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Relationship between root and shoot growth traits during the plant crop and first ratoon in banana and plantain (*Musa* spp.) and its implications for perennial cultivation on degraded Ultisols in south-eastern Nigeria

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ABSTRACT

Objective: This study assessed the relationships of root and shoot growth within and across two consecutive crop cycles in 32 widely differing *Musa* spp. genotypes.

Methodology and results: A reduction in leaf area, corm weight, root dry weight, cord root number and length occurred during the reproductive stage of both the plant crop and the first ratoon cycle. Most leaves died off during the reproductive stage, while the decay of the outer leaf sheets resulted in a reduction of the pseudostem circumference. The corm fresh weight was reduced by 20 and 13 % during the reproductive stage of the first and the second cycle, respectively. A reduction in cord root number of 8 and 12 % was observed during the reproductive stage in the first and second cycle, respectively. Cord root length was reduced by 40 % during the reproductive phase of both cycles. The effect of crop cycle was significant on the different corm traits and the cord root diameter. The corm of the first ratoon plants was bigger and taller than the corm of the plant crop, resulting in a slight increase in number and diameter of cord roots. In contrast, cord root length of the first ratoon was less than that of the plant crop. Number of suckers decreased from 16 to 12, while height of the tallest sucker was 120 cm and 68 cm at flower emergence of the plant crop and the first ratoon crop, respectively. Significant positive correlations were observed between mother plant (plant crop) and sucker growth characteristics, mostly within but not across genotypes.

Conclusion and application of findings: While fast-growing plants may also have better developed suckers, it is not apparent that breeding for genotypes with a larger root system would lead to better suckering. The observed reduction in sucker vigour during the reproductive phase of the ratoon crop may be attributed to the observed high mat and possible soil degradation. This would affect plant anchorage and stability, and limit possibilities for perennial production of bananas and plantains under mono-cropping conditions on degraded Ultisols.

Key words: banana, plantain, plant crop, ratoon crop, root system

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Introduction

Plantain and banana (*Musa* spp.) are grown as perennial crops, in backyards and plantations, because they produce consecutive generations from lateral shoots (*i.e.* suckers) that develop from the main plant (De Langhe, 1961; Swennen & Ortiz, 1997). The first cycle after planting is called the plant crop or mother plant, while the ratoon is the sucker selected from the harvested plant. The second cycle is called the first ratoon crop, while the third cycle is the second ratoon crop. Sucker development consists of three distinct stages: peeper (small sucker appearing just above the ground and bearing scale leaves only), sword sucker (large sucker with lanceolate type leaves), and maiden sucker (large sucker with foliage leaves) (Simmonds, 1966; Swennen, 1984; Swennen & Ortiz, 1997).

The lifetime of banana fields is extremely variable ranging from one crop cycle (12-18 months) to nearly permanent cultivation (Nayar, 1962; Robinson, 1995). For example, plantains grown in mixed cropping systems in south-eastern Nigeria are subject to progressive yield decline, *i.e.*, declining yields in subsequent cycles, mainly due to depletion of fertility and organic matter, soil erosion, low pH and build-up of weeds and pests (Wilson *et al*., 1985; Swennen *et al*., 1988; Salau *et al*., 1992). These plantain fields need to be replanted after 2 to 3 cycles. In contrast, banana fields in the highlands of East and Central Africa extend over many decennia (Swennen & De Langhe, 1989).

After several ratoon crops, corms in aging plantain fields appear above the soil (Stover, 1972; Swennen, 1990). This phenomenon is called 'high mat' and provokes the early death of a substantial number of newly formed roots before they can reach the soil surface (Moreau & Le Bourdelles, 1963). Consequently, plants become weak and tip over easily because they are no longer firmly anchored in the soil (Swennen, 1990). Mulch however protects the above ground emerging roots which would otherwise dry out before reaching the soil (Swennen, 1990). In addition, mulch improves root ramification. Hence, mulch significantly contributes to plant stability and yield.

Vigorous sucker growth reduces the cycle duration (Swennen *et al*., 1984; Ortiz & Vuylsteke, 1994). For example, dessert bananas (*Musa* AAA group) usually have well-developed suckers at maturity of the plant crop and hence the first ratoon cycle is shorter than the plant crop cycle (Barker & Steward, 1962; Robinson & Nel, 1990). In contrast, most plantain (*Musa* AAB group) genotypes have an inhibited suckering which is caused by the strong apical dominance exerted by the main plant (Braide & Wilson, 1980; Swennen & Wilson, 1983; Swennen *et al*., 1984). Swennen *et al*. (1984) also reported that sword sucker development of plantains responds to GA_3 flushes, which only stimulate peepers that are physiologically sensitive to GA_3 at the time of the flush.

The study by Ortiz and Vuylsteke (1994) found that the *Ad* gene controls the production of GA_3 in the suckers. Presence of the dominant allele results in improved ratooning of the plantain hybrids as compared with their plantain parents. As it is generally accepted that root tips are sources of cytokinins and gibberellic acid, root initiation and root development around a corm may be responsible for the distribution and development of buds and suckers on the corm (Swennen, 1984). Swennen *et al*. (1986) has demonstrated that tremendous differences in root ramification exist between *Musa* cultivars under hydroponic conditions with plantains having a much lesser ramified root system than Cavendish bananas. Also plantains have a much more inhibited sucker development than Cavendish bananas.

