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Soil Fertility Status in Relation to Insidious Fruit Rot Incidence at Harumanis Mango Orchard in Perlis: A Case Study

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ABSTRACT

Mango is one of the six important fruits crops besides banana, watermelon, apple, orange, and grapes in the world. Of late, insidious fruit rot (IFR) has been of increasing concern among mango growers in Malaysia as this disease does not exhibit visible symptoms but has the potential to reduce the quality of the fruit. Therefore, the objectives of this study were to evaluate and correlate soil fertility status between mango orchards with and without the IFR incidence by comparing content of selected soil nutrients. The soil samples were collected from orchards planted with Harumanis, a mango variety, with and without IFR incidence. The samples were taken at a depth of 0–30 cm, crushed and then sieved using a 2-mm mesh size prior to laboratory analysis. The analyses followed standard practice. The results showed a significant difference between EC, total C, total N, C/N ratio, and exchangeable bases (Ca, Mg, K and Na) between the soil samples from Harumanis orchards with and without IFR incidences. Although soil nutrient content was higher than the optimal range for Harumanis cultivation in both sites, synergistic and antagonistic effects were discovered mostly in soil samples from Harumanis orchard with IFR incidence. Studies show that application of Ca and K fertilizers can suppress IFR incidence.

Key words: **internal fruit breakdown**, **MA128**, ***Mangifera indica***, **physiological disorder, soil nutrient content**

INTRODUCTION

Mango (*Mangifera indica*) is one of the top six fruit crops in the world (UNCTAD 2016). It has been cultivated mainly in tropical and sub-tropical countries including Malaysia. Common commercial mango varieties in Malaysia and their registered names with the Department of Agriculture (DOA) in Malaysia are Harumanis (MA128), Golek/Foo Fatt (MA162), Maha 65 (MA165), Malele (MA204), and Chokanan (MA224). These varieties are mainly cultivated by smallholder growers with less than 2 ha of land while large mango cultivated areas are managed by government agencies like the DOA and the Muda Agricultural Development Authority (MADA). Harumanis is one of the most popular mango varieties cultivated in parts of northern Peninsular Malaysia, namely Perlis and Kedah. The weather conditions in this region, with long periods of drought (about two months), are suitable for the cultivation of the Harumanis variety. Although the Harumanis cultivation is labour-intensive and requires high maintenance and operational costs, the fruits can be traded at a higher price, up to four times higher than other mango varieties sold domestically. As a result, many rice farmers have converted part of their paddy field into Harumanis orchards due to a higher profit margin. The planted area of Harumanis has increased by 336.5%, from 323 ha in 2011 to 1,410 ha in 2019, accounting for about 5.5% of the agricultural land area in Perlis.

Insidious fruit rot (IFR) or yeasty fruit rot is currently a problem faced by Harumanis growers in northern Peninsular Malaysia. IFR incidence has been reported in the Harumanis cultivar in Malaysia from as early as 1985 (Lim and Khoo 1985) and is characterized by dissolution of flesh tissue in the sinus region, specifically the ventral towards the beak. The tissues become watery, soft, and yellowish-brown with a yeasty odour (Shivashankar 2014). This disorder has been reported to be identical to soft nose (Tarmizi *et al*. 1993). IFR incidence results in poor fruit quality which naturally affects the marketability of the fruit (Tarmizi *et al*. 1993). According to Shivashankar (2014), IFR is caused by physiological disturbance from metabolic imbalance caused by pre- and/or post-harvest factors leading to cell collapse. The main cause of this physiological disorder has yet to be identified but is likely due to environment and poor management practices, including soil and nutrient management (Sauco 2009; Shivashankar 2014). IFR incidence in Harumanis has been noted with respect to nitrogen (N), calcium (Ca) and N/Ca ratio imbalance in both fruits and leaves during the fruiting stage (Tarmizi *et al*. 1993). Although some studies have been conducted on the soil-leaf relationship, there is relatively insufficient information to understand IFR incidence.

Soil fertility is a major limitation of agriculture in Malaysia. According to the Soil Taxonomy (Teh *et al*. 2018), Ultisol and Oxisol orders make up 70% of Malaysian soils. These soils are acidic in nature, with pH values ranging from pH 4 to 5, and are very deficient in available phosphorus (P) due to high sesquioxides fixation within the soil system. These soils also have a very low basic cation status and effective cation exchange capacity (CEC). Therefore, sustainable soil management is necessary under these conditions. Mango trees can survive cultivation in marginal soils, but poor management might affect yield and quality of the fruits. A poor understanding of soil characteristics by local mango growers does not help in resolving this problem. Therefore, the aims of this study were to compare and correlate selected soil nutrient content and evaluate soil fertility status between Harumanis mango orchards with and without IFR incidence.

