151.667b cd	4	49.867 b
T6	166.000 ab	4	43.768 c
T7	181.667 a	4	53.112 a
T8	161.667 bc	4	51.654 a
C.D. (0.05)	17.19	NS	1.72
SE (m)	5.667	0.348	0.567

supply and promoting plant height (Kumar *et al.*, 2016). Number of branches per plant did not change significantly among the treatments.

The leaf area of the observational plants was measured using a leaf area meter and statistically analysed data is given in Table 7. Leaf area differs significantly across the treatments with the maximum value in the T7 treatment (53.112 cm^2), which was on par with T8 (51.654 cm^2). The least value of leaf area was noted in the control treatment T1 (37.647 cm^2). The synergistic effects of boron application with NPK fertilizers on plant growth are well-documented by Soomro *et al*., (2011). Boron plays an indispensable role in plant growth, specifically in cell division and elongation processes within actively growing regions, including new leaves and buds. Additionally, boron facilitates cell wall biosynthesis and maintains structural integrity. These results are corroborated by the findings of Vera-Maldonado *et al*., (2024).

Yield Parameters of Cowpea

Yield parameters of cowpea are summarized in Table 7. No. of pods per plant was counted after harvest and it varied significantly. It was highest in T7 treatment (32) and was on par with T8. The least number of pods were obtained in T1 treatment (21). Boron increases pod number by enhancing tissue differentiation and floral cluster formation, consistent with Mansingh *et al*. (2022).

From the results of statistically analyzed data on pod weight, it was evident that borax application increased the pod weight per plant in T7 treatment (62.92 g). Treatments T3 (54.927 g) and T8 (55.587 g) were comparable to T7. Similar results are reported by Prashantha *et al*. (2019) and Aparna and Puttaiah, (2012).

Test weight is measured by weighing 100-grain weight. Results show that borax application had a significant effect on test weight. The maximum value was observed in T7 treatment (12.647 g) and other treatments were at the same level as T1 having the minimum test weight (9.357 g). Boron application enhances test weight by regulating cell metabolism, promoting pod development and optimizing pod filling capacity.

The greatest pod yield was recorded in the T7 treatment (3955.33 kg ha^{-1}) and the least yield was obtained in T1 (2526 kg ha^{-1}). The studies of Achin and Singh (2018) and Shankar *et al*., (2016) have given the same results. According to Sushma *et al*., (2023), the application of boron at 1.0 kg ha^{-1} enhanced plant

TABLE 7

Effect of amendments on yield parameters of cowpea

Treatment	Number of pods per plant	Pod weight per plant (g)	Test weight (g)	Pod yield (kg/ha)
T1	21 ^{d}	42.900 ^{d}	9.357 ^{b}	2526 ^{f}
T2	26 ^{b}	58.227 ^{ab}	10.053 ^{b}	3428 ^{b}
T3	25 ^{b}	54.927 ^{abc}	10.33 ^{b}	3104.67 ^{d}
T4	23 ^{cd}	48.620 ^{cd}	10.180 ^{b}	2968.67 ^{e}
T5	23b ^{cd}	46.347 ^{cd}	9.733 ^{b}	3168.67 ^{cd}
T6	26 ^{bc}	51.113 ^{bcd}	10.147 ^{b}	3266 ^{c}
T7	32 ^{a}	62.920 ^{a}	12.647 ^{a}	3955.33 ^{a}
T8	30 ^{a}	55.587 ^{abc}	10.547 ^{b}	3482 ^{b}
C.D (0.05)	3.154	9.386	1.622	127.772
SE(m)	1.04	3.094	0.535	42.125

height to 49.41 cm, increased the number of pods to 15.4 and improved seed yield to 1.26 t ha^{-1}. The application of boron fosters an increase in leaf chlorophyll concentration, resulting in enhanced photosynthesis, biomass generation and energy translocation to roots, which facilitates nutrient uptake and culminates in elevated biological yields (Kumar *et al*., 2022).

The study demonstrated that the combined application of borax, soil test-based fertilizers and lime increased boron fractions in the soil. These fractions exist in a dynamic equilibrium, with their levels decreasing as crop growth advances. Readily soluble boron, the most accessible form for plant uptake, is depleted through crop absorption and replenished from other boron fractions to maintain balance. The addition of amendments after lime application can enhance all the boron fraction in the soil. Borax application improved crop growth and yield parameters. The findings indicate that while the total boron content in sandy loam soil is high, boron deficiency is prevalent in the area due to the low levels of labile pools, particularly readily soluble boron. Boron availability in the soil is primarily influenced by the interaction and dynamics of these boron fractions. Therefore, increasing the labile fraction and ensuring adequate replenishment from boron reserves is crucial for maintaining equilibrium and ensuring proper boron availability in the soil.

