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Report

Influence of zinc and boron on nutrient concentration in coffee leaf and on coffee yield in northern Thailand

Jiraporn Inthasan [1,*] Chatprawee Dechjiraratthanasiri [1] and Naruemon Taksa-Udom [2]

[1] Division of Soil Resources and Environment, Faculty of Agricultural Production, Maejo University, Chiang Mai 50290, Thailand
[2] Hillkoff Company Ltd., Chiang Mai 50200, Thailand
* Corresponding author, e-mail: inthasan@mju.ac.th

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Abstract: To study the importance of zinc and boron to the nutrient content of coffee (*Coffea arabica*) leaves and yield of coffee at Maerim district, Chiang Mai, Thailand, a field-level study was conducted. Six foliar treatments were laid out in a randomised complete block design: control (Nitrophoska, formula 15-15-15 (C)), C+Ca-B, C+borax, C+$ZnSO_4$, C+Ca-B+$ZnSO_4$ and C+borax+$ZnSO_4$. Results show that the concentrations of macronutrients (N, K, Ca and Mg) and micronutrients (Zn, B and Mn) increase with addition of $ZnSO_4$, $ZnSO_4$+borax and Ca-B compared with control. The application of C+Ca-B+$ZnSO_4$ results in the highest Zn concentration in coffee leaves. Both the C+Ca-B+$ZnSO_4$ and C+borax+$ZnSO_4$ treatments significantly increase boron content in leaves compared with control. Ca-B+$ZnSO_4$ application produces plants with the highest weight of coffee fruits. In conclusion, we recommend a foliar application of Ca-B, borax and $ZnSO_4$, over the traditional application of Nitrophoska to increase coffee yield and quality.

Keywords: coffee, *Coffea arabica*, coffee leaf, coffee yield, nutrient concentration, foliar fertilisation

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INTRODUCTION

Micronutrients such as zinc (Zn) and boron (B), in addition to macronutrients like nitrogen (N), potassium (K) and phosphorus (P), play an important role in the yield and health of coffee plants [1]. Zinc plays a fundamental role in photosynthesis in carbon transport metabolism, meristematic and reproductive tissue mobility, and is a structural constituent of enzymes [1, 2]. Zn deficiency occurs in soils with properties that influence its availability [3]. Boron is necessary for improving quality and yield of crops [4] and is involved in the synthesis and integrity of the cell wall including cell wall lignification and in RNA metabolism and respiration [5]. Boron can also increase fruit set percentage by promoting pollen germination and elongation of pollen tube [6].

Fertiliser sources of zinc are inorganic salts, synthetic chelates and natural organic complexes [7]. The price of zinc sulfate ($ZnSO_4$) fertiliser is cheaper than Zn chelates or organic complexes [8]. Fertiliser sources of B are borax, boric acid, sodium tetraborate, sodium pentaborate, colemanite ($CaB_3O_4(OH)_3.H_2O$), ulexite ($NaCaB_5O_6(OH)_6.5H_2O$) and boron phosphate [9, 10]. However, calcium-boron liquid fertiliser, borax and $ZnSO_4$ are easy to find as regular fertilisers in Thailand where farmers can easily select the most cost-efficient fertiliser type and fertilisation method.

Coffee production and quality can be enhanced by suitable shading, hard pruning and fertiliser management [11]. Coffee production around northern Thailand mostly follows the good agricultural production (GAP) system. Application of both inorganic and organic fertilisers are recommended for improving yield and quality as a way to ensure sustainable agriculture. Generally, the soils for coffee cultivation in northern Thailand are of acidic nature (pH< 5.5) and deficient in calcium and boron [12]. Boron deficiency reduces root growth, flowering, berry formation and expansion stages. Zinc deficiency causes premature flowering and ovule abortion in coffee trees [4, 9, 10]. The functions of Zn, B and Ca are to promote the growth stage of coffee at flowering, berry quality and yield potential [13-15]. Generally, plants can be satisfied by foliar and soil application depending on the stage of growth [16]. Soil application of Zn and B is less effective than foliar uptake to solve Zn and B deficiency [17, 18], although plant tissue analysis is best evaluated in conjunction with the results of soil analysis. With the goal of improving yield and quality, this study aims to measure the nutrient content of leaves and the yield of Arabica coffee when using foliar fertilisers and to compare the effects of different fertilisers for coffee production.

