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# Determination of Nutrient Uptake Characteristic of Black Pepper (*Piper nigrum* L.)

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**Abstract:** The relationship between the growth and nutrient uptake by perennial crop such as pepper is poorly understood and improved understanding of such relationship is important for the establishment of rational crop management practices. In order to characterize the growth performance and quantify the nutrient removed, this study presents results of three consecutive cropping years, fertilized with 1, 2 and 3 ton $ha^{-1}$ of NPK fertilizer respectively. Plant biomass accumulated was evaluated every two months, separating plant into stems, branches, leaves, berries, fruit spikes and flowers. Total biomass of pepper increased linearly and reach maximum at 22 months after planting. Thereafter, a decrease in dry matter was observed due to fruit export and fallen leaves at harvest. However, at the 28 months of planting, the biomass of pepper vine showing some increasing trend indicating the vegetative growth was reassumed for the next flowering. At 30 months, the pepper had removed 293.08 kg of nitrogen, 46.41 kg of phosphorus, 264.95 kg of potassium, 35.4 kg of magnesium and 74.82 kg of calcium. Based on data obtained, the nutrient uptake rates were lower than nutrient applied suggested that fertilizer had been overused for pepper production. In light of these results obtained, the optimum fertilizer dosage would be 62-10-62-6-18 kg/ha, 237-22-246-22-65 kg/ha and 390-62-352-47-100 kg/ha of N-P-K-Mg-Ca for the year 1, year 2 and year 3 of cropping year.

**Key words:** Black pepper, nutrient uptake, nutrient removal, growth performance, biomass.

## 1. Introduction

Black pepper (*Piper nigrum* L.) is the most important agricultural cash crop of Sarawak and has been a major producer and exporter for many years in Malaysia. Most recent available statistics place its total area at 14,735 hectare and its total pepper production at 25,672 metric tons (t) with the production of giving yield of 4.6 ton per hectare [1]. This yield is relatively low compared to other developing countries like Vietnam (50,000 ha), India (231,000 ha) and Indonesia (171,000 ha) [2]. There are many reasons for this low production of pepper in Malaysia with poor nutrient management constituting the most important limiting factors. For production sustainability, the bioavailability of specific nutrient in soil is crucial as far as plant requirement are concerned. To make a sound fertilizer recommendation, one must clearly understand the dynamic of nutrient availability from which accurate predictions can be made. This is important for black pepper because unlike most other crops, pepper is a perennial crop and the utilization pattern of nutrient over several years, could be uniquely different. Nutrient uptake by pepper has not been as intensively studied as palm oil, cereal, and other crops and previous studies in pepper were mainly focused on yield responses to fertilizer application [3-5]. Thus, the nutrient requirement of pepper has not been cleared, which restricted the implementation of science-based nutrient management in these crop. The objective of this study was to investigate N, P, K, Mg and Ca uptake and its distribution in pepper plant parts during the entire growth cycle. The information

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obtained will be used as a guideline for formulation of nutrient needs in order to sustain the growth and high yield of pepper.

## 2. Materials and Methods

The experiment was carried out during the period of 2010 to 2012 at the farmer land located in Melaka on soil of Melaka-Durian-Munchong Series. The particle size analysis showed that this brownish yellow soil belongs to clay loam of fine sandy clay and had a pH of 3.85 (Table 1). Geographical location of the experimental site is 102°09′549″ N latitude and 02°17′235″ E Longitude with average altitude of 23.21 m above the sea level. The average temperature of ranges between 30 °C-35 °C during the day, and 27 °C-29 °C at night with average annual rainfall being about 1,500 mm.

Pepper vine of the variety "Semongok Aman" were planted in row with spacing of 2.1 m × 2.1 m between and within the row, with a population of 2,000 plants per hectare. Pepper is perennial crops which start producing berries after 18 months of planting (immature stage). The development of the pepper berries to maturity took 8-9 months from flowering to full ripeness. Within an area of 0.2 ha of the established pepper crop 5 plots (replicates) of about 100 plants each were randomly selected to receive the NPK fertilizer (12%: 12%: 17%: 2% (Mg) + Trace elements) at the rate of 1 ton/ha in 2010, 2 ton/ha in 2011 and 3 ton/ha in 2012 [6]. In addition, ground magnesium limestone was applied to neutralize the acid soil.