MATERIALS AND METHODS

Study Site

To compare soil nutrient content of Harumanis orchards with and without IFR incidence, two orchards were selected for the study: (1) Harumanis orchard with IFR incidence (6^o 23’ N, 100^o 17’ E) located at the Perlis-Kedah border and (2) Harumanis orchard without IFR incidence (6^o 27’ N, 100^o 15’ E) located in Arau, Perlis (Figure 1).

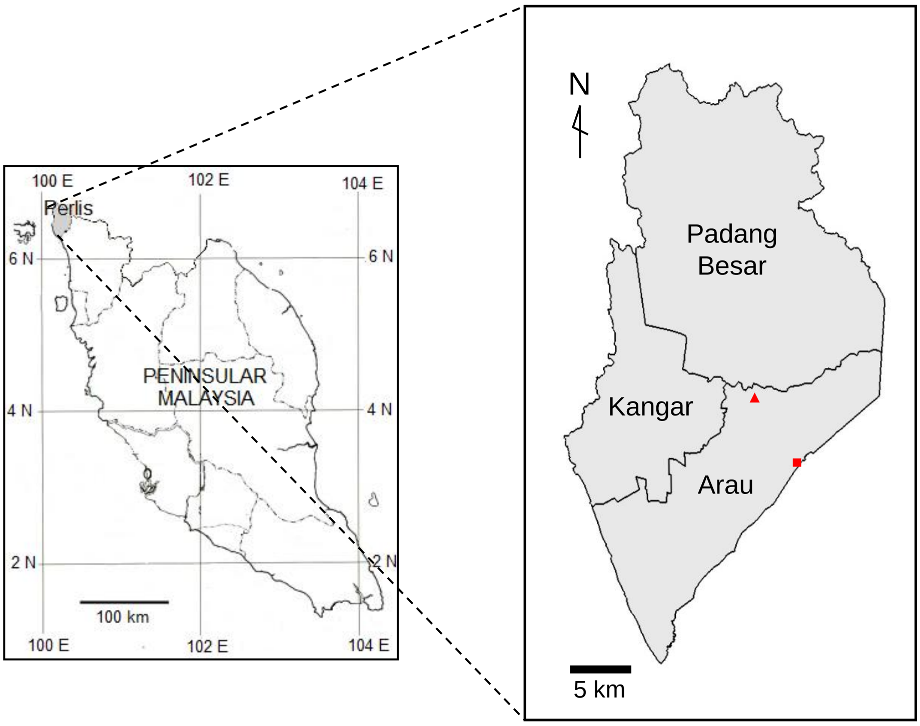

Figure 1. Location of Harumanis orchards with IFR (square) and without IFR (triangle) incidence

At the time of the study, the orchard with IFR incidence was 0.25 in acreage with 70 nine-year-old trees. The trees had been planted in a standard 9 m × 9 m square system with some trees randomly planted without specific distance especially around the fence. The land had previously being a paddy field. As IFR incidence had first surfaced in the orchard in 2019, an attempt had being made to rehabilitate the soil with the addition of dolomite. During the study period, IFR incidence was in stage 1 and/or 2 with the black spot observed clearly when the fruits were cut. Generally, NPK fertilizer (12:12:17+2+TE) was used during the vegetative stage while foliar fertilizers were used during flowering and fruiting stages. Other agrochemicals like pesticide, insecticide and herbicides were used to control pest, disease, and weeds. Standard cultural practices in mango cultivation such as the application of paclobutrazol and pruning were followed.

Meanwhile, the Harumanis trees in the orchard without the IFR incidence were 12 and 38 years old. The trees had been planted in a standard 9 m × 9 m square system. This orchard had a long history of fruit and rubber cultivation before it was fully planted with Harumanis mango. This orchard had experienced IFR incidence in 2007 and recovered fully after three years of rehabilitation. Control release NPK fertilizer (12:12:17+2+TE) was applied once every three months during the vegetative stage while foliar fertilizers were used once every two weeks during the flowering and fruiting stages. Cultural practices were almost similar to the Harumanis orchard with IFR incidence.

