Original research article

Is maize root growth affected by pig slurry application on a tropical acid soil?

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Abstract: The effects of field application of liquid pig (*Sus scrofa*) slurry (*PS*) on the root system of maize (*Zea mays* L.) were assessed during two successive cropping seasons in a tropical environment. Root development was monitored on a plot treated with pig slurry, corresponding to a total nitrogen input of 265 kg N ha^{-1} the first year and 185 kg N ha^{-1} the second year, in comparison to that recorded in an unfertilized control plot (*C* plot). In both treatments, the root system was determined at four phenological stages by the trench-profile method and using a model that calculates root length density from counts of numbers of living roots. The results showed that *PS* had a positive effect on maize aboveground biomass until harvest. Its effect on root development was very positive during the first third of the cycle (+130% for the root length density), but this beneficial impact quickly vanished. At the grain maturation stage, the root length was 18% lower on the *PS* plot as compared to the *C* plot, despite the much higher shoot biomass (+50%). It was concluded that one factor began having an adverse effect on root growth in the surface soil layer during the maize growth cycle. This factor was not fully identified, but several elements suggest that it involved soil acidification associated with the nitrification of ammonium nitrogen in *PS* in this already relatively acid soil. This could lead to a rhizotoxicity problem.

Keywords: pig slurry effect, Réunion Island, root length density, root profile, trench-profile method

Abbreviations: *a*: factor to calculate *RD* from *RLD*, β: fitting parameter (m^{-1}), *C*: control treatment, *CE*: experimental coefficient, CO_t: geometric coefficient to calculate *RLD* (m m^{-2}) from NI_t (root impacts per m^2), *DAS*: days after sowing, *DM*: total dry matter of pig slurry (kg kg^{-1} of fresh matter), *DR*: relative distance of a sampling location from the maize stem base, D_H: horizontal distance of a root impact count from the maize stem base (cm), D_V: vertical distance of a root impact count from the maize stem base (m), D_{Hf} and D_{Vf}: horizontal and vertical distance of the rooting front from the stem base (m), D_{max}: distance of the rooting front from the stem base (m), *LAI*: leaf area index, *N*: number of observations, N_{ef}: Nash coefficient efficiency, *NI*: number of root impacts per m^2, *PS*: pig slurry treatment, *RD*: mean distance between roots (m), *RLD*: root length density (m m^{-3}), RLD_0: fitting parameter (m m^{-3}), *RMSE*: root mean square error, *SD*: standard deviation, *SDD*: sum of degree–days (°C), *TSB*: total dry shoot biomass (kg m^{-2}), $<T_d>$: mean daily air temperature (°C) at day *d*, T_{min}: base temperature, *TRL*: total root length (m m^{-2}).

Introduction

Farmers are applying livestock dejections on their fields to an increasing extent to complement or as an alternative to chemical fertilizers. This reduces fertilization costs and enables them to recycle intensive livestock production waste. Livestock waste slurry, like mineral nitrogen fertilizer, generally boosts crop yields (Brechin and Mc Donald 1994, Cameron et al. 1995, Petersen 1996, Zebarth et al. 1996, Jensen et al. 2000, Dauden and Quilez 2004), but there is a risk of nitrate leaching under the crop rooting zone when the application doses and conditions are ill-adapted (Nielsen and Jensen 1990, Cameron et al. 1995, Beckwith et al. 2002, Harter et al. 2002, Sanchez-Perez et al. 2003, Thomsen 2005, Mantovi et al. 2006).

Assessments of the impact of nitrogen on *in situ*

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root growth in crops have, however, not been the focus of as many studies. Most previous reports highlighted the positive effects associated with enhanced aboveground biomass development (Anderson 1987) whereas a mineral nitrogen application can have much weaker effects on the root system (Mackie-Dawson et al. 1998). A nitrogen deficit may even stall aboveground biomass growth while increasing root growth (Mardanov et al. 1998). In addition, under tropical conditions, studies have shown that nitrogen has a complex effect on maize roots. For instance: (i) mineral nitrogen fertilizer application has no effect, or may just slightly increase, the shoot/root ratio (Lafitte and Edmeades 1994); (ii) at high dosage (120 kg/ha), it induces a reduction in root growth as compared to results obtained with a moderate dose of 30 kg/ha (Oikeh et al. 1999); (iii) when the maize crop is fertilizer banded, the root density is increased in the banded zone, but the total root length is unchanged (Kaspar et al. 1991).