In addition, Swennen (1984) and Janssen (1983) demonstrated that localized mulching enhanced plantain root development at the side of the mulch application and sucker growth was much stimulated at the same side. It was thus hypothesised that improved rooting would lead to better suckering and therefore faster cycling. Hence, it is hypothesized that selection for good rooting varieties can be done by observing above ground characteristics, instead of going into time consuming root studies.

The few root studies conducted so far in *Musa* are mainly devoted to observations during the first months of the first cycle. However, since bananas and plantains are perennials, studies of the plant crop give an incomplete picture. Therefore, studies are needed of the root system during the second cycle when all plant components are in place (*i.e.* the remains of the plant crop, first ratoon and the sucker which will produce the second ratoon). The objectives of this study were to evaluate the relationship between root system development and sucker growth under field conditions and to evaluate root system and shoot development during the plant crop and first ratoon crop of several *Musa* spp. genotypes.

Materials and methods

Site description: The experiments were carried out at the IITA High Rainfall station at Onne in south-eastern Nigeria (4°42' N, 7°1' E, 5 m asl). Its soil is an ultisol derived from coastal sediments, well drained but poor in nutrients and with a pH of 4.3 in 1:1 H_2O. The average annual rainfall is 2,400 mm distributed monomodally from February until November. Further details of the site have been described by Ortiz *et al*. (1997).

Planting materials: Both conventional propagules and *in vitro* material were used in the field experiments. Conventional propagules were vigorous suckers (*i.e.* lateral shoots) (Swennen & Ortiz, 1997) obtained from true-to-type plants. Suckers were uprooted, pared and subsequently planted as recommended by Swennen (1990). Micropropagated plants were produced following standard shoot-tip culture techniques (Vuylsteke, 1989 and 1998). Rooted plantlets were transferred to polybags (height = 25 cm, circumference = 44 cm) in a greenhouse nursery (Vuylsteke & Talengera, 1998; Vuylsteke, 1998) and transplanted to the field within six weeks.

Experimental procedures: Four experiments were done that focus on root and shoot development during two crop generations/cycles. Specific attention was also given to the relationship between root system development and lateral shoot growth.

Experiment 1: Five genotypes including the diploid wild banana 'Calcutta 4' (*Musa* AA group), the dessert banana 'Valery' (*Musa* AAA Cavendish sub-group) and the tetraploid plantain hybrids 'TMPx 548-9', 'TMPx 5511-2' and 'TMPx 1621-1' were assessed (Table 1). All hybrids are progenies from a cross between 'Obino l'Ewai' and 'Calcutta 4' (Vuylsteke *et al*., 1993a & b). Field planting of *in vitro*-derived plants was done on 10 October 1996. Evaluation was done at flower emergence and at harvest of the plant crop and the subsequent first ratoon crop. First ratoon plants were obtained from the tallest sucker at harvest of the plant crop, while other suckers, present at harvest of the plant crop, were systematically eliminated through meristem removal. Four plants per genotype were assessed at each growth stage. The field layout was a completely randomized design. To avoid overlapping of adjacent root systems, plant spacing was 4 m x 4 m. The trial site, which had been under fallow of a *Mucuna* - *Pueraria* mixture for a period of five years, was manually prepared to avoid soil disturbance. The plants were grown under a monocropping system and no mulch was applied.

Experiment 2: Twenty-seven genotypes belonging to a wide range of genomic groups and three ploidy levels of banana and plantain (*Musa* spp.) were analyzed (Table 1). Six weeks old *in vitro*-derived plants were planted in the field in June 1996. The experimental layout was a split plot within a randomized complete block design with two replications of two plants each per genotype. Main plot treatments consisted of different times of observation. Field measurements were done during the vegetative stage of 12, 16 and 20 week old plants. Subplot treatments consisted of genotypes.

A detailed analysis was done at flower emergence on a subset of five genotypes (Table 1), which differ widely in suckering behaviour, but were genetically related. The genotype 'Valery' was included for comparison. The plants were planted in a randomized complete block design with two replications of two plants per genotype.

The trial site, which had been under a grass fallow for eight years, was manually prepared with minimum soil disturbance. To avoid overlapping of adjacent root systems, plant spacing was 2 m x 2 m for plants evaluated during the vegetative stage and 4 m x 4 m for plants evaluated at flower emergence stage.

Experiment 3: Two plantain landraces and six plantain hybrids were assessed (Table 1). Twenty suckers of different size and physiological stage were planted per genotype. Planting was done in early July 1998 and evaluation was done at 20 weeks after planting (WAP). The field layout was a randomised complete block design with 4 replications and 5 plants per genotype. The trial site, which had been under a grass fallow for five years, was manually prepared with minimum soil disturbance. To avoid overlapping of adjacent root systems, plant spacing was 2 m x 2 m.

Experiment 4: The genotypes evaluated included the dessert banana 'Valery' (*Musa* AAA group) and the plantain 'Obino l'Ewai' (*Musa* AAB group) (Table 1). *In vitro* plantlets were planted during June 1998 and evaluation was done at 33 WAP, during the pre-flowering stage. The field layout was a randomised complete block design with five replications of four plants per genotype. Plant spacing was 2 m x 2 m. In this experiment only one sucker (same position for all plants) was allowed to grow. The other suckers were carefully eliminated by destroying their apical meristem. The trial site, which had been under a grass fallow for five years, was manually prepared with minimum soil disturbance.

