Original article

Nutrient and dry matter accumulation in different generations of banana at different growth stages

Jiangzhou Zhang[1,2], Chong Wang[1,2], Zhao Fang[1,2], Baoshen Li[1,2], Peter Christie[1,2] and Xiaolin Li[1,2,a]

[1] College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, China

[2] Key Laboratory of Plant-Soil Interactions, Ministry of Education, Beijing 100193, China

Summary

Dry matter and nutrient contents of Williams B6 banana (*Musa* AAA Cavendish) were studied at vegetative growth (VG), flower-bud differentiation (FB), shooting (S), fruit development (FD) and harvest (H) stages. Experimental generations comprised mother (G1), second ratoon cycle (G3) and fourth ratoon cycle (G5) plants. Dry matter and nutrient accumulation in G3 and G5 were significantly higher than in G1. Dry matter in G1 was distributed mainly in leaves, pseudostems, pseudostems and leaves, pseudostems and fruit, and fruit at VG, FB, S, FD and H, respectively. In G3 and G5 dry matter occurred mainly in pseudostems and leaves before harvest and mainly in fruit at harvest. Both nitrogen (N) and phosphorus (P) in G1 were distributed mainly in leaves at VG and in the pseudostems at FB. However, in G3 and G5 they were mainly in leaves and pseudostems at VG and in leaves at FB. From S to FD, the N and P in G1, G3 and G5 were distributed mainly in the leaves. At harvest the N and P in the different generations were mainly in leaves, except for N in G1. At VG, potassium (K) was mainly in leaves of G1 and in pseudostems of G3 and G5. From FB to H, K was mainly in pseudostems. Moreover, PCA analysis indicated that dry matter, N and K contents significantly affected yields. Our results may provide a theoretical basis for optimum banana nutrient management and minimum wastage of resources.

Keywords
dry matter accumulation, nitrogen, phosphorus, potassium, PCA analysis, plant nutrient distribution

Significance of this study

What is already known on this subject?

- Previous studies on banana nutrient accumulation and distribution have often involved new plantings (first generation) banana.
- Detailed characteristics of nutrient accumulation of different generations of banana plants are still scarce. Understanding the dynamics of nutrient demand of banana plants is crucial and fundamental for agronomic management of banana plantation.

What are the new findings?

- Dry matter and nutrient contents of Williams B6 differ and vary greatly among the different generations. The key stages for G1 are from shooting to fruit development. For G3 and G5, the key growth stages are from flower-bud differentiation to shooting stage. Approximately 30–40% of the total fertilizers should be applied during the key growth stages.

What is the expected impact on horticulture?

- Our results are important for fertilization recommendations in banana plantations in tropical and subtropical regions.

Introduction

Banana is a globally important fruit crop that is grown in tropical and subtropical areas in more than 130 countries. The annual output amounts to 11.4 million tonnes (FAO, 2017), making it the fourth-largest food crop after rice, wheat and maize (Holmes, 2013). Large amounts of N, P and K are applied to obtain high yields (Moreira and Fageria, 2009) and most previous studies have therefore focused on the effects of mineral fertilizers on the growth and yield of banana (Smithson *et al.*, 2004; Wairegi and Van Asten, 2010; Gogoi *et al.*, 2015). Yields have been found to increase with increasing application rate of N over the range of 0–500 kg N ha^{-1} (de Melo *et al.*, 2010). Application of 110 kg P ha^{-1} was found to produce high yields, quality and economic benefits. However, P inputs > 110 kg ha^{-1} have led to declining yields in China (Huang *et al.*, 2011). Lower K inputs can decrease banana growth and yields (de Melo *et al.*, 2010), with maximum production at a rate of 730 kg K ha^{-1} in Brazil (da Silva and Simao, 2015). Application of 100 kg N, 25 kg P and 100 kg K ha^{-1} in southwest Uganda produced higher yields at one location (Muyogo) than another (Buligwe) (Smithson *et al.*, 2004; Nyombi *et al.*, 2010). However, although nutrient uptake patterns form the basis of fertilizer guidelines there is little information available about nutrient uptake at different growth stages. There is therefore an urgent need for studies on nutrient uptake and the optimization of nutrient management in banana plantations.

The accumulation and distribution of dry matter and nutrients have appreciable effects on crop yields and differ among different parts of banana plants. In the vegetative phase the pseudostems contained more N. At harvest > 20% of the N and 20–37% of the K were located in the fruits and the corms were the main repository of P (Turner and Barkus, 1983; Thangaselvabai *et al.*, 2007; Soares *et al.*, 2011). Moreover, the organs of banana have typical functions and influence plant yield. Photosynthetic products in leaves can be allocated to the roots and promote banana growth and dry matter accumulation. The pseudostem is a link between

[a] Corresponding author: lixl@cau.edu.cn.

leaves and underground parts and transports nutrients and water from roots to leaves and fruits. Importantly, dry matter and nutrient contents in leaves and pseudostems have an important effect on the yield of banana (Robinson and Galán Saúco, 2010) and therefore merit investigation in different plant parts.

Banana is an herbaceous and evergreen perennial plant. Based on their growth characteristics, banana plants are divided into newly planted (first generation) banana and first ratoon sucker (second generation), second ratoon sucker (third generation) and so on (Robinson and Galán Saúco, 2010). Ratoon suckers grow up from the base of the mother plant after harvest. The ratoon bananas are taller than first generation plants and can reach a height of three meters (Robinson and Galán Saúco, 2010). Moreover, the nutrients in mother plants (especially N) can be translocated to the ratoon cycle banana (Wortman *et al.*, 1994; Raphael *et al.*, 2012). The proportion of ratoon banana is higher than newly planted banana in production systems. However, previous studies on banana nutrient accumulation and distribution have often involved new plantings (first generation) (Twyford and Walmsley, 1974a, b; Yao *et al.*, 2005; Moreira and Fageria, 2009; Yang *et al.*, 2013). There have been few studies on the nutrient uptake requirements of different generations. It is therefore necessary to investigate the dry matter and nutrient accumulation of different generations of banana.

There are five key growth stages in banana production with different dry matter and nutrient contents at the different growth stages (Twyford and Walmsley, 1974a, b). Moreover, the dry matter and nutrient contents of different generations also differ. We hypothesized that the dry matter and nutrient contents at growth stage G1 differed from those at G3 and G5. We determined the dry matter and NPK accumulation of different plant parts at growth stages G1, G3 and G5. The aim was to explore the dry matter and nutrient contents of the different generations at the various growth stages and to determine their effects on yield.

