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Effects of Three Rainfall Patterns on Soil Chemical Properties in Black Pepper Cultivation in a Hilly Topography

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ABSTRACT

This study was conducted to determine the effect of the rainfall pattern on cation nutrients in black pepper cultivation in a hilly topography. A field study was conducted in black pepper cultivation in a hilly topography around Bintulu, Sarawak, Malaysia, with a 26^o slope during the Northeast monsoon in 2020. Six blocks were established on 462.56 m^2, with four subsequent soil samples (0-20 cm) collected per block after the rainfall. Soil samples were analysed using the standard pH, total organic carbon (TOC), soil texture, total nitrogen (TN), available phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), and manganese (Mn) in triplicate. Rainfall pattern (October < November > December) affects TN (300.31-1422.90 mg/kg) and K availability (13.54-166.68 mg/kg), especially during peak season in November 2020. Available P, Ca, Mg, Fe, and Mn exhibit minimum rainfall effect but are closely related to combined interaction with parent material and topography. Therefore, proper soil management, such as applying fertiliser using top dressing, foliar spray, and manure amendment, including growing cover crop, is recommended to improve nutrient availability.

Keywords: Black pepper, intensity, Northeast monsoon, rainfall pattern, slope, topography

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INTRODUCTION

Agricultural activity on >10^o is highly discouraged due to several reasons. First, farmers might have to bear high maintenance costs and encounter impracticability to sustain productivity while conducting cultivation activity at a steep area (Izzah & Wan Asrina, 2019; Nguyen & Pham, 2018; Paulus et al., 2011). Apart from that, cultivation activity on hilly topography with steep slopes faces the risk of soil loss, leading to infertility. Infertility problems in hilly areas, particularly among smallholders, are prone to happen since the farmers tend to neglect proper land establishment, such as constructing terraces, covering the soil surface with a cover crop, growing perennial with deep taproots to hold and stabilising soil particles. The neglect during farming might contribute to the soil system issues and reduce crop growth due to the lower amount of soil nutrients attributed to climatic conditions (Siswanto & Sule, 2019; Zhang et al., 2011).

Previous research conducted in Tikolod, Sabah confirmed that minimum conservation practices by the farmer on 30^o slope accelerate soil loss when cultivating ginger and hill paddy (Gregersen et al., 2003). A similar study conducted by Mohamad et al. (2018) also found that soil erosion has a significant correlation with slope conditions, as the bare soil surface with low vegetation coverage on steep slopes can speed up the erosion process. Next, slope orientation can affect the nutrient availability in the soil. It is reported that at least 23.60 mg/kg of P is available on tilt-up in the upper slope compared to the steeper area (Samndi & Mahmud, 2014). Several nutrient deficiency problems reported in previous literature involving N, K, and other essential elements eventually lead to lower yields (Izzah & Wan Asrina, 2019; Srinivasan et al., 2007). The effect of the insufficient nutrient is more prominent in a tropical country, especially East Malaysia, which receives higher rainfall up to 4,600 mm annually, and the circumstance facilitates the nutrient movement caused by a breakdown of soil aggregates (Sa'adi et al., 2017).

Rainfall can cause nutrients in soil colloids transported to another area, and this impact can be observed in coarse textural soil. Previous research emphasises that intense rainfall at 60 mm/h can affect N (Zanon et al., 2020), P, and K availability (Luo et al., 2013; Yaşar Korkanç & Dorum, 2019). Zanon et al. (2020) pointed out that increasing supplementation of N in liquid form from dairy manure in 0, 60, 120, and 180 m^3/ha/year sequence on sandy clay loam texture suffers N loss during field simulated rainfall study. A study by Luo et al. (2013) on a hillslope in China has documented a higher P loss when increasing slope gradient from 5^o, 10^o, and 15^o compared to normal practices when applying with inorganic fertiliser in 25-30 days before quantifying the loss with rainfall simulation. On another note, Yaşar Korkanç and Dorum (2019) highlighted a contradicting finding in which they stated that the lower rate of P loss during longer rainfall duration under simulated conditions is caused by the dilution effects with increasing runoff volume.