References

Achin, K. and Singh, A. P., 2018, Direct and residual effect of zinc and boron on growth parameters of rice and wheat grown in sequence in red and alluvial soils of eastern Uttar Pradesh. *Int. J. Chem. Stud.,* **6** (1) : 587 - 592.

Ajayan, A. S. and Thampatti, M. K. C., 2021, Boron dynamics in red loam soil amended with different organic fertilizers. *Int. J. Chem. Stud.*, **9** (1) : 1071 - 76.

Aparna, H. and Puttaiah, E. T., 2012, Residual effect of zinc and boron on growth and yield of french bean (*Phaseolus vulgaris* L.) - rice (*Oryza sativa* L.) cropping system. *Int. J. Environ. Sci.*, **3** (1) : 167 - 171.

Banasode, C. and Channakeshava, S., 2021, Direct and residual effect of zinc and boron on growth, yield and chemical properties of soils under paddy-cowpea cropping system. *Mysore J. Agric. Sci.,* **55** (4) : 104 - 113.

Barman, M., Shukla, L. M., Datta, S. P. and Rattan, R. K., 2014, Effect of applied lime and boron on the availability of nutrients in an acid *soil. J. Plant Nutr.*, **37** (3) : 357-373.

Barman, P., Sen, A., Phonglosa, A. and Bhattacharyya, K., 2017, Depth wise distribution of boron in some soils of red and laterite zone of West Bengal, India. *Int. J. Curr. Microbiol. Appl. Sci.*, **6** (12) : 4126 - 4137.

Bhupenchandra, I., Basumatary, A., Dutta, S., Singh, L. K. and Datta, N., 2020, Impact of boron fertilization on boron fractions at different crop growth stages in cauliflower, cowpea, okra sequence in an inceptisols of North East India. *J. Plant Nutr.,* **43** (8) : 1175 - 1188.

Bray, R. H. and Kurtz, L. T., 1945, Determination of total, organic and available forms of phosphorus in soils. *Soil sci.,* **59** (1) : 39 - 46.

Chatterjee, S., Mukherjee, D., Sharma, S. and Choudhuri, P., 2018, Managing boron and zinc deficiency in vegetable crops. *Innovative Farming*, **3** (2) : 72 - 76.

Datta, S. P., Rattan, R. K., Suribabu, K. and Datta, S. C., 2002, Fractionation and colorimetric determination of boron in soils. *J. Plant Nutr. Soil Sci.,* **165** :179 - 184.

Dey, A., Dwivedi, B. S., Datta, S. P., Meena, M. C. and Agarwal, B. K., 2015, Soil boron status: impact of lime and fertilizers in an Indian long-term field experiment on a Typic Paleustalf. *Soil Plant Sci.*, **65** (1) : 54 - 62.

Emmel, R. H., Sotera, J. J. and Stux, R. L., 1977, Atomic Absorption Methods Manual: Standard Conditions for Flame Operation. Instrumentation Laboratory Inc., Wilmington.

Gupta, S. P., Singh, M. V. and Dixit, M. L., 2008, Deficiency and management of micronutrients. *Indian J. Fertil.,* **3** (5) : 57 - 60.

Hatcher, J. T. and Wilcox, L. V., 1950, Colorimetric determination of boron using carmine. *Anal. Chem.,* **22** (4) : 567 - 569.

Hesse, P. R. and Hesse, P. R., 1971, A Textbook of Soil Chemical Analysis. John Murray Publishers Ltd., London.

Hou, J., Evans, L. J. and Spiers, G. A., 1994, Boron fractionation in soils. Commun. *Soil Sci. Plant Anal.*, **25** (9-10) : 1841 - 1853.

Hou, J., Evans, L. J. and Spiers, G. A., 1996, Chemical fractionation of soil boron: I. method development. *Can. J. Soil Sci.,* **76** (4) : 485 - 491.

Jackson, M. L., 1958, Soil Chemical Analysis. Engle-wood Cliffs: Prentice-Hall.

Jackson, M. L., 1973, Soil Chemical Analysis. Prentice-Hall of India Private Ltd, New-Delhi.

Jin, J., Martens, D. C. and Zelazny, L. W., 1987, Distribution and plant availability of soil; boron fractions. *Soil Sci. Soc. Am. J.,* **51** (5) : 1228 - 31.

Jin, J. Y., Martens, D. C. and Zelazny, L. W., 1988, Plant availability of applied and native boron in soils with diverse properties. *Plant soil.,* **105** : 127 - 132.

John, M. K., Chuah, H. H. and Neufeld, J. H., 1975, Application of improved azomethine-H method to the determination of boron in soils and plants. Anal. Letters., **8** (8) : 559 - 568.

Jyolsna, V. K. and Mathew, U., 2008, Boron nutrition of tomato (*Lycopersicon esculentum* L.) grown in the laterite soils of southern Kerala. *J. Trop. Agric.*, **46** : 73 - 75.

