AGRIVITA
Journal of Agricultural Science
www.agrivita.ub.ac.id

Effect of Different Black Pepper Crop Ages on the Availability of Nitrogen, Phosphorus, and Potassium

Izzah Abd-Hamid[1)], Wan Asrina Wan-Yahaya[1*)] and Wan Mohd Razi Idris[2)]

[1)] Universiti Putra Malaysia, 97008 UPM Bintulu Sarawak Campus, Sarawak, Malaysia
[2)] Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

ARTICLE INFO

Keywords:
Berries
Black pepper
Burnt earth
Correlation
East Malaysia

Article History:
Received: March 11, 2020
Accepted: November 21, 2022

[*)] Corresponding author:
E-mail: asrina@upm.edu.my

ABSTRACT

Black pepper cultivation at different land backgrounds and fertility can affect crop productivity. This study aims to determine soil-plant nutrients for three pepper farms based on crop ages and the correlation of selected physical and chemical properties. Samples were collected in Kapit, Bintulu, and Sri Aman and analyzed for physical and chemical properties. Soil nutrient in Bintulu (6 months old) has revealed higher soil pH (4.95) with higher Fe (0.21 g/kg) and N (1.33 g/kg) contents that is caused by burnt earth residue from the burning of secondary forest. Sri Aman (12 months old) showed greater TOC (3.34%), P (0.0032 g/kg), and K (0.10 g/kg) benefitted from a long year of cultivation and proper pre-establishment earlier. Nutrient removal is high in Bintulu for Fe, Mn, N, and K, while Sri Aman for P is due to early harvesting before its mature phase, whereby the increase in nutrient accumulation in leaves to support berries. Correlation has revealed the role of soil pH in governing the availability of TOC, P, and K. The increasing soil pH increases the availability of P and K. Hence, the availability of N, P, and K is affected by numerous reasons, such as pH and crop management.

INTRODUCTION

Black pepper is a common commodity crop grown in Malaysia and concentrated in Sarawak, East Malaysia. It is known as the best black pepper producer due to its pungent smell and high oleoresin and piperine contents. However, those characteristics often become hampered because of soil constraints. The crop depends on sufficient nutrient uptake to sustain and produce the yield. The need for nutrients varies according to their age; the duration year of cultivation consumes more nutrients compared to early cultivation. About 293.08 kg/ha N, 46.41 kg/ha P, and 264.95 kg/ha K are removed from the soil cultivated with the Semengok Aman variety, which is considered higher than the Indian variety, which reported around 138 kg/ha N and 189 kg/ha P (Ann, 2012; Ravindran, 2000).

Nitrogen availability is essential to black pepper as it is a significant component of chlorophyll that affects photosynthesis. It is important in berry production, whereby each leaf is opposite its berry spike. A similar effect on substantial N uptake by oil palm in which insufficient uptake may affect the leaf development and maturity, leading to reduced chloroplast size and functions (Amirruddin, Muharam, Paing, Singh, & Yusoff, 2017; Liu et al., 2018). The importance of P is also crucial for the development of black pepper, especially in stimulating its growth and influencing its crop yield. Persistent insufficient P may reduce soybean yield (Mallarino & Pecinovsky, 2014) and chili (Emongor & Mabe, 2010). According to George, Abdullah, & Chapman (2005), the lack of P may affect the crop's lateral growth, and further restriction may lead to reduced formation of new shoots.

Meanwhile, K becomes another important element for black pepper uptake that affects berries formation (Ann, 2012). The importance of K was also emphasized by Hartz et al. (1999)

ISSN: 0126-0537

Cite this as: Abd Hamid, I., Wan Yahaya, W. A., & Idris, W. M. R. (2023). Effect of different black pepper crop ages on the availability of nitrogen, phosphorus, and potassium. *AGRIVITA Journal of Agricultural Science, 45*(1), 1-10. http://doi.org/10.17503/agrivita.v45i1.2618

in the improvement of fruit quality and maximizing yield in tomatoes. This situation also resembles the effect in apples and pears, as Brunetto, de Melo, Toselli, Quartieri, & Tagliavini (2015) reported that increased K uptake affects the quality of the fruits. However, these nutrient availabilities often become limited due to soil acidity and the presence of Al, Fe, and Mn in soil systems.

Soil acidity is a significant constraint in agriculture as it limits soil fertility and affects crop productivity. H^+ and Al^{3+} cause acidity, and the increasing acidity cause the solubility of Al, Fe, and Mn to increase. That condition causes limited availability of nutrients such as P, K, Ca, and Mg and insufficient for crop uptake. As Weil & Brady (2017) reported, with pH < 5, the formation of insoluble P with Fe/Al-phosphates or Fe/Al-oxides while K, Ca, and Mg may leach from soil colloidal. The leaching process coincides when the exchangeable site is filled with acid cations. According to Abreu Jr, Muraoka, & Lavorante (2003), about 13.5-105.3 mmol/dm^3 of the exchangeable Al recorded in soil pH 3.78-5.52 significantly affects the availability of nutrients. This condition also resembles the effects in yield reported by numerous researchers on alfalfa (Moreira & Fageria, 2010), black pepper (Zu et al., 2014), soybean (Moreira, Sfredo, Moraes, & Fageria, 2015), and potato (Nduwumuremyi, Ruganzu, Mugwe, & Rusanganwa, 2013). Soil acidity plays an essential role in nutrient availability for crop uptake and causes significant effects on yields.

