NPK Fertilizers for Elephant Foot Yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson) Intercropped with Coffee Trees

Edi Santosa*, Anas Dinurrohman Susila¹, Adolf Pieter Lontoh¹, Arisa Noguchi², Ken Takahata², and Nobuo Sugiyama²

¹Department Agronomy and Horticuture, Faculty of Agriculture, Bogor Agricultural University Jl. Meranti, Kampus IPB Darmaga, Bogor 16168, Indonesia
²Faculty of Agriculture, Tokyo University of Agriculture, Funako, Atsugi, Kanagawa 243-0034, Japan

Received 8 April 2015/Accepted 8 November 2015

**ABSTRACT**

Fertilizer application in elephant foot yams (*Amorphophallus paeoniifolius* (Dennst.) Nicolson) intercropping system is rare in Indonesia, therefore, NPK fertilizers experiment was conducted under the shade of 10-year-old coffee plantation at Leuwikopo Experimental Farm, Bogor, Indonesia, in order to increase the productivity of elephant foot yam intercropped with coffee trees. Prior to planting, 20 ton ha⁻¹ of goat manure was applied. Four NPK combinations, i.e., N, P, O, K at the rate of 0, 0 and 0; 100, 60 and 80; 125, 60 and 100; and 150, 60 and 120 kg ha⁻¹, were applied. Results showed that there were no significant differences in leaf number per plant, petiole size and rachis length among treatments. Application of NPK decreased photosynthetic rates, while increasing rate of N and K had no effect on photosynthetic rates. NPK application at the 100 N, 60 P, O and 80 K, O kg ha⁻¹ (N₁₀₀P₆₀K₈₀ treatment) or larger prolonged growth duration regardless of NPK levels, and there was a close relationship between corm yield and growth duration. As a result, corm fresh mass was higher in the 100:60:80 kg ha⁻¹ treatment than in control. In the N₁₀₀P₆₀K₈₀ and N₁₂₅P₆₀K₁₀₀ kg ha⁻¹ treatments, leaves were damaged by heavy rains and winds, counteracting beneficial effect of NPK on growth duration and corm yield. These results suggested the importance of delay of entering dormancy for an increase in productivity of *A. paeoniifolius*.

**Keywords:** NPK fertilizers, photosynthesis, productivity, prolong growth, tuber crop

**INTRODUCTION**

Elephant foot yam (*Amorphophallus paeoniifolius* (Dennst.) Nicolson, syn. *Amorphophallus campanulatus* (Roxb.) BL. ex Dence) is a native tuberous crop in South Asia (Sugiyama and Santosa, 2008; Ravi et al., 2009). Its corm contains a large amount of starch and a small amount of glucomannan, unlike most *Amorphophallus* species.

In India, elephant foot yam has been commercially cultivated (Srinivas and Ramanathan, 2005). In Indonesia, on the other hand, elephant foot yam is an underutilized crop that commonly grows under shading (Sugiyama and Santosa, 2008). Until 1960s, elephant foot yams had been used as a staple food during the off-season of rice in Central Java. Since the 1960s, the ‘Green Revolution’ boosted
rice production in Indonesia, decreasing the importance of elephant foot yam. However, steamed corms are still used in some districts of Java (Sugiyama and Santosa, 2008).

*A. paeoniifolius* locally called *suweg* is widely and densely distributed in Java, and is also found in some places of Sumatra, Bali, Lombok and Sulawesi islands (Sugiyama et al., 2010). Ravi et al. (2009) reported that the corn yield of elephant foot yams is 84.6 ton ha⁻¹ and 102.3 ton ha⁻¹ with N application at level of 50 kg ha⁻¹ and 150 kg ha⁻¹, respectively. However, the productivity of *A. paeoniifolius* in the field is low in Indonesia, possibly due to bad agricultural practices such as no fertilizer application (Sugiyama and Santosa, 2008).

