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Micronutrient Status in Commercial Sugarcane-growing Alfisols at *Sevanagala*, Sri Lanka

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ABSTRACT

The continuous mono-culture cropping without organic matter addition could deplete the plant available micronutrient reserves in sugarcane-growing soils. This study attempted to investigate the current status of micronutrient availability in commercial sugarcane-growing Alfisols at *Sevanagala*, Sri Lanka, and to assess the potential of these soils to become micronutrient deficient in the future. Sugarcane-growing Alfisols at *Sevanagala*, covering both irrigated and rain-fed cropping systems, and low humic gley (LHG) and reddish-brown earth (RBE) soils were included in this study. A stratified random sampling technique, covering both cropping systems and soil orders, was employed to obtain 263 samples. Soils were analyzed for available Fe, Mn, Zn, and Cu contents using the standard DTPA procedure. Available Fe and Zn contents exhibited significant differences among cropping systems and soil orders. They were significantly higher under RBE soil (75 mg/kg and 1.1 mg/kg in Fe and Mn, respectively) when compared to those under LHG soil (43 mg/kg and 0.6 mg/kg in Fe and Mn, respectively). Available Fe and Mn contents were at sufficient levels for sugarcane in most soils. In contrast, Zn and Cu contents exhibited deficient patches (< 0.1 mg/kg) within the cropping systems and great soil groups in the studied area. The results indicate that appropriate nutrient management practices are required to overcome Zn and Cu deficiencies in *Sevanagala* sugarcane-growing Alfisols and to mitigate any negative effects on crop yield and quality in the future.

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INTRODUCTION

Sugarcane (*Saccharum* hybrid spp.) has been cultivated as a long-term monoculture crop under contrasting cropping conditions, irrigated and rain-fed over 35 years at *Sevanagala,* Sri Lanka. According to Mapa e*t al.* (2010), soils in the *Sevanagala* sugarcane-growing area fall into the Alfisol soil order and are mapped as *Walawe – Mahagal Ara – Ketagal Ara – Sevanagala* associations. The *Walawe – Mahagal Ara* series belongs to Reddish Brown Earth (RBE), and the *Ketagal Ara* series is a Low Humic Gley (LHG) soil (De Alwis and Panabokke, 1972). A detailed study on main chemical characteristics, including macronutrients at *Sevanagala*, revealed that RBE soils under both cropping conditions and LHG soils under irrigated conditions have favorable soil properties for sugarcane cultivation (Weerasinghe *et al*., 2020). Further, the same study reported that the properties of these soils are comparable to undisturbed soils in the area, with minor deviations highlighting their buffering capacity despite long-term sugarcane cultivation. The LHG soils under the rain-fed condition at *Sevanagala* exhibit alkalinity and are considered unfavorable for sugarcane cultivation. Although the acidity, alkalinity, and macronutrient status of these soils have been studied (Anon, 2018; Anon, 2012; Anon, 2000; Dharmawardena, 2004), no attempt has so far been made to study the micronutrient status. Micronutrient deficiency is one of the factors limiting sugarcane yield around the world. It occurs due to the application of fertilizers with low levels of micronutrients, increased agricultural productivity, depletion of soil organic matter, increased cultivation in areas with low fertility, and reduced application of organic residues to cultivated lands (Mellis *et al*., 2016).

Micronutrients contribute to crop productivity along with other major nutrients when present in the soil at required levels. However, when nutrient imbalances occur, the yield is determined by the least limiting nutrient. Even in minute quantities, they are sufficient to produce optimum effects, but slight deficiencies could result in a severe decline in yield (Meyer, 2013). While some have observed no positive response on stalk and sugar yield or juice (Farias *et al*., 2009; Franco *et al*., 2011) some others have reported that sugarcane yield increases due to applications of B, Zn, Mn, and Mo (Mellis *et al*., 2016; Silva *et al*., 2019). It has been pointed out that an average crop of sugarcane removes 3.5 kg Fe, 1.2 kg Mn, 0.6 kg Zn and 0.2 kg Cu from the soil for a cane yield of 100 t/ha (Singh *et al*., 2007).

