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DOI: 10.37722/AAHAE.2023203

Research Article **Advances in Agriculture, Horticulture and Entomology** **AAHE-185**
ISSN 2690-1900

Response of Improved Arabica Varieties in Tanzania to Secondary Macronutrients and Micronutrients

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Received Date: October 15, 2023; **Accepted Date:** October 20, 2023; **Published Date:** October 27, 2023;

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Abstract

A study was conducted to assess the effect of copper, sulphur and a ready-made cocktail "Polyfeed" on leaf retention, plant characteristics and yield of selected new varieties. Two trials were established at Lyamungu onstation and a nearby APK estate in 2015 and 2017 respectively, following a split plot design in randomized complete blocks (three replications). Varieties KP423 (check), TaCRI-6F (new compact) and KP423-1 (new tall) were the main factors and the nutrient cocktails (60g copper oxychloride - Cobox as foliar spray, 60g Cobox and 75g Polyfeed as foliar spray, 75g Polyfeed alone, 50g of SA 21%N applied to the soil, and an untreated control) were sub factors. All plots were equally treated with NPK 20:10:10 at 150g per tree in addition to the cocktails. The trials were run for 3 years with leaf retention, growth characteristics and yield data captured. Data were exposed to ANOVA using the COSTAT software; with means separated by Tukey's HSD method at 0.05 significance level. Leaf retention was not significant ($p > 0.05$), implying that the number of active leaves, and therefore photosynthetic capacity, is not affected by the added cocktails as long as the major nutrients are optimally supplied. Varieties had a deceasing significance trend in yield over the years, implying, probably, that yields of different varieties tend to normalize with age. The treatment cocktails onstation had an increasing significance trend in yield, whereas they were consistently very highly significant ($p<0.001$) onfarm. The dominance of copper oxychloride and SA in the first two rankings partly confirms the tonic effect of copper application in coffee and the soil's responsiveness to sulphur. We therefore encourage the use of NPKS formulations, and recommend a twice-yearly application of 60g copper oxychloride even for the improved varieties.

Keywords: *Improved coffee varieties; Micronutrients; Secondary macronutrients; Tanzania*

Introduction

Coffee is the second most sought after commodity globally after crude oil (Goldschein, 2011). The global coffee industry is estimated to be worth about US$ 100 billion. A total of 70 countries grow coffee in Asia, South America, Africa, the Caribbean and Central America, 45 of which are exporting members of the International Coffee Organization, responsible for over 97% of world output (ITC, 2002). Production from 2017/18 to 2020/21 stood at 163.7, 172.5, 165.0 and 175.3 million bags. The industry has been a source of livelihood for more than 25 million people and their families globally (ICO, 2021). Tanzania is the 15th largest coffee producer in the world and 3rd in Africa after Ethiopia and Uganda (TCB, 2021). The crop accounts for about 5% of total crops exports earning (about an average of US$ 100 million per annum) and supports the livelihoods of over 400,000 farming families. Its importance in the Tanzanian economy is well documented by Agrisystems (1998), Baffes (2003) and Hella *et al* (2005) among others.

Of the challenges that have been facing the coffee industry for a long time, diseases (mainly coffee berry disease and leaf rust for Arabica) had by far been the most limiting. This has been due to the narrow genetic base of the traditional varieties which are derivatives of Bourbon and Kent. The two diseases reduce yields as much as 20-60% and are quite expensive to manage, amounting to 30-50% of the total cost of production (Teri *et al*, 2004). Copper has been traditionally sprayed as a fungicide for control of CBD and CLR (Birikunzira, 2000; Teri *et al*, 2004; Granados and Zambolim, 2019). For the areas with susceptible varieties, copper deficiency is a rarity.

TaCRI has released 19 new improved Arabica varieties that are resistant to the two diseases, which implies that fungicide spraying would normally be unnecessary. On the other hand, copper has been reported to enhance leaf retention in the plant. The delayed leaf senescence allows for longer uptake of soil water and plant nutrients, uninterrupted photosynthesis and more carbohydrates becoming available for grain filling (Brinate *et al*, 2015). In Kenya, yield increases of 40-85% were reported cumulatively over five years. Retention and greening of coffee leaves was enhanced by twice-yearly "tonic" sprays of broad-spectrum fungicides. The average leaf longevity on Arabica coffee was 9-10 months (Van der Vossen and Browning, 1978).