Materials and methods

Experimental site

This study was located at Long'an County, Guangxi Province (23.05°N, 107.89°E). During the experiment the annual average temperature was 22.5 °C in 2012–2013, 21.2 °C in 2013–2014 and 22.2 °C in 2015–2016. The precipitation was 1109.1 mm in 2012–2013, 1065.0 mm in 2013–2014 and 1074.3 mm in 2015–2016. The experimental soil was a laterite with wet tropical conditions with a low pH and rich in iron and aluminum. The topsoil (0–20 cm depth) in the experimental area contained 21.6 g organic matter, 37.4 mg available N, 6.2 mg available P (Olsen-P), 51.5 mg available K (NH_4OAc-K), 264.7 mg exchangeable Ca and 30.9 mg exchangeable Mg kg^{-1} and had a pH of 3.9 (soil:KCl solution 1:5, w/v).

Experimental design and management

Banana cultivar Williams B6 (*Musa* AAA Cavendish) was used. The plant density was 1,875 plants ha^{-1} at 2.6 m × 2 m spacing. The experiment was carried out from 2012 to 2016 in a banana plantation with three replicate plots per treatment of 400 m^2 each. Mother plants (first generation banana, G1) were planted in March 2012 and harvested from December 2012 to January 2013. The second ratoon cycle (third generation banana, G3) started from September 2013 to August 2014 and the fourth ratoon cycle (fifth generation banana, G5) from November 2015 to October 2016. Higher rates of N and P were applied at the vegetative stage. Potassium application was increased from the flower-bud differentiation stage to the fruit development stage. Fertilizer application was completed 20–30 days before harvest. The fertilizers were usually applied about 55 times by fertigation. There were on average five drippers per banana plant with a water dropper interval of 40 cm and a dripper discharge rate of 1.6 L h^{-1}.

Plant sampling and measurements

The different generations were sampled at the vegetative growth, flower-bud differentiation, shooting, fruit development and harvest stages. Three mats of different generations were sampled at each growth stage. G1 plants were sampled on 29th May, 13th July, 11th September, 11th October and 10th December in 2012. G3 plants were sampled on 13th December in 2013 and 11th February, 24th April, 8th June, and 5th August in 2014. G5 samples were collected on 23rd February, 15th April, 4th July, 22nd August and 16th October in 2016. At the vegetative growth and flower-bud differentiation stages, plants were separated into roots, corms, pseudostems and leaves. Roots, corms, pseudostems, leaves, internal stalks and flower buds were collected at the shooting stage. Plants collected at the fruit development stage and harvest were divided into roots, corms, pseudostems, leaves, internal stalks, external stalks and fruits. At harvest, bunches were cut off at the point where the external fruit stalk intersected with the two upper leaf sheets.

The fresh weights of root, corm, pseudostem, leaves, internal stalk, flower bud, external fruit stalk and bunch (fingers without external fruit stalk) samples were determined using a field balance (± 0.01 kg). Subsamples of each plant part were weighed fresh, oven dried at 105 °C for 30 min and then at 70 °C to a constant weight for dry matter determination. The total dry weight of the whole plant parts was calculated by dry matter content × total fresh weight (Nyombi *et al.*, 2009). Plant subsamples were sieved to < 2 mm and digested with H_2SO_4-H_2O_2. Total N was determined using the Kjeldahl method, total P by the molybdenum blue colorimetric method and total K by flame photometry (Twyford and Walmsley, 1973). Nitrogen, P and K concentrations are expressed as a percentage.

Dry matter and nutrient contents were calculated as follows:

$$DMA = \sum_{i=1}^{n} DMC_i \times TFW_i \quad [1]$$

$$NA = \sum_{i=1}^{n} NC_i \times DM_i \quad [2]$$

where DMA is dry matter accumulation, DMC is dry matter content, TFW is total fresh weight, NA is nutrient (N, P, K) accumulation, C is nutrient (N, P, K) content, DM is dry matter concentration, i is the plant part, and n is the number of plant parts.

Statistical analysis

Statistical analysis was conducted using the SPSS 16.0 for Windows software package (SPSS Institute, Inc., Cary, NC). Principal component analysis (PCA) was performed with CANOCO 4.5 software. Mean values were compared using Duncan's multiple range test at the 5% level to determine significant differences among the different banana generations.

TABLE 1. Dry matter accumulation and yields of different banana generations.

Banana generation	Dry matter accumulation (kg plant^{-1})					Yield (t ha^{-1})
	Vegetative growth stage (VG)	Flower-bud differentiation stage (FB)	Shooting stage (S)	Fruit development stage (FD)	Harvest (H)	
G1	0.16±0.0b	2.62±0.07b	4.72±0.02b	8.50±0.002c	10.93±0.31b	42.33±0.36b
G3	0.17±0.06b	5.33±0.03a	10.86±1.06a	11.52±0.33b	17.85±0.38a	58.46±4.58a
G5	1.03±0.10a	6.13±0.73a	9.41±0.01a	12.97±0.17a	16.76±0.47a	55.53±4.29a

Values are means ± SE ($n = 3$). Different letters within columns denote significant difference using Duncan's multiple range test ($P < 0.05$). G1, first banana generation (mother plants); G3, third banana generation (second ratoon cycle); and G5, fifth banana generation (fourth ratoon cycle).

Results

Dry matter accumulation and yields

Dry matter accumulation of G5 at vegetative growth stage was significantly higher than that of G1 or G3 ($p < 0.05$) and there was no significant difference between G1 and G3 (Table 1). Both G5 and G3 were significantly higher than G1 (Table 1, $p < 0.05$) from flower-bud differentiation stage to harvest. Moreover, the yields of G3 and G5 were 58.46 and 55.53 t ha^{-1}, respectively, significantly higher than that of G1. The percentage of different parts was different in the different banana generations (Figure 1). At the vegetative growth stage, dry matter was mainly distributed in the leaves in G1. In G3 and G5, dry matter was mainly distributed in the pseudostems and corms. At the flower-bud differentiation stage, dry matter of G1 was mainly distributed in the pseudostems and was significantly higher than that of G3 or G5 ($p < 0.05$). In G3 and G5 the dry matter was mainly distributed in the leaves and pseudostems. From the shooting stage to the fruit development stage the dry matter was mainly in the pseudostems and leaves of different banana generations. The dry matter distribution in pseudostems of G3 and G5 were significantly higher than G1 at the fruit development stage ($p < 0.05$). However, the percentage of fruit dry matter showed the opposite trend to the pseudostems at the fruit development stage. At harvest the dry matter of G1, G3 and G5 was mainly distributed in the fruit. The percentage of fruit dry matter in G1 was dramatically higher than in G5 ($p < 0.05$). Across all the growth stages the percentage of G1 root dry matter distribution was significantly higher than that of G3 or G5 and there were no differences between G3 and G5 (Figure 1, $p < 0.05$).

