FUNCTIONAL RELATIONSHIP BETWEEN SUGARCANE ROOT BIOMASS AND LENGTH FOR CROPPING SYSTEM APPLICATIONS

By

J.L. CHOPART[1], M.C.B. AZEVEDO[2], L. LE MÉZO[1] and D. MARION[1]

[1]*Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), France*
[2]*Instituto Agronômico do Paraná (IAPAR), Brazil*
chopart@cirad.fr

KEYWORDS: Specific Root Length, Root Length Density, Root Model, Réunion, Côte d'Ivoire.

Abstract

Sugarcane root length density (RLD, m/m^3) and root biomass are key characteristics for respectively determining: (i) the crop nutrient and water uptake capacity, and (ii) carbon partitioning in plants and balance in soil. In previous studies, often only one of these parameters was measured. It is therefore useful to link the RLD and root biomass density (RBD, g/m^3) to evaluate one parameter in relation to the other. Relationships between RLD and RBD and specific root length (SRL, m/g) were studied in Côte d'Ivoire and Réunion. Mean SRLs of fine roots were independent of the root location in the soil profile and plant age but higher in Côte d'Ivoire (68 m/g, SD = 19) than in Réunion (35 m/g, SD = 10). The best fit between the RBD and RLD of thick roots was a power function (RLD = 21.3 RBD∗0.745; R^2 = 0.85). Mean SRL was 7 m/g. When all roots were studied together, the best fit between RBD and RLD was also a power function, with little variation between the two sites or between plant and ratoon sugarcane. The fits calculated with all data except those obtained very close to the plant stem were: RLD = 85.5 RBD∗0.742 (R^2 = 0.88) and mean SRL = 27 m/g (SD =13). Relationships between root length and biomass were neither fixed nor fully random. Due to SRL variability, it was hard to pinpoint any mechanistic links between root length and biomass. Conversely, for simple field evaluations, a rough and ready RLD estimate can be made on the basis of RBD, and vice-versa.

Introduction

Sugarcane root length density (RLD) and root biomass are key characteristics for respectively determining: (i) the crop nutrient and water uptake capacity, and (ii) carbon partitioning in plants and balance in soil. In previous studies, often only one of these parameters was measured, depending on the study objectives and methods used.

Root biomass cannot be evaluated directly with minirhizotron methods (Box, 1996) or different trench profile techniques (Böhm, 1976; Vepraskas, 1988; Chopart, 1999; Chopart *et al.*, 2008) that are focused on RLD evaluation. On the other hand, conventional methods involving soil cores and monoliths (Lee, 1927), in which roots are removed from soil, can be used to measure dry weight easily, whereas RLD measurement is a substantially longer operation that is seldom performed for want of time.

Several sugarcane crop models such as CANEGRO (Inman-Bamber, 1991) or APSIM (McCown *et al.*, 1996) used to model root biomass production require a link between the root biomass density (RBD) and RLD. However, little is currently known about the relationship between root weight and length or evaluation of the specific root length (SRL, in m/g). Initial studies on sugarcane indicated that SRL ranged from 6 to 23 m/g, with a mean of around 18 m/g in Brazil

(Ball-Coello *et al.*, 1992). Other authors (van Antwerpen *et al.*, 1993) obtained substantially lower values in South Africa: around 3 to 5 m/g for plant sugarcane aged 50–180 days after planting (DAP).

This study was carried out to gain further insight into the relationship between root weight and length in plant and ratoon sugarcane, for both fine and thick roots, while focusing only on identifying simple and functional relationships without any deterministic motives. To our knowledge, this is the first root type-based study that has been carried out on sugarcane crops grown in commercial plantation conditions.

Material and methods

Experimental design, environments and treatments

The studies were carried out at two sites: Côte d'Ivoire (Africa) and Réunion (Indian Ocean). The experimental site in Côte d'Ivoire was located at Bouaké (7°40N, 5°5W, 350 m elevation) in a deep (> 2 m) sandy clay oxisol with high coarse element (> 2 mm) contents ranging from 25% in surface horizons to 50% below 1 m. In Réunion, the experimental site was located at Saint-Pierre in the southern part of the island (21°S, 55°E, 250 m elevation) in a deep (over 5 m) clayey cambisol without any coarse elements.