Agronomic practices: The experimental area in all the trials was treated with the nematicide Nemacur (a.i. fenamiphos) at a rate of 15 g plant^{-1} (3 treatments year^{-1}) to reduce nematode infestation. Fertilisation was done with muriate of potassium (a.i. K_20, 60 % K) at a rate of 600 g plant^{-1} year^{-1}, and Urea (47% N) at a rate of 300 g plant^{-1} year^{-1}, split over 6 equal applications during the rainy season (*i.e.* March until November). The fungicide Bayfidan (a.i. triadimenol) was applied three times a year at a rate of 3.6 ml plant^{-1} to control the leaf spot disease black sigatoka (*Mycosphaerella fijiensis* Morelet). Plants were irrigated during the dry season at a rate of 100 mm month^{-1}, while weeding was done regularly using a hoe.

Parameters assessed: All plants were completely excavated; aerial, corm and root characteristics were measured for the main plant, the tallest sucker and the other suckers. Plants exhibiting high mat were recorded. The excavation of the complete root system of a mature *Musa* plant started by digging a small trench at about 2 meters from the pseudostem. As roots can reach up to 3 meters, a garden fork was used for careful removal of the soil. A trench was dug a little deeper than the deepest roots, i.e. 50 cm deep, followed by a small cave under the roots. The upper soil layers were then gradually removed with a garden fork or by hand. First a 45° section of the root system was dug out. This facilitated the removal of the root system in the remaining 315° soil area. The excavation was carefully done to avoid breakage of the roots.

Roots were washed on a large sieve to facilitate the removal of all soil particles. Aerial growth data measured on each plant included plant height (PH, cm), pseudostem circumference at soil level (PC, cm), number of leaves (NL) and height of the tallest sucker (HS, cm). In addition, leaf area (LA, cm^2) was calculated according to Obiefuna and Ndubizu (1979). Corm characteristics measured were fresh corm weight (CW, g), corm height (CH, cm) and corm widest width (WW, cm). The number of suckers (NS) on the corm was also counted.

Root characteristics included the number of adventitious roots or cord roots (NR), root dry weight (DR, g) and the average basal diameter of the cord roots (AD, mm) measured with a Vernier Calliper. The cord root length (LR, cm) was measured using the line intersect method (Newman, 1966; Tennant, 1975). Other root system characteristics measured were total root dry weight (TD, g) of the mat (*i.e.* plant crop and suckers) and total cord root length of the mat (TL, cm). Dry weight of plant tissue was obtained by drying for one week in a drying room (40°) and subsequently for two days in an oven (80°).

Statistical Analysis: Data were analysed using the SAS statistical package (SAS, 1989). In experiment 1, the variability of the different growth characteristics was assessed using PROC GLM in SAS. Total phenotypic variance was partitioned according to the following sources of variation: genotype, crop cycle, genotype by crop cycle interaction and sampling time (*i.e.* flower emergence or harvest). In experiment two, the correlation analysis was done, across genotypes, between sucker characteristics and plant crop growth parameters. In contrast, the correlation analysis was carried out within genotype for experiments 3 and 4.

Table 1: Taxonomic, genomic and agronomic characterisation of evaluated genotypes.

Name	Genome	Ploidy level	Type	haviour	Exp 1(IV*)	Exp 2(IV)	Exp 2 (subset)	Exp 3(SD)	Exp 4(IV)
Niyarma Yik	AA	2	*Musa acuminata* ssp. *banksii*	Inhibited		X			
Calcutta 4	AA	2	*Musa acuminata* ssp. *burmannica*	Non-regulated	X	X	X		
Pahang	AA	2	*Musa acuminata* ssp. *malaccensis*	Non-regulated		X			
Pisang J. Buaya	AA	2	*Musa acuminata* ssp. *microcarpa*	Regulated		X			
Pisang Madu	AA	2	*Musa acuminata* ssp. *microcarpa*	Regulated		X			
Tjau Lagada	AA	2	*Musa acuminata* ssp. *microcarpa*	Regulated		X			
Kisubi	AB	2	Dessert banana	Regulated		X			
Pisang Berlin		2	Diploid indeterminate group	Regulated		X			
TMB2x 9128-3	AA x AA	2	Hybrid (Tjau Lagada x Pisang lilin)	Non-regulated		X			
TMB2x 5265-1	AA x AA	2	Hybrid (Tjau Lagada x Calcutta 4)	Non-regulated		X			
TMP2x 1297-3	AAB x AA	2	Plantain hybrid (Agbagba french reversion x Calcutta 4)	Non-regulated		X			
TMP2x 2829-62	AAB x AA	2	Plantain hybrid (Bobby Tannap x Calcutta 4)	Non-regulated				X	
TMP2x 4600-12	AAB x AA	2	Plantain hybrid (Bobby Tannap x Calcutta 4)	Non-regulated				X	
TM3x 15108-6	AAAB x AA	3	Secondary triploid (Bobby Tannap x Calcutta 4) x SH3362	Regulated				X	
Pisang M. Hijau	AAA	3	Dessert banana	Regulated		X			
Yangambi km5	AAA	3	Dessert banana	Non-regulated		X			
Valery	AAA	3	Dessert banana	Regulated	X	X	X		X
Rajapuri India	AAB	3	Dessert banana	Regulated		X			
Obino l'Ewai	AAB	3	Plantain	Inhibited		X		X	X
Bobby Tannap	AAB	3	Plantain	Inhibited		X		X	
Muracho	AAB	3	Starchy banana	Regulated		X			
Mysore	AAB	3	Dessert banana	Regulated		X			
Pisang Awak	ABB	3	Cooking banana	Regulated		X			
Foulah 4	ABB	3	Cooking banana	Regulated		X			
Cardaba	ABB	3	Cooking banana	Regulated		X			
Fougamou	ABB	3	Cooking banana	Regulated		X			
IC 2	AAAA	4	Dessert banana	Regulated		X			
TMPx 1621-1	AAB x AA	4	Plantain hybrid (Obino l' Ewai x Calcutta 4)	Regulated	X	X	X		
TMPx 548-9	AAB x AA	4	Plantain hybrid (Obino l'Ewai x Calcutta 4)	Regulated	X	X	X	X	
TMPx 5511-2	AAB x AA	4	Plantain hybrid (Obino l'Ewai x Calcutta 4)	Inhibited	X	X	X		
TMPx 2796-5	AAB x AA	4	Plantain hybrid (Bobby Tannap x Pisang lilin)	Regulated				X	
TMPx 6930-1	AAB x AA	4	Plantain hybrid (Obino l'Ewai x Calcutta 4)	Regulated				X	