Most of the coffee growing areas in Tanzania experience very low levels of micronutrients. Cordingley (2010) showed a big variation in soil potassium levels, extreme sulphur deficiencies (as shown in **Figure 1**), very deficient soil and leaf boron levels and very deficient leaf zinc levels.

He pegged optimal soil S for coffee at 40 mg kg^{-1} and the minimum threshold at 20 mg kg^{-1}. The soil sulphur status of the 25 coffee growing districts involved in his survey were low, below the minimum level. He therefore recommended to add sulphur to the compound fertilizer formulation due to its extreme deficiencies. But whether this suggestion leads to a significant increase in yield and quality against the traditional NPK combinations need to be verified experimentally. Therefore, a study was conducted to assess the effect of selected secondary macronutrients and micronutrients on growth, leaf retention and yield of new coffee varieties.

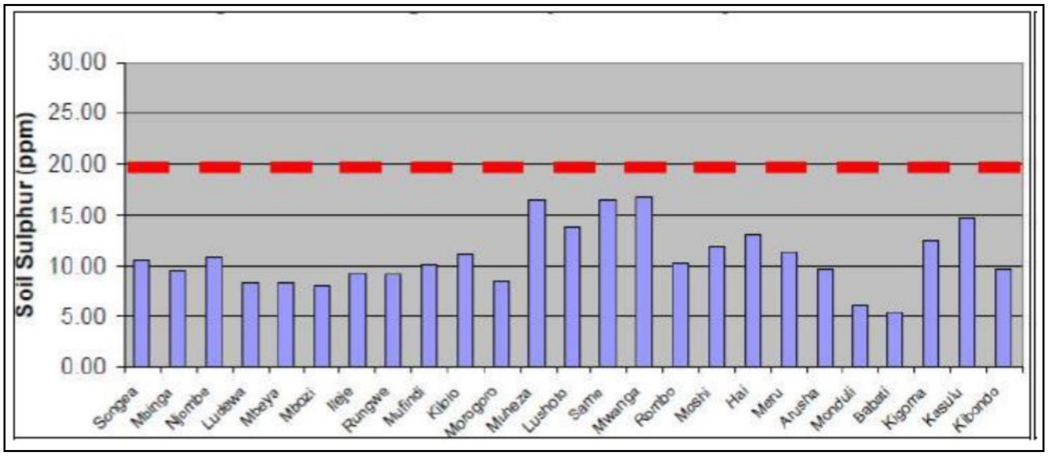

Figure 1: Soil sulphur status of Tanzanian coffee areas (after Cordingley, 2010).

Material and Methods

Study areas

Field trials were established onstation at Lyamungu (Hai) and a nearby estate belonging to the African Plantations of Kilimanjaro (APK) Ltd. Lyamungu lies approximately at Latitude 3º14'158" south and Longitude 37º14'463" east, with altitude 1305 metres above sea level (masl). It experiences a bimodal rainfall pattern with short rains extending from October to December, and the main rains from March to May. Total annual precipitation is 1679 mm. Soil is classified as Haplic Nitisol (Humic, Dystric) according to WRB (IUSS, 2014). The APK Estate, being about 200m away, is assumed to share the same properties.

Experimental set-up

The two field trials were established in 2015 (Lyamungu) and 2017 (APK), using a split plot design in randomized complete blocks (three replications). Varieties KP423 (old variety check), TaCRI-6F (new variety compact) and KP423-1 (new variety tall) constituted the main factor and the nutrient cocktails the sub-factor. Plot size had 16 trees, of which the middle 4 trees formed the net plot. The trials were planted and routinely managed for one year before the application of treatments. All plots were equally treated with NPK 20:10:10 at the rate of 150g per tree. In addition to this blanket application, fertilizer cocktails were as follows: T1: 60g copper oxychloride (Cobox) as foliar spray, T2: 60g Cobox and 75g Polyfeed 19/19/19 (with 500 mg kg^{-1} Fe, 250 mg kg^{-1} Mn, 100 mg kg^{-1} B, 75 mg kg^{-1} Zn, 55 mg kg^{-1} Cu and 35 mg kg^{-1} Mo) as foliar spray, T3: 75g Polyfeed as foliar spray, T4: 50g of SA 21%N applied to the soil, and T5: Control, no treatment. Treatments were applied in two split dosages of six months each.