N and K are important nutrients to increase corn yield of *Amorphophallus* species (Sugiyama and Santosa, 2008; Ravi et al., 2009; Santosa et al., 2011). Ravi et al. (2009) recommends application of N at levels of 50 to 200 kg ha⁻¹ and K₂O at levels of 75 to 150 kg ha⁻¹ dependent on soil types. Mondal et al. (2012) recommend applying 10 tons manure per hectare for high quality *A. paeoniifolius* crops. However, there are few studies on the effect of fertilizer on *A. paeoniifolius* growth under the shade of plantation trees. Singh et al. (2013) stated that the bitter gourd can be profitably grown with *A. paeniifolius* under multilayer vegetable cropping system, although the corn yield of *A. paeoniifolius* was reduced by about 10% under bitter gourd layer. Sumarwoto (2005) reported that application of P₂O₅ and K₂O do not affect growth of *A. muelleri* under the canopy of *Albizia falcataria*. Santosa et al. (2006) reported that productivity of *A. paeoniifolius* growing under 75% shading nets is larger than in 0% shading. Meaning that fertilizers at higher rates is likely required in shading condition than under full sunlight. Hence, we examined the effect of NPK application on the productivity of *A. paeniifolius* in coffee plantation.

**MATERIALS AND METHODS**

The experiment was conducted at Leuwikopo Experimental Farm of IPB, Darmaga (260 m above sea level) from August 2010 to May 2011. Coffee trees (*Coffea robusta*) were planted in Latosol Darmaga type at a distance 6 m between the rows and 4 m in the rows in 1994 (Figure 1). By regular pruning, the canopy of coffee tree was maintained at the height of 4-5 m and width of 4.5 m on average. Average light intensity was reduced by 40% of full sunlight. The soil had pH 5.2, and contained a low amount of total N (0.12% by Kjeldahl method), very low amount of Bray I phosphorus (5.9 mg kg⁻¹) and low amount of exchangeable potassium (26 me 100 g⁻¹). Soil texture was clay (sand:silt:clay = 13.1:22.1:64.8%). Air temperature during experiment was 23 to 32 ºC (25.6 ºC on average) with relative humidity 85-88 %.

Whole one-year-old corms were planted on August 8, 2010. Average seed corm weight was 396 ± 92 g with a diameter of 9 ± 1 cm. Corms were collected from a farmer’s field in Kulonprogo, Yogyakarta. According to the farmer’s information, the harvested corms were derived from plants without any fertilizer, except for natural tree litter on the farm.

The plots were arranged in completely randomized block design with three replicates. Each plot consisted of one bed (1 m wide and 10 m long) where 15 whole corms with about 1 cm bud were planted in a triangle distance of

![Figure 1. *A. paeoniifolius* plants intercropped with coffee trees in Bogor, Indonesia. (A) Condition of plants at 4 weeks after planting (WAP); (B) *A. paeoniifolius* at 12 WAP; (C) Plant height at maximum vegetative phase (20 WAP); (D) Some plants showed leaf collapse at 18 WAP in the N₁₅₀P₆₀K₁₂₀ treatment](image)
60 cm × 60 cm × 60 cm. Land was plowed and harrowed up to a depth of 30 cm using tractor, one month prior to planting. Two weeks prior to planting, goat manure of about 1 kg (equal to 20 ton ha⁻¹) was applied in planting hole (25 cm × 25 cm in a depth of 20 cm). Four combinations of N, P, O, and K were applied at the rate of 0, 0 and 0 (N₀P₀K₀), 100, 60 and 80 (N₁₀₀P₆₀K₈₀); 125, 60 and 100 (N₁₂₅P₆₀K₁₀₀); and 150, 60 and 120 kg ha⁻¹ (N₁₅₀P₆₀K₁₂₀). N, P, O, and K sources were urea (46% N), SP-36 (36% P, O), and KCl (60% K₂O), respectively.

Prior to planting, corms were immersed to 2% solution of mancozeb. Rice husk was spread out to achieve a thickness of 10 cm at the planting hole. Seed corms were planted with bud face up and planted 10 cm below soil surface. NPK was applied twice; one month after planting at which time bud reached about 15 cm, and two months after planting at which time the first leaf had fully expanded. At planting, about 2 g of 3% carbofuran was applied on the surface. NPK was applied twice; one month after planting and one month at rate 400 L ha⁻¹. Plant growth characters, i.e., number of leaves, petiole size, canopy size, photosynthetic rates and time to dormancy, were measured for five plants planted in the center of the beds. Petiole height was measured from 3 cm above soil level to the joint of tripartite rachis. Canopy size was determined by measuring the horizontal diameter of the first and the second leaves among treatments (Table 3). Furthermore, there were no significant differences in canopy size and life span of the first and the second leaves among treatments, although NPK application slightly increased the canopy size and life span of the second leaf (Table 4). In line with this result, Sugiyama and Santos (2008), and Santos et al. (2011) have reported that N and K applications increase petiole length.

