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

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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_2O_5, K_2O 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_2O had no effect on photosynthetic rates. NPK application at the 100 N, 60 P_2O_5 and 80 K_2O kg ha^{-1} ($N_{100}P_{60}K_{80}$ 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 $N_{125}P_{60}K_{100}$ and $N_{150}P_{60}K_{120}$ 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

ABSTRAK

Aplikasi pupuk jarang dilakukan pada tumpangsari suweg (Amorphophallus paeoniifolius (Dennst.) Nicolson) di Indonesia, oleh karena itu, percobaan pemupukan NPK dilakukan di bawah naungan tanaman kopi umur 10 tahun di Kebun Percobaan Leuwikopo, Bogor, Indonesia, untuk meningkatkan produktivitas tanaman suweg tumpangsari dengan kopi. Sebelum tanam, pupuk kandang kambing diberikan sebanyak 20 ton ha^{-1}. Percobaan menggunakan empat kombinasi pupuk NPK yakni N, P_2O_5, K_2O sebanyak 0:0:0 sebagai kontrol, 100:60:80, 125:60:100 dan 150:60:120 kg ha^{-1}. Hasil menunjukkan bahwa tidak ada perbedaan jumlah daun per tanaman, ukuran petiol dan panjang rachis antar perlakuan. Perlakuan NPK nyata menurunkan laju fotosintesis, dan peningkatan dosis N dan K_2O tidak mempengaruhi laju fotosintesis. Perlakuan NPK dosis 100 N, 60 P_2O_5 and 80 K_2O kg ha^{-1} (perlakuan $N_{100}P_{60}K_{80}$) dan dosis di atasnya memperpanjang masa pertumbuhan. Terdapat hubungan antara bobot umbi dengan lama masa pertumbuhan, yakni bobot segar umbi lebih besar pada tanaman dengan perlakuan 100:60:80 kg ha^{-1} dibandingkan kontrol. Daun-daun mengalami kerusakan setelah ada hujan lebat dan angin kencang, yang menghilangkan pengaruh perlakuan NPK terhadap lama masa pertumbuhan dan hasil umbi pada perlakuan $N_{125}P_{60}K_{100}$ dan $N_{150}P_{60}K_{120}$ kg ha^{-1}. Hasil penelitian menunjukkan perlunya menunda awal waktu dormansi dalam upaya meningkatkan produktivitas tanaman umbi A. paeoniifolius.

Katakunci: Fotosintesis, pertumbuhan, pupuk NPK, produktivitas, umbi-umbian

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

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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 corm 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. paeoniifollius* 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 corm 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 K_2O at level 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 corm yield of *A. paeniifolius* was reduced by about 10% under bitter gourd layer. Sumarwoto (2005) reported that application of P_2O_5 and K_2O 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. paeoniifolius* 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