The climate was tropical at both sites. Rainfall (with supplementary irrigation) was sufficient for normal plant growth, especially deep root growth. Varieties under study, namely NCo376 in Côte d'Ivoire and R570 in Réunion, were representative of sugarcane varieties grown by farmers. Conventional cropping systems (tillage, fertilisation, 1.5 m inter-row spacing) were used.

In Côte d'Ivoire, the study was focused on plant sugarcane at two dates (45 and 113 DAP), with measurement depths up to the root front (0.4 m and 1.1 m at 45 and 113 DAP, respectively). In Réunion, the study was undertaken on both plant sugarcane (four replicates, maximum measurement depth 0.8 m) and ratoon crops (eight replicates, maximum measurement depth 1.2 m).

In Réunion, roots were sampled in the soil using the soil core technique with 251 cm^3 metal cylinders. In Côte d'Ivoire, the monolith method used was very similar to the soil core method, but with larger sample volumes (0.2 × 0.2 × 0.25 m) and no replication. At both sites, samples were obtained at three horizontal distances along the sugarcane row: 0–0.25 m, 0.25–0.50 m and 0.5–0.75 m and at several depths, in 0.2 m steps in Côte d'Ivoire and 0.1 m steps in Réunion. Roots were separated from the soil by sieving (1 mm mesh).

Non-root organic fragments were carefully removed. Roots were separated into two sub-samples: fine and thick. We decided to set the diameter boundary at 1 mm because our non quantitative observations suggest that shoot-born roots have a diameter > 1mm and most other lateral roots have a diameter <1 mm. Separation (handmade and with a blade) between the two types of roots was made by visual evaluation. A few fine roots could not be entirely separated from thick roots, but the effect on the specific root length of thick roots samples remained very low. Roots were dried (60°C; 24 h) and weighed separately. Their respective lengths were evaluated using the intersection method (Newman, 1966) modified by Tennant (1975).

Analysis

Relationships between RBD and RLD were investigated by regression analysis of samples distributed throughout the soil profile at various vertical and horizontal distances. All sample SRLs were analysed (mean and standard deviation). We tried to establish links between root sample SRL variability and parameters that are easy to recognise in the field, especially their location in the profile: depth or distance from the stem base (DP).

DP is the diagonal between the depth and horizontal distance. The initial analysis revealed that roots located immediately under the stem or row had a very high RBD, often—but not always—with a high proportion of thick roots. Roots located immediately under the sugarcane row between 0 and 0.2 m depth and 0.25 m on each side of the row were thus analysed separately. It was specified when the results concerned roots close to the stem base, otherwise the roots were located elsewhere. Some samples contained no thick or fine roots, which accounts for the differences noted between the number of pooled root samples and samples with thick and fine roots separated.

Results

Fine root sample analyses (< 1 mm diameter)

In Réunion, linear regressions were obtained between the fine root weight and length for plant and ratoon sugarcane at 113 DAP (Figure 1A, Tables 1 and 2). The SRL did not depend on the sample location in the soil. The SRL determined for plant and ratoon sugarcane roots was 35 m/g (Table 2). Between-sample SRL variability seemed random. In Côte d'Ivoire, the fine root SRL was higher than in Réunion (Table 2).