Meanwhile, it was found that K encounters the highest loss regardless of farmer practices due to higher ion mobility in soil. It was confirmed by Bertol et al. (2003) that K mobility is considered high due to ion affinity to soil colloidal activity, although the soil is covered with vegetation nearly 100%. Regardless of rainfall orientation, the impact can be more profound with the increasing intensity. For example, 60 mm/hr to 120 mm/hr might illustrate soil incapability to store or infiltrate excessive water, which causes rapid surface flow that carries soil particles, including nutrients. However, the nutrient loss is probably lower in clay compared to sandy particles, and it still depends on slope orientation, climatic, and environmental conditions. In several cases, the availability of ferrous ion (Fe^{2+}), aluminium ion (Al^{3+}), and hydrogen ion (H^{+}) increase significantly as the ammonium cation (NH_4^{+}) and potassium ion (K^{+}) are extensively removed (Meda et al., 2002; Mendes et al., 2016).

Black pepper needs a proper drainage system. Thus, growing the black pepper in a hilly topography is preferable, especially in East Malaysia, since it is surrounded by many hill areas previously left as secondary forest. The Malaysian Pepper Board (MPB) is a responsible agency that provides partially free training courses, workshops, and consultations at the field sites to raise farmer awareness in practising Good Agricultural Practices (GAP) in black pepper plantations. However, despite the effort from the agency, there are still some cases where a few farmers have suffered unsuccessful cultivation due to inappropriate farming practices and financial issues. For example, some farmers are still cultivating the black pepper using traditional practices such as using bare soil surface and non-living pole and constructing a minimum terrace (Izzah & Wan Asrina, 2018; Paulus et al., 2011). Subsequently, this might affect soil fertility and contributes to a prominent effect for the nutrient-demanding crop. Therefore, it is crucial to ensure sufficient nutrients during 24 months of growth for good canopy formation. Since black pepper is cultivated in hilly topography within tropical climatic conditions with minimum effort on soil management, lower nutrient availability during rainfall has been observed.

Hence, to understand the problem, the study was conducted to investigate the effect of rainfall patterns on cation nutrients in black pepper cultivation in a hilly topography.

MATERIALS AND METHODS

Study Area

This study was conducted during the Northeast monsoon season in 2020 with 4,600 mm of hilly topography annual precipitation with 26^{o} in Bintulu, Sarawak, Malaysia (3^{o} 0' N, 113^{o} 1' E). This farm was a secondary forest converted into black pepper cultivation (2 ha) with invisible terracing or cover crops. However, for this specific study, only 0.06 ha was utilised. This site was cultivated with a mixed variety (132 vines) of *Uthirancotta*, locally known as *Indian*/*Thambi*, and a wild variety, namely *Rembai*, by the farmer on non-living

Table 1
Soil characteristics at the studied site

Variables	October	November	December
pH	4.44	4.49	4.36
Total organic carbon (%)	1.59	1.33	1.60
Texture		Sandy Loam	

poles from *Commersonia bartramia* bole with 2.1 m x 1.8 m spacing. The crop age was 16 months old and identified as at a young phase (<24 months) with the soil of Bekenu Series developed over mixed sedimentary rock with sand >76.00%, recognised as a sandy loam [United States Department of Agriculture (USDA) triangle, Table 1]. Soil mound was prepared for each vine and re-mounded yearly to restore soil loss, including amendment of 1 kg lime/mould as standard practices. The NPK green (15:15:15) was given at 100 g/vine twice in October and once in November and December. Due to several factors, such as market price instability and farm location in a remote area, the farmer has to limit agricultural inputs.

Soil Sampling and Data Processing

About six blocks were established with a size of 7.78 m x 9.80 m around 462.56 m^2 (23.60 m x 19.60 m), and four surface soil samples (0-20 cm) were collected per block after <12 hours of a rainfall event. An automatic rain gauge with a tipping bucket (Model WS2310CA, Misol, China) was installed at the top of the site. The samples were air-dried, grounded, and sieved through 2 mm mesh. Acid digestion procedure was performed using standard protocol by Food and Agriculture Organization (FAO) (2021) and analysed for total nitrogen (TN), while available phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), and manganese (Mn) extracted using Mehlich-1 method with a 1:5 ratio of weak double acid (Tan, 2005) were carried out in triplicate. The TN was determined using AutoAnalyser 3 (Model HR, SEAL Analytical, USA) by high-range working standard, while P using colourimetric, which was then determined through UV-Vis Spectrometer at 820 nm absorption (Model Lambda 25, Perkin Elmer, USA). Other samples were analysed using Atomic Absorption Spectrometer (Model AA800, Perkin Elmer, USA). Meanwhile, pH value from using water by one part of the soil and five parts of water (1:5), soil texture with hydrometer procedure, and total organic carbon (TOC) through dry combustion were investigated by following the method described by Tan (2010) and Sutherland (1998), respectively.