*: IV: *in vitro*-derived plants; SD: sucker-derived plants

RESULTS

Experiment 1: Suckering behaviour influenced the cycle duration. 'Calcutta 4' exhibits a non-regulated suckering (*i.e.* all suckers have unrestricted growth) and the first ratoon crop was harvested only one month after the plant crop (Table 2). In contrast, the tetraploid plantain hybrids exhibit a regulated (*i.e.* 2-3 suckers grow vigorously) or inhibited suckering and the period between two successive harvests was at least eight months, and the cycle duration depends on the size of the competing bunch. In 'Calcutta 4' the bunch is much smaller than in the plantain hybrids.

Some plants were unable to complete the second cycle for the plantain tetraploid hybrids 'TMPx 548-9' and 'TMPx 5511-2' (Table 2), which is attributed to the observed high mat phenomenon which prevents new cord roots to penetrate in the soil. No high mat was observed for 'Calcutta 4' and 'Valery', while a moderate high mat was observed for 'TMPx 1621-1'. There was a significant effect of cycle on leaf area and number, pseudostem circumference, corm weight, plant crop root traits and height of the tallest sucker (Table 3). Most leaves died off during the reproductive stage (Table 4), while the decay of the outer leaf sheaths resulted in a reduction of the pseudostem circumference (Table 4). The corm fresh weight was reduced by 20 and 13 % during the reproductive stage of the first and the second cycle, respectively (Table 4).

Table 2: Days to flowering (DTFL) and to harvest (DTHPC) of the plant crop and days to harvest of the ratoon (DTHR) for 5 genotypes.

Genotype	DTFL	DTHPC	DTHR
Calcutta 4	255±14	395±13	429±7
Valery	429±53	514±56	641±32
TMPx 548-9	408±25	499±30	747±25
TMPx 1621-1	422±10	495±14	774±37
TMPx 5511-2	431±29	499±23	779

Values are Mean ± standard error

In this study, a reduction in cord root number of 8 and 12 % was observed during the reproductive stage in the first and second cycle, respectively (Table 4). Cord root length was however reduced by 40 % during the reproductive phase of both cycles (Table 4).

Corm and roots of the plant crop were still alive during the ratoon growth of the tetraploid plantain hybrids and 'Valery'. 'TMPx 5511-2' plant crop had 51 cord roots with a length of 7.6 m at flowering of the first ratoon crop, while the 'TMPx 1621-1' plant crop had 37 cord roots with a length of 5.7 m at flowering of the first ratoon. In addition, the plant crop of 'Valery' had 23 cord roots with a length of 2.9 m at harvest of the first ratoon crop.

There was a significant effect of crop cycle on the number of suckers and the height of the tallest sucker (Table 3). The number of suckers decreased from 16 to 12, while height of the tallest sucker was 120 cm at flower emergence of the plant crop and 68 cm at flower emergence of the first ratoon (Table 4). There was a reduction in sucker vigour during the reproductive phase of the ratoon crop (Tables 4 & 5). The percentage of sucker root dry weight to the mat in 'TMPx 1621-1' decreased from 58 % at harvest of the plant crop to 25 % at harvest of the first ratoon. The mat root system size at harvest also decreased during the ratoon cycle (Tables 4 & 5). The cord root length of the 'TMPx 1621-1' mat at harvest of the plant crop was 62.5 m, while 25.7m cord root length was observed at harvest of the ratoon crop.