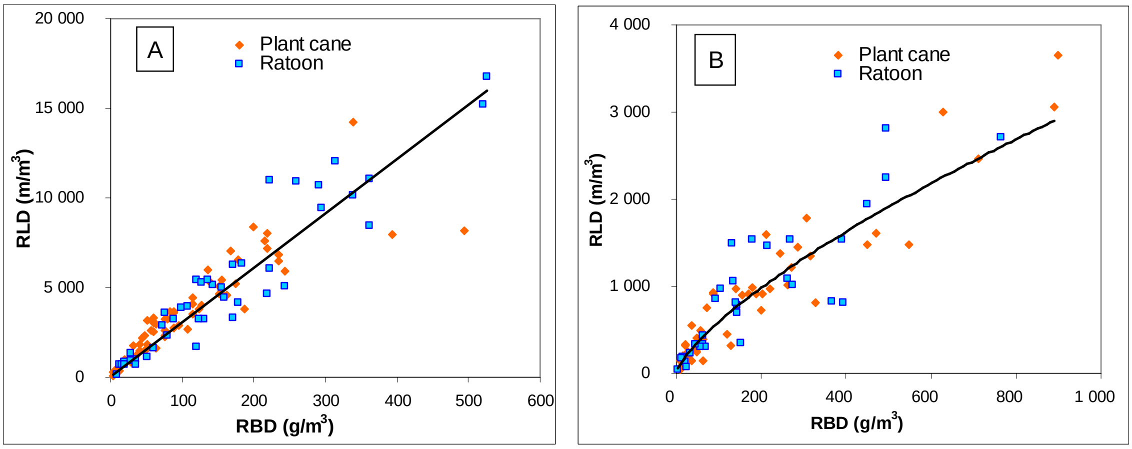

Fig. 1—Relationships between the root biomass density (RBD) and root length density (RLD) at the Réunion site with plant sugarcane and ratoon crop. A: fine roots (Ø <1 mm). B: thick roots (Ø >1 mm).

Table 1—Features of linear regressions between the root biomass density (g/m^3) and root length density (m/m^3) in Réunion. Regressions were arbitrarily given an intercept of 0.

	Cycle	Number of samples	Slope	R^2
Fine roots	Plant cane	64	29.4	0.72
	Ratoon cane	44	31.3	0.65
	Plant & ratoon cane	108	30.5	0.83
Thick roots	Plant cane	43	4.0	0.83
	Ratoon cane	31	4.1	0.77
	Plant & ratoon cane	74	4.1	0.78

Table 2—Specific root length (m/g) of roots in Réunion, Côte d'Ivoire and both sites together. (SD: standard deviation).

Specific root length				
	Sites	Number of samples	Mean	SD
Fine roots	Réunion	108	35.4	10.1
	Côte d'Ivoire	26	68.1	18.8
	All	134	41.7	17.8
Thick roots	Réunion	74	6.9	3.7
	Côte d'Ivoire	28	7.0	3.7
	All	102	7.0	3.7
All roots	Réunion	108	27.1	13.0
	Côte d'Ivoire	28	26.7	13.3
	All	136	27.0	13.0

Thick roots

In Réunion, relationships between the thick root weight and length in plant and ratoon sugarcane were a power function (Figure 1B and Eq. 1):

$RLD = 21.3\ RBD^{0.724}$ $R^2 = 0.85$ n = 74 (1a)

$RBD = 0.0482\ RLD^{1.2}$ $R^2 = 0.85$ n = 74 (1b)

SRL was therefore not fixed. According to the equation (Eq. 1), it ranged from 9.3 to 2.6 m/g when the RBD ranged from 20 to 2 000 g/m^3. However, for simple estimates, a linear relationship could be assumed between the root weight and length. The mean SRL obtained from the pooled SRLs was thus 7 m/g, but with a high standard deviation of 3.7 (Table 2).

All roots (thick and fine)

Relationships between root weight and length in plant sugarcane and ratoon crops in Réunion (Figure 2) showed that: (i) the plant sugarcane and ratoon crop results were very close, (ii) in both cases, the best fit was a power function (Eq. 2). This equation was used to evaluate the root length according to weight, and the symmetrical equation was used to determine the RBD on the basis if the RLD:

$RLD = 85.5\ RBD^{0.742}$ $R^2 = 0.88$ n = 108 (2a)

$RBD = 0.0097\ RLD^{1.18}$ $R^2 = 0.88$ n = 108 (2b)

The nonlinearity of the relationship between RLD and RBD could have been partly due to a slight increase in SRL as the distance to the stem base increased. However, even when data obtained close to the root front were eliminated (very low RLD, under 80 cm for plant sugarcane), the relationship between the SRL (m/g) and the distance to the plant (DP, m) was not very close (SRL = 0.19 DP + 14; $R^2 = 0.11$; n = 118), indicating that DP was not the only SRL variation factor in the soil profile. However, this relationship could be used to take this slight influence of distance to the stem base into account when evaluating the SRL of pooled root samples.