Therefore, the objectives of this study are: (1) to determine soil-plant nutrients for three pepper farms based on crop ages; and (2) to evaluate the correlation between selected physical and chemical properties.

MATERIALS AND METHODS

Study Area and Sampling

The research was conducted in 2019. The farms are located in Sarawak, East Malaysia, in three different divisions located in Kapit, Bintulu, and Sri Aman. The selected crops cultivated on tropic soil inherent low fertility caused by excessive weathering, nutrient leaching, and the abundance of Al and Fe. Generally, Sarawak receives about 2,800-4,700 mm/year of rainfall and 27.3°C temperature (Sa'adi, Shahid, Chung, & bin Ismail, 2017).

Black pepper farm in Kapit has uneven topography, is slightly steep, and elevation ranges from 195-201 m above sea level (m.a.s.l). This farm was previously cultivated with oil palm and hilly paddy. The farm in Bintulu is similar to Kapit, slightly steep, with eroded drains caused by soil erosion and developed on the secondary forest. The elevation of this farm ranged from 37-48 m.a.s.l. Another black pepper farm, Sri Aman, has a flat and uniform terrain with an elevation range of 21-30 m. This farm was historically used to cultivate oil palm. This study used a 0.80 ha farm in total, including 0.18 ha of Kapit, 0.15 ha of Bintulu, and 0.47 ha of Sri Aman. The farms in Kapit and Bintulu had black pepper aging six months, and Sri Aman is 12 months old.

The soil samples were collected in September-November 2018. Surface soil samples (0-20 cm) were collected using purposive sampling techniques to represent the active growing areas. A 2 m border was set from the first non-living pole at every end of the farm. Each point was subsampled (0.5 m from the sampling point) for four augured soil and mixed as composite samples. The leaves were collected from six black pepper stems in each sampling point (four leaves per crop) and from the active production stem localized in the middle and external portion of the canopy (Srinivasan, Dinesh, Hamza, & Parthasarathy, 2007). 96 soil and leaf samples were collected, with 20 samples in Kapit, 52 in Bintulu, and 24 in Sri Aman.

Analysis of Soil and Leave Samples

Soil samples were air dried at room temperature for three days, pulverized, and sieved through 2 mm mesh before soil texture, total organic carbon (TOC), soil pH, total Fe, Mn, N, P, and K, and available Fe, Mn, P, and K analysis. The leaves were cleaned using tap water to eliminate debris and soaked in distilled water. The leaves were then air-dried for 12 hours and placed in the oven (Memmert ULM 400) for two days at 60°C. Dried leaves samples were ground using a laboratory blender (Wiring® Commercial Blender, Model HGBSSSS6) into fine particles and analyzed for total Fe, Mn, N, P, and K.

The soil texture was analyzed using the hydrometer technique (Beretta et al., 2014), TOC using loss on ignition method described by Roper, Robarge, Osmond, & Heitman (2019), soil pH by 1:2 ratio of soil and water (Tan, 2011), total Fe, Mn, N, P, and K on soil and leaves were extracted using sulfuric acid digestion (Sáez-Plaza, Navas, Wybraniec, Michałowski, & Asuero, 2013). The soil availability of Fe, Mn, P, and K used double acid extraction (Wuenscher, Unterfrauner, Peticzka, & Zehetner, 2015). Acid digestion was then analyzed using AutoAnalyzer 3 (SEAL Analytical, Model HR) for total N, the blue color method using UV-Vis Spectrometer at 300 nm (Lambda 25) on P and Atomic Absorption Spectrometer (Perkin Elmer, Model AA800) on Fe, Mn, and K. While double acid extraction was analyzed using the same equipment for total P and K except for wavelength for available P were set to 882 nm. All types of equipment for this study were calibrated accordingly using the calibration solution provided by the manufactured equipment.

Statistical Analysis

Analysis of variance (ANOVA) was used to test the significance of different nutrient concentrations. Tukey's test compared means at p=0.05 using Statistical Analysis System (SAS Ver. 9.4). The Pearson correlation study between soil properties in each black pepper area was calculated by principal component analysis using Addinsoft™ (XLSTAT Ver. 2019), 2015).

RESULTS AND DISCUSSION

Chemical and Physical Properties of Study Areas

Black pepper in all farms exhibited a dominant sandy particle ranging from 56.9-79.9%. According to the soil texture triangle in Table 1, Kapit and Bintulu are identified as sandy clay loam, while Sri Aman is sandy loam. The soil group in Kapit and Bintulu were red-yellow podzolic soils, with Kapit identified as the Merit soil series while Bintulu was the Bekenu soil series. However, the soil in Sri Aman was classified as organic soil, known as the Anderson 2 soil series, and later identified as the Igan soil series subjected to subsidence of organic soil.

Table 1. The fraction of soil particles

Farms	Sand	Clay	Silt	Textural class
	-------%-------			
Kapit	56.9	26.4	16.7	Sandy Clay Loam
Bintulu	62.5	21.4	16.1	Sandy Clay Loam
Sri Aman	79.9	17.8	2.3	Sandy Loam

The chemical properties of three black peppers soil in Table 2 have indicated more excellent total Fe in Bintulu compared to Kapit and Sri Aman. In contrast, Mn lessened in Bintulu compared to other farm areas. In general, total N, P, and K were greater in 6 months of black pepper farms compared to 12 months. The comparable complete nutrient may originate from soil parent material and fertilizer added to the soil surface.