The dry matter contents of different growth stages were different among the different generations (Table 2). In general, the root, corm, pseudostem, leaf and fruit dry matter contents tended to increase at the whole growth stages and achieved their maximum values at harvest, and the dry matter contents in different parts of G3 and G5 were significantly higher than G1. However, the pseudostem dry matter contents in G3 and G5 were highest at the fruit development stage.

N accumulation and distribution in different banana generations

At the vegetative growth stage, N accumulation of G5 was significantly higher than G1 and G3, and N accumulation was

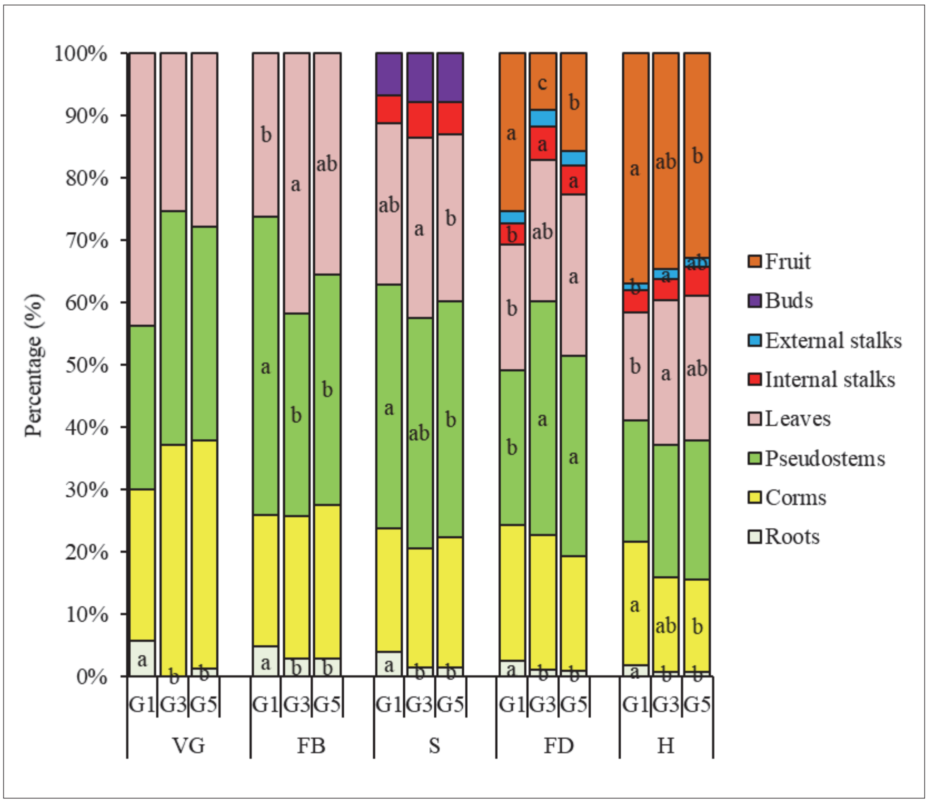

FIGURE 1. Dry matter distribution at different stages in different banana generations. Values are means ± SE ($n = 3$). Different letters are significant difference ($P < 0.05$). G1, first banana generation (mother plants); G3, third banana generation (second ratoon cycle); and G5, fifth banana generation (fourth ratoon cycle). VG, vegetative growth stage; FB, flower-bud differentiation stage; S, shooting stage; FD, fruit development stage; H, harvest.

Table 2. Dry matter accumulation in different plant parts of different banana generations.

Organs	Banana generation	Dry matter accumulation (kg plant^{-1}) Vegetative growth stage (VG)	Flower-bud differentiation stage (FB)	Shooting stage (S)	Fruit development stage (FD)	Harvest (H)
Roots	G1	0.01±0.003a	0.13±0.01a	0.19±0.005a	0.21±0.001a	0.20±0.01a
	G3	0.00±0.00b	0.15±0.01a	0.16±0.02ab	0.13±0.005b	0.13±0.02b
	G5	0.01±0.002a	0.17±0.02a	0.13±0.01b	0.12±0.01b	0.12±0.01b
Corms	G1	0.04±0.01b	0.56±0.06b	0.94±0.07b	1.86±0.14b	2.17±0.29a
	G3	0.09±0.06b	1.22±0.05a	2.10±0.32a	2.48±0.16a	2.70±0.27a
	G5	0.39±0.09a	1.55±0.32a	1.97±0.06a	2.38±0.10a	2.49±0.23a
Pseudostems	G1	0.04±0.01b	1.24±0.07c	1.84±0.03b	2.10±0.14b	2.13±0.07b
	G3	0.05±0.003b	1.74±0.12b	4.02±0.43a	4.34±0.34a	3.78±0.10a
	G5	0.35±0.04a	2.23±0.16a	3.56±0.15a	4.19±0.32a	3.74±0.11a
Leaves	G1	0.07±0.003b	0.69±0.04b	1.22±0.04b	1.70±0.03c	1.90±0.13b
	G3	0.04±0.01b	2.23±0.15a	3.14±0.32a	2.59±0.08b	4.14±0.15a
	G5	0.28±0.03a	2.17±0.28a	2.52±0.12a	3.34±0.11a	3.89±0.05a
Internal stalks	G1			0.21±0.02b	0.30±0.01b	0.38±0.04c
	G3			0.61±0.04a	0.63±0.02a	0.62±0.01b
	G5			0.49±0.07a	0.60±0.001a	0.76±0.05a
External stalks	G1				0.17±0.02b	0.13±0.002b
	G3				0.30±0.02a	0.28±0.01a
	G5				0.31±0.02a	0.27±0.02a
Buds	G1			0.32±0.003b		
	G3			0.83±0.04a		
	G5			0.74±0.04a		
Fruit	G1				2.15±0.02a	4.03±0.09b
	G3				1.06±0.07b	6.19±0.16a
	G5				2.01±0.19a	5.50±0.51a

Values are means ± SE ($n=3$). Different letters within columns denote significant difference by Duncan's multiple range test ($P<0.05$). G1, first banana generation (mother plants); G3, third banana generation (second ratoon cycle); and G5, fifth banana generation (fourth ratoon cycle).