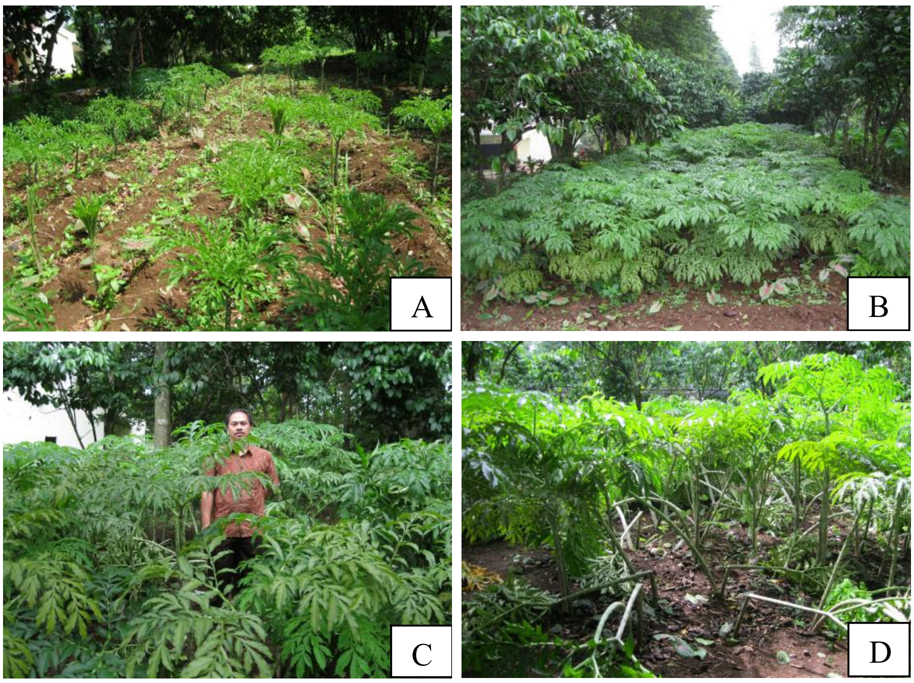

Figure 1. *A. paeoniifolius* plants intercropped with coffee trees in Bogor, Indonesia. (A) Condition of plants at 4 weeks after planting (WAP); (B) *A. paeoniifolius* at 12 WAP; (C) Plant height at maximum vegetative phase (20 WAP); (D) Some plants showed leaf collapse at 18 WAP in the $N_{150}P_{60}K_{120}$ treatment

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_2O_5 and K_2O were applied at the rate of 0, 0 and 0 ($N_0P_0K_0$); 100, 60 and 80 ($N_{100}P_{60}K_{80}$); 125, 60 and 100 ($N_{125}P_{60}K_{100}$); and 150, 60 and 120 kg ha^{-1} ($N_{150}P_{60}K_{120}$). N, P_2O_5 and K_2O sources were urea (46% N), SP-36 (36% P_2O_5), and KCl (60% K_2O), 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 expand. At planting, about 2 g of 3% carbofuran was applied on the cavity of bud. Soil was regularly raised every month. Prior to harvest, daughter corm position was marked by putting stick close to plants.

Watering was applied every three days, if rainfall was less than 20 mm per day each for three consecutive days. Hand weeding was carried out twice a month. Pesticides, i.e., 2% diazinon and 2% mancozeb were mixed and applied monthly 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 distance between the tips of a tripartite leaf and petiole. Photosynthetic rate was measured on February 15, 2011 (at the peak vegetative stage) using LICOR 6400 XT Portable Photosynthetic System. Harvest was carried out after all plants had entered dormancy (May 15, 2011). Dormancy was determined based on complete senescence of leaves.

Daughter corm size and weight were measured. Corms were peeled, sliced, then oven dried at 120 ^oC for three days for the measurement of dry matter content. Statistical analysis was performed using ANOVA, and mean separation was carried out by Tukey's range test. A chi-square (χ^2) test was performed to test the fit between a theoretical frequency distribution and a frequency distribution of observed data on corm size and time to dormancy. Analysis of covariance was used to compare the slopes and intercepts of the regression lines.

RESULTS AND DISCUSSION

Leaf Number

First leaf emerged 2 to 4 weeks after planting (WAP), irrespective of NPK treatments. During vegetative growth, plants in all treatments generated more than one leaf from 2 to 6 months after planting (MAP) (Table 1). At 2 MAP, leaf number was significantly larger in the $N_{125}P_{60}K_{100}$ treatment than in others, but there were no significant differences in leaf number among treatments from 6 MAP and onward (Table 1). This in the contrary with the result of Santosa *et al*. (2013) that in *A. muelleri*, application of KNO_3 significantly delayed harvesting time and increased number of leaves.

From 10 WAP to 20 WAP (September to December 2010), monthly rainfall ranged from 178 to 601 mm. On November 10, 2010, there was heavy rain (50 mm day^{-1}) and wind up to 43 km h^{-1}. As a result, leaf number decreased at 4 MAP due to leaf collapse at 14 WAP in the $N_{125}P_{60}K_{100}$ and $N_{150}P_{60}K_{100}$ treatments (Table 2). Occurrence of leaf collapse increased thereafter in all treatments.

Leaf Size

There were no significant differences in petiole size (length and diamater) and rachis length of both 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 Santosa (2008), and Santosa *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

Table 1. Temporal changes in leaf number of *A. paeoniifolius* plants grown with different levels of NPK fertilizers [X]

NPK treatment	Times after planting (months)						
	2	3	4	5	6	7	8
No NPK	1.5±0.2b[Y]	1.8±0.3ab	1.7±0.2b	1.7±0.2b	1.6±0.2a	0.7±0.1a	-[Z]
$N_{100}P_{60}K_{80}$	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
$N_{125}P_{60}K_{100}$	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
$N_{150}P_{60}K_{125}$	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

[X]Senescent leaves (yellowing leaves) were not included in leaf number. Leaf number larger than one means the coexistence of leaves; [Y]Mean ± S.E; different letters indicate statistical differences within columns; [Z]no leaf