Data analysis was performed by calculating the mean value, including statistical analysis, using SAS ver. 9.4, and a significant difference was tested using Tukey's honest significant difference test (Tukey's HSD). The graph was plotted using SigmaPlot ver. 14.0 and arranged into three rainfall patterns (October, November, and December). Rainfall intensity was calculated by dividing rainfall volume by duration.

RESULTS AND DISCUSSION

Figure 1 presents the data on TN in October 2020, which shows a decreasing trend until day nine (D9). The result escalated 2.5-folds on day 10 (D10) with a moderate decrease and gradually increased in November and December 2020, respectively. Lower intensity on day 22 (D22) displays an increasing TN (1104 mg/kg). Phosphorus availability exhibits unaffected (~3 mg/kg) throughout rainfall intensity, but it only indicates a higher concentration on day 19 (D19) (5.9 mg/kg). A sharp decrease in K was recorded on day 3 (D3) by almost 7-folds, and it slowly increased at the end of October ranged from 53 to 59 mg/kg. Potassium was continuously kept <34 mg/kg with increasing intensity from November until December. A similar trend was observed in Ca, where the declination of concentration has occurred from day 2 (D2) until day 22 (D22), although a slight increase was visible on day 3 (D3) (5 mg/kg), day 16 (D16) (4.4 mg/kg), and day 20 (D20) (4.2 mg/kg). Furthermore, Mg, Fe, and Mn exhibit a similar nutrient pattern apart from Fe and Mn availabilities were prominent in November on day 14 (D14) (400 mg/kg) and day 13 (D13) (3 mg/kg), respectively. From the analysis, rainfall intensity has a lower impact on Mg, Fe, and Mn than N and K. Meanwhile, Figure 2 shows nutrient availability according to rainfall patterns with significant value is presented in total N and available K. Meanwhile, available P, Ca, Mg, Fe, and Mn exhibit comparable value throughout three rainfall months.

This study revealed that TN in the black pepper farm was affected by constant rainfall and intensity between October and November (Figures 1 and 2). Total N decreased from day 1 (D1), day 9 (D9), day 11 (D11), and day 18 (D18), even when the cultivation was fertilised with NPK green on day 4 (D4), day 14 (D14), and day 18 (D18) at the rate of 100 g/vine. This situation underlines that most nutrients can be washed away when practising surface application, with a prominent effect shown in day 5 (D5) by 2-folds lower than day 4 (D4). A rapid TN movement is accelerated by steep topography (26^{o}) with a bare surface and is dominated by a sand particle (Arunrat et al., 2020). Moreover, high rainfall significantly lowers the TN availability in soil due to incapable soil particles holding or retaining the ion, leading to repetitive N application (two times a month). N in soil may be available to the crop in two different forms: nitrogen-nitrate (N-NO_3^-) and nitrogen-ammonium (N-NH_4^+). These two forms are easily lost in the soil system, especially in nitrate (NO_3) that is heavily available during the wet season. It is easily transported due to rapid nitrification (Gu & Riley, 2010; Hagedorn et al., 1997).

Moreover, a higher coarse particle may yield <80 cmol/kg of cation exchange capacity (CEC) compared to anion exchange capacity (AEC) for Bekenu soil, which is lower than the CEC value, and the effects can be seen on lower ion adsorption on soil colloidal. This continuous TN decrease