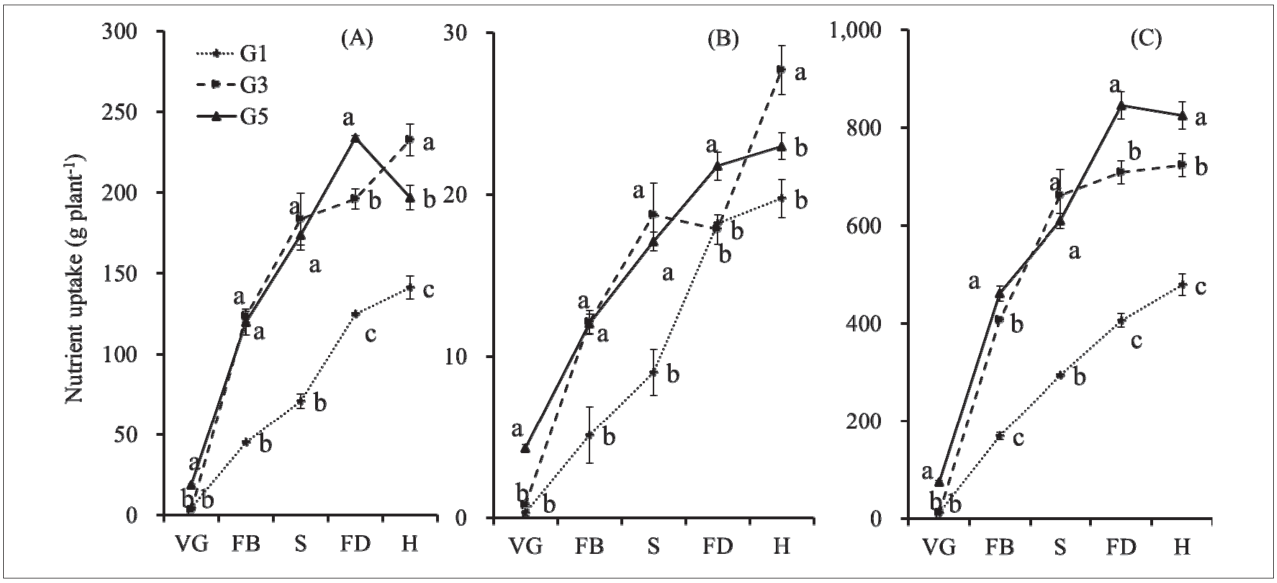

Figure 2. The (A) N, (B) P, (C) K accumulation at different stages in different banana generations. Values are means ± SE ($n=3$). Different letters are significant difference ($P<0.05$). G1, first banana generation (mother plants); G3, third banana generation (second ratoon cycle); and G5, fifth banana generation (fourth ratoon cycle). VG, vegetative growth stage; FB, flower-bud differentiation stage; S, shooting stage; FD, fruit development stage; H, harvest.

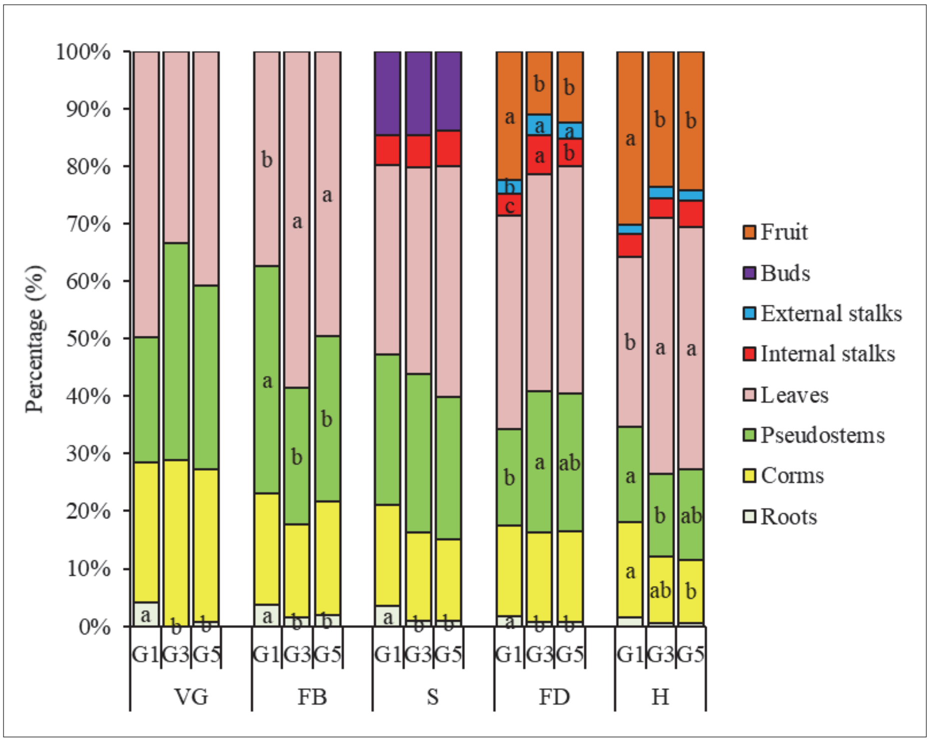

FIGURE 3. N distribution at different stages in different banana generations. Values are means ± SE ($n=3$). Different letters are significant difference ($P<0.05$). G1, first banana generation (mother plants); G3, third banana generation (second ratoon cycle); and G5, fifth banana generation (fourth ratoon cycle). VG, vegetative growth stage; FB, flower-bud differentiation stage; S, shooting stage; FD, fruit development stage; H, harvest.

significantly lower in G1 than G3 and G5 from the flower-bud differentiation stage to harvest. There was no significant difference between G3 and G5 at the flower-bud differentiation and shooting stages (Figure 2A). At the vegetative growth stage the percentage of N distribution in G1 was mainly in the leaves, and the N in G3 and G5 was mainly in the pseudostems and leaves. At the flower-bud differentiation stage, N distribution in G1 was mainly in the pseudostems and the percentage of G1 N distribution in pseudostems was significantly higher than that of G3 or G5. However, the percentage of N distribution in leaves showed the opposite trend to the pseudostems. From the shooting stage to the fruit development stage the N was mainly distributed in leaves of G1, G3 and G5. At harvest the N was mainly in the leaves and fruits of the different generations. Moreover, the percentage of G1 N distribution in fruits was significantly higher than that of G3 and G5 from the fruit development stage to harvest. The percentage of G1 root N distribution was significantly higher than that of G3 and G5, and no significant difference was observed between G3 and G5 from the vegetative growth stage to the fruit development stage (Figure 3).