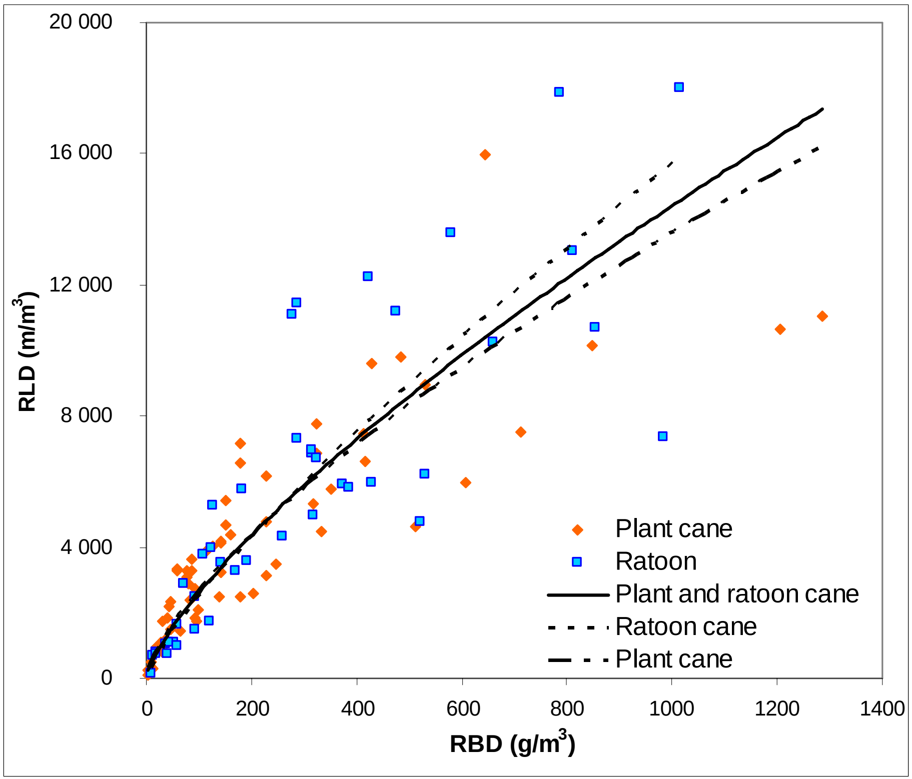

Fig. 2—Relationship between the root biomass density (RBD) and root length density (RLD) in plant sugarcane and ratoon sugarcane with all samples pooled from both sites (Côte d'Ivoire and Réunion).

Relationships determined between the root weight and volume in Côte d'Ivoire plant sugarcane were very close to those obtained in Réunion (data not shown). Côte d'Ivoire and Réunion SRLs were therefore pooled. SRLs were relatively stable at various root depths (Table 3), with a slight increase between 0.4 and 0.8 m depths, then a slight decrease from 1 m depth. For roots located less than 0.25 m below the stem base, the mean SRL calculated from the pooled SRLs was 16 m/g (SD = 6). It was 27 m/g for all other samples (Table 2).

Table 3—Mean specific root length (g/m^3) at various soil depths for both sites (Réunion and Côte d'Ivoire) pooled. (SD = standard deviation).

Depth	SRL (m/g)	SD
0–20 cm	25.2	12.2
20–40 cm	26.7	13.0
40–80 cm	29.8	13.0
80–120 cm	24.1	14.0

Discussion

The root system located less than 0.25 m vertically and horizontally under the stem base had a high but variable proportion of thick roots. SRLs in this area were clearly lower than those in other parts of the soil profile (approx. 16 m/g). These roots located under the stem base are not discussed hereafter. In Réunion, as in Côte d'Ivoire, fine root (Ø < 1 mm) SRL variability was not associated with easy-to-characterise explanatory factors such as depth, distance to the plant, crop age, etc., so this parameter seemed random.

A single SRL value was thus selected for this first stage of the analysis. SRL was clearly higher in Côte d'Ivoire than in Réunion. This difference was unexplained. It may have been due to factors related to the varieties or soils, which differed markedly: in Côte d'Ivoire, for instance, there was a substantial proportion of coarse elements of a few millimetres in diameter in the soil.

For thick roots, both in Côte d'Ivoire and in Réunion, the SRL increased with the distance from the plant—at least in the area between the row and 1.2 m away, i.e. increasing from under 3 m/g to approximately 9 m/g at 1 m depth. This was correlated with the larger root diameters near the stem base and with the presence of finer rank 2 roots in deep horizons. The root weight and length were linked by a power function.

For a simple evaluation, it was also possible to select a single value of 7 m/g for SRL of thick roots. A power function was also established between the root weight and length in the pooled root samples (all, thick and fine roots). However, the relationship was not very useful for predictions as the ratio between thick and fine roots could be variable.

To evaluate the root length on the basis of the root sample weight or vice-versa, it would be advisable to separate roots according to diameter. The root classification used in this study only very partially represents the sugarcane root system complexity, and the 1 mm limit between the two classes may seem arbitrary.