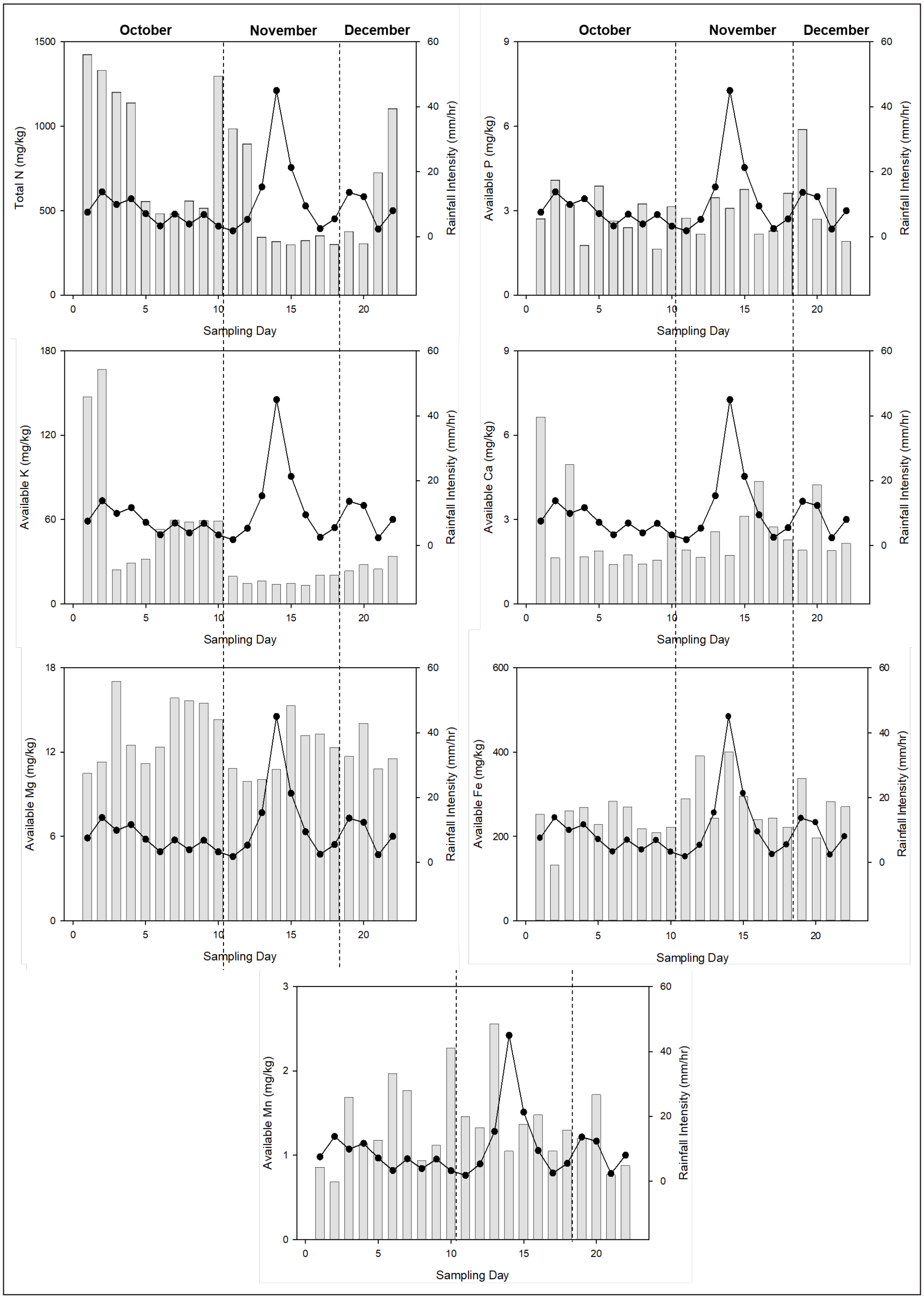

Figure 1. Nutrient concentration in the soil after three rainfall patterns (October, November, and December 2020) with 22 sampling days (D)