Photosynthetic Rate

Photosynthetic rates increased with an increase in photosynthetic active radiation (PAR) in any treatment (Figure 2). PAR ranged from 500 to 1,000 µmol photon m⁻² s⁻¹ under coffee trees during the sunny days. At this range

| NPK treatment | Times after planting (months) |
|---------------|-----------------------------|
|               | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
| No NPK        | 1.5±0.2b  | 1.8±0.3ab | 1.7±0.2b | 1.7±0.2b | 1.6±0.2a | 0.7±0.1a | 0.6±0.2a |
| N₁₀₀P₆₀K₈₀   | 1.6±0.1b  | 2.1±0.1a  | 2.0±0.0a  | 2.0±0.0a  | 1.7±0.3a  | 0.9±0.4a  | 0.2±0.2a  |
| N₁₂₅P₆₀K₁₀₀  | 1.9±0.4a  | 1.9±0.4ab | 1.7±0.2b  | 1.7±0.2b  | 1.8±0.3a  | 0.9±0.2a  | 0.3±0.2a  |
| N₁₅₀P₆₀K₁₂₀  | 1.6±0.2b  | 1.8±0.0b  | 1.7±0.1b  | 1.7±0.1b  | 1.5±0.1a  | 0.6±0.0a  | 0.2±0.2a  |

Notes:
- Senescent leaves (yellowing leaves) were not included in leaf number. Leaf number larger than one means the coexistence of leaves;
- Mean ± S.E; different letters indicate statistical differences within columns; ‘no leaf’
of PAR, photosynthetic rate was 108 to 173 μmol CO₂ m⁻² s⁻¹ with an average of 130 μmol CO₂ m⁻² s⁻¹. Stomatal conductance ranged from 0.005 to 0.024 mol CO₂ m⁻² s⁻¹ with an average of 0.019 mol CO₂ m⁻² s⁻¹.

Photosynthetic rates were significantly higher in control than in NPK treatments at a PAR of 1,000 μmol photon m⁻² s⁻¹ or higher, but there were no significant differences in photosynthetic rates among three NPK treatments, regardless of light intensity (Figure 2). It is considered that actual photosynthetic rates in control plants were almost the same as those in NPK treatments in this study because PAR ranged between 500 and 1,000 μmol photon m⁻² s⁻¹ under the canopy of coffee trees. This might be the reason why there were no differences in leaf size and leaf number among the treatments (Table 1).

Regarding with the time to dormancy, there were no significant differences among treatments (Table 5), but a large variation was found among plants within the same treatments (Table 6). When chi-square (χ²) test was performed using data on the time to dormancy and corm size in the N₁₀₀P₆₀K₈₀ treatment and control, the frequency distribution were significantly different between two treatments; the N₁₀₀P₆₀K₈₀ treatment increased the percentage of corms entering dormancy at 28 WAP or later (Table 6) and also the percentage of corms heavier than 1,000 g as compared to control plants (Table 7).

### Table 2. Incidence of leaf collapse (%) in *A. paeoniifolius* plants grown with different levels of NPK fertilizers

| NPK treatment | Time (weeks after planting) | 10 | 14² | 18 | 22 | 26 |
|---------------|-----------------------------|----|-----|----|----|----|
| No NPK        | 2±3                        | 6±3b| 31±10ab | 52±2b | 53±3b|
| N₁₀₀P₆₀K₈₀    | -                          | 4±2b| 28±1b | 54±7ab | 54±7ab|
| N₁₂₅P₆₀K₁₀₀   | 3±3                        | 28±11a | 41±4a | 54±5a | 60±9a|
| N₁₅₀P₆₀K₁₂₅   | -                          | 17±6a | 41±4a | 68±8a | 73±6a|