Perlis state has a tropical monsoon (*Am*) climate according to the Köppen-Geiger Classification System, with an average annual temperature of 27.4^{o}C and a mean annual precipitation of 1,893.7 mm over the past 30 years (1990–2021) (MMD 2022).

Field Survey and Soil Sampling

The field survey and soil sampling were done in April 2021. A total of 22 soil samples were collected with 10 and 12 samples being collected from Harumanis orchards with and without IFR incidence, respectively. One soil sample per tree was collected using a soil auger at a depth of 30 cm under the tree canopy. All selected trees had a canopy diameter of about 2 to 3 m. The soil samples were brought back to the laboratory, air-dried, ground using mortar and pestle and sieved to pass through a 2-mm mesh for laboratory analysis.

Laboratory Analysis

Soil pH was determined using a pH meter at a soil-water ratio of 1:2.5 while soil electrical conductivity (EC) was measured using an EC meter at a soil-water ratio of 1:5. Total carbon (C) and total N were simultaneously determined by CHNS Elemental Analyzer (Perkin Elmer 2400 Series II, Waltham, Massachusetts). Available P was extracted using Bray & Kurtz No. 2 and determined by the molybdenum blue method using an UV-visible spectrophotometer (Varian Cary 50 Scan, California, United States). Exchangeable bases such as calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) were extracted with 1 M ammonium acetate buffered at pH 7, and their concentrations were determined by inductively coupled plasma–optical emission spectrometry (Perkin Elmer Optima, Waltham, Massachusetts). Exchangeable acidity was measured by alkaline titration after extraction with 1 M potassium chloride. Effective CEC was calculated by the summation of exchangeable bases and effective CEC. Base saturation was defined as the ratio of the sum of exchangeable bases to effective CEC in percentage (%).

Statistical Analysis

All statistical analyses i.e. mean, median, minimum, maximum, standard deviation (SD), and coefficient of variation (CV) were done using R software version 4.2.0 (R Core Team, R Foundation for Statistical Computing). CV was categorized into three classes: high (CV > 90%), intermediate (CV = 90–10%) and low (CV < 10%) (Kamarudin *et al*. 2019). Pearson correlation was used to identify the relationship among the variables in each Harumanis orchard while the Welch T-test was run to compare the measured soil parameters in both the Harumanis orchards.

RESULTS AND DISCUSSION

The descriptive statistics of soil samples taken from Harumanis orchards with and without the IFR incidence are shown in Table 1. Soil samples from the Harumanis orchard with IFR incidence had a slightly acidic to slightly alkaline condition (pH 6.93 ± 0.82) with exchangeable acidity ranging from 0.3 to 1.9 cmol kg^{-1} while the soil samples from the Harumanis orchard without IFR incidence was moderately acidic to neutral (pH 6.48 ± 0.84) with exchangeable acidity ranging from 0.4 to 3.4 cmol kg^{-1}. The pH at both sites was suitable for Harumanis cultivation as mango cultivation requires soil with a pH ranging from 5.5 to 6.5 (MDOA 2009). Though this mildly acidic condition is suitable for tree root development, it is recommended that soil pH be maintained in the range of 6.6 to 7.5 as most of the nutrients are available within this range for plant uptake (Nyi *et al*. 2017).

TABLE 1
Descriptive statistics of soil samples from Harumanis orchards with and without IFR incidence

Variable	**pH**	**EC**	**Total C**	**Total N**	**C/N ratio**	**Avai. P**	**Exch. Ca**	**Exch. Mg**	**Exch. K**	**Exch. Na**	**Exch. acidity**	**Effective CEC**	**BS**
Harumanis orchard with IFR incidence (n = 10)													
Mean	6.93	0.09	16.67	2.56	6.52	80.92	4.01	4.61	2.06	3.51	0.57	14.76	96.23
SD	0.82	0.05	6.49	0.58	2.07	32.61	2.76	1.95	1.41	2.42	0.48	6.03	1.57
Median	7.16	0.08	14.30	2.50	5.89	75.60	3.16	4.63	1.62	2.76	0.40	12.14	96.44
Minimum	5.00	0.04	10.00	1.60	4.38	44.80	1.03	1.91	0.53	0.90	0.32	8.68	92.63
Maximum	7.68	0.17	28.40	3.90	11.36	134.40	8.74	7.40	4.48	7.65	1.92	26.07	98.62
CV	11.81	53.88	38.91	22.64	31.82	40.30	68.76	42.43	68.76	68.76	84.62	40.88	1.63
Harumanis orchard without IFR incidence (n = 12)													
Mean	6.48	0.05	4.71	1.54	3.02	116.40	6.63	0.81	3.40	5.80	1.03	17.66	93.04
SD	0.84	0.02	2.23	0.63	0.74	67.47	2.23	0.17	1.14	1.95	0.94	4.88	7.98
Median	6.57	0.05	4.60	1.70	2.89	102.20	7.37	0.80	3.78	6.45	0.72	19.05	96.33
Minimum	5.21	0.02	1.70	0.70	2.29	42.00	3.66	0.56	1.88	3.21	0.40	9.83	73.48
Maximum	7.93	0.08	8.20	2.40	4.67	257.60	9.86	1.06	5.06	8.63	3.36	25.28	98.11
CV	13.00	38.70	47.37	40.69	24.42	57.95	33.61	21.23	33.61	33.61	91.89	27.62	8.58