Table 2. Selected total chemical properties

Farms	Fe	Mn	N	P	K
	--------------- g/kg ---------------				
Kapit	2.58	3.76	1.26	2.03	0.60
Bintulu	7.25	0.07	1.33	1.78	5.47
Sri Aman	2.39	3.81	0.60	0.23	0.11

Nutrient Availability in Soil

Nutrient availability in all three farms has indicated various concentrations (Table 3). Soil pH in Bintulu exhibited relatively more excellent value than others. This occurrence may be caused by burnt earth residues left on soil surface after clearing secondary forests with a pH of 7-8 (Hesammi, Talebi, & Hesammi, 2014; Ravindran, 2000). A similar finding reported by Qian, Miao, Gu, & Li (2009) stressed the benefits of burnt earth in alleviating soil acidity. The increase of pH from 3.30 to pH 3.70 after using burnt ground was also reported by Tabi, Mvondo Ze, Boukong, Mvondo, & Nkoum (2013). Another reason contributing to lower soil pH in all farms was the presence of coarser textured soil (56.9-79.9%) that promoted the leach of base cations from soil colloid (Tan, 2011; Weil & Brady, 2017).

Meanwhile, TOC availability seems to be greater in Sri Aman, which has already grown with 12 months old black pepper. According to Tahir & Marschner (2016), TOC value may be greater in higher clay fraction content (Table 1). However, this study's results behaved differently. It may indicate other possible reasons attributable to this behavior. More extended years of cultivation in Sri Aman may help retain plant litter and increase TOC compared to Kapit and Bintulu.

Iron value in 6 months old crops was significantly higher than the 12 months old crops. However, Mn availability was considerably higher in Kapit than in Bintulu and Sri Aman. Fe availability is less (0.07 g/kg) in organic soil (Sri Aman) compared to Kapit and Bintulu. Organic soil was known to have a more negative exchangeable site which may influence the absorption of Fe and Mn, which temporarily become insoluble in the soil system (Rengel, 2015; Weil & Brady, 2017). Fan, Wang, Li, Zhou, & Friedman (2015) reported a similar finding, emphasizing the benefits of organic soil toward lowering metal ion (e.g., Fe and Mn) solubility even though the soil pH is slightly lower than red-yellow podzolic soils. Moreover, the longer year of cultivation on Sri Aman was evident in the residual effect of modifying the farm area using animal manure (Oluwadare, Voncir, Mustapha, & Mohammed, 2013).

Generally, the total N in 6 months old farm was significantly higher (~2 folds) than the 12 months old farm. The greater N concentration in Kapit and Bintulu may be derived from early fertilization before farm establishment. A similar trend of increasing N concentration in early crop establishment on another farm was also reported by Nascente & Lanna (2016) on upland rice plants. About 0.60 g/kg of N was recorded in Sri Aman, comparable with its age, whereas the active absorption was reported for enhanced growth of black pepper. Ann (2012) stated that the absorption of N was higher to support the formation of flower spikes (e.g., fleshy catkin) as it is located opposite to the leaves. This study also observed increased TOC (3.34%) recorded in this farm, comparable with the amount of plant litter returned to the soil and served as a C source and elevated N availability. Therefore, the decreasing total N in this study indicated an active absorption by black pepper.

The P availability in all farms was significantly different between both ages, with the older farm having the most significant concentration (0.0032 g/kg). Besides using animal manure and more prolonged crop cultivation, this farm has benefited from reduced Fe solubility (0.07 g/kg) in this soil, reflecting the increase in P solubility. Soil pH < 5 has a problem with P fixation caused by Fe and Al, which are present in soluble form (Tan, 2011; Weil & Brady, 2017). Kapit and Bintulu showed this effect on restricted lateral growth, very dull-looking matured leaves, and tend to be stiff (Paulus, Sim, Eng, Megir, & Rosmah, 2011). Even though the pH (4.95) is higher in Bintulu, comparable P availability was recorded in Kapit with a pH of 4.59. This problem may arise from the equal amount of clay in these farms, in which Kapit has 26.4% and Bintulu has 21.4%. These findings were also supported by Tahir & Marschner (2017), that reported a similar problem caused by increasing clay content in their study that reduced P availability compared to sandy soil. Our result also showed a similar pattern on K availability in 12 months old crops, which indicated significantly higher availability than six-month-old crops, even though Sri Aman has the highest sandy particle (79.9%). Accordingly, a coarser fraction may promote excessive leach of cations such as K, Ca, and Mg, leaving the soil acidic (Izzah & Wan Asrina, 2019). However, our study showed a different pattern where the long year of cultivation in Sri Aman may contribute to the efficiency in nutrient uptake due to a fully developed crop. A similar effect on 12 months old sugarcane was reported by Smith, Inman Bamber, & Thorburn (2005), where the roots are distributed deeply in the soil and have advantages on nutrient uptake. Generally, Kapit and Bintulu may experience insufficient nutrient uptake of K caused by other effects such as soil pH and greater concentration of Fe. In their findings, Çelík, Aşik, Gűrel, & Katkat (2010) reported a limited K uptake by crop when higher Fe is captured in maize, which can limit the flowering and growth cycle.