The effect of crop cycle was also significant on the different corm traits and the cord root diameter (Table 3). The corm of the first ratoon plants was bigger and taller than the corm of the plant crop, resulting in a slight increase in number and diameter of cord roots (Table 4). In contrast, cord root length of the first ratoon was inferior to that of the plant crop (Table 4).

Table 3: Mean square and significance tests for different growth characteristics of 5 genotypes.

		Trait#								
Source of variation	df	LA	NL	PH	PC	CW	CH	WW	NS	HS
Genotype	4	273728345	10	26498**	1014*	38187156**	182	180***	72*	6893
Cycle	1	171055579	3	3669	5	20046310*	406*	57***	196*	56821*
Genotype*Cycle	4	644753347*	3	883	156**	1062210	35**	1	10	2751
Sampling time	1	57998584250***	1322***	236	927***	6552360*	1	7	4	16902**
Residual	63	182328055	4	486	30	1036285	7	3	8	1827

Source of variation	df	%suckerDR	%suckerLR	DR	NR	LR	AD	TD	TL
Genotype	4	2421	1473	11691	9666**	3567912	8.0***	87583	183549734*
Cycle	1	988	278	17	1551	8023351	4.5**	29266	91641058
Genotype*Cycle	4	460	291	6588*	538	4953019**	0.1	52916*	11979964
Sampling time	1	2132**	2481***	24212***	5054*	36324990***	0.7	16444	89
Residual	63	208	160	1816	1121	1071197	0.3	18566	18867009

#: LA: leaf area of the mother plant (cm^2), NL: number of leaves of the mother plant, PH: plant height of the mother plant (cm), PC: pseudostem circumference at soil level of the mother plant (cm), CW: corm weight of the mother plant (g), CH: corm height of the mother plant (cm); WW: corm widest width of the mother plant (cm), NS: number of suckers, HS: height of the tallest sucker (cm), %suckerDR: percentage root dry weight of the suckers to the root dry weight of the mat (*i.e.* mother plant and suckers), %suckerLR: percentage cord root length of the suckers to the cord root length of the mat, DR: root dry weight of the mother plant (g), NR: number of cord roots of the mother plant, LR: cord root length of the mother plant (cm), AD: average basal cord root diameter of the mother plant (mm), TD: total root dry weight of the mat (g), TL: total length of the cord roots of the mat (cm); *, **, ***: significant at $P<0.05$, 0.01 and 0.001, respectively

Experiment 2: Very few significant correlations were observed, across different genotypes, between plant crop traits and the height of the tallest sucker during the vegetative stage (Table 6). The number of suckers was positively correlated with height of the tallest sucker at 12 ($p<0.001$), 16 ($p<0.001$) and 20 ($p<0.05$) weeks after planting (Table 6).

A detailed analysis of 5 genotypes at flower emergence revealed that 'Calcutta 4' and 'Valery' had the shortest plant statures (Table 7). They also had lower values for leaf area, corm weight, root dry weight and cord root length. However, 'Calcutta 4' and 'Valery' have the best sucker development in terms of length of the sucker as a percentage of the mother plant height (Table 7). In addition, 'TMPx 5511-2' had a well-developed root system but had the poorest sucker development. 'TMPx 548-9' exhibited poor sucker development but had the best-developed root system in terms of root dry weight and cord root length.

Experiment 3: Positive correlations between plant crop development and sucker growth characteristics were observed for 'Obino l'Ewai' and 'TMPx 548-9' (Table 8). Similar correlation coefficients were observed for the other genotypes (data not shown).

As the sucker development at 20 WAP is still depending on the mother plant, which is visible by the presence of mostly scale or lanceolate leaves, no correlation between the mother plant growth traits and the leaf area of the sucker was found (Table 8).

Experiment 4: Positive correlations were observed between most aerial, corm and root system characteristics at the level of the plant crop, the sucker and the mat (Table 9). In this study, significant positive correlations were also detected between length of the sucker and plant crop growth characteristics for 'Obino l'Ewai' (Table 10). However, no significant correlations were found between length of the sucker on one hand and root dry weight, length of the cord roots and root dry weight of the mat on the other hand for the dessert banana 'Valery' (Table 10).

Table 4: Mean values for plant growth characteristics at flower emergence (FL) and harvest (H) of the plant crop and first ratoon crop for five genotypes.

	Plant crop			First ratoon		
Trait#	FL	H	% *	FL	H	% *
LA	65,801±4,579	8,161±2,368	-88	61,166±3,114	7,025±3,019	-89
NL	10.5±0.5	1.9±0.4	-82	9.9±0.4	1.5±0.5	-85
PH	195±9	196±11	1	215±8	201±13	-7
PC	55±2	47±3	-15	54±2	46±2	-15
CW	3,836±380	3,067±302	-20	4,760±426	4,131±565	-13
CH	24±1	23±1	-4	28±1	28±1	0
WW	16±1	15±1	-6	18±1	17±1	-6
NS	16±1	16±1	0	12±1	13±1	8
HS	120±1	158±12	32	68±11	93±12	37
%suckerDR	50±2	69±4	na	51±4	54±6	na
%suckerLR	49±2	68±3	na	52±4	57±5	na
DR	130±12	111±13	-15	146±13	90±8	-38
NR	134±11	123±7	-8	149±8	131±11	-12
LR	3,778±355	2,268±192	-40	3,003±333	1,841±121	-39
AD	4.9±0.2	5.2±0.2	6	5.5±0.2	5.5±0.2	0
TD	274±28	409±37	49	336±38	260±35	-23
TL	7,699±783	9,677±1,619	26	7,327±1,309	5,665±959	-23