In G1 the root and leaf N accumulation reached their maximum values at the fruit development stage. The corm, pseudostem and fruit N accumulation achieved their maximum values at harvest. The nutrient accumulation in G3 and G5 differed from that in G1. The N accumulation in roots, corms and fruits were at their maximum values at the flower-bud differentiation stage, fruit development stage and harvest, respectively. The N accumulation in pseudostems and leaves in G3 were at their maximum values at the shooting stage and harvest, respectively. In G5 the N accumulation in the pseudostems and leaves was maximum at the fruit development stage (Table 3).

Phosphorus accumulation and distribution in different generations

At the vegetative growth stage, P accumulation in G5 was significantly higher than in G1 or G3 (Figure 2B). From the flower-bud differentiation stage to the shooting stage, P accumulation of G1 was dramatically lower than that of G3 or G5. At harvest, P accumulation of G3 was significantly higher than G1 or G5 and there was no significant difference between G1 and G5 (Figure 2B). The P distribution in G1, G3 and G5 at different growth stages was the same as that of N (Figure 4). At the fruit development stage the percentage of G1 leaf P distribution was significantly higher than in G3 or G5 but the percentage of G1 internal and external stalk P distribution was significantly lower than G3 or G5. At harvest the percentage of leaf P distribution in G1 was higher than G5 and the percentage of external stalk and fruit P distribution in G1 was lower than G3 or G5 (Figure 4).

Root, corm and fruit P accumulation in G1 reached their maximum values at harvest. The P accumulation in pseudostems and leaves peaked at the shooting and fruit development stages, respectively. In G3 and G5 the P accumulation in roots and corms peaked at the flower-bud differentiation and fruit development stages, respectively. The leaf and fruit P accumulation was maximum at harvest. Corm P accumulation in G5 was significantly higher than in G1 or G3 from the vegetative growth stage to the fruit development stage, except in G3 at the shooting stage. Generally, the pseudostem, leaf, internal stalk, external stalk and bud P accumulation in G3 and G5 from the flower-bud differentiation stage to harvest were significantly higher than in G1.

K accumulation and distribution in different banana generations

Potassium accumulation was similar to that of N. Potassium accumulation in G3 and G5 was significantly higher than in G1 over the whole growth period except at the vegetative growth stage. There was a significant difference between G3 and G5 over the whole growth period except at the shooting stage (Figure 2C). At the vegetative growth stage the K distribution in G1 was mainly in the leaves and K accumulation was mainly distributed in the pseudostems in G3 and G5. G1 had significantly higher percentage leaf K distribution than

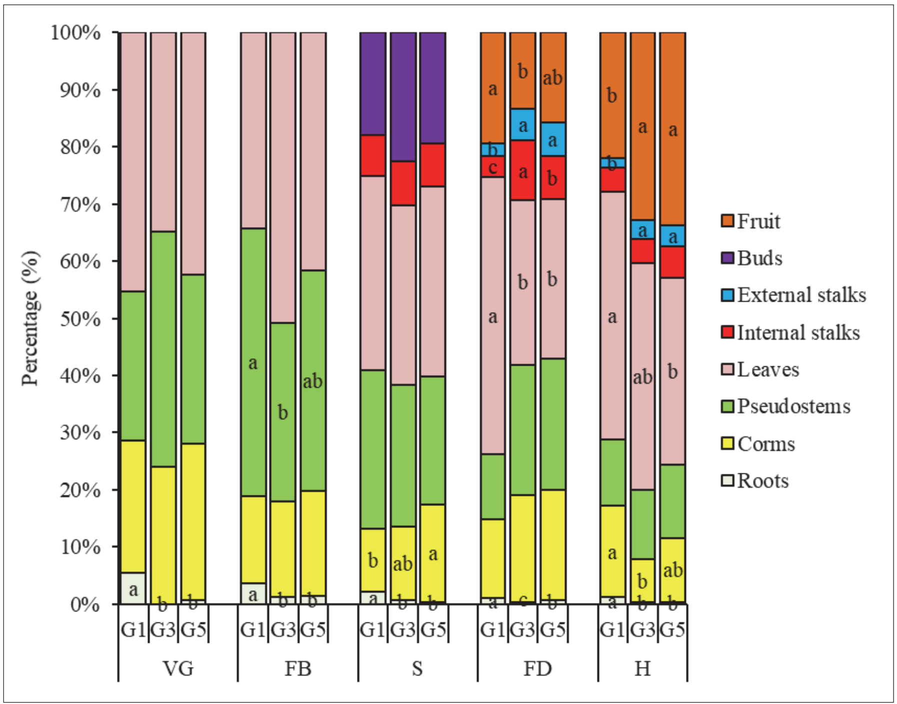

FIGURE 4. P distribution at different stages in different banana generations. Values are means ± SE ($n=3$). Different letters are significant difference ($P<0.05$). G1, first banana generation (mother plants); G3, third banana generation (second ratoon cycle); and G5, fifth banana generation (fourth ratoon cycle). VG, vegetative growth stage; FB, flower-bud differentiation stage; S, shooting stage; FD, fruit development stage; H, harvest.

TABLE 3. The N accumulation in different plant parts of different banana generations.