**Table 1 The initial chemical characteristics of the Sg Udang soil.**

| Property | Value obtained (0-25 cm) |
|---|---|
| pH | 3.85 |
| CEC (cmol $kg^{-1}$) | 9.7 |
| Exchangeable ($K^+$) | 0.79 |
| Exchangeable ($Mg^{2+}$) | 0.72 |
| Exchangeable ($Ca^{2+}$) | 1.72 |
| Exchangeable ($Na^+$) | 0.09 |
| Organic carbon (%) | 1.68 |
| C/N ratio | 6.61 |
| Total nitrogen (%) | 0.25 |
| Available Phosphorus (mg/kg) | 10.32 |
| Total Potassium (mg/kg) | 28.52 |

Destructive whole plant dry matter analysis was performed every two months for the period of 30 months. At each sampling, vine was sampled into various plant parts: stems, branches, leaves, berries, fruit spikes and flowers. These plant parts were dried at 70 °C for 72 hours and digested in concentrated sulfuric acid [7]. The solutions were analyzed for N, P, K, Mg and Ca contents. Nutrient removed by the components of pepper vine were calculated from the percentage of nutrient composition and their dry weight as described by Mills and Jone [8]:

$$Nitrogen\ removal = DM \times \frac{Concentration\ of\ N\ (\%)}{100} \times 2000\ vines \quad (1)$$

$$Phosphorus\ removal = DM \times \frac{Concentration\ of\ P\ (\%)}{100} \times 2000\ vines \times 2.29 \quad (2)$$

$$Potassium\ removal = DM \times \frac{Concentration\ of\ P\ (\%)}{100} \times 2000\ vines \times 1.20 \quad (3)$$

$$Magnesium\ removal = DM \times \frac{Concentration\ of\ N\ (\%)}{100} \times 2000\ vines \quad (4)$$

$$Calcium\ removal = DM \times \frac{Concentration\ of\ N\ (\%)}{100} \times 2000\ vines \quad (5)$$

Abbreviations and notes: DM = dry matter; N = Nitrogen; P = Phosphorus; K = Potassium; Mg = Magnesium, Ca = Calcium.

## 3. Results and Dicussion

### *3.1 Dry Weight of Different Plant Parts*

Dry weight of the total plant biomass accumulation as a function of time (Fig. 1), shows that the dry matters increased continuously and reached a maximum at 22 months after planting with the total biomass accumulating 5.124 kg. Thereafter, a decrease in DM was observed due to fruit export and fallen leaves at harvest (20-26 months after planting). However, at the 28 months of planting, the biomass of

pepper vine showed some increasing trend indicating the vegetative growth was reassumed for the next flowering (Fig. 1). The large increase in total pepper biomass was mainly due to the growth of main stems, leaves and branches. In the first 18 months (immature stage), the main total plant biomass was focused on pepper stems (28.07%), branches (29.90%) and leaves (34.26%) but at the 26 months, more than 34% of total plant biomass was contributed by pepper berries, followed by stems (22.51%), leaves (20.20%) and branches (17.23%).

The biomass of root also increased at gradual rate throughout the experiment. During the entire growth period, the root biomass was characterized by greater growth rates in the period of leaf production and fruit formation especially during the flowering season, with a slowing down towards fruit maturity and harvest. From the results obtained, the growth rate of the root was positive throughout the entire planting period with a maximum of 0.80 g DM day$^{-1}$ reached.

The total leaves, stems and branches dry matter accumulation from 0 to 24 months of planting presented a sigmoidal behavior with a maximum growth rate of 2.27 g, 1.69 g and 2.17 g DM day$^{-1}$, respectively was achieved. The average growth rate of pepper varied considerably, and ranged from 0.19 g to 7.78 g DM day$^{-1}$. The average height of pepper vine were about 1.2 m (± 0.12 m) at 12 months after planting but average height increased to 2.4 m (± 0.14 m) at 18 months and to 3.1 M (± 0.47 m) at 30 months after planting. During the study, it was observed that the height and biomass gain of the pepper vine was affected by the amount of rainfall between sampling time which varied considerably (Fig. 2). The amount of the rain between the sampling time (in mm per day) was plotted versus the growth rate (g DM day$^{-1}$), and the relation was as follows:

$$y = 0.0018 \times (\text{mm per day}) + 3.9591 \quad (6)$$

In general, the increasing in rainfall will increase the growth of pepper. This finding is expected because the rain could increase the bioavailability of nutrient required by pepper in the soil. On average, pepper growth rates increased about 3.98 DM per day for each 10 mm of rain per day.