The effects of pig slurry (*PS*) applications on root systems have not been the focus of much research, especially under tropical climatic conditions. It is actually the depth and spatial distribution of the root system that determines the proportion of soilborne nitrogen that can be utilized by the crop (thus environment-friendly) and that cannot (thus potentially polluting groundwater resources). The depth of the soil layer colonized by roots should therefore be considered when making decisions on slurry amounts to apply. Moreover, most macroscopic mechanistic models that simulate water and nitrate dynamics in cropped soils (Feddes et al. 1978, Prasad 1988, Jarvis 1989, Bergström et al. 1991, Vanclooster et al. 1994, Ducheyne et al. 2001) contain a spatially distributed sink term so that root uptake of these elements can be taken into account. Although very author-dependent, formulation of this term requires relatively detailed data on the root geometrical characteristics.

The effects of *PS*-borne nitrogen input could be as complex as the impact of mineral nitrogen fertilizer. *PS* application can also have specific effects due to its high ammonium nitrogen content and the complexity of this organic product, which contains many compounds that could generate other soilborne organic products. This applies especially in tropical environments where organic matter breaks down at a much faster rate than in temperate areas. Moreover, the island of Réunion has steep slopes and is undergoing a sharp increase in livestock manure production. Consequently, this waste must be recycled on the island with the risk of excess nitrate transport to coastal regions, which are highly susceptible to nitrate pollution. Decision makers are thus very attentive to risks of pollution, especially nitrogen. The aim of this study was to gain insight into the impact of pig slurry (*PS*) application on maize root growth in the field under tropical conditions. The root system was studied at different vegetation stages and its growth pattern, with and without *PS* input, was correlated with the crop age and the explored soil zone – the results therefore may be useful for modelling and decision-making support.

Materials and Methods

Experimental design and site characteristics

The study was conducted on the western side of the island of Réunion (21°7’ *S*, 55°18’ *E*, 780 m *ASL*) during the southern summers (November-March) of 2003-2004 and 2004-2005. The climate is tropical with a hot humid season between December and April. During the study period of each year, the daily mean temperature slowly increased from 19.5 to 21°C. According to Feder and Findeling (2007), the soil is classified as an andic Cambisol characterized in the surface horizon (0–0.2m) by a pH_{water} of 5.3, an organic matter of about 7% and N and P contents of about 4.2 x 10^{-3} kg kg^{-1} and 0.1 x 10^{-3} kg kg^{-1}, respectively. Between 0.2 and 1 m, pH_{water}, OM, N and P were estimated at 6.1, 2.5 %, 1.7 x 10^{-3} kg kg^{-1} and 0.04 x 10^{-3} kg kg^{-1}, respectively. An unfertilized maize-oat rotation was implemented in 2002-2003 in order to reduce soil nitrogen storage prior to the experiment. In 2003 and 2004 it was split into two parts: one 620 m^2 plot (*PS*) was fertilized yearly with pig slurry from a nearby piggery, and another 570 m^2 control plot was left unfertilized (*C*). The field was cropped with rainfed maize adapted to a tropical climate. The total cycle duration was about 120 days. Before sowing the maize crop (local open-pollinated variety) three weeks in 2003 and two weeks in 2004 respectively, pig slurry was applied to the surface at a rate of about 65 m^3 ha^{-1}. Table 1 gives the main physicochemical properties of pig slurry applied. The field was cultivated using conventional practices. Rainfall during cycle duration was 0.72 and 1.04 m of water in 2003 and 2004, respectively.

