Estimation of root development from shoot traits in plantain and banana (*Musa* spp.)

G. Blomme, R. Swennen, A. Tenkouano, R. Ortiz and D. Vuylsteke

The root system is the link between the plant and the soil. It is responsible for the absorption of water and nutrients, anchorage, synthesis of some plant hormones and storage (De Langhe *et al.* 1983, Martin Prével 1987, Stover and Simmonds 1987, Lahav and Turner 1989, Price 1995). Root system development and shoot growth are highly related (Pearsall 1927, Broschat 1998, Fort and Shaw 1998). Russell (1977) mentioned that nodal root development in winter wheat and pearl millet could be estimated from the number of leaves. Henderson *et al.* (1983) found that the extent of coarse root branching was very regular for Sitka spruce and could be estimated using the aboveground stem diameter. Smith (1964) reported that root spread of several tree species could be estimated from aboveground measurements. In the case of banana, Swennen (1984), and Blomme and Ortiz (1996) observed positive correlations between root system development and aerial growth characteristics, while Gousseland (1983) estimated the number of cord roots of the 'Giant Cavendish' dessert banana from the leaf area. The objective of this study was to develop a method for estimation of root development from shoot characteristics, across a wide range of *Musa* genotypes.

Materials and methods

This study was carried out at the IITA High Rainfall station at Onne in southeastern Nigeria. 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 2400 mm distributed monomodally from February to November. Details of the site were described by Ortiz *et al.* (1997). Twenty-seven genotypes representing the various *Musa* genomic and ploidy groups were assessed in this study. The planting material was obtained through meristem culture using the methods of Vuylsteke

Table 1. Correlation coefficients (P<0.05) between aerial growth and root system characteristics at 20 WAP (weeks after planting)

Trait	LA	PH	PC	LS
DR	0.72***	0.65***	0.65***	-0.09
NR	0.46*	0.41*	0.29	0.16
LR	0.64***	0.54**	0.46*	0.08
AD	0.47*	0.51**	0.70***	-0.38*
TL	0.41*	0.25	0.01	0.49*
TD	0.65***	0.53**	0.38	0.25

LA: leaf area (cm^2), PH: height of the plant (cm), PC: plant circumference (cm), LS: length of the tallest sucker (cm), DR: root dry weight (g), NR: number of cord roots, LR: cord root length (cm), AD: average diameter at the base of the cord roots (mm), TL: total length of the cord roots of the mat (cm), TD: total dry weight of the roots of the mat (g).

*, **, *** Significant at P<0.05, 0.01 and 0.001, respectively.

Table 2. Regression models to predict root system characteristics at 20 WAP using aerial growth characteristics and ploidy level as independent variables.

	Trait				
Trait	**LA^**	**PC**	**LS**	**PL**	**R^2**
B+z10>DR	0.001628***	0.596934**			0.93
NR	0.001459***	1.255633***			0.93
LR	0.066704***	23.476717**			0.94
AD		0.093835***		0.681434***	0.97
TL	0.099478***		14.69139***		0.92
TD	0.002066***	0.426590	0.171415*		0.93

for abbreviations see Table 1; PL: ploidy level.

^: independent variables.

*, **, *** Significant at P<0.05, 0.01 and 0.001, respectively.

(1989, 1998). The plantlets were acclimatized for six weeks in a greenhouse nursery (Vuylsteke and Talengera 1998, Vuylsteke 1998), prior to transplantation in the field in June 1996. The experimental layout was a randomized complete block design with two replications of two plants per genotype.

The trial sites, which had been under grass fallow for eight years, were manually prepared with minimum soil disturbance. Planting was done using a spacing of 2 m x 2 m to avoid overlapping of adjacent root systems. The experimental area was treated with the nematicide Nemacur (a.i. fenamiphos) at a rate of 15 g per plant (three treatments $year^{-1}$) to reduce the nematode infestation. Plants were fertilized at 300 N and 450 K ($kg \cdot ha^{-1} \cdot year^{-1}$) split over six equal applications during the rainy season (i.e. February-November). The fungicide Bayfidan (a.i. triadimenol) was applied three times per year at a rate of 3.6 ml per plant to control the leaf spot disease black Sigatoka (*Mycosphaerella fijiensis* Morelet).