*Incidence of leaf collapse was judged whether or not petiole was bent down and damaged. Senescent leaf was excluded for the judgment of leaf collapse; ²No incidence of leaf collapse; ³Mean ± S.E; different letters indicate statistical differences within columns; ⁴F value of 4.17 in ANOVA on data at 14 WAP indicates significant differences within a column at P = 0.10*

### Table 3. Petiole size of the first and the second leaves (cm) of *A. paeoniifolius* grown with different levels of NPK fertilizers

| NPK treatment | First leaf | Second leaf |
|---------------|------------|-------------|
|               | Petiole length ² | Petiole diameter ² | Rachis length | Petiole length | Petiole diameter | Rachis length |
| No NPK        | 83.2±12.3a   | 3.0±0.4a    | 62.2±10.5a  | 96.8±6.4a  | 3.1±0.0b  | 59.7±1.5b  |
| N₁₀₀P₆₀K₈₀    | 87.8±13.3a   | 3.1±0.5a    | 65.1±9.1a  | 116.4±13.6a | 3.9±0.3a  | 70.7±5.8a  |
| N₁₂₅P₆₀K₁₀₀   | 84.6±15.6a   | 3.3±0.6a    | 64.9±11.5a | 101.5±9.5a | 3.8±0.1a  | 67.9±2.3a  |
| N₁₅₀P₆₀K₁₂₅   | 84.8±14.4a   | 3.2±0.7a    | 63.7±12.4a | 110.7±14.0a | 3.7±0.5a  | 71.1±8.5a  |

*²A leaf which first emerges from corm; ³Measured from soil surface to a tripartite branch of rachis; ⁴Mean ± S.E; different letters indicate statistical differences within columns*

### Table 4. Number of leaflets, canopy width and life span of the first and the second leaves of *A. paeoniifolius* grown with different levels of NPK fertilizers

| NPK treatment | First leaf ⁵ | Second leaf ⁵ |
|---------------|--------------|---------------|
|               | Canopy size  ⁶ (m²) | Life span  ⁷ (weeks) | Canopy size  ⁶ (m²) | Life span  ⁷ (weeks) |
| No NPK        | 1.1±0.3a ²   | 16.7±0.7a  | 1.0±0.1a  | 21.2±0.7a  |
| N₁₀₀P₆₀K₈₀    | 1.2±0.2a  | 16.7±0.2a  | 1.4±0.3a  | 23.6±1.4a  |
| N₁₂₅P₆₀K₁₀₀   | 1.1±0.4a  | 16.5±0.3a  | 1.3±0.1a  | 22.5±3.3a  |
| N₁₅₀P₆₀K₁₂₅   | 1.1±0.4a  | 16.3±0.3a  | 1.4±0.3a  | 22.8±2.0a  |

⁵A leaf which first emerges from corm; ⁶Estimated from canopy length and width at the maximum leaf expansion; ⁷Weeks from emergence to senescence of leaves; ⁸Mean ± S.E; different letters indicate statistical differences within columns.

...
Analysis of covariance indicated that there were no differences in the slopes of the regression lines whether regressions were calculated for each treatment data or for combined data. Figure 3 which was obtained using combined data indicated that fresh mass of corms linearly increased with a delay of harvest. This suggests that yield of *A. paeoniifolius* was dependent on growth duration, not on the levels of NPK fertilizers (Figure 3). In the N$_{125}$P$_{60}$K$_{125}$ and N$_{150}$P$_{60}$K$_{125}$ treatments, a high incidence of leaf collapse decreased the percentage of corms which were harvested later than 32 weeks, resulting in low corm weight in the N$_{125}$P$_{60}$K$_{100}$ and N$_{150}$P$_{60}$K$_{125}$ treatments. Saikia and Borah