Table 3. Nutrients content in the soil

Farms	pH	TOC	Fe	Mn	N	P	K
		%	-- g/kg	--			
Kapit	4.59b ± 0.05	2.54b ± 0.03	0.18a ± 0.004	0.008a ± 0.0002	1.26a ± 0.07	0.0015b ± 0.00007	0.05b ± 0.002
Bintulu	4.95a ± 0.05	2.57b ± 0.05	0.21a ± 0.01	0.003b ± 0.0003	1.33a ± 0.06	0.0014b ± 0.0002	0.06b ± 0.003
Sri Aman	4.57b ± 0.05	3.34a ± 0.05	0.07b ± 0.006	0.003b ± 0.0007	0.60b ± 0.04	0.0032a ± 0.0005	0.10a ± 0.007

Remarks: Means with different alphabet was significantly different at p=0.05; ± indicated standard error

Nutrient Availability in Leaves

The quantities of nutrients removed from crop leaves are shown in Table 4. From the results, nutrient removal followed this order K > N > P > Mn > Fe. This finding contradicted other researchers who highlighted nutrient removal on black pepper following this order N > K > Ca > Mg > P > S > Fe > Mn > Zn (Ann, 2012; Srinivasan, Dinesh, Hamza, & Parthasarathy, 2007). Nutrient removal on Fe was significantly higher in Bintulu (0.19 g/kg) compared to Kapit and Sri Aman. The greater Fe removal in Bintulu was affected by the higher Fe availability in soil (Table 3). Generally, Fe is important to the crop in its chlorophyll synthesis and biological processes such as photosynthesis (Krohling et al., 2016; Rout & Sahoo, 2015). As Ravindran (2000) mentioned, Fe plays a vital role in improving black pepper yield. Iron removal in Kapit and Sri Aman has indicated a similar concentration at 0.10 g/kg. All values were considered acceptable with invisible Fe toxicity symptoms present at the farm level, even though the optimum value of Fe in black pepper leaves was reported as about 0.126-0.445 g/kg in Kerala and Karnataka, India (Hamza, Srinivasan, & Dinesh, 2007). While Mn was significantly different among farms, Bintulu has the highest Mn removal. Mn also plays an important role in plant growth, just like Fe. However, it focuses more on the predisposing crop to disease incidence (Ravindran, 2000). According to Hamza, Srinivasan, & Dinesh (2007), the optimum range for Mn in black pepper leaves is 0.109-0.321 g/kg. However, our results on Bintulu were slightly more incredible than what caused Mn toxicity to appear and can be seen at the farm level with dark brown and black spots at the edges of the leaves. In comparison, Kapit and Sri Aman have equivalent amounts that can facilitate photosynthesis, improve another nutrient uptake, and increase photosynthesis efficiency (Mousavi, Shahsavari, & Rezaei, 2011).

The removal of N in Bintulu was 12.30 g/kg, two folds greater than Kapit and Sri Aman. The increasing removal of N may benefit from the highest total N in soil (Table 2). Bearing flower spikes opposite the leaves may facilitate higher N uptake even though it was not a recommended practice to bear fruit for crops < 12 months (Ann, 2012). This flower spike removal was necessary to allow maximized crop development and preparation for berries production in the following months (Paulus, Sim, Eng, Megir, & Rosmah, 2011). Moreover, cultivating *Uthirancotta* or Lada India is another reason for increasing N uptake because this cultivar bears abundant flowers. While Kapit and Sri Aman indicated a comparable amount of N (~6.30-6.66 g/kg), the removal of flower spike may be at minimal concentration. Phosphorus removal from the leaves meant higher removal on Sri Aman with 1.29 g/kg, followed by Bintulu and Kapit.

Alternatively, Sri Aman may have significantly higher P than other farms, resulting from nutrient absorption during pre-establishment, such as adding chicken manure before cultivating the crop. The good P can affect the length and surface area of the root itself and reflect increasing other nutrient absorption (Shreckhise, Owen Jr, & Niemiera, 2018). Even though the soil pH between Kapit and Sri Aman are quite similar (4.57-4.59), Sri Aman exhibited a good P removal compared to Kapit, which benefits from a proper earlier crop establishment and reflected comparable absorption of P from soil and later accumulates in the leaves. At the same time, Bintulu indicated significantly higher P than Kapit, even though the crop age was the same (6 months). The reason that affects this problem may be caused by the higher soil pH recorded in Bintulu (4.95), which is the increased concentration of P removal in leaves compared to Kapit (Rapatsa & Terapongtanakorn, 2010).

Table 4. Nutrient content in leaves

Farms	Fe	Mn	N	P	K
	g/kg				
Kapit	0.10b ± 0.005	0.15c ± 0.03	6.66b ± 0.35	1.10c ± 0.02	11.70c ± 0.32
Bintulu	0.19a ± 0.003	0.59a ± 0.02	12.30a ± 0.29	1.17b ± 0.007	19.88a ± 0.13
Sri Aman	0.10b ± 0.002	0.27b ± 0.004	6.30b ± 0.63	1.29a ± 0.01	15.62b ± 0.51

Remarks: Means with different alphabet was significantly different at p=0.05; ± indicated standard error

In contrast, K removal was significantly higher in Bintulu compared to other farms. According to Prajapati & Modi (2012), K plays a vital role in water and nutrient transport in soil. The higher K concentration can see this in Sri Aman has facilitated higher K removal. However, K removal in Sri Aman was slightly reduced compared to Bintulu. The lower K removal in Sri Aman is attributed to the preparation for black pepper fruit development, thus, indicated an equivalent K. This finding confirmed by significantly higher K availability in soil that meant the importance of sufficient K availability before bearing fruit especially improved fruit size. However, Bintulu exhibit greater removal than Sri Aman, which reflects allowing the flower spike on early cultivation (6 months old) to remove higher K from soil systems. This eventually may interfere with the growth of crop canopy as the crop actively uptake nutrients for flower spike and fruit development (Paulus, Sim, Eng, Megir, & Rosmah, 2011). In another farm, Kapit show significantly lower K removal compared to other farms, which is caused by lessened K availability in soil that limit K uptake.