Data collection and analysis

In order to assess leaf retention, two trees within the treated plots were selected. Three branches per tree (lower, middle and upper) were tagged at both ends. Leaf count was done between these tags 1, 2, 3 and 4 months after the first application and means per tree calculated. Leaf retention was determined as a percentage of initial tagged leaves still intact after 4 months as in Brinate *et al* (2015). Other growth characteristics were measured during the first harvest year. The trials were run for 3 years with yield data collected. Cherry yield per plot was

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converted to clean coffee yield per ha. Data were exposed to ANOVA using the COSTAT statistical software according to the split plot model suggested by Kuehl (2000); with means separated by Tukey's HSD method at 0.05 significance level.

Results and Discussion

Leaf retention

Average percent leaf retention per treatment is shown in **Figure 2**. No significant difference in leaf retention was noted among treatments and between each treatment and the control. This implies that the number of active leaves, and therefore photosynthetic capacity, is not affected by the added cocktails as long as the major nutrients are optimally supplied. The slight increase in the number of retained leaves with the upper primaries was expected, because the uppermost primaries are supposedly the youngest.

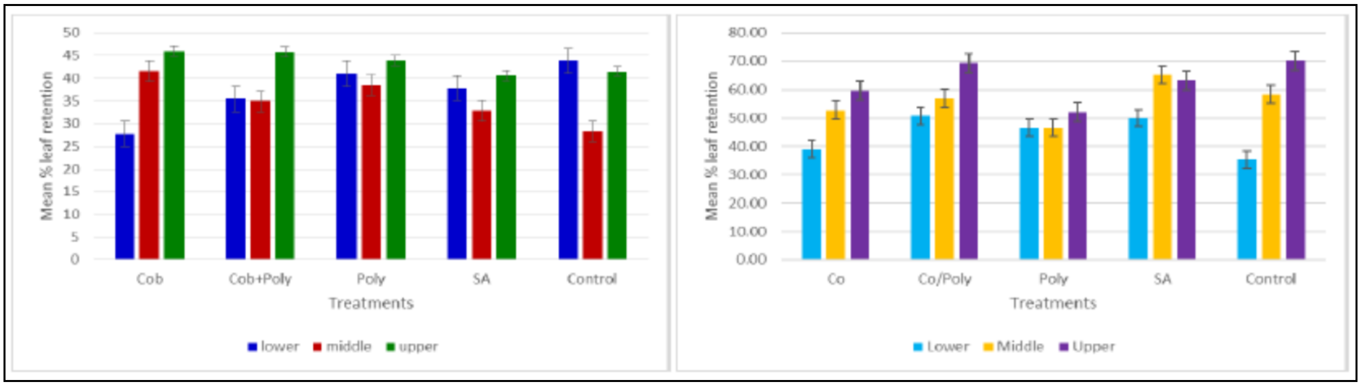

Figure 2: Mean percent leaf retention per treatment onstation (left), onfarm (right).

Plant Characteristics

A summary of the ANOVA for plant characteristics is given in **Tables 1** and **2** for onstation and onfarm trials respectively. Blocks, treatments and variety-treatment interaction had no significant variation throughout ($p > 0.05$) with the exception of stem girth onfarm where it showed unexpected significance ($p<0.05$). Varieties differed significantly in terms of berry clusters, both onstation and onfarm. They also differed highly significantly in terms of number of bearing branches ($p < 0.01$).

SV	Berry Cluster	Int. length	B/branches	C/width	Tree height	Stem girth
Rep	0.7546	0.3487	0.2889	0.6150	0.9761	0.7694
Variety	0.0322*	0.0008***	0.0029**	0.2039	0.9339	0.0112*
Treatment	0.8712	0.8849	0.6209	0.7365	0.9016	0.7369
Var x Treat	0.8564	0.8844	0.9582	0.7514	0.9996	0.8099

Table 1: ANOVA summary for plant characteristics onstation.