Abbreviation: SD = standard deviation, CV = coefficient of variation, EC = electrical conductivity, Effective CEC = effective cation exchange capacity, and BS = base saturation

Unit: EC = mS cm^{-1}, Total C = g kg^{-1}, Total N = g kg^{-1}, Avail. P = mg kg^{-1}, Exch. bases (Ca, Mg, K, Na) = cmol kg^{-1}, Exch. Acidity = cmol kg^{-1}, ECEC = cmol kg^{-1}, and BS = %

Both sites had a low content of total C (<25 g/kg), EC (<1 mS cm^{-1}) (MDOA 2009), and C/N ratio (<10) (Kirkby *et al*. 2011). It is well known that low total C content indicates low soil organic materials. This low EC value is suitable for Harumanis cultivation as mango is one of the crops sensitive to saline (0–2 mS cm^{-1}) soil condition. The general C/N ratio of soils ranged from 10–12 which is often referred to as humus (Kirkby *et al*. 2011) while the low C/N ratio at both sites suggest that the amount of N available for microbes (i.e, C/N ratio 25) is more than than sufficient. A medium content of total N (1.5–2.6 g kg^{-1}) (Nyi *et al*. 2017) was observed in both sites which was below the optimum range required for Harumanis cultivation (2.7–4.0 g kg^{-1}) (MDOA unpublished). Meanwhile, a high content of available P (>15 mg kg^{-1}) (Nyi *et al*. 2017) was observed in both sites which was higher than the optimum range required for Harumanis cultivation (16–25 mg kg^{-1}) (MDOA unpublished).

Low contents of exchangeable Ca (<5 cmol kg^{-1}) and exchangeable K (<2.3 cmol kg^{-1}) were observered in the soil samples from Harumanis orchard with IFR incidence. Meanwhile, medium contents of exchangeable Ca (5–10 cmol kg^{-1}) and exchangeable K (2.3–3.8 cmol kg^{-1}) were observed in the soil samples from Harumanis orchard without IFR incidence (Marx *et al*. 1999; Nyi *et al*. 2017). Although exchangeable Ca content was low in the soil samples from the Harumanis orchard with IFR incidence, this value is within the optimum range (2.5–4.0 cmolc kg^{-1}) required for Harumanis cultivation while exchangeable K at both sites is higher than optimum level (0.8–1.4 cmolc kg^{-1}) (MDOA unpublished). Meanwhile, a high (>1.5 cmol kg^{-1}) and medium (0.5–1.5 cmol kg^{-1}) exchangeable Mg content (Marx *et al*. 1999) was measured in the soil samples from Harumanis orchard with and without IFR incidence, respectively. However, exchangeable Mg content in the soil samples from the Harumanis orchard without IFR incidence is lower than the optimum range (3.0–10.0 cmolc kg^{-1}) for Harumanis cultivation. Meanwhile, exchangeable Na in the soil samples from both sites was higher than the optimum level (0.7–2.0 cmolc kg^{-1}) required for Harumanis cultivation (MDOA unpublished).