Correlation Studies on Selected Soil Properties

The correlation of all soil variables was 56.17% (Fig. 1), with the first component (F1) indicating positive TOC, P, and K availability and negative pH, N, Fe, and Mn availability. However, all soil variables were independently positive in the second component (F2) except K. This result revealed that soil pH plays a vital role in governing the availability of TOC, P, and K. The decline in soil pH has restricted the amounts of P and K for plant uptake, which is attributed to various chemical reactions in the soil system (Weil & Brady, 2017; Zu et al., 2014). Increasing Fe and Mn will suppress P and K availability as it promotes insoluble P as it is bound tightly to Fe and as the replacement of metal cations with K. Similar declination pattern was observed in total N, whereas increasing N concentration may decrease available TOC, P, and K. Generally, increasing N was derived from the mineralization of OM which contains TOC as a part of itself and eventually the mineralization process will decrease TOC. Moreover, repetitive use of urea as an N fertilizer has become a source of soil acidity and further declined the availability of P and K in the soil. As soil becomes acidic, metal cations such as Al, Fe, and Mn become soluble in the soil system and disturb the primary nutrient uptake process.

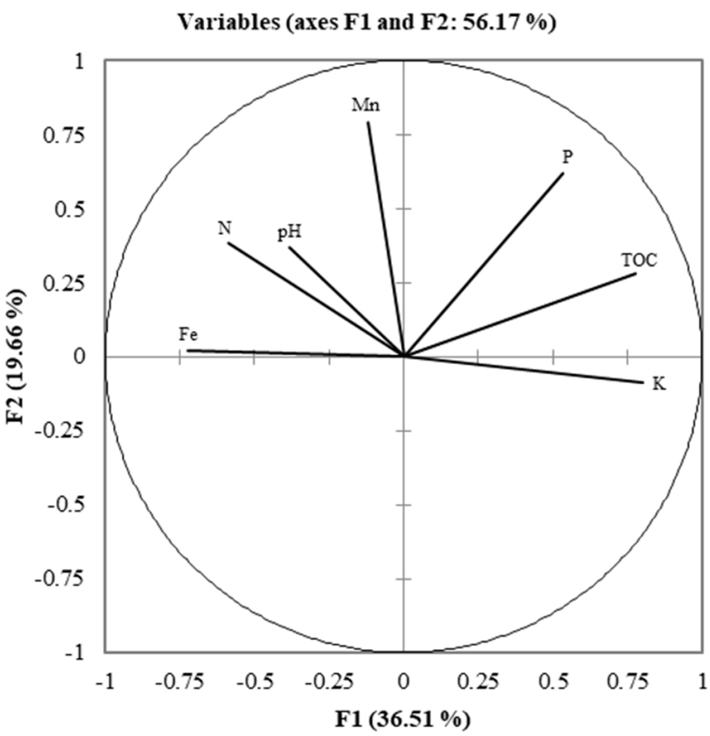

Fig. 1. Circle of correlation on soil pH, total N, available P and K

The soil samples in this study are clustered into three different groups (Fig. 2). The first group (Kapit) is dominated by negative F1 and positive F2 axis. A specific part of the farm experience in relatively acidic soil resulted from the conversation of ammonium-based fertilizer to nitrate that produces H^+ and increases the availability of Fe and Mn in soil systems. The rest of the Kapit farm area experienced insufficient nutrient availability that arises from lower soil pH. This will promote the leaching of basic cations and inefficient nutrient uptake by limited root penetration in soil systems due to young crop ages.

Meanwhile, the second group (Bintulu) concentrated in negative F1 and F2 axis, which may conclude a primary nutrient insufficiency is occurring across the farm. This problem may be derived from a burning secondary concern which may volatilize some nutrients, for example, N, P, and S, and rapid loss of OM that act as binding agents for other cations (Norouzi & Ramezanpour, 2013). Moreover, the positive effect on the presence of burned earth may only be visible several years after the burning occurs. The last group, Sri Aman, is majorly found in positive F1 and negative F2 axes. This somehow explains the farm within F1 has an equivalent concentration of TOC, P, and K, while others in F2 may experience nutrient deficiency. The advantages of greater nutrient availability may be caused by higher crop age, which has accelerated nutrient absorption for flowering before berries production.