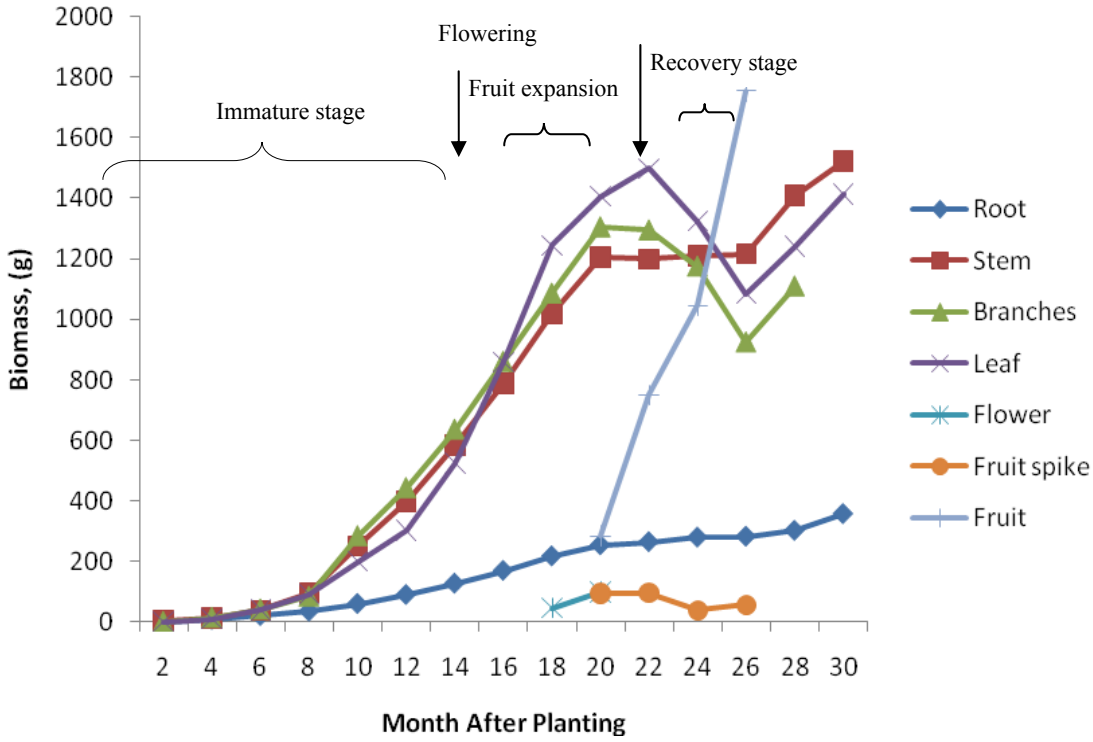


**Fig. 1 Dry matter accumulation of pepper for 30 months period at Sg Udang, Melaka.**

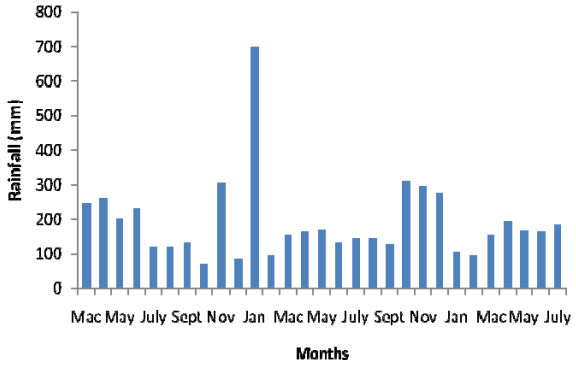


**Fig. 2 Rainfall at the experimental site of Sg Udang, Melaka.**

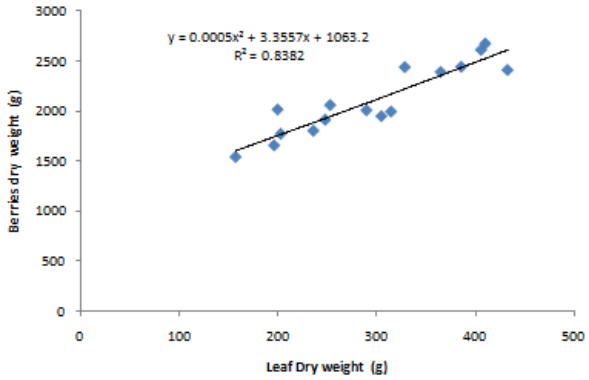


**Fig. 3 Relationship between leaves dry weight and pepper yield correlation coefficient: r > 0.8382 are significant at *P* = 0.05.**