MATERIALS AND METHODS

Arabica coffee trees (*Coffea arabica*) were selected from an experimental field (357 m above sea level) of Hillkoff Company in Maerim district, about 50 km north of Chiang Mai city, Thailand. The top soil (0-30 cm) was classified as a red-yellow, sandy clay loam, low in pH (5.08) with low organic matter (1.35%). The soil concentrations of extractable forms of phosphorus via Bray II (0.03M NH_4F, 0.1M HCl); potassium, calcium and magnesium via ammonium acetate (1M NH_4OAc, pH 7); iron, manganese, copper and zinc via diethylenetriaminepentaacetic acid; and boron via hot water and azomethine-H method [19] were 10, 48, 350, 38, 154, 85, 3.5, 3.0 and 0.45 mg/kg respectively.

The Arabica coffee trees had been grown for four years with 3×1 m tree spacing. Six foliar application treatments with one coffee tree per treatment were laid out in a randomised complete block design with four replications. The treatments were as follows: control (Nitrophoska fertiliser formula 15-15-15, 200 g/tree (C)), C+Ca-B (calcium-boron liquid fertiliser, 1 mL/L water), C+ borax (H_3BO_3, 0.5g/L water), C+$ZnSO_4$ ($ZnSO_4$, 1 g/L water), C+Ca-B (calcium-boron liquid fertiliser, 1 mL/L water)+$ZnSO_4$ (1 g/L water), and C+borax (H_3BO_3, 0.5 g/L water)+$ZnSO_4$ (1 g/L water). The foliar sprays were applied once a week between July-September 2018. Twenty leaf samples (3-4th from the top of coffee tree) were collected from each tree after two weeks from the cessation of foliar application and the leaves were oven-dried at 70 °C for 48 hr.

N content was analysed by the Kjeldahl digestion and distillation method. Leaf samples were digested by nitric acid : perchloric acid (6:1), and this solution was analysed for P, K Ca, Mg,

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Fe, Mn, Zn and Cu [20]. Boron content was evaluated by hot water extraction and spectrophotometric method by azomethine-H [21]. Coffee yields and quality were recorded for each tree at harvest time by counting branches per tree, rosettes per branch and beans per rosette. One hundred fruits per tree were then collected for measurement of fresh and dry weights.

All parameters and regression were analysed for statistically significant differences between treatments using Statistix 10 software for analysis of variance (ANOVA), mean separation and least significant difference (LSD) test at significance levels of $P<0.05$ and 0.01.

RESULTS AND DISCUSSION

Macro Element Concentrations in Coffee Leaf Samples

From Table 1, N, P and Mg concentrations are not significantly different for the six treatments with average concentrations of 2.04% N, 0.12% P and 0.45% Mg. $ZnSO_4$ application results in the highest K concentration of 2.21% ($P<0.05$), but K concentration is not significantly different between treatments with application of borax, borax+$ZnSO_4$ and Ca-B+ $ZnSO_4$. The Ca concentrations in coffee leaf samples in all treatments are higher than in control. Kanwal et al. [22] found that foliar applications of calcium chloride and borax or trace elements have no significant impact on N, P, K and Mg in shoot tissues of maize. The Ca concentration in coffee leaves of this experiment shows a higher average when compared with that by Ojeniyi [23], who reported the mean concentrations of 0.70% Ca and 0.21% Mg in coffee leaves without application of NPK fertiliser. Hue [24] reported that the application of Ca + Zn fertiliser increases the nutrient composition in leaves of coffee trees growing in Andisol and Ultisol soils in Hawaii. He further reported that Zn treatment can increase P, Ca and Mg concentrations, which may illustrate the roles of Zn in cell division and protein synthesis [15].

Table 1. Effects of application of trace elements on macronutrient concentrations in coffee leaf at two weeks after foliar application

Treatment	N	P	K	Ca	Mg
	(-------------------	-------------------	-----%-----	-------------------	-------------------)
Control	1.86	0.13	1.52 c[1/]	5.35 b	0.43
Ca-B	1.89	0.12	1.68 bc	6.15 ab	0.46
Borax	2.05	0.13	1.76 abc	6.10 ab	0.45
$ZnSO_4$	2.13	0.12	2.21 a	5.94 ab	0.45
Borax +$ZnSO_4$	2.14	0.11	2.20 a	5.96 ab	0.45
Ca-B + $ZnSO_4$	2.21	0.12	2.18 ab	6.56 a	0.47
Grand mean	2.04	0.12	1.93	6.01	0.45
C.V.(%)	22.35	11.12	17.43	6.81	14.20
F-test	ns	ns	*	*	ns

Note: * Significant difference at $P< 0.05$ level
ns = non-significant difference
[1/] Values followed by different letters are significantly different according to LSD.