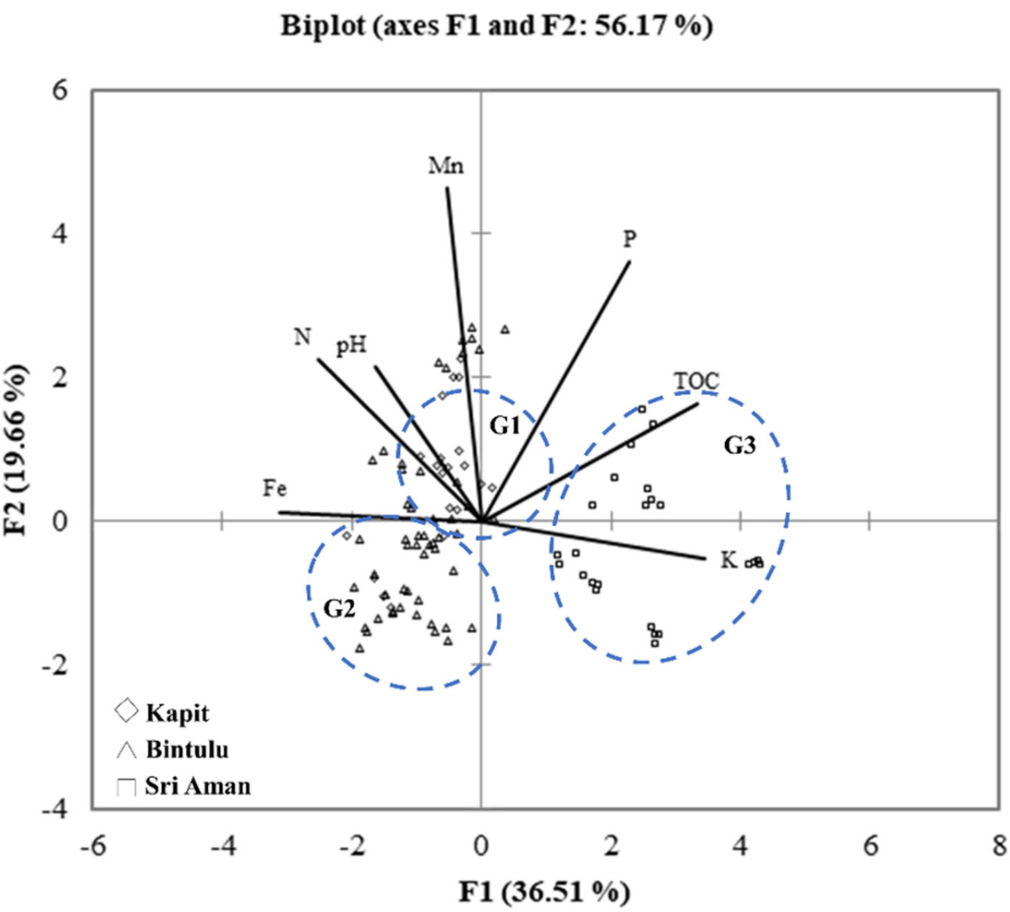

Fig. 2. Distribution of soil samples according to soil variables

CONCLUSION

Nutrient content in the soil for Kapit revealed high availability of Mn, Bintulu high in pH, Fe, and N, while Sri Aman was high in TOC, P, and K. High removal of Fe, Mn, N, and K recorded in Bintulu compared to matured black pepper area, Sri Aman has high removal of P. Correlation revealed soil pH affects the availability of TOC, P, and K; however, decreased soil pH eventually increases the availability of Fe, Mn, and N in the soil.

ACKNOWLEDGEMENT

This research was supported by the project number GP-IPB/2018/9557605 from Universiti Putra Malaysia.

REFERENCES

Abreu Jr, C. H., Muraoka, T., & Lavorante, A. F. (2003). Relationship between acidity and chemical properties of Brazilian soils. *Scientia Agricola, 60*(2), 337-343. https://doi.org/10.1590/S0103-90162003000200019

Amirruddin, A. D., Muharam, F. M., Paing, T. N., Singh, D. S. K., & Yusoff, M. M. (2017). Nitrogen effects on growth and spectral characteristics of immature and mature oil palms. *Asian Journal of Plant Sciences, 16*(4), 200-210. https://doi.org/10.3923/ajps.2017.200.210

Ann, Y. C. (2012). Determination of nutrient uptake characteristic of black pepper (*Piper nigrum* L.). *Journal of Agricultural Science and Technology, 2*(10B), 1091-1099.

Beretta, A. N., Silbermann, A. V., Paladino, L., Torres, D., Bassahun, D., Musselli, R., & García-Lamohte, A. (2014). Soil texture analyses using a hydrometer: modification of the Bouyoucos method. *Ciencia e Investigación Agraria, 41*(2), 263-271. https://doi.org/10.4067/S0718-16202014000200013

Brunetto, G., de Melo, G. W. B., Toselli, M., Quartieri, M., & Tagliavini, M. (2015). The role of mineral nutrition on yields and fruit quality in grapevine, pear and apple. *Revista Brasileira de Fruticultura, 37*(4), 1089-1104. https://doi.org/10.1590/0100-2945-103/15

Çelík, H., Aşik, B. B., Gűrel, S., & Katkat, A. V. (2010). Effects of potassium and iron on macro element uptake of maize. *Zemdirbyste-Agriculture, 97*(1), 11-22. Retrieved from http://zemdirbyste-agriculture.lt/97(1)tomas/97_1_tomas_str2.pdf

Emongor, V. E., & Mabe, O. (2010). *Effects of phosphorus on growth, yield and yield components of chilli pepper (Capsicum annuum L.)*. Paper presented at XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on Quality-Chain Management of Fresh Vegetables: From Fork to Farm. *Acta Horticulturae, 936*, 327-334. https://doi.org/10.17660/ActaHortic.2012.936.42