The foregoing discussion highlights the need for further scientific information, interpreted spatially and temporally, for better management of sugarcane growing soils. Even in the largest sugar-producing countries, micronutrient research for sugarcane is still scarce and inconclusive (Madhuri *et al.,* 2013; Mellis *et al*., 2016; Robinson *et al*., 2011; Silva *et al*., 2019). Heavy removal of biomass with only macronutrients applied as fertilizer and limited organic manure added over the years have led to the hypothesis that deficiencies of soil micronutrients are affecting the local sugarcane crop productivity. On the other hand, there are hardly visible symptoms of micronutrient deficiencies observed in the *Sevanagala* sugarcane plantations indicating that the deficiencies would be in the phase of Hidden Hunger. Therefore, the objective of this study was to investigate the micronutrient status of sugarcane-growing soils at *Sevanagala* and identify the potential micronutrients that could be deficient in the future. This study is an extended component of Weerasinghe *et al.* (2020), and will be the first local investigation on this subject under sugarcane.

METHODOLOGY

Study site

The study area covered the sugarcane-growing soils at *Sevanagala,* located in the *Moneragala* District of the *Uva* province, Sri Lanka. This included soils under irrigated and rain-fed cropping systems, covering a land area of 4208 ha, managed by Lanka Sugar Company (Pvt) Ltd – *Sevanagala* unit. The land was divided into sub-sections for its convenience in management. The elevation of the field ranges from 50 to 100 m amsl with an average slope of 1.5 %. The irrigated and rain-fed sections were respectively located at the lower and upper parts of the catena (Weerasinghe *et al*., 2020). The rain-fed cropping system covering Divisions 1, 2, 3, and a part of 4 (2266 ha) and irrigated cropping system (1685 ha) covering Divisions 5, 6, and the other part of 4 were considered for the study (Figure 1).

Soil sampling and analysis

This study was an extension of Weerasinghe *et al.* (2020), and 263 separate soil samples were obtained from 0-15 cm depth using a stratified random sampling technique covering the six divisions under the two cropping systems of the sugarcane-growing area at *Sevanagala*. Out of the 263 samples, soil samples on LHG and RBE represented 55 and 208, respectively.

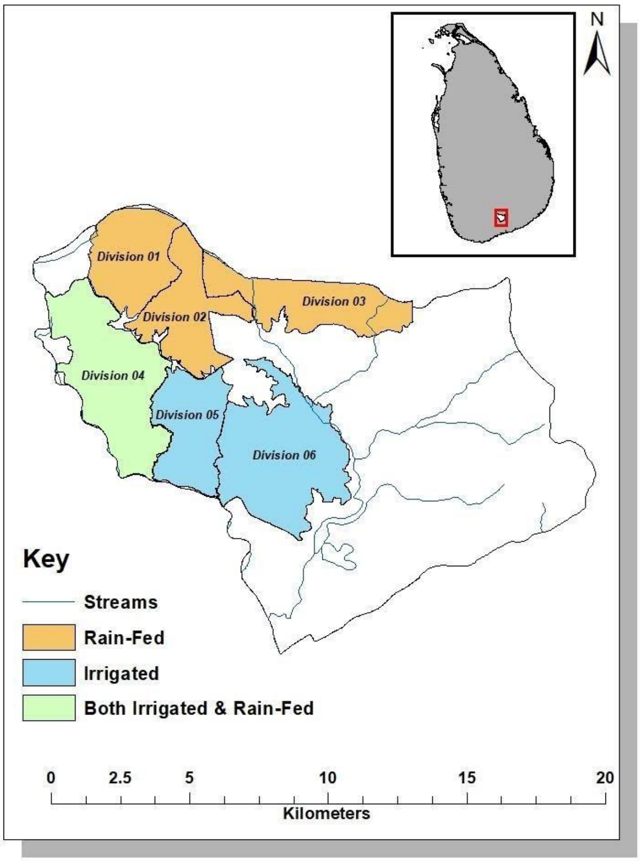

Figure 1: Location of the study area highlighting the irrigated and rain-fed cropping systems at *Sevanagala*, Sri Lanka.