**Fig. 4 The growth performance of pepper flowers as affected by the growth of pepper leaves.**

The leaf canopy architecture of pepper vine is an important growth character for determining vigor and productivity of black pepper. In general, there was a significant correlation between leaf dry weight and dry pepper berries (r = 0.833) with the regression between leaf dry weight and berries dry weight (y = 0.0005 $x^2$ + 3.3557 x + 1063.2) showed that an increase in leaf dry weight, will increase the pepper yield (Fig. 3). This finding is expected because the production of pepper is based on the number of leaves as production of pepper having a production concept of "1 leaf 1 flower". The emergence of every new leaf will cause the formation of new flower on the opposite site (Fig. 4).

*3.2 Nutrient Concentration and Accumulation*

The quantities of nutrient removed by the components of the pepper vine are presented in Table 2. Nutrient removed by the pepper vine make a basis for nutrient management for these crop. From the results obtained, the nutrient removed by the flowers, fruit spikes, roots, stems, branches, leaves and fruits (pepper berries) was in the increasing order. The element of removal followed the order of N > K > Ca > Mg > P. Of the 7 components of pepper vine, the fruit removed the highest amount of N which contributed to 29.61% of total annual N uptake, followed by leaves (25.20%), stems (20.63%), branches (15.64%), roots (4.83%) flowers (2.65%) and fruit spikes (1.44%) with the quantity on hectare basis was 293.08 kg/ha (Table 2). This finding is slightly higher than report published by Sim [9]. She reported that the Kuching variety removed 255.6 kg $ha^{-1}$ of N annually. Similarly, Azmil and Yau [3] also reported that the N removed by pepper plant was 255 kg/ha. This phenomenon is expected because the planting density used in the previous year has been increased from 1,680 vines $ha^{-1}$ to 2,000 vines $ha^{-1}$. Besides, the uptake of nutrient also varies among varieties. This might probably due to the different characteristics and growth performance of different varieties. E.g., variety Semongok Aman is having longer fruit spike and better fruit set than Kuching variety [6]. This phenomenon can also be further confirmed by the removal of 292 and 183 kg $ha^{-1}$ $year^{-1}$ of N respectively in variety Penniyur 1 and Karimunda [10].

**Table 2 Major nutrient accumulation and distribution (kg ha$^{-1}$) in various parts of pepper vines, over 30 months period at Sg. Udang, Melaka**