Organs	Banana generation	N accumulation (g plant^{-1})				
		Vegetative growth stage (VG)	Flower-bud differentiation stage (FB)	Shooting stage (S)	Fruit development stage (FD)	Harvest (H)
Roots	G1	0.18±0.06a	1.68±0.05a	2.46±0.12a	2.24±0.17a	2.07±0.12a
	G3	0.00±0.00b	1.90±0.22a	1.52±0.19b	1.41±0.04b	1.07±0.15b
	G5	0.14±0.02a	2.31±0.24a	1.61±0.08b	1.50±0.11b	1.03±0.03b
Corms	G1	1.07±0.15b	8.75±0.88b	12.39±0.89b	19.51±0.39c	23.76±4.02a
	G3	1.07±0.65b	19.94±0.07b	28.87±5.30a	30.56±0.40b	27.05±1.40a
	G5	4.97±0.97a	23.72±3.00a	24.51±1.20a	37.01±1.23a	21.58±1.03a
Pseudostems	G1	0.97±0.24b	17.81±1.36b	18.65±1.11b	20.95±2.49b	23.32±2.12b
	G3	1.08±0.15b	28.98±2.23a	50.78±4.79a	48.36±3.50a	33.27±0.78a
	G5	5.99±0.71a	34.72±3.84a	42.93±0.41a	56.44±5.75a	30.91±1.98a
Leaves	G1	2.16±0.05b	16.93±1.21b	23.58±3.09b	46.26±1.94c	41.74±4.76c
	G3	1.00±0.19b	72.41±5.70a	66.08±7.79a	74.06±1.40b	104.03±7.08a
	G5	7.49±1.01a	59.17±3.70a	70.10±8.37a	92.08±4.37a	83.23±2.93b
Internal stalks	G1			3.66±0.16b	4.77±0.45c	5.77±0.46b
	G3			10.27±0.50a	13.19±0.39a	7.94±0.66a
	G5			10.87±1.08a	11.42±0.44b	8.70±0.51a
External stalks	G1				2.97±0.03b	2.32±0.11b
	G3				6.78±0.53a	4.47±0.15a
	G5				6.66±0.40a	3.90±0.26a
Buds	G1			10.23±0.27b		
	G3			25.97±1.65a		
	G5			23.75±0.85a		
Fruit	G1				27.98±1.64ab	42.29±1.47b
	G3				21.77±2.10b	54.62±1.08a
	G5				28.86±1.09a	47.57±4.03ab

Values are means ± SE ($n=3$). Different letters within columns denote significant difference by Duncan's multiple range test ($P<0.05$). G1, first banana generation (mother plants); G3, third banana generation (second ratoon cycle); and G5, fifth banana generation (fourth ratoon cycle).

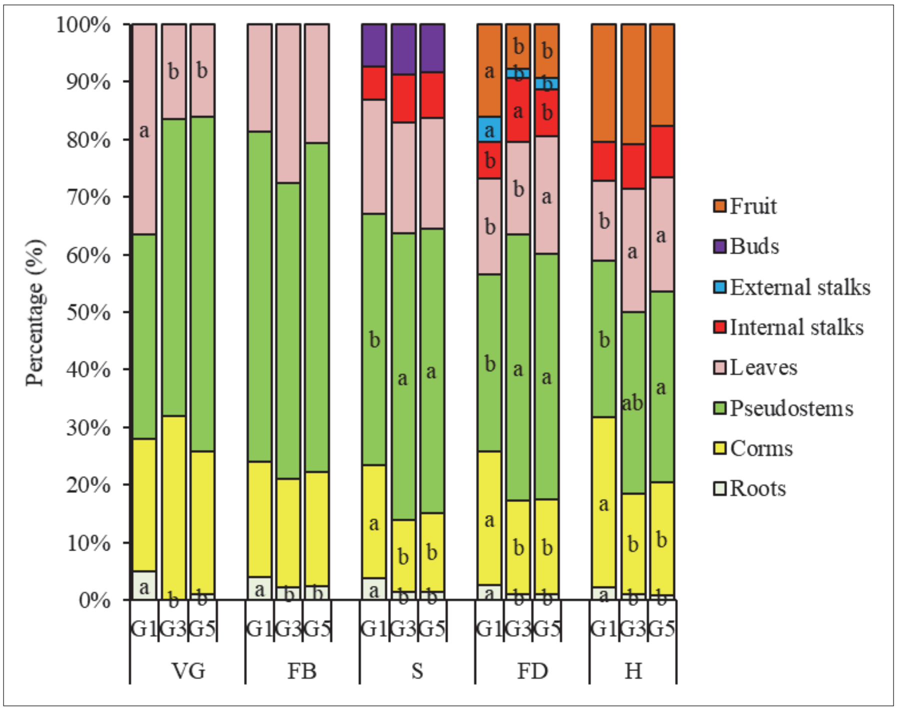

FIGURE 5. K distribution at different stages in different banana generations. Values are means ± SE ($n=3$). Different letters are significant difference ($P<0.05$). G1, first banana generation (mother plants); G3, third banana generation (second ratoon cycle); and G5, fifth banana generation (fourth ratoon cycle). VG, vegetative growth stage; FB, flower-bud differentiation stage; S, shooting stage; FD, fruit development stage; H, harvest.

TABLE 4. The P accumulation in different plant parts of different banana generations.

Organs	Banana generation	P accumulation (g plant^{-1}) Vegetative growth stage (VG)	Flower-bud differentiation stage (FB)	Shooting stage (S)	Fruit development stage (FD)	Harvest (H)
Roots	G1	0.02±0.01ab	0.18±0.02a	0.21±0.05a	0.21±0.03a	0.23±0.02a
	G3	0.00±0.00b	0.16±0.01a	0.13±0.01ab	0.06±0.001c	0.10±0.02b
	G5	0.03±0.01a	0.18±0.04a	0.07±0.01b	0.15±0.005b	0.09±0.01b
Corms	G1	0.10±0.003b	0.80±0.22b	0.96±0.10b	2.48±0.41a	3.08±0.52a
	G3	0.23±0.16b	1.99±0.13a	2.48±0.60a	3.30±0.54a	2.09±0.34a
	G5	1.19±0.25a	2.21±0.40a	2.92±0.11a	4.27±1.03a	2.55±0.34a
Pseudostems	G1	0.11±0.04b	2.38±0.26b	2.53±0.51b	2.08±0.28b	2.32±0.47a
	G3	0.30±0.03b	3.71±0.34a	4.60±0.28a	4.12±0.77ab	3.32±0.18a
	G5	1.28±0.14a	4.59±0.25a	3.78±0.17a	4.93±0.45a	2.98±0.18a
Leaves	G1	0.19±0.01b	1.75±0.22b	3.14±0.74a	8.85±0.13a	8.51±0.58ab
	G3	0.26±0.03b	6.24±1.13a	6.02±1.24a	5.13±0.18c	11.05±1.20a
	G5	1.79±0.13a	5.03±0.52a	5.72±0.55a	6.04±0.16b	7.49±0.32b
Internal stalks	G1			0.66±0.16b	0.65±0.002b	0.85±0.16a
	G3			1.44±0.10a	1.85±0.18a	1.17±0.17a
	G5			1.27±0.10a	1.64±0.18a	1.25±0.11a
External stalks	G1				0.41±0.002c	0.33±0.02b
	G3				0.99±0.08b	0.93±0.08a
	G5				1.29±0.04a	0.86±0.04a
Buds	G1			1.52±0.02c		
	G3			4.10±0.13a		
	G5			3.34±0.24b		
Fruit	G1				3.53±0.46a	4.42±0.77b
	G3				2.38±0.23a	9.01±0.36a
	G5				3.43±0.33a	7.77±0.87a

Values are means ± SE ($n=3$). Different letters within columns denote significant difference by Duncan's multiple range test ($P<0.05$). G1, first banana generation (mother plants); G3, third banana generation (second ratoon cycle); and G5, fifth banana generation (fourth ratoon cycle).