Measurements

The leaf area index (*LAI*) of 20 plants of maize was determined at four dates after sowing and total shoot biomass (5 replications) was measured at harvest. In this study, 2-D root density length profiles of maize were determined by the trench-profile method. It involves digging a pit perpendicular to rows and placing a grid of squares on one pit wall, covering a soil area from the surface to the maximum rooting depth and from midrow to midrow. Root impacts were counted using a 1-m wide grid with a 0.05 × 0.05 m grid mesh. Measurements were made on two profiles perpendicular to the sowing rows at 0.06 and 0.18 m from the maize stalks. Data were collected in the two treatments (*C* and *PS*) at four stages: 71 and 100 DAS in 2004, 43 and 59 DAS in 2005, with two replicates performed 10 m apart for each stage. Overall, 32 impact profiles were noted within a 1 m width and a depth that varied according to the root front, i.e. 0.6-1.6 m. The main problem with this method is the lack of direct relationship between the number of observed impacts and the root length density (Van Noordwijk 1987, Vepraskas and Hoyt 1988, Chopart and Siband 1999). It actually depends on the orientation of the roots relative to the monitoring plane. A model that considers root impacts according to the root length per soil volume unit was described by Chopart and Siband (1999). According to these authors, the root length density, i.e. *RLD* ($m\ m^{-3}$), can be expressed as:

$$RLD = NI_x \quad CO_x \quad CE \qquad (1)$$

where NI_x is the number of root impacts per unit area, CO_x is a geometric coefficient to calculate *RLD* from NI_x (Eqs. 2) and *CE* is an empirical coefficient (-) that depends on the age of the crop and the distance of the root impacts from the stem base (Eq.3).

For maize roots observed in a t-plane perpendicular to rows, as was the case in the present experiment, these authors proposed the following expressions:

$$\text{if } NI_t > 100 \text{ impacts per m}^2\text{:} \quad CO_t = 2.11 \qquad (2a)$$

otherwise:

$$CO_t = (0.0086\ NI_t^2 - 2.9\ NI_t + 245) / (41.2 - 0.232\ NI_t) \qquad (2b)$$

Table 1. Main physicochemical characteristics of pig slurry applied in 2003 and 2004.

	2003		2004	
	Mean	SD	Mean	SD
DM (1x 10^{-3} kg kg^{-1} of *FM*)	32.7	7.6	12.7	1.2
Total *OM* (% of *DM*)	66.1	4.8	43.2	3.3
Total *C* (% of *DM*)	37.3	2.0	26.3	1.6
Total *N* (% of *DM*)	12	2.5	23	1.2
Ammonium-*N* (% of *DM*)	9.05	2.1	20.4	2.0
K (% of *DM*)	7.9	2.1	22.0	2.5
P (% of *DM*)	3.6	0.4	2.5	0.2
Dose applied (m^3 ha^{-1})	67	-	64	-
Dose applied (kg N ha^{-1})	264	-	185	-

FM and *DM*: Fresh and Dry matter of pig slurry.
NO_3-N (% of *DM*) was nil and pH_{water} was 7.7
SD = standard deviation of three measurements

and:

$$CE = 9.8\ 10^{-4}\ SDD - 1.06\ DR + 1.25 \qquad (3)$$

SDD is the sum of degree-days (°*C*) since sowing calculated at day d:

$$SDD = \sum_{1}^{d} (<T_d> - T_{min}) \qquad (4)$$

where $<T_d>$ is the mean air temperature on day *d* and T_{min} = 10°C is the base temperature below which rooting growth is assumed to be hampered.

Eq. (2a) corresponds to a root system close to isotropy. In Eq. (3), *DR* is the relative distance of a root impact count from the maize stem base, observed on day d. It is expressed as:

$$DR = (D_H^2 + D_V^2)^{0.5} / D_{max} \qquad (5)$$

D_H and D_V are the measured horizontal and vertical distances of a root impact count from the stem base and D_{max} is the distance between the root front and the stem base on the same day.

This model has been successfully tested on maize (Chopart and Siband 1999, Chopart et al. 2001) in environmental conditions close to those of Réunion. The mean distance between roots (*RD*) is estimated from *RLD*:

$$RD = a\ (RLD^{\ 0.5})^{-1} \qquad (6)$$

with $a = (4/\pi)^{0.5}$ following Newman (1966).

A software package named RACINE (Chopart, 2004) designed for this root analysis method was used for the data management and root parameter calculations. It is available free upon request to the corresponding author.

Profiles for the observed *RLD* values were fitted by the following exponential decay function:

$$RLD\ (z) = RLD_0 \exp\ (-\beta z) \qquad (7)$$

where *z* is the depth (m), RLD_0 ($m\ m^{-3}$) and β (m^{-1}) are two fitting parameters.