A high (>12 cmol kg^{-1}) (Nyi *et al*. 2017) content of effective CEC was noted for soil samples taken from both orchards. Generally, soils with effective CEC > 7 cmolc kg^{-1} (or CEC > 10 cmolc kg^{-1}) are suitable for mango cultivation (MDOA 2009) but the optimum range for Harumanis cultivation is 12–17 cmolc kg^{-1} (or CEC = 15–20 cmolc kg^{-1}) (MDOA unpublished). This value indicates that the capacity of the soil to hold the nutrients is higher when a higher effective CEC value is obtained. Meanwhile, a higher BS (>80.0%) value was observed in the soil samples taken from both sites indicating the percentage of the effective CEC occupied by the basic cations such as Ca^{2+}, Mg^{2+}, K^{+} and Na^{2+}. Several published soil standards are available to help in interpreting analytical results. The recommended optimal ranges for soil analysis should only be considered as a general guideline (Bally 2009). For a better interpretation, selected soil standards and previous soil analysis should be compared and read together with the previous season's fertilization history.

In this study, all the measured soil parameters in both sites show an intermediate CV indicating intermediate variation except for BS and exchangeable acidity. The BS in both sites show a low CV while soil exchangeable acidity in soil samples from the Harumanis orchard without IFR incidence shows a high CV indicating low and high variation, respectively (Kamarudin *et al*. 2019).

The correlation between the measured parameters of soil samples from Harumanis orchards with and without IFR incidences is shown in Table 2. Soil pH of samples from Harumanis orchard with IFR incidence had a moderate (R = -0.40–0.69) and high (R = -0.70–0.89) negative correlation with total N and exchangeable acidity, respectively and a high positive correlation with BS. In the same orchard, the soil EC and total C were found to have a high positive correlation with the C/N ratio. Total N was found to have a moderate positive correlation with exchangeable Ca, exchangeable K, exchangeable Na, exchangeable acidity and effective CEC. Available P was found to have a moderate positive correlation with total C and a high postive correlation with the C/N ratio and exchangeable Mg. Meanwhile, exchangeable Ca was found to have a very high positive (R = 0.90–1.00) correlation with exchangeable K, exchangeable Na and effective CEC. Exchangeable K was found to have a very high positive correlation with exchangeable Na and effective CEC while exchangeable Na had a very high positive correlation with effective CEC. A moderate positive correlation was found between exchangeable acidity and effective CEC whileexchangeable acidity had high negative correlation with BS.

The pH of soil samples from the Harumanis orchard without IFR incidence had a high positive correlation with exchangeable Ca, exchangeable K, exchangeable Na, effective CEC and BS. Exchangeable acidity was found to have a moderate negative correlation with pH, EC, exchangeable Ca, exchangeable K and exchangeable Na. Total C was found to have a high positive correlation with total N. Exchangable Ca was found to have a very high positive correlation with exchangeable K, exchangeable Na and effective CEC. Exchangeable K was found to have a very high positive correlation with exchangeable Na and effective CEC. A very high positive correlation was also found between exchangeable Na and effective CEC while a very high negative (R = 0.90–1.00) correlation was found between exchangeable acidity and BS. Meanwhile, BS was found to have a moderate positive correlation with EC, exchangeable Ca, exchangeable K and exchangeable Na.

TABLE 2
Pearson correlation coefficient among the measured parameters of soil samples from Harumanis orchards with and without IFR incidence