| Nutrient | Plant parts | Months after planting | | | | | | | | | | | | | | | Net accumulation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | |
| N | Leaves | 0.13 | 0.58 | 2.25 | 6.78 | 10.75 | 16.3 | 26.75 | 46.06 | 67.89 | 78.62 | 73.57 | 64.88 | 58.34 | 67.95 | 73.87 | 73.87 |
| | Stem | 0.12 | 0.51 | 1.41 | 4.52 | 9.01 | 14.38 | 21.35 | 29.83 | 39.75 | 47.93 | 42.66 | 44.12 | 46.78 | 52.38 | 60.57 | 60.45 |
| | Branches | 0.03 | 0.28 | 0.71 | 2.84 | 6.54 | 11.97 | 23.42 | 30.98 | 38.86 | 48.52 | 46.86 | 45.07 | 34.4 | 41.25 | 45.87 | 45.84 |
| | Root | 0.07 | 0.31 | 0.83 | 1.66 | 2.04 | 3.82 | 5.71 | 7.43 | 9.26 | 10.74 | 12.01 | 12.34 | 13.2 | 13.98 | 14.22 | 14.15 |
| | Flower | / | / | / | / | / | / | / | / | 2.58 | 7.76 | / | / | / | / | / | 7.76 |
| | Spike | / | / | / | / | / | / | / | / | / | 2.62 | 4.42 | 3.64 | 4.22 | | / | 4.22 |
| | Fruit | / | / | / | / | / | / | / | / | / | 19.49 | 28.75 | 51.04 | 86.79 | | / | 86.79 |
| | Total plant | 0.35 | 1.68 | 5.2 | 15.8 | 28.34 | 46.47 | 77.23 | 114.3 | 158.3 | 215.6 | 208.2 | 221.0 | 257.7 | 175.5 | 194.5 | 293.08 |
| P | Leaves | 0.02 | 0.07 | 0.25 | 0.69 | 1.28 | 1.94 | 3.32 | 5.56 | 6.09 | 7.31 | 8.03 | 7.73 | 6.42 | 6.84 | 7.43 | 7.43 |
| | Stem | 0.03 | 0.09 | 0.26 | 0.85 | 1.74 | 2.81 | 4.06 | 5.84 | 7.33 | 8.64 | 8.18 | 8.83 | 8.74 | 9.26 | 10.21 | 10.18 |
| | Branches | 0.01 | 0.07 | 0.19 | 0.66 | 1.29 | 2.27 | 3.61 | 4.96 | 5.84 | 7.35 | 7.16 | 6.21 | 5.81 | 6.19 | 6.65 | 6.64 |
| | Root | 0.01 | 0.04 | 0.09 | 0.19 | 0.29 | 0.44 | 0.6 | 0.83 | 1.09 | 1.14 | 1.26 | 1.43 | 1.56 | 1.61 | 1.68 | 1.67 |
| | Flower | / | / | / | / | / | / | / | / | 0.79 | 1.62 | / | / | / | / | / | 1.62 |
| | Spike | / | / | / | / | / | / | / | / | / | 0.52 | 0.55 | 0.54 | 0.5 | | / | 0.5 |
| | Fruit | / | / | / | / | / | / | / | / | / | 4.39 | 8.76 | 11.79 | 18.37 | | / | 18.37 |
| | Total plant | 0.07 | 0.27 | 0.79 | 2.39 | 4.6 | 7.46 | 11.59 | 17.19 | 21.14 | 30.97 | 33.94 | 36.53 | 41.4 | 23.9 | 25.97 | 46.41 |
| K | Leaves | 0.1 | 0.45 | 1.99 | 5.62 | 10.25 | 15.21 | 27.26 | 42.92 | 63.28 | 74.83 | 70.34 | 63.86 | 51.53 | 65.31 | 68.21 | 68.21 |
| | Stem | 0.12 | 0.45 | 1.31 | 4.37 | 9.08 | 14.66 | 21.98 | 30.24 | 38.64 | 44.8 | 42.86 | 43.57 | 45.24 | 51.72 | 54.4 | 54.28 |
| | Branches | 0.03 | 0.36 | 0.99 | 3.99 | 7.85 | 14.36 | 20.76 | 32.01 | 43.59 | 49.77 | 45.38 | 37.34 | 31.82 | 42.32 | 47.94 | 47.91 |
| | Root | 0.28 | 0.32 | 0.65 | 1.17 | 1.72 | 2.71 | 3.92 | 4.85 | 6.21 | 7.35 | 8.2 | 8.68 | 9.012 | 9.52 | 10.15 | 9.87 |
| | Flower | / | / | / | / | / | / | / | / | 2.98 | 6.04 | / | / | / | / | / | 6.04 |
| | Spike | / | / | / | / | / | / | / | / | / | 6.46 | 6.25 | 6.13 | 6.16 | | / | 6.16 |
| | Fruit | / | / | / | / | / | / | / | / | / | 15.41 | 38.73 | 65.98 | 72.48 | | / | 72.48 |
| | Total plant | 0.53 | 1.58 | 4.94 | 15.12 | 28.9 | 46.94 | 73.92 | 110.0 | 154.7 | 204.6 | 211.7 | 225.5 | 226.2 | 168.8 | 187.7 | 264.95 |
| Mg | Leaves | 0.01 | 0.04 | 0.17 | 0.56 | 1.05 | 1.76 | 2.52 | 4.82 | 6.46 | 7.53 | 7.39 | 5.96 | 5.63 | 6.94 | 8.81 | 8.81 |
| | Stem | 0.01 | 0.03 | 0.06 | 0.27 | 0.56 | 1.05 | 1.58 | 2.36 | 3.02 | 3.38 | 3.12 | 3.15 | 3.28 | 4.62 | 6.52 | 6.51 |
| | Branches | 0.01 | 0.03 | 0.08 | 0.29 | 0.61 | 1.07 | 1.64 | 2.23 | 2.84 | 3.39 | 2.91 | 2.1 | 1.84 | 2.68 | 4.52 | 4.51 |
| | Root | 0.01 | 0.04 | 0.12 | 0.22 | 0.32 | 0.53 | 0.78 | 0.92 | 1.26 | 1.38 | 1.51 | 1.62 | 1.701 | 1.81 | 3.26 | 3.25 |
| | Flower | / | / | / | / | / | / | / | / | 0.48 | 0.92 | / | / | / | / | / | 0.92 |
| | Spike | / | / | / | / | / | / | / | / | / | 0.51 | 0.47 | 0.49 | 0.52 | | / | 0.52 |
| | Fruit | / | / | / | / | / | / | / | / | / | 1.77 | 4.35 | 6.64 | 10.88 | | / | 10.88 |
| | Total plant | 0.04 | 0.14 | 0.43 | 1.34 | 2.54 | 4.41 | 6.52 | 10.33 | 14.06 | 18.88 | 19.75 | 19.96 | 23.85 | 16.05 | 23.11 | 35.4 |
| Ca | Leaves | 0.03 | 0.13 | 0.61 | 1.53 | 2.91 | 4.55 | 8.75 | 13.06 | 21.39 | 25.32 | 23.25 | 20.19 | 18.43 | 21.35 | 22.34 | 22.34 |
| | Stem | 0.03 | 0.11 | 0.31 | 1.13 | 2.32 | 3.75 | 5.37 | 7.41 | 9.95 | 11.32 | 11.5 | 8.95 | 9.45 | 14.09 | 14.53 | 14.5 |
| | Branches | 0.02 | 0.14 | 0.42 | 1.42 | 2.74 | 4.16 | 6.36 | 8.95 | 11.51 | 13.3 | 11.79 | 10.35 | 9.92 | 10.04 | 11.04 | 11.01 |
| | Root | 0.01 | 0.05 | 0.17 | 0.33 | 0.56 | 0.87 | 1.18 | 1.83 | 2.08 | 2.41 | 2.54 | 2.61 | 2.68 | 2.89 | 3.05 | 3.04 |
| | Flower | / | / | / | / | / | / | / | / | 0.11 | 1.98 | / | / | / | / | / | 1.98 |
| | Spike | / | / | / | / | / | / | / | / | / | 2.05 | 2.04 | 1.98 | 1.68 | | / | 1.68 |
| | Fruit | / | / | / | / | / | / | / | / | / | 4.44 | 11.56 | 15.59 | 20.27 | | / | 20.27 |
| | Total plant | 0.09 | 0.43 | 1.51 | 4.41 | 8.53 | 13.33 | 21.66 | 31.25 | 45.04 | 60.82 | 62.68 | 59.67 | 62.43 | 48.37 | 50.96 | 74.82 |