| Treatment | Weight$^a$ (g) | Diameter (cm) | Height (cm) | Number | Weight (g) | Time to dormancy (WAP$^b$) |
|-----------|----------------|---------------|-------------|--------|------------|---------------------------|
| No NPK    | 726±19b        | 12.0±0.2a     | 6.6±0.2c    | 19.6±5.3a | 166.3±52.4a | 26.6±0.7a                |
| N$_{100}$P$_{60}$K$_{80}$ | 1,324±157a | 13.9±0.8a     | 8.1±0.5a    | 26.0±3.6a | 308.0±77.4a | 29.0±0.7a                |
| N$_{125}$P$_{60}$K$_{100}$ | 917±24b     | 12.4±0.2a     | 7.3±0.2b    | 21.7±5.8a | 198.7±69.4a | 27.8±1.2a                |
| N$_{150}$P$_{60}$K$_{125}$ | 889±264b   | 12.3±1.6a     | 7.3±0.9abc | 23.5±3.7a | 194.3±46.1a | 28.3±1.4a                |

$^a$ Cormels larger than 0.5 cm in length were measured; $^b$ Fresh mass of corm without cormels; $^c$ Average week after planting; Mean ± S.E; followed by different letters indicate statistical differences within columns

Table 6. Percentage of corms which were categorized into four classes by the time to dormancy (weeks)

| NPK treatment | Time to dormancy (Weeks)$^d$ |
|---------------|------------------------------|
|               | 20-24 | 24-28 | 28-32 | >32  |
| No NPK        | 26.7  | 26.7  | 46.6  | 0.0  |
| N$_{100}$P$_{60}$K$_{80}$ | 0.0    | 33.3  | 60.0  | 6.7  |
| N$_{125}$P$_{60}$K$_{100}$ | 13.3   | 26.7  | 60.0  | 0.0  |
| N$_{150}$P$_{60}$K$_{125}$ | 6.7    | 20.0  | 73.3  | 0.0  |

$^d$ $\chi^2$ value was 7.84 (P<0.05, d.f.=3) when $\chi^2$ test was performed using frequent distribution data of corm weight in the N$_{100}$P$_{60}$K$_{80}$ treatment control
(2008) reported that early planting is associated with large leaf, thick petiole, heavy corms and prolonged growth duration in *A. paeoniifolius*, as compared with late planting. This is similar to the present experiment in that prolonged growth period increased yield. Therefore, it is likely that N, P$_2$O$_5$, and K$_2$O applications at the rate of 100 kg, 60 kg and 80 kg ha$^{-1}$, respectively, prolongs growth period possibly due to the delay in entering dormancy, leading to larger fresh masses of corms. It is possible that NPK fertilizer could enhance root function in absorbing water for a long time. Santosa *et al.* (2004) reported that *A. paeoniifolius* growing in a greenhouse enters dormancy earlier under limited water supply than under sufficient water supply.

The result of the present study showed that growth duration and yield of *A. paeoniifolius* increased by the application of NPK in addition to 20 ton ha$^{-1}$ manure, but N, P$_2$O$_5$, and K$_2$O applications at the rate higher than 100 kg, 60 kg and 80 kg ha$^{-1}$, respectively, did not show any effect on growth duration and yield. This detrimental finding is likely coincident with collapse leaves due to heavy rainfall and winds. Santosa *et al.* (2013) stated that application of KNO$_3$ at the level of 4% favors plant growth and yield when it is applied through foliar than soil application in *A. muelleri*. Meaning that, collapse leaves resulted in reduction ability of *A. paeoniifolius* to conduct photosynthesis and to utilize nutrients.

Table 7. Percentage of corms which were categorized into five classes by corm weight (g)$^2$

| NPK treatment | Categories of corm weight (%)$^2$ | <500 g | 501-1,000 g | 1,001-1,500 g | 1,501-2,000 g | >2,000 g |
|---------------|-----------------------------------|--------|-------------|---------------|----------------|---------|
| No NPK        |                                   | 20.0   | 66.7        | 13.3          | 0.0            | 0.0     |
| N$_{100}$P$_{60}$K$_{80}$ |                               | 6.7    | 33.3        | 26.7          | 20.0           | 13.3    |
| N$_{125}$P$_{60}$K$_{100}$ |                                 | 13.3   | 46.7        | 26.7          | 6.7            | 6.7     |
| N$_{150}$P$_{60}$K$_{125}$ |                               | 20.0   | 40.0        | 26.7          | 6.7            | 6.7     |