#: LA: leaf area of the mother plant (cm^2), NL: number of leaves of the mother plant, PH: plant height of the mother plant (cm), PC: pseudostem circumference at soil level of the mother plant (cm), CW: corm weight of the mother plant (g), CH: corm height of the mother plant (cm); WW: corm widest width of the mother plant (cm), NS: number of suckers, HS: height of the tallest sucker (cm), %suckerDR: percentage root dry weight of the suckers to the root dry weight of the mat (*i.e.* mother plant and suckers), %suckerLR: percentage cord root length of the suckers to the cord root length of the mat, DR: root dry weight of the mother plant (g), NR: number of cord roots of the mother plant, LR: cord root length of the mother plant (cm), AD: average basal cord root diameter of the mother plant (mm), TD: total root dry weight of the mat (g), TL: total length of the cord roots of the mat (cm); *: percentage difference between harvest and flower emergence; na: non applicable

Discussion

The high mat phenomenon and related loss of plant vigour observed during the second cycle for the tetraploid plantain hybrids is similar to observations made for plantain by Stover (1972) and Swennen (1990). In accordance with our results, Robinson (1996) reported a 15 % reduction in corm dry matter for dessert banana during the reproductive stage and related this to a redistribution of assimilates towards the bunch and the developing suckers. New cord roots are formed continuously until flowering occurs (Beugnon & Champion, 1966; Lavigne, 1987). In accordance with our results, Walmsley and Twyford (1968) found for dessert banana that roots of the plant crop were still functional at harvest, as indicated by the translocation of P^{32} from the mother plant roots to the young suckers. In addition, Lassoudière (1980) stated that roots of a harvested plant crop of the 'Poyo' dessert banana were still alive (and presumably functioning) at harvest of the first ratoon. The plant crop root system may thus contribute to sucker development for at least several months after the plant crop harvest.

This study shows that a reduction occurs in leaf area, corm weight and root system traits during the reproductive stage of both the plant crop and the first ratoon cycle. First ratoon plants were slightly taller than the plant crop, had a bigger corm resulting in a higher number of cord roots. However, cord root length was reduced in the first ratoon crop. In addition, there was a reduction in sucker vigor during the ratoon crop, which may be attributed to the high mat phenomenon and possible soil degradation. This poor sucker growth is likely to negatively influence plant anchorage and stability and demonstrates the limited possibilities of degraded Ultisols for production of consecutive ratoon crops under monocropping conditions with inorganic fertilizer application and no mulch.

The lack of correlations between height of the tallest sucker and plant crop growth characteristics indicates that different genotypes with similar root system development will not necessarily have a similar sucker development. Therefore, root system size, across genotypes, may not be related to sucker growth. 'TMPx 548-9' exhibited poor sucker development contrary to Vuylsteke *et al*. (1993b) who stated that 'TMPx 548-9' develops big suckers. This poor sucker growth could have been due to poor root development, if there is a link between both parameters. However, 'TMPx 548-9' had the best-developed root system in terms of root dry weight and cord root length.

Within genotype, a better growing plant crop will produce faster growing suckers (Table 8). As such, this will favourably contribute to the life span of a field, as already seen in backyards and mulched plantain fields (Swennen *et al*., 1984) where tall suckers are attached to vigorously developing mother plants. Also a better-developed root system of the mother plant will result in a taller sucker with a better-developed root system.

The strong relationships observed between the different parts of an individual *Musa* plant confirm earlier observations on banana (Blomme & Ortiz, 2000) and on other crops (Pearsall, 1927; Broschat, 1998; Fort & Shaw, 1998). Significant positive correlations were most often observed between plant crop and sucker growth characteristics when the analysis was done for a single genotype. Fast-growing plants will thus be associated with better-developed suckers. Fertile soil and agronomic practices, e.g. mulching, that favours root development and aerial growth will enhance subsequent sucker development and will thus shorten the cycle duration and enhance perennial cultivation. However, across genotypes very few significant correlations were found between plant crop and sucker growth characteristics, indicating that breeding for genotypes with a larger root system size will not necessarily lead to a better suckering.

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Table 5: Plant growth characteristics at flower emergence (FL) and harvest (H) of the plant crop and the first ratoon crop for the different genotypes assessed in experiment 1.