Net accumulated N, P, K, Mg and Ca in leaves, fruits, flowers and spikes equal to total accumulated in the last sampling. Net accumulated N, P, K, Mg and Ca in branches, stems, and roots equal to N, P, K, Mg and Ca accumulated in the last sampling values minus N accumulated in the first sampling value.

The high N content in leaves indicated the importance of N nutrient in the preparation these pepper crop for berries production since the pepper flower will bear on these leaves (Fig. 4).

Phosphorus is classified as a major nutrient, meaning that it is frequently deficient for crop production and is therefore required by crops in relatively large amounts. Phosphorus is vital to plant growth and involved in several key plant functions, including energy transfer, photosynthesis and transformation of sugar and starch [11]. In this study, the pepper vine accumulated 46.41 kg $ha^{-1}$ during the growing season (Table 2). The phosphorus levels were the highest in the fruit which contributed to 39.58% of annual P uptake. It is clear that sufficient supply of P could stimulate and enhance the pepper production. This finding is in agreement to Jadin [12] who found that higher P application resulted in the increase in flower and yield of Cocoa. During the study period, the accumulation of phosphorus in leaves, stems and branches were evenly distributed with the removed amount of P were 16%, 21.93% and 14.31% respectively. The total P remained in the plant after harvest was 55.85%, while 44.15% of the remaining P was removed by fruits, spikes and flowers.