Profiles for *RD* values in both treatments at four dates were also calculated by the following expression:

$$RD(z) = \exp\{\mathrm{Ln}(2/\sqrt{\pi}) - 0.5\ \mathrm{Ln}(RLD_0) + \beta z/2\} \qquad (8)$$

which was obtained straightforward by inserting Eq. (7) into (6). Ln is the neperian logarithm.

The fit of Eqs. (7) and (8) on measured *RLD* and *RD* values for both treatments were tested with the Nash coefficient efficiency (N_{ef}), (Nash and Sutcliffe 1970) and the root mean square error (*RMSE*) (Loague and Green 1991). N_{ef} and *RMSE* should be as close as possible to 1 and 0, respectively.

Volumetric water content profiles were measured using TDR probes (Campbell® CS616 connected to a Campbell® CR 10X data logger) at depths of 0.15 m, 0.3 m and every 0.3 m down to 2.4 m. In each treatment, the soil profile was sampled by augering every 2 weeks to measure total mineral nitrogen. Samples were taken at 0-0.1 m, 0.1-0.3 m, and 0.3 m up to a depth of 2.1 m. At each depth, four samples were pooled and nitrate and ammonium concentrations were determined in the 1:3 soil extract with 1 M KCl solution by continuous flux colorimetry.

Rainfall, air temperature and global incoming solar radiation were automatically recorded at the site and potential evapotranspiration was calculated using the Penman-Monteith equation. More details can be found in Payet (2005).

Results

Environmental conditions

Neither temperature (lying between 20° and 23°) nor soil moisture stalled root growth during the two study years. Moreover, the soil water balance estimates (Payet, 2005) revealed that the plant had never undergone water stress, which would have affected its photosynthetic capacity. However, solar radiation was relatively low which could have reduced the expression of the potential of this crop.

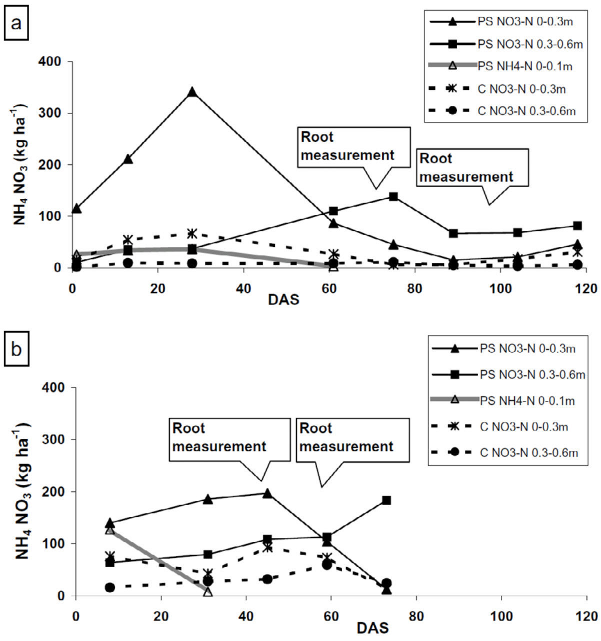

Fig. 1. Amount of ammonium measured in the 0-0.1 m soil layer in the pig slurry (*PS*) plot during the 2003-2004 (a) and 2004-2005 (b) cropping seasons. Amount of nitrate measured in two soil layers (0-0.3, 0.3-0.6 m) in control (*C*) and pig slurry (*PS*) plots.

Pig slurry applied from 2 to 3 weeks prior to sowing contained high level of nitrogen (Table 1). This led to a sharp increase in nitrogen content in the superficial soil layers (Fig. 1). This pig slurry application first increased the NH_4 content in the surface soil layer (Fig. 1). This ammonium nitrogen was still present in the soil in the days following sowing, especially the second year, with 130 kg NH_4 N ha^{-1} in the 0–0.1m soil layer around 10 DAS (Fig. 1). It dropped quite quickly, being transformed into NO_3, but there was still some that remained, i.e. in 2004 there was 40 kg NH_4 N ha^{-1} in the 0-0.1 m soil layer 30 DAS. We also noted a nitrate peak corresponding to a drop in *PS*-derived ammonium. In 2003-2004, this peak was close to 35 DAS around 55 days after *PS* application (Fig. 1). In 2004–2005, this peak was maintained until around 45 DAS (Fig. 1), but since the slurry was applied closer to the sowing date, the time between *PS* application and the nitrate peak (60 days) was close to that observed in the first cropping year.