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

NPK treatment	Time (weeks after planting)				
	10	14[Z]	18	22	26
No NPK	-[X]	6±3b[Y]	31±10ab	52±2b	53±3b
$N_{100}P_{60}K_{80}$	-	4±2b	28±1b	54±7ab	54±7ab
$N_{125}P_{60}K_{100}$	3±3	28±11a	41±5a	66±9a	69±9a
$N_{150}P_{60}K_{125}$	-	17±6a	41±4a	68±8a	73±6a

[W]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; [X]no incidence of leaf collapse; [Y]Mean ± S.E; different letters indicate statistical differences within columns; [Z]F 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[W]			Second leaf		
	Petiole length[X]	Petiole diameter[Y]	Rachis length	Petiole length	Petiole diameter	Rachis length
No NPK	83.2±12.3a[Z]	3.0±0.4a	62.2±10.5a	96.8±6.4a	3.1±0.0b	59.7±1.5b
$N_{100}P_{60}K_{80}$	87.8±13.3a	3.1±0.5a	65.1±9.1a	116.4±13.6a	3.9±0.3a	70.7±5.8a
$N_{125}P_{60}K_{100}$	84.6±15.6a	3.3±0.6a	64.9±11.5a	101.5± 9.5a	3.8±0.1a	67.9±2.3a
$N_{150}P_{60}K_{125}$	84.8±14.4a	3.2±0.7a	63.7±12.4a	110.7±14.0a	3.7±0.5a	71.1±8.5a

[W]A leaf which first emerges from corm; [X]Measured from soil surface to a tripartite branch of rachis; [Y]Measured at 5 cm above soil surface; [Z]Mean ± 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 [W]		Second leaf	
	Canopy size [X] (m^2)	Life span [Y] (weeks)	Canopy size (m^2)	Life span (weeks)
No NPK	1.1±0.3a[Z]	16.7±0.7a	1.0±0.1a	21.2±0.7a
$N_{100}P_{60}K_{80}$	1.2±0.2a	16.7±0.2a	1.4±0.3a	23.6±1.4a
$N_{125}P_{60}K_{100}$	1.1±0.4a	16.5±0.3a	1.3±0.1a	22.5±3.3a
$N_{150}P_{60}K_{125}$	1.1±0.4a	16.3±0.3a	1.4±0.3a	22.8±2.0a

[W]A leaf which first emerges from corm; [X]Estimated from canopy length and width at the maximum leaf expansion; [Y]Weeks from emergence to senescence of leaves; [Z]Mean ± S.E; different letters indicate statistical differences within columns

of PAR, photosynthetic rate was 108 to 173 μmol CO_2 m^{-2} s^{-1} with an average of 130 μmol CO_2 m^{-2} s^{-1}. Stomatal conductance ranged from 0.005 to 0.024 mol CO_2 m^{-2} s^{-1} with an average of 0.019 mol CO_2 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). Gopi *et al.* (2009) stated that net photosynthetic rate of elephant foot yam increases after triazole (paclobutrazol) application due to increasing in chlorophyll and carotenoid contents.

Daughter Corm

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 (χ^2) test was performed using data on the time to dormancy and corm size in the $N_{100}P_{60}K_{80}$ treatment and control, the frequency distribution were significantly different between two treatments; the $N_{100}P_{60}K_{80}$ 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).