Further, irrigated and rain-fed included 141 and 122 samples respectively. The soil samples were air-dried at room temperature for a week. Stones were removed, and aggregates of the remaining soil were crushed gently with a wooden roller. The obtained samples were sieved using a 2 mm sieve. The available amounts of Fe, Mn, Zn, and Cu were extracted using Diethylene-triamine-penta acetic acid (DTPA) extractant (0.0005 M DTPA in Tri-ethanolamine and $CaCl_2$) as described in Dharmakeerthi *et al*., (2007) and Esterfan *et al*., (2013). The concentrations of Fe, Mn, Zn, and Cu in the extracts were determined using the Atomic Absorption Spectrophotometer (AA 6300-Shimadzu). Our values were then compared against critical values proposed in the literature (Porch and Hunter, 2002; Verma, 2004; Calcino, 2010) to identify micronutrient sufficient/deficient soils in the study area. All three references have used the same extractant and similar determination techniques to those of this study. The first reference quoted above was not crop-specific, while the other two are specifically for sugarcane.

Statistical analysis

Since the data of soil Fe, Mn, Zn, and Cu were normally distributed, analysis of variance was carried out using the Proc GLM procedure of the SAS software system (Version 9.1.3) to determine the effect of the cropping system and soil types, separately. All the interpretations were made based on 95 % probability level (α=0.05).

RESULTS AND DISCUSSION

Table 1 shows the mean, median, and ranges of the considered micronutrients. The available Fe and Mn exhibited wider ranges where the former was from 7.4 to 342.3 mg/kg and the latter from <1 to 1162.8 mg/kg. On the other hand, Zn and Cu showed narrow ranges where the former was from <0.1 to 4.3 mg/kg and the latter from <0.1 to 23.5 mg/kg. The various details of micronutrients are discussed concerning soil types and cropping systems.

Available Fe

The available Fe content showed significant differences (p<0.05) between the two cropping systems and the two soil types (Table 2). Further, the difference between the two cropping systems also varied with the soil type as observed by the significant (p<0.05) interaction effect. The RBE soil showed significantly higher available Fe content in soil compared to that of LHG soils. It was significantly higher under rain-fed conditions than under irrigated soils.

The mean available Fe contents in RBE soil were 42 mg/kg and 108 mg/kg under irrigated and rain-fed cropping systems, respectively. Similarly, LHG soils also depicted a higher value of 49 mg/kg under rain-fed conditions compared to that of irrigated conditions (37 mg/kg), albeit by a narrow margin. Kumaragamage and Indraratne (2011) observed that Alfisols in the low country dry zone (North Central Province) of Sri Lanka contain available iron contents varying from 104 mg/kg to 138 mg/kg. However, the same study observed isolated patches with very low available Fe contents, 18 mg/kg. In comparison, sugarcane-growing soils had low available iron contents except for RBE soils under rain-fed conditions.

Table 1: Mean, median and range of available micronutrients (mg/kg) in the topsoil (0-15 cm) of Sugarcane-growing Alfisols at *Sevanagala*.

Micronutrient	Mean	Median	Minimum	Maximum	CV %
Fe	66	43.9	7.4	342.3	98
Mn	136	115.3	<1	1162.8	95
Zn	1	0.9	<0.1	4.3	71
Cu	2	1.8	<0.1	23.5	127

Table 2: Mean ± standard deviation of available Fe content (mg/kg) in the surface soils of LHG and RBE under irrigated and rain-fed conditions.

	Irrigated (*n*=141)	Rain-fed (*n*=122)	Mean
LHG (*n*=55)	37 ± 14	49 ± 38	43 [b]
RBE (*n*=208)	42 ± 15	108 ± 90	75 [a]
Mean	40 [b]	79 [a]	

Note: Means with the same letters are not significantly different at p=0.05 and *n*=no. of samples.