Micronutrient Concentrations in Coffee Leaf Samples

Fe, Cu and Mn concentrations are not significantly different between treatments with averages of 85.7, 5.0 and 49.7 mg/kg respectively (Table 2). Ca-B+$ZnSO_4$ application results in the highest Zn concentration at 36.7 mg/kg (P<0.05). Maximum B content of coffee leaf samples can be observed at 37.3 mg/kg with B+$ZnSO_4$ treatment, compared with control at 20.1 mg/kg (P<0.05). In another study the concentrations of Zn, B, Mn and Cu in coffee leaf increased with application of boric acid, Zn and Cu salts [25]. Martinez et al. [26] proved that foliar application of both $ZnSO_4$ at 0.4% (w/v) and Zn salt tablets (1.8 g $ZnSO_4$) in Arabica coffee in Brazil provided higher Zn content in young leaf samples than control. For coffee seedlings in Hawaii, Zn application increased Zn concentration in leaf samples but decreased the levels of Mn and B [24]. Zn and B nanofertiliser caused nutrient uptake of coffee seedlings leaf in the greenhouse by increasing Zn content at 60 and 100 days after spraying [27]. The averages of all micronutrient concentrations in coffee leaf samples showed that they were at sufficient levels (15-30 mg/kg Zn, 40-100 mg/kg B, 16-20 mg/kg Cu, 50-100 mg/kg Mn and 70-200 mg/kg Fe) [13].

Table 2. Effects of application of trace elements on micronutrient concentrations of coffee leaf at two weeks after foliar application

Treatment	Fe	Zn	B	Cu	Mn
	(------------------------------------		mg/kg		------------------------------------)
Control	81	14.2 b[1/]	20.1 b	4.2	41.7
Ca-B	79	17.0 b	28.3 ab	4.9	42.0
Borax	84	18.1 b	30.5 ab	4.9	43.5
$ZnSO_4$	92	25.5 b	27.5 ab	5.8	55.7
Borax +$ZnSO_4$	83	29.5 b	37.3 a	5.2	58.8
Ca-B + $ZnSO_4$	95	36.7 a	35.2 a	5.0	56.5
Grand mean	85.7	23.5	29.5	5.0	49.7
C.V.(%)	14.01	28.65	17.37	13.23	21.32
F-test	ns	*	*	ns	ns

Note: *Significant difference at P< 0.05 level
ns = non-significant difference
[1/] Values followed by different letters are significantly different according to LSD.

Quality and Yield

The number of branches per tree and the number of beans per rosette (Table 3) are not significantly different among the treatments. Application of borax + $ZnSO_4$ results in the highest number of rosettes per branch with an average of 10.3 (P<0.05), while the lowest number of rosettes per branch is found in control (7.4). The highest fresh and dry weights are obtained from Ca-B + $ZnSO_4$ treatment (P<0.05). This result agrees with the work of Junia [25] who reported increased coffee berry production with treatments of B + Cu and B + Zn (35.01% and 22.82% higher than control). Further, Filho and Malavolta [28] found that the application of B and Zn increased the dry biomass in coffee seedlings (21% higher than control). Usenik and Stampar [29] confirmed that combined Zn and B foliar fertilisation improved fruit yield and biomass compared to control trees. It is possible that Zn participates in the metabolism of carbohydrates and proteins and is involved in

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gene transcription to increase plant growth and fruit size [30] while B is a key component of cell walls and stimulates the flowering and fruiting processes of plants [15]. Our data indicated low Ca, B and Zn concentrations in the top soil before foliar application and Ca-B, borax and $ZnSO_4$ apparently increased all parameters compared with control treatment.

Table 3. Effects of application of trace elements on quality and yield of coffee at harvesting time

Treatment	Branches/tree	Rosettes/branch	Beans/rosette	Fresh weight (100 beans)	Dry weight (100 beans)
Control	18.4	7.4 b	10.3	112.2 c	32.95 c
Ca-B	20.5	8.7 ab	10.4	130.0 bc	43.11 b
Borax	22.8	9.0 ab	10.6	134.4 bc	44.68 ab
$ZnSO_4$	20.1	9.6 ab	11.6	136.3 b	46.95 ab
Borax +$ZnSO_4$	20.4	10.3 a	11.8	161.3 a	47.59 ab
Ca-B + $ZnSO_4$	20.8	9.5 ab	12.6	165.0 a	51.12 a
Grand mean	20.5	9.08	11.21	139.84	44.400
C.V.(%)	19.41	18.40	20.19	9.09	10.86
F-test	ns	*	ns	*	*

Note: * Significant difference at $P< 0.05$ level
ns = non-significant difference
1/ Values followed by different letters are significantly different according to LSD.

The relationships between concentrations of Zn and B and fresh bean weight and beans per rosette are shown in Figures 1 and 2. The Zn and B concentrations in coffee leaf are positively correlated with the number of beans per rosette and bean fresh weight. Zn applied by foliar spraying was reported to have a strong positive relationship ($R^2 = 0.9547$) with coffee berry production [24]. Similar results were also obtained by Santinato et al. [31]. They explained that during the reproductive growth stage of coffee, B is translocated to fruits and leaves of node bearing fruits. However, in some cases there was no observed correlation between leaf boron content and coffee yield [28, 31].