		Plant crop		First ratoon	
Genotype	**Trait#**	**FL**	**H**	**FL**	**H**
Calcutta 4	%suckerDR	44±6	90±3	58±9	84±4
	%suckerLR	43±5	88±4	56±9	80±4
	TD	126±19	539±16	439±106	448±16
	TL	5,354±540	21,424±2,058	14,664±4,425	11,560±992
Valery	%suckerDR	53±8	73±3	58±7	61±3
	%suckerLR	56±8	73±2	57±5	61±4
	TD	273±78	437±67	284±43	203±47
	TL	8,263±1,741	7,847±730	5,389±523	4,507±780
TMPx 548-9	%suckerDR	58±3	70±4	62±6	59±10
	%suckerLR	52±4	65±3	63±5	60±7
	TD	377±49	443±102	482±65	307±52
	TL	10,096±1,552	8,109±2,523	8,173±822	4,692±611
TMPx 1621-1	%suckerDR	44±3	58±5	30±10	25±4
	%suckerLR	44±3	60±2	35±9	33±3
	TD	346±47	389±25	213±33	138±12
	TL	9,168±2,571	6,250±482	3,387±598	2,565±237
TMPx 5511-2	%suckerDR	52±4	48±8	43±9	13
	%suckerLR	49±4	48±5	49±7	28
	TD	246±32	178±74	239±84	93
	TL	5,615±1,032	3,111±1,169	4,251±1,375	2,034

#: %suckerDR: percentage root dry weight of the suckers to the root dry weight of the mat (*i.e.* mother plant and suckers), %suckerLR: percentage cord root length of the suckers to the cord root length of the mat, TD: total root dry weight of the mat (g), TL: total length of the cord roots of the mat (cm).

Table 6: Correlation coefficients between height of the tallest sucker and different plant crop growth characteristics during the vegetative stage of 5 genotypes (experiment 2).

	Week After Planting		
Trait#	12	16	20
LA	0.11	0.26	0.18
NL	0.04	0.41*	0.26
PH	0.31	0.30	0.06
PC	-0.29	-0.41*	-0.46*
CW	0.16	-0.10	-0.41*
CH	0.10	-0.07	-0.09
WW	0.18	-0.08	-0.44*
DR	-0.03	0.04	-0.09
NR	0.40*	0.49**	0.16
LR	0.36	0.31	0.08
AD	-0.37	-0.35	-0.38*
TL	0.37	0.47*	0.49*
TD	-0.02	0.14	0.25
NS	0.69***	0.73***	0.48*

#: LA: leaf area of the mother plant (cm^2), NL: number of leaves of the mother plant, PH: plant height of the mother plant (cm), PC: pseudostem circumference at soil level of the mother plant (cm), CW: corm weight of the mother plant (g), CH: corm height of the mother plant (cm); WW: corm widest width of the mother plant (cm), DR: root dry weight of the mother plant (g), NR: number of cord roots of the mother plant, LR: cord root length of the mother plant (cm), AD: average basal cord root diameter of the mother plant (mm), TL: total length of the cord roots of the mat (cm), TD: total root dry weight of the mat (g), NS: number of suckers; *, **, *** Significant at P<0.05, 0.01 and 0.001, respectively.

Table 7: Mean values, least significant difference and CV for the different growth characteristics for sucker, plant crop and mat at flower emergence of the plant crop of 5 genotypes (experiment 2).

	Trait#							
Genotypes	LA	NL	PH	PC	CW	CH	WW	DR
Obino l'Ewai	87,229	11	274	62	6,415	20	23	329
Calcutta 4	50,676	10	163	39	1,159	16	10	142
TMPx 548-9	107,943	15	251	62	5,226	20	22	333
TMPx 5511-2	102,674	16	236	60	4,704	19	21	279
Valery	74,770	9	197	55	3,530	20	17	151
LSD (0.05)	25,666	2	27	8	1,402	3	3	72
CV (%)	31	24	19	18	48	14	28	39
	NR	LR	AD	TL	TD	NS	HS	%HS
Obino l'Ewai	153	5,905	6.3	8,011	418	10	120	44
Calcutta 4	96	3,781	4.2	7,644	323	8	146	89
TMPx 548-9	193	7,948	5.7	11,963	476	9	72	28
TMPx 5511-2	149	7,021	5.9	9,305	353	11	46	19
Valery	154	4,019	5.2	11,730	373	12	114	61
LSD (0.05)	58	2,369	0.7	7,052	181	3	45	25
CV (%)	31	38	15	47	31	23	46	61

#: LA: leaf area of the mother plant (cm^2), NL: number of leaves of the mother plant, PH: plant height of the mother plant (cm), PC: pseudostem circumference at soil level of the mother plant (cm), CW: corm weight of the mother plant (g), CH: corm height of the mother plant (cm); WW: corm widest width of the mother plant (cm), DR: root dry weight of the mother plant (g), NR: number of cord roots of the mother plant, LR: cord root length of the mother plant (cm), AD: average basal cord root diameter of the mother plant (mm), TL: total length of the cord roots of the mat (cm), TD: total root dry weight of the mat (g), NS: number of suckers, HS: height of the tallest sucker (cm), %HS: height of the tallest sucker as percentage of the height of the plant crop.

Table 8: Correlation coefficients between mother plant and sucker growth characteristics for sucker-derived plants of 'TMPx 548-9' and 'Obino l'Ewai' at 20 WAP (Experiment 3).