Table 5. The K accumulation in different plant parts of different banana generations.

Organs	Banana generation	K accumulation (g plant^{-1})				
		Vegetative growth stage (VG)	Flower-bud differentiation stage (FB)	Shooting stage (S)	Fruit development stage (FD)	Harvest (H)
Roots	G1	0.60±0.18a	6.68±0.43b	11.32±0.10a	10.80±0.34a	10.21±0.29a
	G3	0.00±0.00b	9.15±0.85ab	8.94±1.13a	7.28±0.32b	6.76±0.85b
	G5	0.75±0.12a	11.71±1.10a	8.52±0.94a	8.51±0.76b	6.77±0.75b
Corms	G1	2.76±0.38b	33.59±2.12b	57.53±4.09b	94.09±12.47b	137.49±16.78a
	G3	4.73±3.22b	77.00±5.08a	83.60±10.25a	114.76±4.22b	122.27±4.67a
	G5	18.60±1.01a	90.77±4.28a	84.11±3.38a	139.72±5.06a	155.93±24.72a
Pseudostems	G1	4.58±1.59b	97.71±11.62c	128.82±2.43b	124.79±0.48b	126.30±5.35b
	G3	5.44±0.61b	209.41±18.62b	328.98±28.73a	327.97±19.21a	219.13±20.16a
	G5	43.91±3.72a	263.09±4.12a	299.77±8.22a	361.11±30.61a	264.79±18.44a
Leaves	G1	4.32±0.31b	31.39±2.55b	57.82±1.07b	67.22±3.36c	63.95±4.54b
	G3	1.86±0.45b	112.41±11.18a	128.81±17.20a	114.47±2.41b	148.36±4.53a
	G5	12.02±1.38a	95.81±14.74a	116.90±7.31a	172.67±4.43a	157.33±6.43a
Internal stalks	G1			16.96±1.73b	25.84±2.38b	30.62±2.78b
	G3			54.10±3.15a	77.61±1.92a	53.77±3.06a
	G5			48.98±4.21a	68.76±4.12a	69.90±7.23a
External stalks	G1				17.93±2.05a	16.02±0.21b
	G3				12.37±0. 84b	29.12±0.87a
	G5				16.66±0.46a	28.54±2.53a
Buds	G1			22.32±0.38b		
	G3			56.68±2.40a		
	G5			51.61±1.00a		
Fruit	G1				65.50±0.97ab	94.84±1.82b
	G3				54.54±2.14b	144.04±2.09a
	G5				78.20±5.52a	142.21±12.18a

Values are means ± SE ($n=3$). Different letters within columns denote significant difference by Duncan's multiple range test ($P<0.05$). G1, first banana generation (mother plants); G3, third banana generation (second ratoon cycle); and G5, fifth banana generation (fourth ratoon cycle).

G3 or G5. At other growth stages the K was mainly distributed in the pseudostems in G1, G3 and G5. From the shooting stage to the fruit development stage the percentage of pseudostem K distribution in G1 was significantly lower than in G3 or G5. However, the percentage of corm K distribution showed the opposite trend from the shooting stage to harvest. The percentage of root K distribution was similar to N and P (Figure 5).

In G1 the K accumulation of roots and pseudostems reached maximum values at the shooting stage and corm and fruit K accumulation peaked at harvest. In G3 and G5 the root K accumulation achieved maximum values at the flower-bud differentiation stage and the corms and fruits reached their maximum values at harvest. The internal stalk, external stalk, bud and fruit K accumulation of G3 and G5 were significantly higher than of G1 from the shooting stage to harvest (Table 5).

Discussion

Dry matter and nutrient accumulation in different banana generations

In the present study the dry matter and nutrient accumulation in G3 and G5 were significantly higher than in G1 (Table 1; Figure 2). There are three possible explanations for this. Firstly, from banana morphological characteristics the pseudostems in G1 had a minimum height of 2 m but those in G3 and G5 were taller than G1 (Robinson and Galán Saúco, 2010). Secondly, G3 and G5 had a symbiotic stage of about 60 d with the mother plant, and a large amount of available nutrient would have been transferred from the pseudostems of harvested banana to the suckers which grew from the corms of the mother plant (Wortman *et al.*, 1994). In addition, the decomposition of crop residues and the fertilizers applied provided nutrients (Prasertsak *et al.*, 2001; Nyombi *et al.*, 2010; Raphael *et al.*, 2012). Finally, G3 and G5 had longer growth periods than G1, and this would have favored the formation of photosynthetic products to obtain higher biomass and yield (Huang *et al.*, 2016; Xu *et al.*, 2016). Our results are in agreement with a study carried out in east Africa (Nyombi *et al.*, 2010).

Dry matter and nutrient accumulation are related to crop yield (Su *et al.*, 2015; Cao *et al.*, 2017). The correlation coefficients were calculated between yield and dry matter, N, P, and K accumulation, and the Pearson correlation coefficients were 0.852, 0.810, 0.604 and 0.735, respectively. Furthermore, the dry matter and N and K accumulation significantly affect the yield of banana.