Pepper required large quantities of K for growth and fruiting and its requirement are related with the content of other nutrient in the plant, mainly nitrogen [2]. This phenomena was further confirmed by the removal of large quantity of N with N removal was 293.08 kg $ha^{-1}$. From the data obtained, the total annual K accumulated amounted to over 264.95 kg $ha^{-1}$, which was mainly distributed among fruits (27.36%), leaves (25.74%), stems (20.49%) and branches (18.08%) (Table 2). This finding is in accordance with the report published by Sadanandan [13] who reported that some pepper varieties also showed a high K removal to the extent of 313-337 kg $ha^{-1}$. Besides, the high K concentration in fruit were further confirmed by Aldana [14] who reported that higher potassium rate had a significant effect on the fruit dry weight and mineral fruit content when applied at flowering stage. During the fruit development period, more than 30% of the potassium is needed. Therefore, in order to increase the production of pepper berries per vine, the K supply must meet maximum plant demand that occurs just prior to fruit expansion.

Magnesium is another indispensable mineral for plant growth, which plays a vital role in the production of chlorophyll, on which photosynthesis depends. Although magnesium (Mg) is an essential element for plant growth, but they were only be required in small quantity. From the analysis, the pepper vines only removed 35.4 kg $ha^{-1}$ of magnesium annually with more than 20% are used by leaves and pepper berries (Table 2). This was in conformity with Azmil and Yau [3] and Sadanandan [10] who had the same reports for magnesium uptake on *Piper nigrum*. Similar results were also observed by Sadanandan [15] and mentioned that the maximum Mg uptake can be achieved by applying 40 kg $ha^{-1}$. According to the content range defined by Wong and Paulus [16] and Srinivasan [2], Magnesium content was good. As no case of deficiency was recorded, indicating that this nutrient was sufficient to enhance the growth the production of pepper berries.

Calcium is an essential plant nutrient that plays a significant role in seed development. Previous studies have shown a positive effect of calcium on seed development, e.g., in coffee [17] and maize [18]. From the result obtained, calcium was removed to an extent of 74.82 kg/ha by different plant parts of pepper with more than 60% being used for vegetative growth (Table 2). This finding is slightly higher than those reported in literature possibly due to the application of different cultural practice in pepper cultivation as well as the characteristic of the pepper variety itself. The high calcium content used in vegetative growth indicated that calcium plays an important role in regulating the pepper growth and development including biomass partitioning [19], induction of early

auxin-responsive genes [20], resistance to pathogens [21] and signal transduction [22].

Variation in nutrient uptake data was considerable which resulted from variation in both dry matter production and nutrient analysis. Despite this variation, it was found that the order of nutrient accumulation for pepper is as followed: N > K > Ca > Mg > P. From this nutrient uptake study, three distinct stages of pepper growth were focused, including, (1) early stage development (first 18 month of planting), (2) the period between fruit development and fruit maturity (18-26 months) and (3) the period after harvesting (recovery period), (28-30months). These respective periods showed 26.02%, 52.47%, 21.51% of the total N accumulation, 28.20%, 61.51%, 21.47% of P accumulation, 26.28%, 52.26%, 21.46% of K accumulation, 24.66%, 51.08%, 24.26% of Mg accumulation and 26.79%, 52.12% and 21.08% of Ca accumulation. According to the characteristics of nutrient uptake during the growing season, more than 50% of the nutrient uptake was mainly distributed during fruit development stage. In order to sustain the growth and the pepper production, nutrient application should be split evenly between the three stages of nutrient demand described above.

Table 3 summarized the recovery rate of nutrient removed by pepper vine for three consecutive cropping years. After 12 months of planting when approximately 1 ton of fertilizer were used, the pepper vine presented a recovery of 38.85% of N, 6.18% of P, 27.36% of K and 4.38% of Mg. For the second year of planting, the recovery rates of nutrient applied were slightly increased compared with the first year which the recovery rate of nitrogen were 74.33%; P, 6.64%; K, 54.39% and Mg, 42%. This finding is expected because at this stage, the entire plant organ had been fully developed and therefore required large quantity of nutrient for the next production. In general, only 19.19% and 44% of the nutrient applied were recovered for the year 1 and year 2, respectively. This suggested that N, P, K, Mg and Ca have been overused for pepper production.