SV	Berry Cluster	Int. length	B/branches	C/width	Tree height	Stem girth
Rep	0.9589	0.2540	0.1073	0.0527	0.2609	0.0118*
Variety	0.0102*	0.0014**	0.0029**	0.0005***	0.0319*	0.4559
Treatment	0.7172	0.6077	0.9038	0.8997	0.9859	0.5920
Var x Treat	0.9650	0.6296	0.7765	0.2542	0.9144	0.9209

Table 2: ANOVA summary for plant characteristics onfarm.

Lack of significant varietal difference in canopy width and tree height onstation was rather unexpected when comparing tall and compact varieties. In contrast, the two were very highly significant ($p<0.001$) and significant ($p<0.05$) respectively onfarm. Again, lack of significant effect of treatments on any of the six growth parameters implies that growth is not affected by the added cocktails as long as the major nutrients are optimally supplied, as also noted in Brinate *et al* (2015).

Yields Onstation

Both blocks and variety x treatment had no significant variation throughout ($p > 0.05$). Varieties showed to have significant ($p<0.05$) effect on yield for the first and second year, but not for the third year. The treatment cocktails did not result into any significant yield difference for the first year, but showed to be highly significant ($p<0.01$) in the second year, and very highly significant ($p < 0.001$) in the third year. The model was also significant to highly significant in the second and third years, with respective R^2 = 0.58 and 0.63; CV = 27.66% and 23.26%.

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Ranking	Year 1		Year 2		Year 3	
	Entry name	Mean	Entry name	Mean	Entry name	Mean
1	TaCRI-6F	437.44 a	TaCRI-6F	665.83 a	TaCRI-6F	829.72 a
2	KP423	338.94 ab	KP423-1	541.72 b	KP423-1	778.88 b
3	KP423-1	286.94 b	KP423	518.94 b	KP423	710.55 c

Table 3: Mean ranking for Varieties.

Ranking	Year 1		Year 2		Year 3	
	Entry name	Mean	Entry name	Mean	Entry name	Mean
1	SA	429.07 a	Co	718.15 a	Co	934.26 a
2	Co	412.22 a	SA	649.16 b	SA	887.04 b
3	Poly	334.16 b	Co+Poly	600.00 b	Co+Poly	864.81 b
4	Co+Poly	327.31 b	Poly	479.63 c	Poly	619.91 c
5	Control	269.44 c	Control	430.55 c	Control	559.26 d

Table 4: Mean ranking for Treatments.

Mean ranking for varieties is given in **Table 3**, whereby rankings with same letter are not considered significant. The new compact variety TaCRI-6F ranked the first throughout. For the first year, the second ranking went to the traditional variety KP423 followed by the new tall variety KP423-1. The order was reversed for the second and third years, whereby KP423-1 "regained" its second ranking; as it has been widely established that potential yields tend to decrease in the order new compact > new tall > traditional. Mean ranking for cocktail treatments is given in **Table 4**. Cobox (i.e., copper oxychloride), applied as foliar spray, and SA, applied to the soil, occupied the first two positions, with SA topping the list in the first year and Cobox in the subsequent years. In the first year, Polyfeed and a mixture of Cobox and Polyfeed ranked the third and fourth respectively, the order reversed in the subsequent years. This implies that the additive effect with the mixture of Cobox and Polyfeed started to manifest itself as from the second year. The untreated control, expectedly, maintained the last ranking throughout. Considering the overall mean varietal and cocktail influence of yield over years, we note a steady increase onstation.

Yield Onfarm

Both blocks and variety x treatment had no significant variation throughout ($p > 0.05$). Varieties showed to have very highly significant ($p<0.001$) effect on yield for the first year, decreasing to significant ($p<0.05$) effect for the second year, and insignificant ($p>0.05$) for the third year. The treatment cocktails were consistently very highly significant ($p < 0.001$) through the years. The model was also very highly significant throughout, with respective R^2 = 0.754, 0.88 and 0.764; CV = 19.46%, 16.86% and 13.94%.

Ranking	Year 1		Year 2		Year 3	
	Entry name	Mean	Entry name	Mean	Entry name	Mean
1	TaCRI-6F	685.55 a	KP423	411.67 a	TaCRI-6F	983.61 a
2	KP423	541.11 b	TaCRI-6F	380.00 ab	KP423-1	927.22 a
3	KP423-1	492.22 b	KP423-1	344.72 b	KP423	922.06 a

Table 5: Mean ranking for Varieties onfarm.