The critical value of available soil Fe for sugarcane is less than 5 mg/kg (Calcino, 2010; Verma, 2004). It suggests that iron is not a deficient element in all sampled sites. According to Meyer (2013), iron is mainly taken up by roots as ferrous (Fe^{2+}); through the cell membrane to the cytoplasm, suggesting that this ionic state would be dominant in these soils. On the other hand, the major factor affecting the uptake of iron by plants is soil pH. High pH (> 8) makes iron less available and could give rise to chlorosis. According to Weerasinghe *et al.* (2020), mean soil pH in both cropping systems and soil types at *Sevanagala* are favorable for sugarcane cultivation but they observed that LHG soils under rain-fed conditions had pH values up to 9.3. Under such specific sites, Fe could become deficient for sugarcane cultivation.

Available Mn

The average available Mn contents did not show differences between (p=0.70) soils and cropping systems (Table 3). However, few samples obtained on irrigated RBE soil had very low Mn levels (<1 mg/kg). Those areas should be further investigated to explore the need of applying Mn containing fertilizers.

Table 3: Mean ± standard deviation of available Mn content (mg/kg) in the surface soils of LHG and RBE under irrigated and rain-fed conditions.

	Irrigated (*n*=141)	Rain-fed (*n*=122)	Mean
LHG (*n*=55)	79 ± 38	95 ± 95	87 [a]
RBE (*n*=208)	104 ± 33	202 ± 186	149 [a]
Mean	92 [a]	180 [a]	

Note: Means with the same letters are not significantly different at p=0.05 and *n*=no. of samples.

Kumaragamage and Indraratne (2011) reported that Alfisols in the low country dry zone contained 6 to 35 mg/kg of available Mn. It indicates that the study site at *Sevanagala* is rich in available Mn. As highlighted by Verma (2004), Mn has a multi-functional role in the sugarcane crop, and high available Mn levels indicate the possibility to perform the relevant tasks in improving cane yield and quality. Since the availability of Mn to plants depends on soil pH where it decreases with the increase in soil pH (Meyer, 2013), the availability of Mn could be a potential limitation to achieving high yields in places where Weerasinghe *et al.* (2020), observed extremely high pH (>8.5) in this study site.

Classifications developed by Calcino (2010) and Verma (2004) specifically for sugarcane identified < 5.9 mg/kg and 3 mg/kg as critical levels of Mn, respectively. Thus, it indicated that greater than 98 % of sampled land at *Sevanagala* has sufficient levels of available Mn for sugarcane cultivation. However, few samples showed very low concentrations having < 1 mg/kg, which require further investigations.

Available Zn

The available Zn at the study site varied significantly (p<0.05) only with soil type. The RBE soils had significantly higher available Zn content than that of LHG soils (Table 4). However, very low values of < 0.1 mg/kg were observed in all categories. A maximum of around 4 mg/kg was observed in RBE soils under rain-fed conditions

Alfisols in the low country dry zone have been reported to contain between 1.1 mg/kg to 6.9 mg/kg of available Zn content, and the lower margin is considered deficient (Kumaragamage and Indraratne, 2011). Verma (2004) and Calcino (2010) have proposed 0.85 mg/kg and < 0.6 mg/kg of plant-available Zn contents, respectively as critical values for sugarcane. Considering the latter classification by Calcino (2010), the mean values indicated that 73 % of sampled soils are sufficient in plant-available Zn.

Table 4: Mean ± standard deviation of available Zn content (mg/kg) in the surface soils of LHG and RBE under irrigated and rain-fed conditions.

	Irrigated (*n*=141)	Rain-fed (*n*=122)	Mean
LHG (*n*=55)	0.7 ± 0.3	0.6 ± 0.6	0.6 [b]
RBE (*n*=208)	1.1 ± 0.7	1.1 ± 0.8	1.1 [a]
Mean	0.9 [a]	0.8 [a]	

Note: Means with the same letters are not significantly different at p=0.05 and *n*=no. of samples.

However, 27 % of isolated locations are deficient in plant-available Zn contents. According to the former classification by Verma (2004), 64 % of sampled soil is sufficient in plant-available Zn, and 36 % of sampled land is deficient in plant-available Zn. There are sites with very low Zn available concentrations of < 0.1 mg/kg. Therefore, these locations could be deficient in plant-available Zn, which requires site-specific attention.