Fan, T.-T., Wang, Y.-J., Li, C.-B., Zhou, D.-M., & Friedman, S. P. (2015). Effects of soil organic matter on sorption of metal ions on soil clay particles. *Soil Science Society of America Journal, 79*(3), 794-802. https://doi.org/10.2136/sssaj2014.06.0245

George, C. K., Abdullah, A., & Chapman, K. (2005). *Pepper production guide for Asia and the Pacific.* Bangkok, TH: International Pepper Community. Retrieved from https://agris.fao.org/agris-search/search.do?recordID=XF2016001124

Hamza, S., Srinivasan, V., & Dinesh, R. (2007). Nutrient diagnosis of black pepper (*Piper nigrum* L.) gardens in Kerala and Karnataka. *Journal of Spices and Aromatic Crops, 16*(2), 77-81. Retrieved from https://updatepublishing.com/journal/index.php/josac/article/view/4873

Hartz, T. K., Miyao, G., Mullen, R. J., Cahn, M. D., Valencia, J., & Brittan, K. L. (1999). Potassium requirements for maximum yield and fruit quality of processing tomato. *Journal of the American Society for Horticultural Science, 124*(2), 199-204. https://doi.org/10.21273/JASHS.124.2.199

Hesammi, E., Talebi, A. B., & Hesammi, A. (2014). A review on the burning of crop residue on the soil properties. *Walia Journal, 30*(1), 192-194. Retrieved from https://www.researchgate.net/publication/274063964_A_review_on_the_burning_of_crop_residue_on_the_soil_properties

Izzah, A. H., & Wan Asrina, W. Y. (2019). Black pepper in Malaysia: An overview and future prospects. *Agricultural Reviews, 40*(4), 296-302. Retrieved from https://arccjournals.com/journal/agricultural-reviews/R-129

Krohling, C. A., Eutrópio, F. J., Bertolazi, A. A., Dobbss, L. B., Campostrini, E., Dias, T., & Ramos, A. C. (2016). Ecophysiology of iron homeostasis in plants. *Soil Science and Plant Nutrition, 62*(1), 39-47. https://doi.org/10.1080/00380768.2015.1123116

Liu, Z., Gao, J., Gao, F., Liu, P., Zhao, B., & Zhang, J. (2018). Photosynthetic characteristics and chloroplast ultrastructure of summer maize response to different nitrogen supplies. *Frontiers in Plant Science, 9*, 1-13. https://doi.org/10.3389/fpls.2018.00576

Mallarino, A., & Pecinovsky, K. (2014). Phosphorus and potassium fertilization for corn and soybean grown in rotation for 30 years. *Iowa State Research Farm 09-13.* Iowa State University. Retrieved from https://dr.lib.iastate.edu/server/api/core/bitstreams/f5a3a8c9-b8b2-4f12-9327-0ec6235403ae/content

Moreira, A., & Fageria, N. K. (2010). Liming influence on soil chemical properties, nutritional status and yield of alfalfa grown in acid soil. *Revista Brasileira de Ciência do Solo, 34*(4), 1231-1239. https://doi.org/10.1590/S0100-06832010000400022

Moreira, A., Sfredo, G. J., Moraes, L. A. C., & Fageria, N. K. (2015). Lime and cattle manure in soil fertility and soybean grain yield cultivated in tropical soil. *Communications in Soil Science and Plant Analysis, 46*(9), 1157-1169. https://doi.org/10.1080/00103624.2015.1033542

Mousavi, S. R., Shahsavari, M., & Rezaei, M. (2011). A general overview on manganese (Mn) importance for crops production. *Australian Journal of Basic and Applied Sciences, 5*(9), 1799-1803. Retrieved from http://ajbasweb.com/old/ajbas/2011/September-2011/1799-1803.pdf

Nascente, A. S., & Lanna, A. C. (2016). Straw and early nitrogen fertilization affect soil properties and upland rice yield. *Pesquisa Agropecuária Tropical, 46*(3), 284-291. https://doi.org/10.1590/1983-40632016v4641386

Nduwumuremyi, A., Ruganzu, V., Mugwe, J. N., & Rusanganwa, A. C. (2013). Effects of unburned lime on soil pH and base cations in acidic soil. *International Scholarly Research Notices, 2013*, 707569. https://doi.org/10.1155/2013/707569

Norouzi, M., & Ramezanpour, H. (2013). Effect of fire on soil nutrient availability in forestes of Guilan, North of Iran. *Carpathian Journal of Earth and Environmental Sciences, 8*(1), 157-170. Retrieved from http://www.cjees.ro/viewTopic.php?topicId=305

Oluwadare, D. A., Voncir, N., Mustapha, S., & Mohammed, G. U. (2013). Evaluation and enhancement of available micronutrients status of cultivated soil of Nigeria Guinea Savanna using organic and inorganic amendments. *IOSR Journal of Agriculture and Veterinary Science, 3*(5), 62-68. Retrieved from https://www.iosrjournals.org/iosr-javs/papers/vol3-issue5/J0356268.pdf

Paulus, A. D., Sim, S. L., Eng, L., Megir, G., & Rosmah, J. (2011). *Pepper Production Technology in Malaysia.* Sarawak, MY: Malaysian Pepper Board and Department of Agriculture Sarawak.