Ranking	Year 1		Year 2		Year 3	
	Entry name	Mean	Entry name	Mean	Entry name	Mean
1	Co	713.89 a	Co	598.61 a	Co	1226.85 a
2	SA	643.52 ab	SA	416.67 b	SA	1017.59 ab
3	Co+Poly	619.44 ab	Co+Poly	374.53 bc	Poly	892.59 b
4	Poly	527.77 b	Poly	312.50 bc	Co+Poly	887.22 b
5	Control	360.19 c	Control	191.67 c	Control	697.22 c

Table 6: Mean ranking for Treatments onfarm.

Mean ranking for varieties is given in **Table 5**, with the same rule as above. The new compact variety TaCRI-6F ranked the first in Year 1 and 3, coming up second in Year 2. Surprisingly enough for the second year, the top ranking went to the traditional variety KP423. Expected ranking (TaCRI-6F > KP423-1 > KP423) was attained during the third year, though their differences were not significant. Mean ranking for cocktail treatments is given in **Table 6**. Cobox, applied as

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foliar spray, and SA, applied to the soil, occupied the first two positions throughout. The order for Year 1 was exactly followed in Year 2 (Cobox > SA > Cobox+Polyfeed > Polyfeed > Control) while for Year 3, the positions of Cobox+Polyfeed and Polyfeed alone were reversed. The untreated control, expectedly, maintained the last ranking throughout. Considering the overall mean varietal and cocktail influence of yield over years, we note that onfarm, year 2 performed less than years 1 and 3, implying clearly the old phenomenon of biennial bearing (Wrigley, 1988).

General Discussion

Balanced plant nutrition requires availability of primary macronutrients N, P and K, secondary macronutrients Ca, Mg and S, and also micronutrients B, Cu, Zn, Mn, Fe, and Mo (Oberthur *et al*, 2012). Whereas secondary macronutrients and micronutrients requirement by coffee plant for normal growth and high yield are smaller than those of the primary macronutrients, they are equally important for productivity and quality (Epstein and Bloom, 2005; Dell *et al*, 2003). Their deficiencies greatly limit the effectiveness of the primary macronutrients (CRI, 1991), and may lead to metabolic disturbances that affect coffee production and beverage quality (Clemente *et al*, 2018). The dominance of copper oxychloride in the first two rankings partly confirms the so-called "tonic effects" of copper application in coffee (Burdekin, 1964; Mulinge and Griffiths, 1974; Van der Vossen and Browning, 1978; Birikunzira, 2000) by increasing yield, even though the claimed relationship between yield increase and leaf retention was not clearly shown. On the other hand, the observed reduction in varietal yield significance over years suggests that, as different varieties get older, their yield difference gets smaller; but this needs scientific verification.

Copper has many functions in plants. It is a constituent of the chloroplast protein plastocyanin, which forms part of the electron transport chain linking the two photochemical systems of photosynthesis (Boardman, 1975). It is also a constituent of several enzymes and a co-factor in enzyme synthesis. Other functions include mediation of some oxidation reactions and enhancement of symbiotic N_2 fixation (Mengel *et al*, 2001). As for the "tonic effect", Brinate *et al* (2015) noted that greater productivity occurs because: (a) plants supplied with copper have higher foliar copper concentration and lower intensity of rust, and thus have fewer injured leaves. This allows the plant to have higher photosynthetic activity to meet the demand of fruit, given the available assimilates, thereby enabling its full development; (b) In addition to its role as a co-factor in numerous enzymes (Mengel *et al*, 2001), copper supports in the formation of pollen and in fertilization, thus facilitating greater fruit set and production of a greater number of fruits.