	Trait# of mother plants								
TMPx 548-9	LA	PH	PC	CW	CH	WW	DR	NR	LR
HS	0.78***	0.42	0.76***	0.69**	0.51*	0.55*	0.63**	0.46	0.55*
NS	0.59*	0.62**	0.63**	0.47	0.60*	0.58*	0.46	0.64**	0.45
LA-sucker	0.57*	0.07	0.52*	0.53*	0.33	0.29	0.43	0.19	0.39
CW-sucker	0.95***	0.71**	0.89***	0.90***	0.73***	0.74***	0.79***	0.73***	0.67**
DR-sucker	0.88***	0.56*	0.82***	0.78***	0.59*	0.56*	0.67**	0.57*	0.56*
NR-sucker	0.78***	0.76***	0.75***	0.63**	0.47	0.57*	0.58*	0.66**	0.43
LR-sucker	0.87***	0.68**	0.82***	0.76***	0.58*	0.60*	0.66**	0.65**	0.56*
Obino l'Ewai									
HS	0.73***	0.76***	0.78***	0.68**	0.74***	0.69***	0.74***	0.78***	0.66**
NS	0.75***	0.69***	0.73***	0.66**	0.78***	0.64**	0.74***	0.78***	0.68**
LA-sucker	0.22	0.29	0.40	0.34	0.41	0.28	0.23	0.33	0.15
CW-sucker	0.83***	0.74***	0.75***	0.86***	0.82***	0.75***	0.84***	0.77***	0.80***
DR-sucker	0.72***	0.64**	0.68**	0.78***	0.79***	0.65**	0.77***	0.70***	0.68**
NR-sucker	0.86***	0.79***	0.79***	0.85***	0.88***	0.78***	0.85***	0.87***	0.76***
LR-sucker	0.78***	0.73***	0.77***	0.81***	0.86***	0.74***	0.84***	0.79***	0.76***

#: LA: leaf area of the mother plant (cm^2), PH: plant height of the mother plant (cm), PC: pseudostem circumference at soil level of the mother plant (cm), CW: corm weight of the mother plant (g), CH: corm height of the mother plant (cm); WW: corm widest width of the mother plant (cm), DR: root dry weight of the mother plant (g), NR: number of cord roots of the mother plant, LR: cord root length of the mother plant (cm), HS: height of the tallest sucker (cm), NS: number of suckers.

Table 9: Correlation coefficients between growth characteristics of, the plant crop, the tallest sucker and the mat for 'Obino l'Ewai' (above the diagonal) and 'Valery' (below the diagonal) (experiment 4).

Plant crop	**LA**	**PH**	**PC**	**CW**	**DR**	**NR**	**LR**
LA		0.83***	0.88***	0.94***	0.60**	0.64**	0.73***
PH	0.79***		0.91***	0.92***	0.71***	0.70***	0.74***
PC	0.78***	0.82***		0.94***	0.62**	0.69***	0.71***
CW	0.74***	0.88***	0.94***		0.64**	0.78***	0.81***
DR	0.57*	0.56*	0.83***	0.79***		0.51*	0.77***
NR	0.80***	0.69**	0.69**	0.67**	0.52*		0.68***
LR	0.56*	0.64**	0.80***	0.81***	0.94***	0.59*	
Tallest sucker							
LA		0.86***	0.87***	0.89***	0.65**	0.58**	0.62**
PH	0.78***		0.98***	0.95***	0.75***	0.62**	0.81***
PC	0.69**	0.97***		0.95***	0.78***	0.68**	0.82***
CW	0.70**	0.90***	0.92***		0.72***	0.69***	0.75***
DR	0.26	0.65**	0.69**	0.66**		0.77***	0.91***
NR	0.59*	0.74***	0.76***	0.76***	0.68**		0.68***
LR	0.42	0.63**	0.66**	0.59*	0.89***	0.63**	
Mat							
LA		na	na	0.94***	0.67**	0.65**	0.77***
PH	na		na	na	Na	na	na
PC	na	na		na	Na	na	na
CW	0.78***	na	na		0.69***	0.78***	0.84***
DR	0.54*	na	na	0.78***		0.59**	0.82***
NR	0.87***	na	na	0.73***	0.59*		0.74***
LR	0.55*	na	na	0.81***	0.95***	0.65**	

#: LA: leaf area of the mother plant (cm^2), PH: plant height of the mother plant (cm), PC: pseudostem circumference at soil level of the mother plant (cm), CW: corm weight of the mother plant (g), DR: root dry weight of the mother plant (g), NR: number of cord roots of the mother plant, LR: cord root length of the mother plant (cm); na: non applicable

Table 10: Correlation coefficients between the height of the tallest sucker and different plant crop and mat characteristics for 'Obino l'Ewai' and 'Valery' (experiment 4).

	Obino l'Ewai	Valery
LA	0.79***	0.71**
NL	0.72***	0.74***
PH	0.77***	0.80***
PC	0.74***	0.63**
CW	0.76***	0.65**
CH	0.71***	0.56*
WW	0.74***	0.67**
DR	0.57**	0.39
NR	0.57**	0.71**
LR	0.70***	0.44
LA-mat	0.79***	0.86***
CW-mat	0.80***	0.72**
DR-mat	0.65**	0.44
NR-mat	0.65**	0.78***
LR-mat	0.77***	0.51*

#: LA: leaf area of the mother plant (cm^2), NL: number of leaves of the mother plant, PH: plant height of the mother plant (cm), PC: pseudostem circumference at soil level of the mother plant (cm), CW: corm weight of the mother plant (g), CH: corm height of the mother plant (cm); WW: corm widest width of the mother plant (cm), DR: root dry weight of the mother plant (g), NR: number of cord roots of the mother plant, LR: cord root length of the mother plant (cm).

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