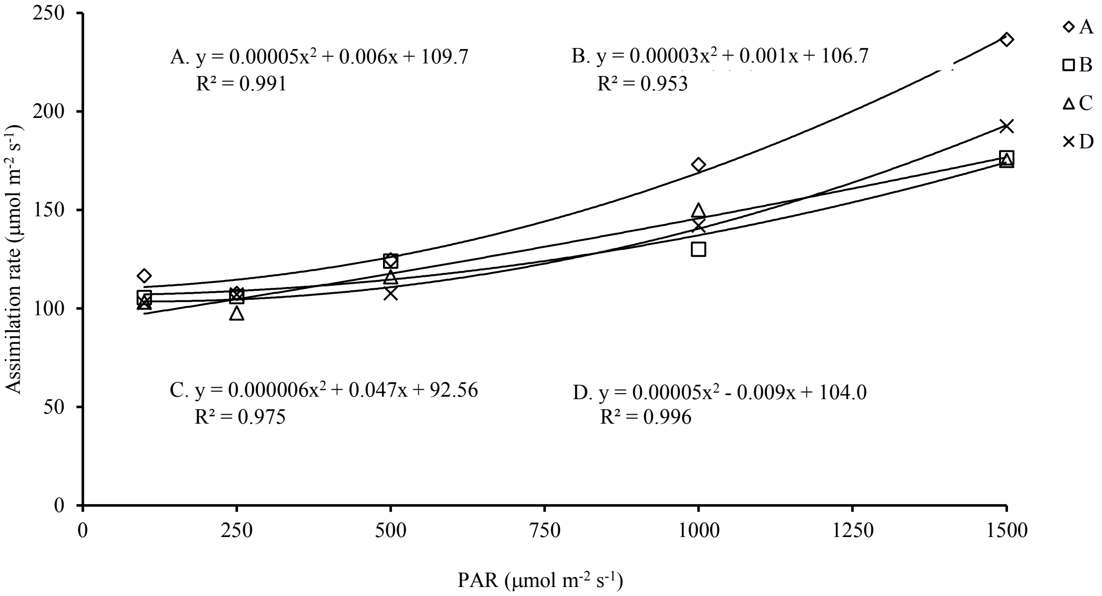

Figure 2. Photosynthetic rates of *A. paeoniifolius* grown with different levels of NPK fertilizers. A, No NPK (◊); B, $N_{100}P_{60}K_{80}$ (□); C, $N_{125}P_{60}K_{100}$ (Δ); and D, $N_{150}P_{60}K_{125}$ (x) treatments. Measurements were carried out three times for a leaf, without respect of leaf number

Table 5. Yield of elephant foot yams grown with different level of NPK fertilizers

Treatment	Corm size			Cormel^X		Time to dormancy
	Weight^Y (g)	Diameter (cm)	Height (cm)	Number	Weight (g)	(WAP^Z)
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

^{X} Cormels larger than 0.5 cm in length were measured; ^{Y}Fresh mass of corm without cormels; ^{Z}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)^X			
	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

^{X} χ^2 value was 7.84 (P<0.05, d.f.=3) when χ^2 test was performed using frequent distribution data of corm weight in the $N_{100}P_{60}K_{80}$ treatment control

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 $N_{125}P_{60}K_{100}$ 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

(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_2O_5, and K_2O 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_2O_5, and K_2O 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)[z]

NPK treatment	Categories of corm weight (%)[z]				
	<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

[Z] 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

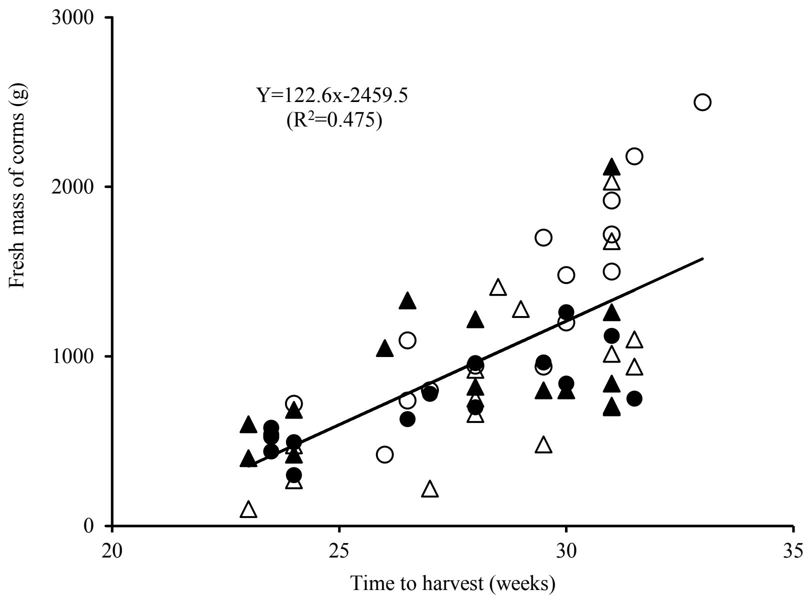

Figure 3. Correlation between corm fresh mass and time to harvest of *A. paeoniifolius* grown with different levels of NPK fertilizers. A, No NPK (●); B, $N_{100}P_{60}K_{80}$ (○); C, $N_{125}P_{60}K_{100}$ (▲); and D, $N_{150}P_{60}K_{125}$ (△)

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.

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