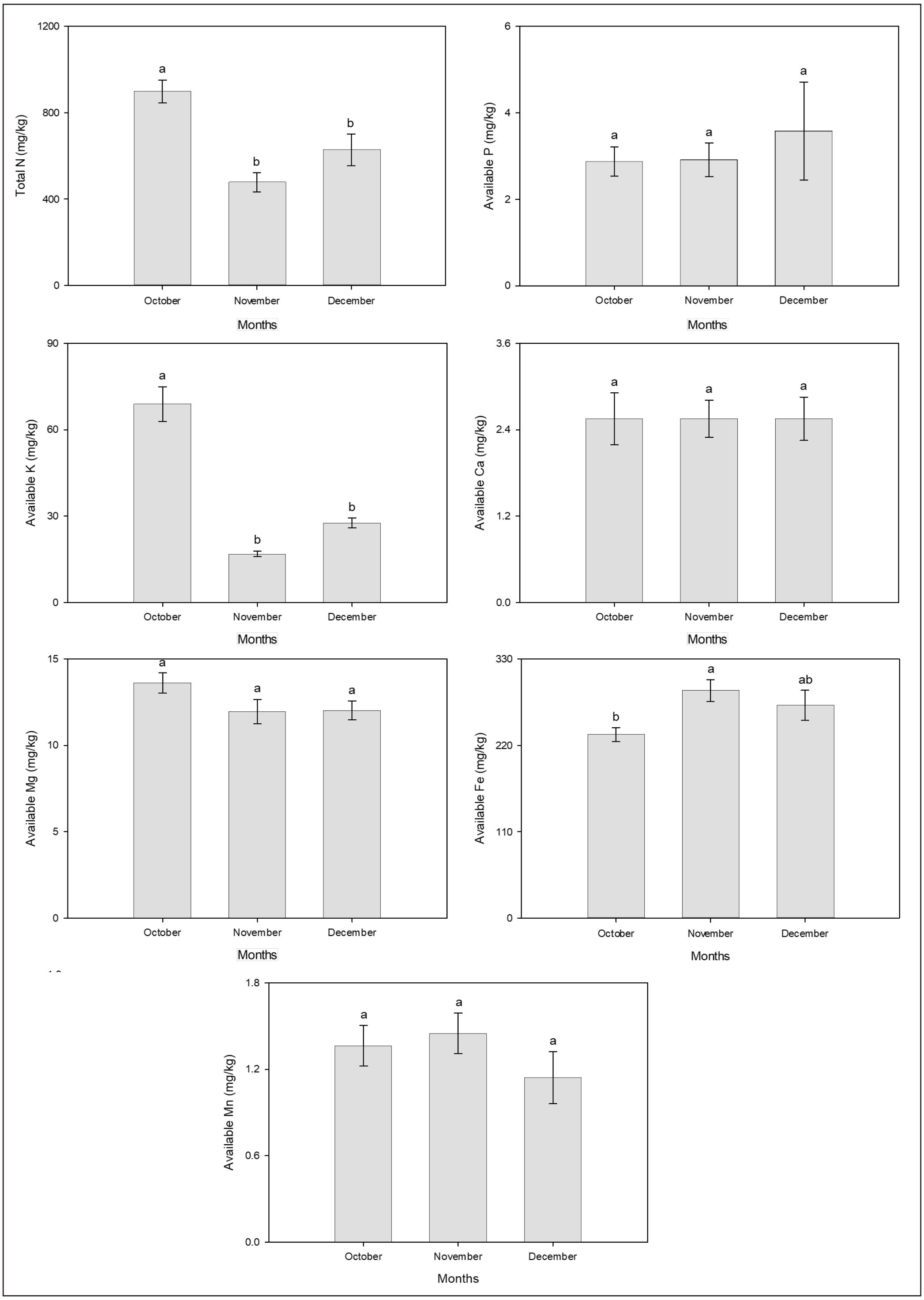

Figure 2. Average nutrient concentration in October, November, and December. Different letters indicate statistically significant differences at $p = 0.05$ using Tukey's HSD with standard error

can impact nutrient uptake in black pepper, which might endanger catkin growth and berries yield (Izzah & Wan Asrina, 2019; Sharangi, 2011). Accordingly, lower TN on black pepper affects yield, plant height, and weight (Sharangi, 2011; Sivaraman et al., 1999). These results offer compelling evidence in November by representing lower TN on peak rainfall than on early October and end of December rainfall events (Figure 2). In addition, the amendment of manure or leguminous crops can increase TN availability by enhancing the mineralisation rate naturally, and sustainability will protect the soil surface (Hua et al., 2020; Saka et al., 2017; Stagnari et al., 2017). Sharangi (2011) proved that a 25% farmyard manure mixture with 75% urea has a promising effect on the black pepper crop.