At the beginning of the experiment, prior to *PS* application, the soil was slightly acid, especially in the surface horizon ($pH_{water} = 5.3$). The soil *pH* was not measured in the field during the cropping cycle, but it could be assumed that the nitrification process − involving H^+ proton release − could have prompted a drop in the *pH* of the soil solution and the soil during the most active nitrification phase. In the control treatment, soil ammonium nitrogen contents were virtually nil and nitrate contents were never above the total value of 60 kg N ha^{-1} in the 0−0.3 m soil layer during the cropping period (Fig. 1).

The slurry application thus induced marked modifications in the soil nitrogen content in the *PS* plot, with a substantial difference between the *C* and *PS* plots. The overall growth conditions were similar in the first and second cropping years. In both treatments, the soil nitrogen contents at the beginning of the cropping cycle and the effects of slurry input were comparable for both years.

Effect of PS on aboveground biomass

The maize crop in the *PS* plot had a higher leaf area index (*LAI*) than in the control (*C*) plot in 2004 and 2005 (Table 2). These *LAI* values were, however, relatively low as compared to those generally noted in temperate regions, which could mainly be attributed to the low solar radiation during the cropping cycle. Plants were taller in the *PS* plot than in the *C* plot. At 36 DAS, their height was 0.44 ± 0.07 m and 0.26 ± 0.1

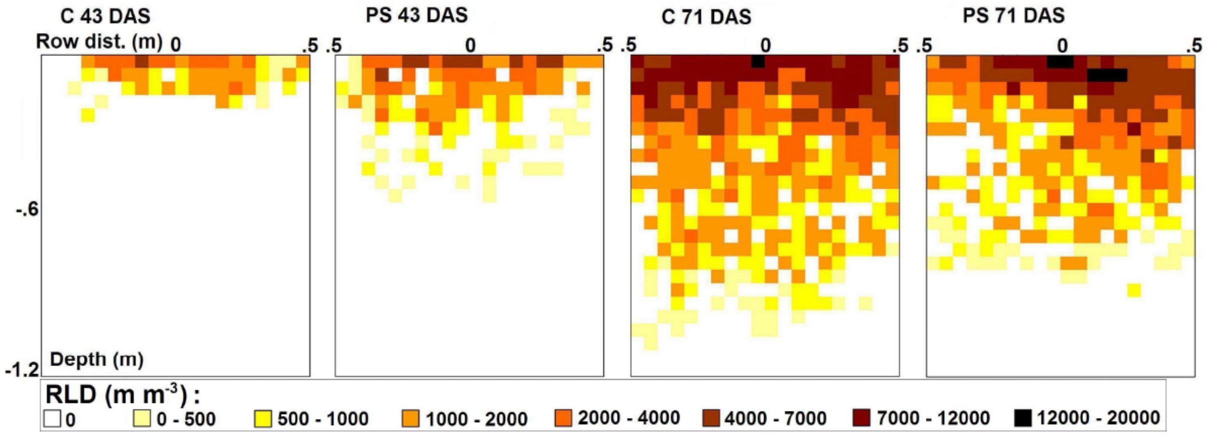

Fig. 2. Example of 2D-mapping of the root length density (*RLD*, m m^{-3}) obtained at two dates for the pig slurry (*PS*) and control (*C*) plots by counting the number of root impacts on 0.05 x 0.05 m squares.

m, respectively, and 2.23 ± 0.43 m and 1.65 ± 0.43 m at 59 DAS. At harvest, the total shoot biomass (*TSB*) was still higher in the *PS* plot. In 2004, it was 1.36 ± 0.21 kg m^{-2} as compared to 0.85 ± 0.18 kg m^{-2} in the *C* plot, while it was 1.24 ± 0.19 kg m^{-2} as compared to 0.86 ± 0.16 kg m^{-2} in the *C* plot in 2005.