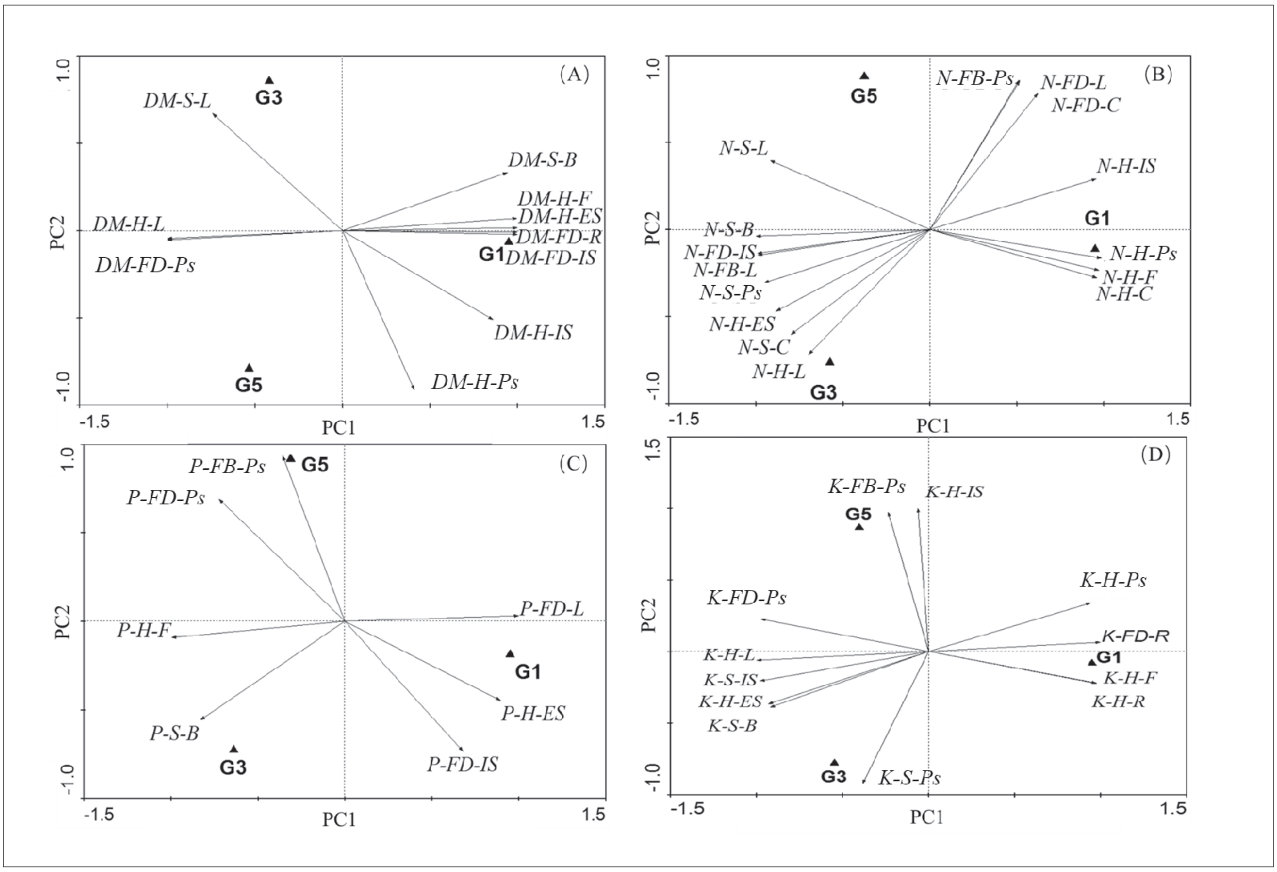

FIGURE 6. Correlations between banana yield and (A) dry matter, (B) N, (C) P and (D) K nutrient accumulation in different parts revealed by PCA analysis. G1, first banana generation (mother plants); G3, third banana generation (second ratoon cycle); and G5, fifth banana generation (fourth ratoon cycle). VG, vegetative growth stage; FB, flower-bud differentiation stage; S, shooting stage; FD, fruit development stage; H, harvest. R, roots; C, corms; Ps, pseudostems; L, leaves; IS, internal stalks; ES, external stalks; B, buds; F, fruit. DM, dry matter; N, nitrogen; P, phosphorus; and K, potassium.

Dry matter and nutrient accumulation at different growth stages and banana yield

In general the dry matter and nutrient accumulation data showed an increasing trend from the vegetative growth stage to harvest. The maximum values of dry matter and nutrient accumulation were at harvest (Table 1, Figure 2). The corm, pseudostem and leaf NPK accumulation in G1 were different from G3 and G5 from the fruit development stage to harvest (Tables 3, 4, and 5). This may be related to banana growth characteristics. In G1 the corms and pseudostems provide nutrients for the growth of suckers, thus the corm and pseudostem nutrient contents at harvest were higher than at the fruit development stage. Leaf nutrients at the fruit development stage were allocated to the fruits and the leaf nutrient accumulation at harvest was therefore lower than at the fruit development stage. Similar results have been reported in apple (Ding *et al.*, 2016).

The percentage of pseudostem and leaf dry matter and nutrient accumulation gradually declined as photosynthetic products were allocated to the fruits from the vegetative growth stage to the harvest (Figure 1). Similar behavior has been observed in rice and maize (Ntanos and Koutroubas, 2002; Kosgey *et al.*, 2013). From the flower-bud differentiation stage to harvest the yield was significantly and positively correlated with the dry matter and nutrient contents of the pseudostems and leaves (Figure 6) because dry matter and nutrients from the pseudostems and leaves were reallocated simultaneously to the developing banana bunch after flowering (Eckstein *et al.*, 1995). The reproductive stage therefore made a greater contribution to the yield of banana in all three generations, *i.e.*, G1, G3 and G5.

The yields of G3 and G5 were significantly higher than G1 (Table 1) because the dry matter and nutrient uptake of G3 and G5 were significantly higher than G1 (Table 1, Figure 2). A previous study of banana also found higher biomass always associated with higher yield (Taulya, 2013). Higher nutrient uptake was beneficial to the growth of banana functional leaves, girth at base and fruit fingers. The banana functional leaves are photosynthetically active and the number of functional leaves affected the photosynthetically active leaf area and distribution to fill the fruits (Nyombi *et al.*, 2010). In G3 and G5, more photosynthate was allocated to the fruit fingers. The diameters of fruit fingers and finger fruit weights are important classification standards that affect banana yields and fresh fruit consumption in international trade (Robinson and Galán Saúco, 2010). Furthermore, the girth at base is significantly and positively related to aboveground biomass and bunch fresh weight (Nyombi *et al.*, 2009).

In conclusion, dry matter and nutrient accumulation had positive effects on banana yield. Generally, the dry matter and nutrient uptake increased from the vegetative growth stage to harvest in G1, G3 and G5. Moreover, the dry matter and nutrient accumulation in G3 and G5 were significantly higher than in G1. Therefore, more fertilizer, and especially N and K fertilizers, were applied to G3 and G5. In G1, the key growth stages were from shooting to fruit development. However, the key growth stages for G3 and G5 were from flower-bud differentiation to shooting. At the key growth stages, 30–40% of the total fertilizers should be applied by fertigation and these results have very important implications for the effective nutrient management of banana plantations.

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