However, simplification was necessary to be able to take SRL differences in relation to measured root diameters into account and to be able to use SRL in crop models. The SRL of roots located immediately under the sugarcane stem and less than 25 cm from the stem core should also be assessed separately.

Some authors suggest values of 3–5 m/g (van Antwerpen *et al.*, 1993) based on pot studies, while others report a very broad range of values, i.e. 6 to 26 m/g (Ball-Coello *et al.*, 1992). The SRLs obtained were higher than those suggested by these authors. This difference could be due to environmental and genetic factors. It could also be due to the method used to calculate the mean

SRL based on a dataset containing highly variable RLD or RBD values, with an asymmetrical distribution. In this study, we decided to calculate the mean of SRLs, not the SRL from the mean length and the mean weight.

Conclusion

It seemed that the thick root SRL results obtained in Côte d'Ivoire and Réunion could be applicable in a broad range of conditions. However, the fine root SRLs obtained at both sites seemed to depend on the variety, physical environment or even genotype x environment interactions. It would be interesting to gain greater insight into the factors responsible for this variability. The fine root SRLs depended relatively little on the crop age and root location in the profile, which should facilitate future studies. The results obtained at both sites are not mechanistically representative of SRLs under all conditions, but they should be helpful for making rough and ready RLD estimations on the basis of RBD and vice-versa. They should also be useful for establishing better correlations and for modelling two agronomically and ecophysiologically important root functions: water and mineral uptake, and the carbon sink/source that the root system represents in the soil/crop system.

REFERENCES

Ball-Coello, B., Sampaio, E.V.S.B., Tiessen, H. and Steward, JWB. (1992). Root dynamics in plant and ratoon crops of sugarcane. Plant Soil, 142: 297–305.

Böhm, W. (1976). *In situ* estimation of root length at natural soil profiles. J. Agric. Camb. 87: 365–368.

Box, J.E. (1996). Modern methods for root investigations. In: Waisel *et al.* (ed.) Plant Roots the Hidden Half Dekker YM, New York, USA, 193–237.

Chopart, J.L., Rodrigues, S.R., Azevedo, M. and Medina, C. (2008). Estimating sugarcane root length density through root mapping and orientation modelling. Plant Soil, 313: 101–112.

Chopart, J.L. (1999). Relations entre état physique du sol systèmes racinaires et fonctionnement hydrique du peuplement végétal: Outils d'analyse in situ et exemples d'études en milieu tropical à risque climatique élevé. (Relationships between soil physical conditions, root systems and crop water uptake. In situ tools and examples of results in high climatic risk tropical areas. PhD Thesis, Univ. Grenoble, France, 115 p.

Inman-Bamber, N.G. (1991). A growth model for sugarcane based on a simple carbon balance and the CERES-Maize water balance. S. Afr. J. Plant Soil, 8, 2: 93–99.

Lee, H.A. (1927). The Method of Measuring Extent of Roots in the Soil. Rep. Hawaii Sug. Tech, 6: 56–59.

McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P. and Freebairn, D.M. (1996). APSIM: A novel software system for model development, model testing, and simulation in agricultural systems research. Agric. Syst., 50: 255–271.

Newman, E.I. (1966). A method of estimating the total length of roots in a sample. J. App. Ecol., 3: 139–145.

Tennant, D. (1975) A test of a modified line intersect method of estimating root length. J. Ecol., 63: 955–1001.

Vepraskas, M.J. and Hoyot, G.D. (1988). Comparison of the trench-profile and core methods for evaluating root distribution in tillage studies. Agronomy J., 80: 166–172.

van Antwerpen, R., Meyer J.H. and Inmam-Bamber, N.G (1993). Proc. S. Afr. Sug. Technol. Ass.: 73–77.

RELATION FONCTIONNELLE ENTRE LA BIOMASSE ET LA LONGUEUR RACINAIRE DE LA CANNE A SUCRE POUR DES APPLICATIONS A L'ETUDE DES SYSTEMES DE CULTURE

Par

J.L. CHOPART[1], M.C.B. AZEVEDO[2], L. LE MÉZO[1] et D. MARION[1]

[1]*Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), France*

[2]*Instituto Agronômico do Paraná (IAPAR), Brazil*

chopart@cirad.fr

MOTS CLES: Longueur Massique Racinaire, Longueur Racinaire Volumique, Modèle Racinaire, Réunion, Côte d'Ivoire.