On the contrary, P continues to show lower availability regardless of rainfall pattern and after NPK fertilisation. The result is subjected to low inheritance by parent material developed in mixed sedimentary rocks (Bekenu Series) (Emmanuel et al., 2020; Yokoyama et al., 2018). Bekenu Series is well-drained soil and extensively used in agriculture with low fertility. Paramananthan (2000) emphasised that proper fertilisation and land soil conservation techniques can sustain the soil series for extensive cultivation. However, this soil series may exhibit fertiliser supplementation that can absorb aluminium/iron (Al/Fe) oxides and hydroxides in extremely acidic forms, forming various complexes. Under those circumstances, P will become unavailable for black pepper uptake, and the best way to improve P solubility is through the lime application (Opala, 2017; Penn & Camberato, 2019; Simonsson et al., 2018). Active P adsorption is common due to the fixation mentioned previously. Therefore, alternative management should enhance P availability, showing a promising outcome by using certain animal manure or selected compost (Shamshuddin et al., 2011). During this study, about 400 g chicken manure (average 8 g/kg total P) was placed three hours before rainfall on day 4 (D4) to increase adsorption sites effectively; however, no effect on P availability was observed. This outcome might be influenced by lower P application than the recommended concentration at 27.5 g/vine/year (Srinivasan et al., 2007). Moreover, lower P in this study could potentially appear through repetitive rainfall events. In addition, the hilly topography provides a minimum effect on P availability as it distributes continual through rainfall patterns.

Notably, K was affected by peak rainfall in November 2020 and exhibited lower availability attributed to solubility where excess water could displace ions to deeper soil layers or fate in a runoff (Figure 1 and Figure 2). Deficient K can contribute to nutrient hunger, and alternatively, the foliar spray was performed on day 13 (D13) and day 18 (D18). Unfortunately, the application failed to improve K uptake, which is vital for fruit development, and it remained depleted until the end of this study. Concerns have arisen on the amount of NPK fertiliser given in October, which is 200 g/vine (100 g/vine per application) because it could cause depletion of K resources since the actual amount recommended by MPB is 500 g/vine (Paulus et al., 2011). Previous studies summarised that declination on K concentration in this study could be subjected to the combined effects of conditions such as acidic soil, high coarse soil fraction, high rainfall intensity, steeper slope, and competition between cations for the adsorption sites, which less favourable for K ion compared to other divalent and trivalent cation nutrients (Izzah & Wan Asrina, 2018; Mendes et al., 2016; Tan, 2010).

Ca, Mg, Fe, and Mn was also observed according to the rainfall patterns in which Ca displayed increasing intensity in November, although 4 kg lime was applied on the soil surface on day 4 (D4). Liming process increased soil pH from 4.44 to 4.49. However, it decreased again to 4.36 in December, representing lower Ca availability due to the dilution effect replacing H^{+}. Acidic conditions, including frequent rainfall and intensity, will intensify leaching occurrence, and liming will displace aluminium ion (Al^{3+}) and manganese ion (Mn^{2+}) from soil colloids then precipitate in soil solution (Goulding, 2016; Hess et al., 2020; Yao et al., 2021). Additionally, liming on sandy soil has proven the low mobility, minimum reaction, and lack of soluble by-product (anions) of reaction with acidity (Meda et al., 2002; Nunes et al., 2019), evident by small pH increments.

Meanwhile, Mg showed persistent interveinal chlorosis, which could be noticeable on older leaves in this study, representing chlorophyll degradation. These results extend the knowledge of the possibility antagonism effect occurs in the sandy due to weakly bounded Mg that imply high mobility in soil, especially in the wet season in the steep areas (Senbayram et al., 2015; Yan & Hou, 2018). Besides, Fe was unaffected by rainfall patterns in this study. Nevertheless, its solubility was regulated by lower soil pH (4.36-4.49). Therefore, the result on Mn is probably influenced by the proper drainage system and sufficient aeration caused by the nature of the soil in the research site that inherits lower Mn caused by a weak bond with soil colloids (Siskawardani et al., 2016).

CONCLUSION

The findings of this study indicate that TN and K are highly affected by rainfall patterns, especially in November, which is during the peak monsoon season, compared to P, Ca, Mg, Fe, and Mn, with combined interaction on parent material and topography. Fertiliser amendment as a top dressing, foliar spray, manure supplementation, and growing legume cover crop is recommended to improve nutrient availability. This finding might not represent a well-established site with proper soil management, but it might provide a picture when minimum consideration is taken. This study will serve as a foundation for future studies to the extent of the research on the direct implication of cultivating crops on a steeper slope.

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