	pH	**EC**	**Total C**	**Total N**	**C/N ratio**	**Avail. P**	**Exch. Ca**	**Exch. Mg**	**Exch. K**	**Exch. Na**	**Exch. acidity**	**Effective CEC**	**BS**
Harumanis orchard with IFR incidence (n = 10)													
pH	1.00												
EC	0.40	1.00											
Total C	-0.32	0.23	1.00										
Total N	-0.65^{*}	-0.6	0.60	1.00									
C/N ratio	0.11	0.74^{*}	0.79^{**}	-0.01	1.00								
Avail. P	0.11	0.55	0.64^{*}	-0.01	0.83^{**}	1.00							
Exch. Ca	-0.44	-0.58	0.31	0.73^{*}	-0.18	-0.31	1.00						
Exch. Mg	0.28	0.61	0.18	-0.44	0.58	0.80^{**}	-0.56	1.00					
Exch. K	-0.44	-0.58	0.31	0.73^{*}	-0.18	-0.31	1.00^{***}	-0.56	1.00				
Exch. Na	-0.44	-0.58	0.31	0.73^{*}	-0.18	-0.31	1.00^{***}	-0.56	1.00^{***}	1.00			
Exch. acidity	-0.87^{***}	-0.39	0.54	0.82^{*}	0.02	0.02	0.62	-0.30	0.62	0.62	1.00		
Effective CEC	-0.47	-0.46	0.44	0.72^{**}	-0.01	-0.08	0.96^{***}	-0.31	0.96^{***}	0.96^{***}	0.66^{*}	1.00	
BS	0.82^{**}	0.22	-0.26	-0.51	0.09	0.06	-0.15	0.26	-0.15	-0.15	-0.83^{**}	-0.14	1.00
Harumanis orchard without IFR incidence (n = 12)													
pH	1.00												
EC	0.29	1.00											
Total C	0.31	-0.06	1.00										
Total N	0.18	0.12	0.87^{***}	1.00									
C/N ratio	0.30	-0.27	0.56	0.11	1.00								
Avail. P	-0.13	0.44	-0.14	0.00	-0.25	1.00							
Exch. Ca	0.85^{***}	0.44	0.35	0.36	0.01	0.05	1.00						
Exch. Mg	0.10	0.28	-0.34	-0.11	-0.52	0.00	0.30	1.00					
Exch. K	0.85^{***}	0.44	0.35	0.36	0.01	0.05	1.00^{***}	0.30	1.00				
Exch. Na	0.85^{***}	0.44	0.35	0.36	0.01	0.05	1.00^{***}	0.30	1.00^{***}	1.00			
Exch. acidity	-0.65^{*}	-0.61^{*}	-0.48	-0.50	-0.26	-0.16	-0.59^{*}	-0.16	-0.59^{*}	-0.59^{*}	1.00		
Effective CEC	0.81^{**}	0.38	0.27	0.29	-0.06	0.02	0.99^{***}	0.33	0.99^{***}	0.99^{***}	-0.45	1.00	
BS	0.73^{**}	0.59^{*}	0.51	0.51	0.28	0.11	0.69^{*}	0.18	0.69^{*}	0.69^{*}	-0.99^{***}	0.57	1.00

Abbreviation: EC = electrical conductivity, Effective CEC = effective cation exchange capacity, BS = base saturation

*, **, *** indicate a significant level of $p < 0.05$, 0.01 and 0.001, respectively

In comparing the soil samples from both sites, significant differences ($p < 0.05$) were found in the EC, total C, total N, C/N ratio and exchangeable bases (Figure 2). Soil samples from the Harumanis orchard with the IFR incidence showed significantly higher content in EC, total C, total N, C/N ratio and exchangeable Mg at 0.04 mS cm^{-1}, 11.96 g kg^{-1}, 1.02 g kg^{-1}, 3.5, and 3.80 cmol kg^{-1}, respectively as compared with the orchard without IFR incidence. Meanwhile, soil samples from the Harumanis orchard without IFR incidence showed significantly higher content of exchangeable Ca, exchangeable K and exchangeable Na at 2.62 cmol kg^{-1}, 1.34 cmol kg^{-1}, and 2.29 cmol kg^{-1}, respectively, compared to the Harumanis orchard with IFR incidence.