Kasture, M. C., More, S. S., Kapse, V. D. and Jadhav, S. C., 2020, Distribution of Different Fractions of Boron in Soils of Konkan Region of India. *J. Indian Soc. Coast. Agric. Res.,* **38** (1) : 36 - 42.

Kumar, B. A., Upperi, S., Nethravathi B. and Raghu, A., 2016, Influence of boron and magnesium on growth and yield parameters of groundnut (*Arachis hypogaea* L.). *Int. Q. J. Life Sci.*, **11** (4) : 2541 - 2543.

Kumar, A. M., Umesha, C. and Raju, G. V., 2022, Effect of phosphorus and boron levels on growth and yield of chickpea (*Cicer arietinum* L.). *Int. J. Plant Soil Sci.*, **34** (21) : 266 - 271.

Mansingh, M. D. I., Pandian, P. S., Mary, P. C. N., Geetha, R. and Veeramani, A., 2022, Interaction effect of calcium and boron on growth, yield attributes and yield of Groundnut in Vylogam soil series of Madurai district. Biological Forum - An International Journal, **14** (1) : 1135 - 1139.

Massoumi, A. and Cornfield, A. H., 1963, A rapid method for determining sulphate in water extracts of soils. Analyst, **88** (1045) : 321 - 322.

Padbhushan, R. and Kumar, D., 2017, Fractions of soil boron: *A review. J. Agric. Sci.,* **155** (7) : 1023 - 1032.

Prashantha, G. M., Prakash, S. S., Umesha, S., Chikkaramappa, T., Subbarayappa, C. T. and Ramamurthy, V., 2019, Direct and residual effect of zinc and boron on yield and yield attributes of finger millet - groundnut cropping system. *Int. J. Pure App. Bio. Sci.,* **7** (1) : 124 - 134.

Ranjbar, F. and Jalali, M., 2013, Release kinetics and distribution of boron in different fractions in some calcareous soils. *Environ. Earth Sci.*, **70** (3) : 169- 77.

Sathya, S., Mahendran, P. P. and Arulmozhiselvan, K., 2013, Influence of soil and foliar application of borax on fractions of boron under tomato cultivation in boron deficient soil of typic Haplustalf. *Afr. J. Agric. Res.,* **8** (21), 2567 - 2571.

Shankar, M. A., Thimmegowda, M. N., Lingaraju N. N. and Bhavitha, N. C., 2016, Studies on zinc sulphate and boron nutrition on cowpea - finger millet crop rotation system. *Mysore J. Agric. Sci.,* **50** (1) : 39 - 46.

Sims, J. T. and Johnson, G. V., 1991, Micronutrient soil tests. *Micronutrients Agric.*, **4** : 427 - 476.

Soomro, Z. H., Baloch, P. A. and Gandhai, A. W., 2011, Comparative effects of foliar and soil applied boron on growth and fodder yield of maize. *Pakistan J Agric. Eng. Vet. Sci.,* **27** (1) :18 - 26.

Subasinghe, S., Dayatilake, G. A. and Senaratne, R., 2003, Effect of B, Co and Mo on nodulation, growth and yield of cowpea (*Vigna unguiculata*). Trop. Agric. Res., Ext. **6** : 108 - 112.

Subbaiah, B. V. and Asija, G. L., 1956, A rapid procedure for the estimation of available nitrogen in soil. *Curr. Sci.,* **25** : 258 - 260.

Sushma, C., Dawson, J. and Swaroop, B. T., 2023, Effect of potassium and boron on growth, yield and economics of cowpea. *Int. J. Plant Soil Sci.,* **35** (18), 275 - 281.

Tsadilas, C. D., N. Yassoglou, C. S. Kosmas, and C. H. Kallianou, 1994, The availability of soil boron fractions to olive trees and barley and their relationships to soil properties. *Plant and Soil.*, **162** (2) : 211 - 7.

Vera-Maldonado, P., Aquea, F., Reyes-Díaz, M., Cárcamo-Fincheira, P., Soto-Cerda, B., Nunes-Nesi, A. and Inostroza-Blancheteau, C., 2024, Role of boron and its interaction with other elements in plants. Front. *Plant Sci.* **15**:1332459.

Wakley, A. J., 1934, Standard operating procedure for soil organic carbon Walkley-Black method. Rome: FAO.

Xu, J. M., Wang, K., Bell, R. W., Yang, Y. A. and Huang, L. B, 2001, Soil boron fractions and their relationship to soil properties. *Soil Sci. Soc. Am. J.,* **65** : 133 - 138.

Yadav, A. D., Jondhale, D. G., Khobragade, N. H., Bedse, T. J., Dahiphale, A. V., Bhagat, S. B. and Dodake, S. B., 2021, Performance of zinc and boron on content, uptake of micronutrient and yield of cowpea (*Vigna unguiculata* Walp.) in Alfisols of Konkan region of Maharashtra. *J. Pharmacognosy Phytochem.,* **10** (1) : 1180 - 1186.