Résumé

LA LONGUEUR (RLD m/m^3) et la biomasse racinaires sont des paramètres clés pour déterminer respectivement : (i) les capacités d'alimentation hydrique et minérale, et (ii) la partition du carbone dans les plantes et le bilan de carbone dans le sol. Dans des études précédentes, très souvent, un seul de ces deux paramètres était mesuré. Il est donc utile de relier la RLD et la densité de biomasse racinaire (RBD) pour évaluer l'un des paramètres à partir du second. Des relations entre RLD et RBD et donc les longueurs massiques des racines (SRL) ont été étudiées en Côte d'Ivoire et à la Réunion. Les SRLs moyennes des racines fines n'étaient pas dépendantes de la localisation dans le profil et de l'âge de la culture, mais plus élevées en Côte d'Ivoire (68m/g, SD = 19) qu'à la Réunion (35 m/g, SD = 10). Le meilleur ajustement entre la RBD et la RLD des grosses racines a été une fonction puissance (RLD = 21.3 RBD∗0.745; R^2 = 0.85), avec une SRL moyenne de 7m/g. En étudiant toutes les racines ensemble, le meilleur ajustement est aussi une fonction puissance, avec peu de différence entre les deux sites et entre des cannes à sucre vierge ou en repousse. L'ajustement calculé avec toutes les données, sauf celles situées très près du pied, a été: RLD = 85.5 RBD∗0.742 (R^2 = 0.88). En moyenne, la SRL = 27 m/g (SD=13). Les relations entre longueurs et poids racinaires n'ont été ni fixes ni complètement aléatoires. A cause de la variabilité de la SRL, il est difficile d'établir un lien mécaniste entre poids et longueur racinaire. Toutefois, pour des évaluations agronomiques simples, la RLD peut être estimée grossièrement sur la base de la RBD et vice versa.

RELACION FUNCIONAL ENTRE BIOMASA Y LONGITUD DE RAICES PARA APLICACIONES EN EL SISTEMA DE CULTIVO DE LA CAÑA DE AZUCAR

Por

J.L. CHOPART[1], M.C.B. AZEVEDO[2], L. LE MÉZO[1] y D. MARION[1]

[1]*Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), France*

[2]*Instituto Agronômico do Paraná (IAPAR), Brazil*

chopart@cirad.fr

PALABRAS CLAVE: Longitud específica de raíces, Densidad de longitud de raíces, Modelo de raíces, Réunion, Costa de Marfil.

Resumen

LA DENSIDAD de longitud de raíces (RLD, m/m^3) de la caña de azúcar y la biomasa de la raíz son características claves para determinar respectivamente: (i) la capacidad de la absorción de nutrimentos y agua del cultivo, y (ii) el particionamiento de carbono en las plantas y su balance en el suelo. En estudios anteriores, a menudo solamente uno de estos parámetros fue medido. Por lo tanto es muy útil ligar la RLD y la densidad de biomasa de raíces (RBD, g/m^3) para evaluar cada parámetro y su relación con el otro. Las relaciones entre RLD y RBD y longitud específica de raíz (SRL, m/g) fueron estudiadas en Costa de Marfil y Réunion. Las SRL’s de raíces finas fueron independientes de la localización de las raíces en el perfil de suelo y de la edad de planta pero mayores en Costa de Marfil (68 m/g, SD = 19) que en Réunion (35 m/g, SD = 10). El mejor ajuste entre RBD y RLD de raíces gruesas se logró con una función de potencia (RLD = 21.3 RBD* 0.745; $R^2 = 0.85$). La SRL promedio fue de 7 m/g. Cuando todas las raíces fueron estudiadas juntas, el mejor ajuste entre RBD y RLD fue también una función de potencia, con poca variación entre los dos sitios o entre plantilla y soca. Los ajustes calculados con todos los datos excepto aquellos obtenidos cerca de los tallos de las plantas fueron: RLD = 85.5 RBD∗0.742 ($R^2 = 0.88$) y el promedio de SLR = 27 m/g (SD=13). Las relaciones entre la longitud de la raíz y la biomasa no fueron fijas ni completamente aleatorias. Debido a la variabilidad de la SRL, fue difícil establecer claramente alguna relación entre longitud de raíces y biomasa. Por el contrario, para realizar evaluaciones simples en campo, se puede hacer una estimación aproximada y rápida de la RLD con base en la RBD, y viceversa.