The grain yield differed between years, but was always higher in the *PS* plot than in the *C* plot, i.e. around 0.42 kg m^{-2} on average in the control treatment and around 0.68 kg m^{-2} in the *PS* treatment. The slurry application thus enhanced maize shoot biomass development.

Table 2. Leaf area index (*LAI)* on control (*C*) and pig slurry (*PS*) plots

DAS (year)	Plot	*LAI*
36 (2005)	*C*	0.31 ± 0.19
	PS	0.47 ± 0.17
59 (2005)	*C*	1.90 ± 0.63
	PS	2.39 ± 0.68
62 (2004)	*C*	1.34 ± 0.53
	PS	2.38 ± 0.51
74 (2004)	*C*	1.82 ± 0.46
	PS	2.65 ± 0.73

DAS is day after sowing. Mean and standard deviation of 20 measurements

Table 3. Effect of pig slurry on total root length (m m^{-2})

	C plot	*PS* plot	*CV* %
43 DAS	199^{a}	474^{b}	13.7
59 DAS	653^{a}	876^{a}	26.7
71 DAS	2076^{a}	1902^{a}	18.1
100 DAS	3302^{a}	2716^{a}	18.2

DAS is day after sowing. Data are values of four replications. Values followed by the same letter within a line are not significantly different (P<0.05)

Effect of PS on root growth

Figure 2 gives an example of *RLD* spatial distribution maps (single replicate) as calculated by Eq. (1) at 43 and 71 DAS. These maps highlight patterns that varied almost deterministically according to the depth and horizontal distance from the sowing row. A brief analysis of the effect of *PS* on the *RLD* distribution per depth level is presented in the last part of the results.

We estimated the total root length (*TRL*) per soil area unit according to the sum of the root length densities noted at different depths and horizontal distances from the base of the maize stalk. Table 3 gives the corresponding *TRL* values for both treatments. In the *C* treatment, the growth rate was lower than in the *PS* treatment during the first phase of the cycle (0–43 DAS*)*. Conversely, the growth rate was faster than in the *C* plot between 43 and 59 DAS. The total root length dropped below that of the control treatment as of 71 DAS, i.e. before flowering onset. The differences (8% at 71 DAS and 18% at 100 DAS*)* were not spectacular or statistically significant but still seemed objective and were especially remarkable since the shoot biomass in the *PS* treatment was always higher than in the *C* treatment throughout the cropping cycle (Table 3), with a total shoot biomass at harvest about 50% higher.

Figure 3 shows the *RLD* profiles calculated by equations (1) to (5) on the basis of root impacts recorded in both treatments on four dates (43, 59, 71 and 100 DAS). The *RLD* distribution in the profile clearly confirmed previous observations concerning the total root length dynamics. The *RLD* increase rate in the profile was thus faster in the *PS* treatment than in the *C* treatment at the beginning of the cropping cycle (up to 59 DAS). However, as of earing (71 DAS), the *RLD* values were almost identical in both treatments. At a later date (100 DAS*) RLD*s for the *C* plot