Available Cu

The available Cu content depicted no significant differences (p=0.4) among cropping systems and soil types (Table 5). Both great soil groups had areas with very low concentrations (< 0.1 mg/kg) of available Cu, suggesting a possibility of Cu deficiency in sugarcane grown in these soils.

Table 5: Mean ± standard deviation of available Cu content (mg/kg) in the surface soils of LHG and RBE under irrigated and rain-fed conditions.

	Irrigated (*n*=141)	Rain-fed (*n*=122)	Mean
LHG (*n*=55)	2 ± 1.0	3.1 ± 5.1	2.5 [a]
RBE (*n*=208)	2.4 ± 2.5	2.1 ± 3.0	2.2 [a]
Mean	2.2 [a]	2.6 [a]	

Note: Means with the same letters are not significantly different at p=0.05 and *n*=no. of samples.

According to Kumaragamage and Indraratne (2011), Alfisols in the low country dry zone showed available Cu ranging from 1.9 mg/kg to 9.5 mg/kg. The soil critical value identified specifically for sugarcane by Calcino (2010) is < 0.22 mg/kg, where only 17 % of the sampled sites were deficient in plant-available Cu. The minimum values indicated that all soil and cropping system combinations had deficient sites in available Cu, which require site-specific attention.

As an initial step for micronutrients in sugarcane-growing soils at *Sevanagala,* the classification systems of Portch and Hunter (2002), Verma (2004), and Calcino (2010), irrespective of the analytical method were used to summarise the availability of deficient percentages of sampled sites within cropping systems (Table 6). The Verma (2004) and Calcino (2010) systems are specifically for sugarcane. As the levels are comparatively high in the general system than that of the systems specifically for sugarcane, it shows more deficient nutrient patches but not so with the specific systems for sugarcane.

Table 6: Summarised micronutrient deficient percentages (%) of sampled sites under contrasting cropping conditions and soil types at *Sevanagala*.

Cropping system	Classification system	Fe	Mn	Zn	Cu
Irrigated LHG	1	53	0	100	100
	2	0	0	36	-
	3	0	0	40	6
Irrigated RBE	1	48	2	100	88
	2	0	1	30	-
	3	0	2	17	17
Rain-fed LHG	1	56	0	100	92
	2	0	0	72	-
	3	0	0	64	20
Rain-fed RBE	1	21	1	100	92
	2	0	1	34	-
	3	0	1	22	20

Note: 1 = Portch and Hunter (2002), 2= Verma (2004), 3= Calcino (2010).

Table 6 indicates that the reference classifications provided a base to calculate percentages of sampled sites deficient in micronutrients for optimum crop growth. The study identified that Fe and Mn are comparatively at sufficient levels for sugarcane, but there are Zn and Cu deficient samples within all four (4) cropping systems and soil types covering the sugarcane-growing area at *Sevanagala*, which need further investigations.

CONCLUSIONS

Micronutrient availability in sugarcane growing soils at *Sevanagala* is significantly affected by cropping systems, irrigated and rain-fed cropping systems, and great soil groups namely low humic gley (LHG) and reddish-brown earth (RBE). The available Fe content ranged from 7 to 342 mg/kg with a mean of 66 mg/kg, and available Mn ranged from < 1 to 1163 mg/kg with a mean of 136 mg/kg where means of both were comparatively higher in rain-fed RBE soils compared to irrigated LHG soils. The available Zn ranged from < 0.1 to 4.3 mg/kg with a mean of 1 mg/kg, and available Cu ranged from < 0.1 to 23 mg/kg with a mean of 2.3 mg/kg, where the former was comparatively high in RBE soils compared to that of LHG soils. In the latter, the highest mean value was observed in rain-fed LHG soils. According to this study, Fe and Mn in both RBE and LHG under irrigated and rain-fed conditions are ranged sufficient except for very few patches. However, Zn and Cu deficiency are more prevalent in both great soil groups under irrigated and rain-fed conditions in sugarcane growing Alfisols.

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