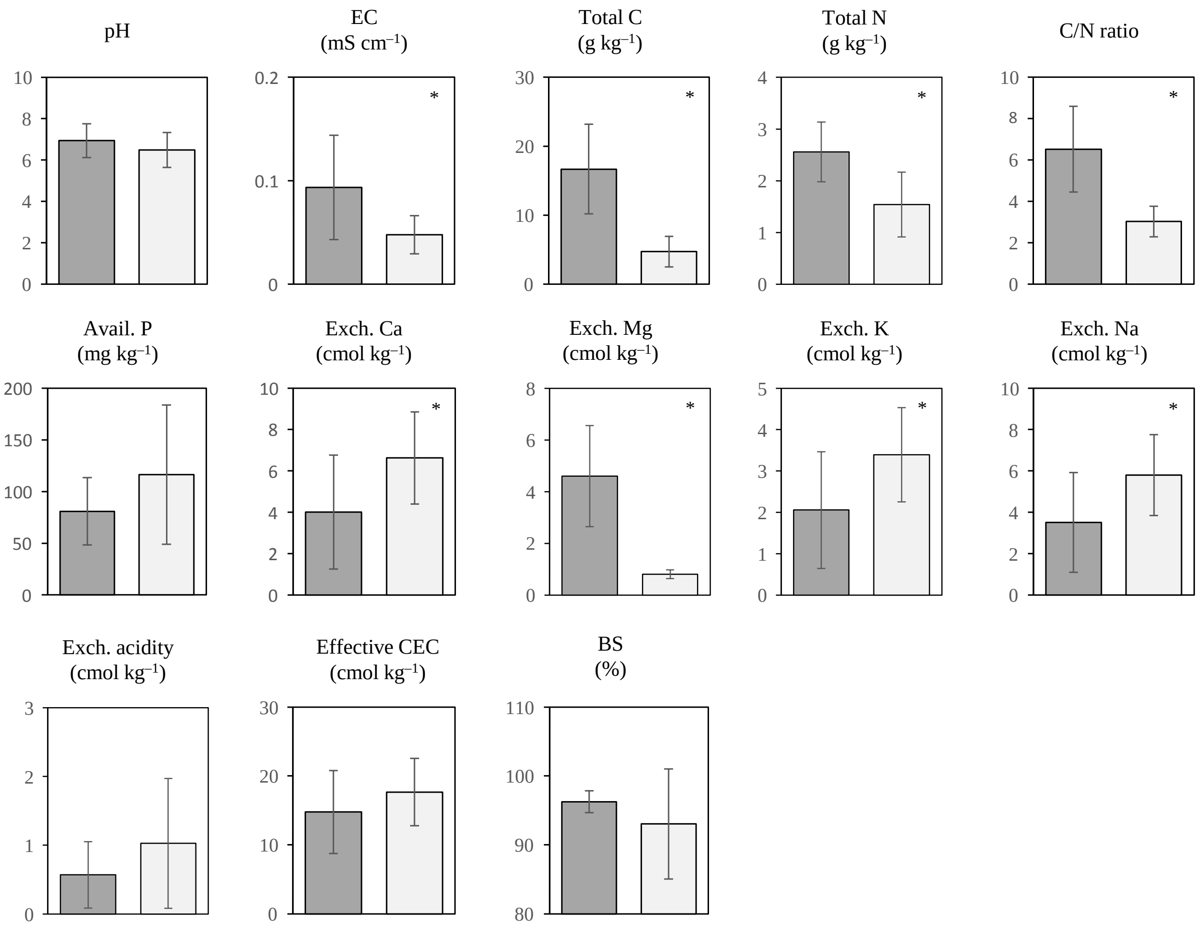

Figure 2. Comparison of Harumanis mango orchards with IFR (dark grey) and without IFR (light grey) incidence

Insidious fruit rot in Harumanis is associated with plant nutrient imbalance especially N and Ca. The antagonistic effects of N and Ca accumulation in mango leaves and fruit has been very well established and the N/Ca ratio has been used widely to indicate the balance between these two nutrients (Tarmizi *et al.* 1993). IFR incidence is higher when the N/Ca ratio of ≥ 0.5 is found in Harumanis leaves. Nitrogen plays an important role in mango growth, yield, and fruit quality, while Ca is important for pection polymers that strengthen the cell walls (Bally 2009). Thus, when Harumanis trees take in high N and less Ca, the cell walls become thinner and weaker, leading to cell damage. However, calculating this N/Ca ratio from soil nutrient content is less practical. This is because both N and Ca can be removed from the soil system by crops and as well as the leaching process. In fact, soil analysis can help to determine the availability of essential minerals required by mango trees and ensure their levels are in the optimal range (Bally 2009).

Soil nutrient availability differed in both sites (see Table 2). The availability of soil nutrients can be affected by the synergistic and antagonistic effects of each nutrient (Rietra *et al.* 2017; Jakobsen 1993). The former and latter effects may increase or decrease the availability of other nutrients for uptake by the plant (Rietra *et al.* 2017). A moderate positive correlation between total N and exchangeable Ca, exchangeable K, exchangeable Na, exchangeable acidity or effective CEC indicates synergistic effect. This condition shows that besides the application of N fertilizer, of Ca, K and Na fertilizer application is required as well. Without a good balance of Ca, K and Na fertilizers, mango trees tend to absorb more N, resulting in this physiological disorder (Singh *et al.* 2013). Concurrently, application of N fertilizer will increase soil acidity, which can lead to soil acidification (R = 0.82; $p < 0.05$) due to a decrease in soil pH (R = -0.65; $p < 0.05$) although the current soil pH was at the optimum level. This can be explained by the decomposition process of fertilizers which produce hydrogen ions and increase soil acidity (Barak *et al.* 1997).