Prajapati, K., & Modi, H. A. (2012). The importance of potassium in plant growth – A review. *Indian Journal of Plant Sciences, 1*(02-03), 177-186. Retrieved from https://www.researchgate.net/publication/304246278_THE_IMPORTANCE_OF_POTASSIUM_IN_PLANT_GROWTH_-_A_REVIEW

Qian, Y., Miao, S. L., Gu, B., & Li, Y. C. (2009). Effects of burn temperature on ash nutrient forms and availability from cattail (*Typha domingensis*) and sawgrass (*Cladium jamaicense*) in the Florida Everglades. *Journal of Environmental Quality, 38*(2), 451-464. https://doi.org/10.2134/jeq2008.0126

Rapatsa, J., & Terapongtanakorn, S. (2010). Some physiological measurements on growth, pod yields and polyamines in leaves of chili plants (*Capsicum annuum* cv. Hua Reua) in relation to applied organic manures and chemical fertilisers. *Pakistan Journal of Biological Sciences, 13*(6), 263-270. https://dx.doi.org/10.3923/pjbs.2010.263.270

Ravindran, P. N. (2000). *Black pepper: Piper nigrum.* London: CRC Press. https://doi.org/10.1201/9780203303870

Rengel, Z. (2015). Availability of Mn, Zn and Fe in the rhizosphere. *Journal of Soil Science and Plant Nutrition, 15*(2), 397-409. https://doi.org/10.4067/S0718-95162015005000036

Roper, W. R., Robarge, W. P., Osmond, D. L., & Heitman, J. L. (2019). Comparing four methods of measuring soil organic matter in North Carolina soils. *Soil Science Society of America Journal, 83*(2), 466-474. https://doi.org/10.2136/sssaj2018.03.0105

Rout, G. R., & Sahoo, S. (2015). Role of iron in plant growth and metabolism. *Reviews in Agricultural Science, 3*, 1-24. https://doi.org/10.7831/ras.3.1

Sa'adi, Z., Shahid, S., Chung, E.-S., & bin Ismail, T. (2017). Projection of spatial and temporal changes of rainfall in Sarawak of Borneo Island using statistical downscaling of CMIP5 models. *Atmospheric Research, 197*, 446-460. https://doi.org/10.1016/j.atmosres.2017.08.002

Sáez-Plaza, P., Navas, M. J., Wybraniec, S., Michałowski, T., & Asuero, A. G. (2013). An overview of the Kjeldahl method of nitrogen determination. Part II. Sample preparation, working scale, instrumental finish, and quality control. *Critical Reviews in Analytical Chemistry, 43*(4), 224-272. https://doi.org/10.1080/10408347.2012.751787

Shreckhise, J. H., Owen Jr, J. S., & Niemiera, A. X. (2018). Growth response of three containerized woody plant taxa to varying low phosphorus fertilizer concentrations. *HortScience, 53*(5), 628-637. https://doi.org/10.21273/HORTSCI12449-17

Smith, D. M., Inman Bamber, N. G., & Thorburn, P. J. (2005). Growth and function of the sugarcane root system. *Field Crops Research, 92*(2-3), 169-183. https://doi.org/10.1016/j.fcr.2005.01.017

Srinivasan, V., Dinesh, R., Hamza, S., & Parthasarathy, V. A. (2007). Nutrient management in black pepper (*Piper nigrum* L.). *CABI Reviews, 2*(62), 1-14. https://doi.org/10.1079/PAVSNNR20072062

Tabi, F. O., Mvondo Ze, A. D., Boukong, A., Mvondo, R. J., & Nkoum, G. (2013). Changes in soil properties following slash and burn agriculture in the humid forest zone of Cameroon. *African Journal of Agricultural Research, 8*(18), 1990-1995. https://doi.org/10.5897/AJAR2012.1713

Tahir, S., & Marschner, P. (2016). Clay addition to sandy soil: Effect of clay concentration and ped size on microbial biomass and nutrient dynamics after addition of low C/N ratio residue. *Journal of Soil Science and Plant Nutrition, 16*(4), 864-875. http://dx.doi.org/10.4067/S0718-95162016005000061

Tahir, S., & Marschner, P. (2017). Clay addition to sandy soil—influence of clay type and size on nutrient availability in sandy soils amended with residues differing in C/N ratio. *Pedosphere, 27*(2), 293-305. https://doi.org/10.1016/S1002-0160(17)60317-5

Tan, K. H. (2011). *Principles of soil chemistry* (4th ed.). Boca Raton, FL: CRC Press. https://doi.org/10.1201/9781439894606

Weil, R. R., & Brady, N. C. (2017). *The nature and properties of soils* (15th ed.). Pearson. Retrieved from https://www.pearson.com/en-us/subject-catalog/p/nature-and-properties-of-soils-the/P200000000825/9780137516933?tab=accessibility

Wuenscher, R., Unterfrauner, H., Peticzka, R., & Zehetner, F. (2015). A comparison of 14 soil phosphorus extraction methods applied to 50 agricultural soils from Central Europe. *Plant, Soil and Environment, 61*(2), 86-96. Retrieved from https://www.agriculturejournals.cz/web/pse.htm?type=article&id=932_2014-PSE

Zu, C., Li, Z., Yang, J., Yu, H., Sun, Y., Tang, H., … Wu, H. (2014). Acid soil is associated with reduced yield, root growth and nutrient uptake in black pepper (*Piper nigrum* L.). *Agricultural Sciences, 5*(5), 466-473. http://dx.doi.org/10.4236/as.2014.55047