At the third year of planting, more than 50% of the nutrients applied were recovered except for the P with the recovery rate was only 12.89%. This finding is expected because this year is the production year and more nutrients were required for fruit development especially during fruit expansion period. The low P recovery rate was observed continuously for consecutive three years. This phenomenon might probably due to less P available forms in the soil that can be uptaken by the pepper vine. Under normal condition, phosphate is the most immobile major plant nutrients and it is difficult for plants to absorb it. This finding is in agreement with research reported by Schachtman [23].

In term of calcium supply, since this nutrient is served as trace elements in the fertilizer applied, therefore, their content will be less than 2%. Based on the nutrient uptake data, it can be concluded that the calcium supply is insufficient to stimulate the growth and production of pepper, especially during the fruit development stage.

**Table 3 Recovery rate of nutrient removed by pepper vine for three consecutive cropping years.**

| | Year 1 | | | Year 2 | | | Year 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Nutrient applied (kg/ha) | Nutrient removed (kg/ha) | Recovery rate (%) | Nutrient applied (kg/ha) | Nutrient removed (kg/ha) | Recovery rate (%) | Nutrient applied (kg/ha) | Nutrient removed (kg/ha) | Recovery rate (%) |
| N | 120 | 46.25 | 38.54 | 240 | 178.37 | 74.33 | 360 | 293.08 | 81.41 |
| P | 120 | 7.41 | 6.18 | 240 | 15.93 | 6.64 | 360 | 46.41 | 12.89 |
| K | 170 | 46.51 | 27.36 | 340 | 184.94 | 54.39 | 510 | 264.95 | 51.95 |
| Mg | 20 | 4.38 | 21.9 | 40 | 16.88 | 42 | 60 | 35.40 | 59 |
| Ca | nd | 13.27 | nd | nd | 48.74 | nd | nd | 74.82 | nd |

nd: not determined.

Different locations and varieties of pepper need different quantity of fertilizer to get higher yield [3, 5, 9, 13]. Regardless of the variation between studies, all agreed that pepper required significant quantity of N, P, K, Ca and Mg to sustain high yield and soil nutrient balance. Currently, it is difficult to quantify accurate fertilizer recommendation by using soil testing or Diagnosis and Recommendation integrated system norm system (DRIS) developed by Sadanandan [13, 15]. However, the site's nutrient balance can be monitored and annual nutrient removal by senesced leaves and harvested fruits can be supplemented by applying appropriate amounts of nutrient. Assuming that two third of accumulated nutrient are derived from fertilizer and using fertilizer N use efficiency of 50%, the recommendation application rate would be 62-10-62-6-18 kg/ha; 237-22-246-22-65 kg/ha and 390-62-352-47-100 kg/ha of N-P-K-Mg-Ca for the year 1, year 2 and year 3 of cropping year.

As indicated, the recommended rates of fertilizer in this study were significant higher than nutrient uptake. This suggested that N, P, K, Mg and Ca had been overused for pepper production. However, it still needed to be confirmed whether this new recommendation is rational according to pepper growth demand which is able to sustain high yield and soil nutrient balance.

## 4. Conclusions

The growth of the pepper vine in terms of biomass accumulation was sigmoidal for the first 22 months of planting. Thereafter, a decrease in DM was observed due to fruit export and fallen leaves at harvest. At the 28 months of planting, the biomass of pepper vine showed some increasing trend indicating the vegetative growth was reassumed for the next flowering.

The results also showed that 293.08 kg of Nitrogen, 46.41 kg of phosphorus, 264.95 kg of potassium, 35.4 kg of magnesium and 74.82 kg of calcium were removed by one hectare of pepper Variety Semongok Aman. Several studies had been conducted on fixing the optimum fertilizer schedule for black pepper. Based on the data obtained, the optimum NPK dosage is found to be 390-62-352-47-100 kg N-P-K-Mg-Ca per hectare. The results obtained may give applicable advice to farmer and pepper related researches for the establishment of science-based nutrient management and proper use of fertilizer in pepper cultivation. Through this recommendation, the income of pepper farmer is expected to be increased by increasing the pepper production with lower fertilizer input.

In light of the results obtained, the major nutrients must be applied in amounts sufficient to meet the uptake values indicated. Black pepper is a high nutrient demanding crop. Fertilizer use and management are therefore important to sustain the growth and high yield. But, for sustainable crop production, integrated uses of chemical and organic fertilizer appear to be the best bet.

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