$^2$χ$^2$ value was 12.95 (P<0.05, d.f.=4) when χ$^2$ test was performed using frequent distribution data of corm weight in the N$_{100}$P$_{60}$K$_{80}$ treatment control

![Figure 3. Correlation between corm fresh mass and time to harvest of *A. paeoniifolius* grown with different levels of NPK fertilizers. A, No NPK (●); B, N$_{100}$P$_{60}$K$_{80}$ (○); C, N$_{125}$P$_{60}$K$_{100}$ (▲); and D, N$_{150}$P$_{60}$K$_{125}$ (△).](image)

**CONCLUSION**

NPK application prolonged growth duration, but did not increase photosynthetic rate. Growth duration changed even in the same treatment, causing a large variation in corm size. NPK treatment of 100:60:80 kg ha$^{-1}$ produced largest corm fresh mass than those of other treatments. Therefore, it seems necessary to elucidate the cultural practices for lengthening growth duration to get higher yield.
ACKNOWLEDGEMENTS

Thanks to Mr Haryanto and Mr Joko Mulyono for assisting data collection in the field and laboratory works. This collaborative study between Bogor Agricultural University, Indonesia and Tokyo University of Agriculture, Japan was fully supported by the Incentive Grant No RT-2010-0864 and RT-2011-2608 from Ministry of Research and Technology (Menristek), Republic of Indonesia.

REFERENCES

Gopi, R., C.A. Jaleel, M.M. Azooz, R. Panneerselvam. 2009. Photosynthetic alterations in Amorphophallus campanulatus with triazoles drenching. Global J. Mol. Sci. 4:15-18.

Mondal, S., P. Bandopadhyay, R. Kundu, S. Pal. 2012. Arsenic accumulation in elephant foot yam (Amorphophallus paeoniifolius Dennst. Nicolson) in Deltaic West Bengal: Effect of irrigation sources and nutrient management. J. Root Crops 38:46-50.

Ravi, V., C.S. Ravindran, G. Suja. 2009. Growth and productivity of elephant foot yam (Amorphophallus paeoniifolius (Dennst. Nicolson): an overview. J. Root Crops 35:131-142.

Saikia, J., P. Borah. 2008. Effect of planting dates on growth and corm yield of Amorphophallus in Assam. p. 147-149. In Proceeding National Seminar on Amorphophallus: Innovative technologies. Indian Council of Agriculture Research, 19-20 July 2008, New Delhi, India.

Santosa, E., I. Setiasih, Y. Mine, N. Sugiyama. 2011. Nitrogen and potassium applications on growth of Amorphophallus muelleri Blume. J. Agron. Indonesia 39:118-124.

Santosa, E., N. Sugiyama, E. Sulistyono, D. Sopandie. 2004. Effect of watering frequency on the growth of elephant foot yams. Jpn. J. Trop. Agric. 48:235-239.

Santosa, E., N. Sugiyama, M. Nakata, O.N. Lee. 2006. Growth and corn production of Amorphophallus at different shading levels in Indonesia. Jpn. J. Trop. Agric. 50:87-91.

Santosa, E., S. Halimah, A.D. Susila, A.P. Lontoh, Y. Mine, N. Sugiyama. 2013. Application KNO₃, on the growth and development of Amorphophallus muelleri Blume. J. Agron. Indonesia 41:228-234.

Singh, R.P., S. Bhushan, S. Kumar, R. Shanker. 2013. Yield assessment of elephant foot yam grown under multilayer vegetable cropping system. Bioscan 8:1237-1239.

Srinivas, T., S. Ramanathan. 2005. A study on economic analysis of elephant foot yam production in India. Agric. Econ. Res. Review 18:241-252.

Sugiyama, N., E. Santosa. 2008. Edible Amorphophallus in Indonesia-Potential Crops in Agroforestry. Gajah Mada Press, Yogyakarta. Indonesia.

Sugiyama, N., E. Santosa, M. Nakata. 2010. Distribution of elephant foot yams (Amorphophallus paeoniifolius) in Indonesia. Trop. Agric. Dev. 54:33-34.

Sumarwoto. 2005. Iles-iles (Amorphophallus muelleri Blume): description and its characteristics. Biodivertas 6:185-190.