Shoot and root traits were assessed during the mid-vegetative growth (i.e. 20 week-old plants). Shoot growth characteristics included plant height (PH, cm), circumference of the pseudostem at soil level (PC, cm) and leaf area (LA, cm^2). Leaf length and leaf widest width were measured and LA was calculated according to Obiefuna and Ndubizu (1979). In addition, length of the tallest sucker (LS, cm) was measured. The root system was completely dug out and number of adventitious roots or cord roots (NR), average diameter at the base of the cord roots (AD, mm), dry weight of the roots (DR, g), length of the cord roots (LR, cm), total dry weight of the whole mat (i.e. plant crop and suckers) root system (TD, g) and total length of the cord roots of the whole mat (TL, cm) were measured. The average diameter of the cord roots was measured with a Vernier calliper, while the length of the cord roots was estimated according to the method of Newman (1966) and Tennant (1975).

Statistical analysis was carried out on the data set comprising 27 genotypes, using the SAS statistical package (SAS 1989). Relationships between aerial growth and root system characteristics were evaluated using correlation analysis. In addition, multiple regression analysis using stepwise selection was carried out. The dependent variables, i.e. the root system characteristics, were regressed on shoot growth characteristics and ploidy level (PL). Both correlation and regression analysis were carried out on 27 genotypes.

Results and discussion

Significant correlations between aerial growth and root system characteristics were found during the vegetative development (Table 1) and confirmed earlier reports (Beugnon and Champion 1966, Gousseland 1983, Swennen 1984, Lavigne 1987, Blomme and Ortiz 1996).

Regression analysis produced several equations, which attributed at least 90% of the variation in root growth to variation in shoot development. The best shoot indicators of root growth were leaf area, pseudostem circumference and length of the tallest sucker (Table 2).

These models suggest that reduced leaf area, as may be caused by black Sigatoka, will adversely affect root development. Conversely, increased leaf area as a result of fertilizer application would stimulate root development. The pseudostem is made up of leaf sheathes and hence reflects the number of leaves and plant vigour. Plant pseudostem circumference will thus reflect shoot growth and is an important determinant of root vigour in the regression models. The size of the tallest sucker contributed positively to the extent of the mat root system. Most suckers observed on 20 week-old plants were peepers (i.e. small sucker with scale leaves) or sword suckers (i.e. larger sucker with lanceolate leaves). These suckers had their own root system, confirming observations by Robin and Champion (1962) and Beugnon and Champion (1966) who reported that sword suckers of the dessert banana 'Poyo' had a well-developed root system. The observed positive effect of ploidy on cord root diameter confirms earlier observations by Monnet and Charpentier (1965).

Shoot to root ratios depend on the developmental stage of a plant (Brouwer 1966). In the case of banana, Gousseland (1983) estimated banana cord root number from leaf area and reported an effect of plant developmental phase on the accuracy of the regression model. The author reported an underestimation of the number of cord roots during the early vegetative phase. Hence, regression models will have to be fine-tuned according to the developmental phase of a plant.

In addition, shoot-root ratios are highly influenced by environmental conditions (Brouwer and De Wit 1969, Squire 1993, Martinez Garnica 1997, McMichael and Burke 1998). Therefore, fine-tuning of these models is needed when growing plants under different environmental conditions.

This study shows that *Musa* root system development can be estimated from shoot growth characteristics. This provides a means of relating above-ground development to root growth, which may prove useful for non-destructive assessment of root development.

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G. Blomme*, A. Tenkouano and **R. Ortiz** work at the Crop Improvement Division, International Institute of Tropical Agriculture (IITA), c/o L.W. Lambourn & Co., Carolyn House, 26 Dingwall Road, Croydon CR9 3EE, United Kingdom. *Guy Blomme is currently working in Kampala, Uganda as the INIBAP Assistant Regional Coordinator for East and Southern Africa. **R. Swennen** works at the Laboratory of Tropical Crop Improvement, K.U. Leuven, Kasteelpark Arenberg 13, 3001 Leuven, Belgium. **D. Vuylsteke** (IITA) died in a tragic air flight accident on 30 January 2000.