Further a high content of exchangeable Mg and/or available P in the soil samples from Harumanis orchard with IFR incidence might show a synergistic effect. This is supported by a very high positive correlation between both nutrients. A high content of exchangeable Mg or available P may increase the availability of one of them, which may cause cell tissues to breakdown. This is supported by a previous study that observed a high content of Mg and P in the broken tissue (Selvaraj *et al.* 2000). At the same time, exchangeable Mg and available P have an antagonistic effect through a negative correlation with exchangeable Ca (Rietra *et al.* 2017). Although no significant differences were found in these antagonistic effects, it may have an influence if the condition is not corrected. This is because the antagonistic effect can be caused by precipitation of less soluble calcium phosphates at the vicinity of nutrient-absorbing roots (Jakobsen 1993). In contrast, the soil sample from the Harumanis orchard without IFR incidence showed an optimal reaction for a healthy soil. The synergistic effects can be observed between soil pH, exchangeable bases (Ca, K and Na), effective CEC and/or BS.

The significant difference in soil parameters between both sites may be caused by differences in soil texture (Shahidin *et al.* 2022). Soil samples from the Harumanis orchard with IFR incidence had a sandy clay loam texture (clay = 31.1%; silt = 20.4%; coarse sand = 25.0%; fine sand = 23.5%), while the soil samples from the Harumanis orchard without IFR incidence had a fine sandy loam texture (clay = 14.8%; silt = 17.5%; coarse sand = 10.2%; fine sand = 57.5%). Soil texture may strongly influence nutrient availability and retention (Brady and Weil 2008), particularly in highly weathered soils as in Malaysia and consequently may affect nutrient uptake by mango trees. Soil nutrients are available for plant uptake in the form of ammmonium (NH_4^+), monovalent phosphate anion ($H_2OP_4^-$; pH < 7), divalent anion (HOP_4^{2-}; pH > 7), Ca ions (Ca^+), and Mg ions (Mg^{2+}) which are immobile in the soil, and K ions (K^+) which are less immobile while nitrate (NO_3^+) is highly mobile in the soil. The highly mobile nutrients in the soil are prone to loss though the leaching process. For instance, soil N often limits mango tree growth especially in sandy soil because N is easily leached from the soil (Musvoto *et al.* 2000). Although Ca^+ is immobile in the soil, the exchangeable Ca is weakly bound and capable of rapid exchange with the soil solutions. Therefore, it is prone to leaching (Mengel and Kirkby 2001).

A significantly low content of N and a significantly high content of Ca and K in the soil samples from the Harumanis orchard without IFR incidence could suggest that IFR incidence can be suppressed through application of Ca and K fertilizers (Singh *et al.* 2013). This suggestion is also supported by Lim and Khoo (1985) who state in their study that the IFR incidence can be treated with a well-balanced, split application fertilization program containing adequate amounts of N, P, K and Ca. However, the type and frequency of fertilizer application should be considered based on the soil texture. In a leachable soil environment, a slow release fertilizer adopting inhibitors technology or controlled release fertilizers should be more suitable. This has being practised by the owner of Harumanis orchard without IFR incidence. Moreover, this grower also applied dolomite after the harvesting stage in order to maintain the soil pH by adding Ca and Mg since 2007 which has been imitated later by the owner of Harumanis orchard with IFR incidence.

Due to low total C in the soil samples from both Harumanis orchards, it is suggested that soil organic matter be added to increase C content. The function and capability of soil can be sustained by adding organic matter (optimum level = 3–5%) (MDOA unpublished) like compost and manure to increase nutrient retention by increasing soil CEC (Nyi *et al.* 2017; Shahidin *et al.* 2022). In a tropical environment, organic matter can be highly decomposed and can therefore be added to the soil after each harvest as the standard practice.

CONCLUSION

In conclusion, significant differences were found in EC, total C, total N, C/N ratio and exchangeable bases (Ca, Mg, K, Na) in the soil samples from Harumanis orchards with and without IFR incidence. Although soil nutrient contents were higher than optimal range for Harumanis cultivation in both sites, synergistic and antagonistic effects were mostly discovered from soil samples from the Harumanis orchard with IFR incidence. Application of Ca and K fertilizers can suppress IFR incidence (Lim and Khoo 1985; Singh *et al.* 2013).

It is suggested that a further study be carried out on soil micronutrients like boron, manganese, copper, molydbenum and zinc. This is because access to these micronutrients in the soil can also influence the availability of other nutrients through synergistic and antagonistic effects.

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