On the other hand, continuous use of copper-based fungicides is said to have caused Cu accumulation in soils (Loland and Singh, 2004). Such accumulation may be through drops of solution containing the fungicide falling on the soil, and when Cu-containing leaves fall naturally or are pruned, and undergo mineralization (Dos Santos *et al*, 2009). This poses a potential hazard to the environment and may be harmful to human beings (Lamb *et al*, 2009) through contamination of the food chain (Senkondo *et al*, 2015; Maro, 1994). Jaiswal *et al* (2019) noted nausea and vomiting as two obvious symptoms of copper toxicity in humans. Others are diarrhea (may have a bluish colour or contain blood), fever and bodily chills, muscular convulsion or weakness, pain or burning sensation in the abdominal area, yellowing of the eyes and skin (jaundice), anemia, metallic taste in the mouth and lack of urine due to kidney malfunction. Taylor *et al* (2019) recommended a threshold daily intake of 0.04 mg kg^{-1}. Fortunately, Utomo (2008) hinted that drinking coffee may help the human body in copper detoxification through binding of the free Cu^{2+} ions by soluble organic ligands. Kyzas *et al* (2013) also noted the potential of using coffee grounds as organic adsorbents in removing Cu from aqueous solutions.

Sulphur is a constituent of important amino acids (e.g. cysteine and methionine), multiple enzymes such as Coenzyme A, and some vitamins such as biotine and thiamine (Mengel *et al*, 2001). It is essential for the efficient utilization of nitrogen, and sulphur deficiency in soils can result in excess free nitrogen in crops, which is a condition very attractive to pests and diseases. Sulphur also adds to the cupping qualities of coffee. The total S content in plant tissues is in the order of 0.2-0.5% S in dry matter. The SA treatment was included to add sulphur to the soil and evaluate the claim by Cordingley (2010) that most soils in Tanzania do not have enough sulphur, and the modified NPKS formulations are the best for coffee. By its maintenance of first two rankings, the claim is tentatively confirmed, at least in the Lyamungu area where the trial is located. Following the recommendation given by Cordingley (2010), already a number of NPKS formulations are available in the market. He discouraged the SA used in this particular study due to the long-term soil acidification effects. We wouldn't recommend it here either, despite its topping the list in Year 1 (onstation), and maintenance of second position throughout (onfarm).

Conclusion

This study was conducted to assess the effect of tonic application of copper, sulphur and a ready-made cocktail "Polyfeed" on leaf retention, plant characteristics and yield of new varieties. Leaf retention did not show any significant difference among treatments and between each treatment and the control. This implies that the number of active leaves, and therefore photosynthetic capacity, is not affected by the added cocktails as long as the major nutrients are optimally supplied. The slight increase in the number of retained leaves with the upper primaries was expected, because the uppermost primaries are supposedly the youngest. Varieties showed to have a decreasing significance trend in yield over the years. The treatment cocktails onstation did not result into any significant yield difference for the first year, but were highly significant in the second year and very highly significant in the third year. On the other hand, they were consistently very highly significant onfarm. The dominance of copper oxychloride and SA in the first two rankings partly confirms the so-called "tonic effects" of copper application in coffee and the soil's responsiveness to sulphur. To enhance the productivity of the improved coffee varieties, this paper therefore recommends a twice-yearly application of 60g Copper oxychloride, notwithstanding their resistance to CBD and CLR. It is also advised to switch to the new NPKS formulations to balance the supply of Sulphur to crops.

Abbreviations

ANOVA: Analysis of variance; **APK:** African Plantations of Kilimanjaro; **CBD:** Coffee berry disease; **CLR:** Coffee leaf rust; **CV:** Coefficient of variability; **ICO:** International Coffee Organization; **ITC:** International Trade Centre; **IUSS:** International union of soil science; **NPK:** Nitrogen, Phosphorus and Potassium compound fertilizer; **NPKS:** Nitrogen, Phosphorus and Potassium compound fertilizer with additional Sulphur; **SA:** Sulphate of ammonia fertilizer; **TaCRI:** Tanzania Coffee Research Institute; **TCB:** Tanzania Coffee Board; **WRB:** World reference base for soil resources.

Author contributions

This work was carried out in collaboration among all authors. Author GM designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors SM, HM and EN managed the literature searches. Authors HM, EN and EM handled the field study and data collection. All authors read and approved the final manuscript.

Competing interests

Authors have declared that no competing interests exist.

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Citation: *Maro, Godsteven P, Mbwambo, Suzana G, Monyo, Harrison E, Nkya, Emmanuel O, Mosi, Epafra J (2023) Response of Improved Arabica Varieties in Tanzania to Secondary Macronutrients and Micronutrients. Adv Agri Horti and Ento: AAHE-185.*