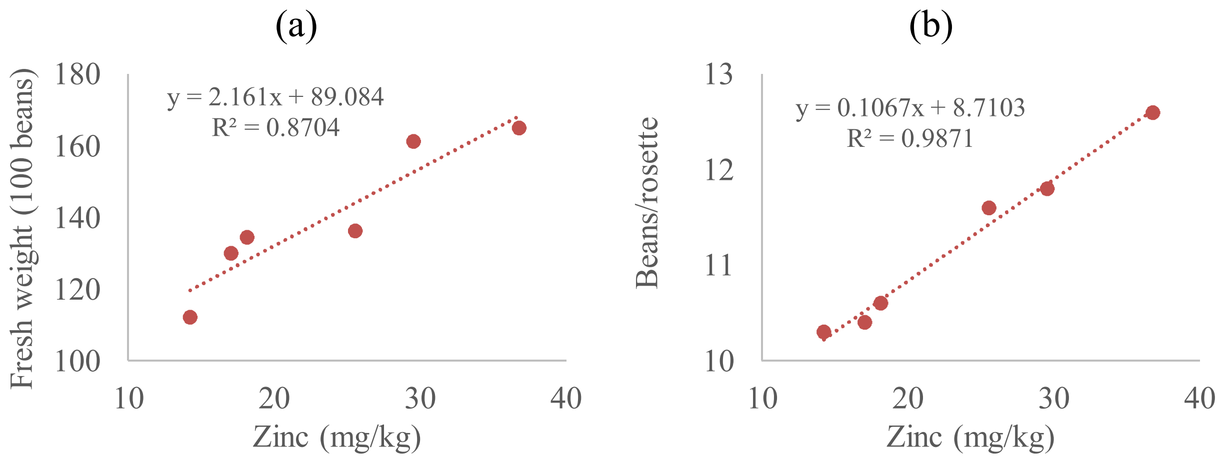

Figure 1. Relationships between Zn concentration in coffee leaf and (a) fresh weight of 100 beans; (b) beans per rosette

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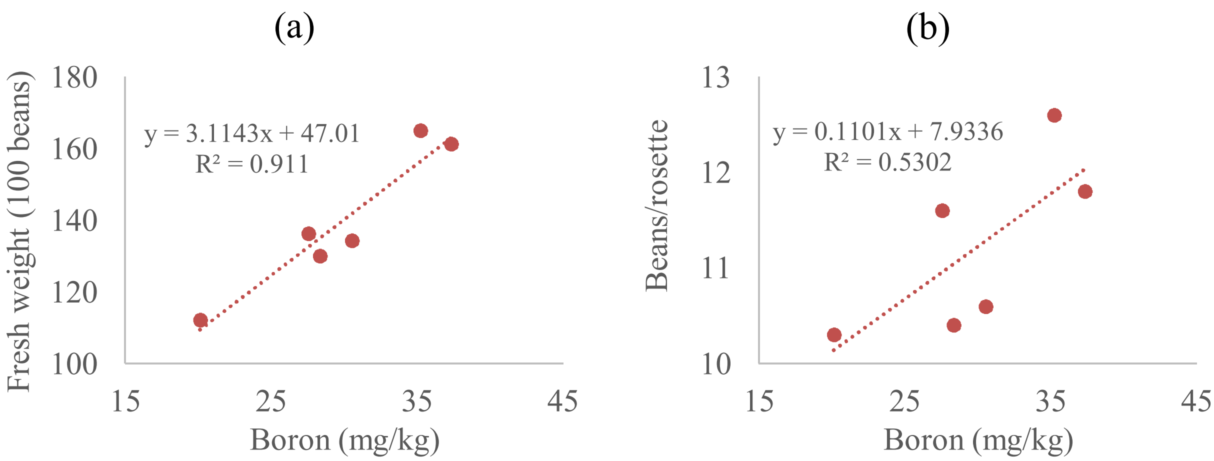

Figure 2. Relationships between B concentration in coffee leaf and (a) fresh weight of 100 beans; (b) beans per rosette

CONCLUSIONS

Generally, foliar application of boron and zinc fertilisers tends to increase the concentrations of N, K, Ca and Mg in coffee leaf samples. Additional Ca-B + $ZnSO_4$ treatment results in the highest Zn concentration in coffee leaf at 36.7 mg/kg. Both Ca-B and borax with $ZnSO_4$ can increase boron concentration in coffee leaf. Ca-B + $ZnSO_4$ produces highest fresh and dry weights of coffee fruits.

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