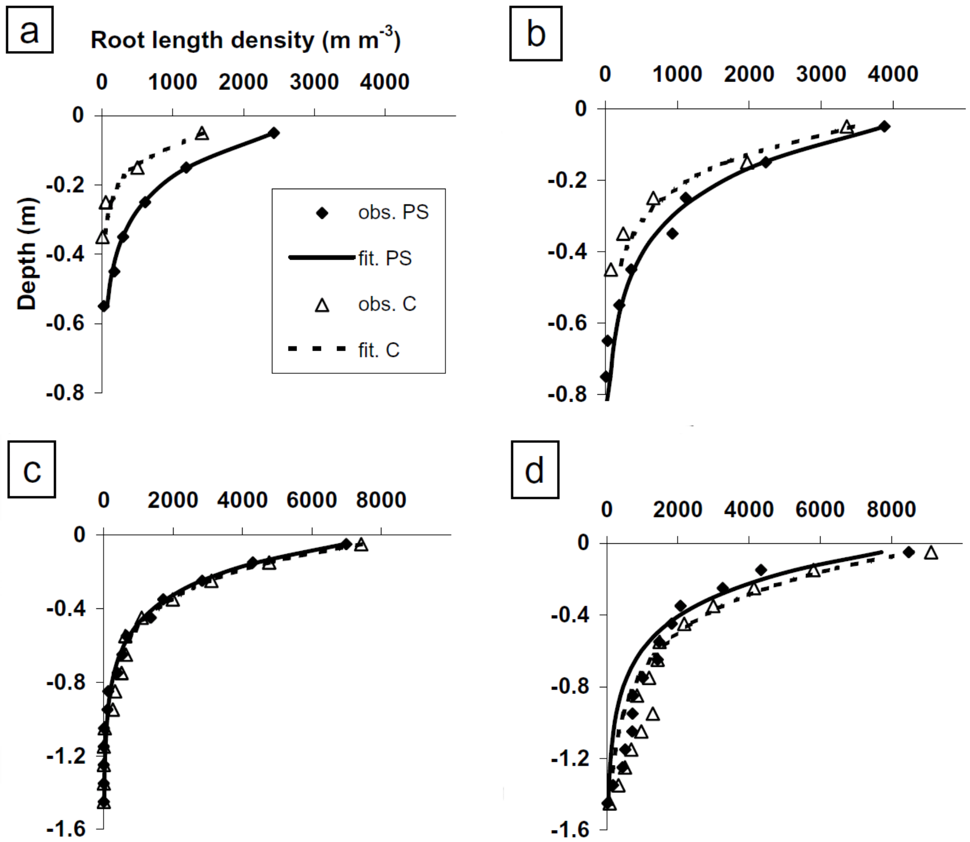

Fig. 3. Root length density (m m^{-3}) profiles for the pig slurry (*PS*) and control (*C*) plots at four dates after sowing (*DAS*): 43 (a), 59 (b), 71 (c) and 100 (d). Comparison between values observed and calculated (Eq. 7).

were even slightly higher at all depths. Profiles for the observed *RLD* values were fitted by an exponential decay function (Eq.7). The results are reported in Fig. 3 and the corresponding values of the fitting parameters RLD_0 and β are given in Table 4. The resulting Nash efficiency coefficients (N_{ef}) were very close to unity for the first three measurement dates and the *RMSE* values were lower than 10%, except in the control plot at 43 and 59 DAS (Table 4). This indicates that the *RLD* profiles of maize are adequately represented by an exponential decay function of depth. At 100 DAS, however, the fit was not as good from the surface to 0.6 m depth (Fig. 3). For deeper horizons, it underestimated the *RLD* values, and the statistical results were not quite as satisfactory. Between the earing (71 DAS) and grain filling (100 DAS) stages, the *RLD* in the 0-0.6 m soil horizon increased very little, whereas in the 0.6-1.2 m horizon it increased more substantially (*C* +260%, *PS* +340%). This modification in the *RLD* growth pattern, and thus in the root distribution in the soil, was likely due to the fact that some roots had disappeared due to senescence. The impact of *PS* on the root length density is summarized in Table 5. The beneficial effect of *PS* at the beginning of the cycle and the reversal of this trend as of the third measurement date are obvious, especially in the deeper horizons.

Profiles for the mean distance between roots calculated on the same four dates by Eq. (6) are reported in Fig. 4. The *PS* effects were also noted in the *RD* profiles, but the root system features were assessed in a slightly different manner. Concerning the first two measurements, *PS* had a positive impact throughout the profile, except in the topmost 0-0.1 m layer (Fig. 4 a, b). *PS* application thus clearly improved access to water and mineral elements. In contrast, as of earing and grain filling (71 and 100 DAS), *RD*s were similar until around 0.6 m depth in the two treatments (Figs. 4 c, d), but they were lower in the *C* plot below 0.8 m depth. *PS* application enhanced the water and mineral element uptake capacity of the root system at the beginning of the cycle, but this trend was reversed after earing until the end of the cropping cycle, at least in the lower part of the root profile. Profiles for *RD* values in both treatments at four dates were also calculated by Eq. (8). The *RD* values and the corresponding calculated curves (Eq. 8, Tab. 4) are plotted in Fig. 4. There was close agreement between the observed and calculated values in the top part of the root profile, but they differed markedly at the deeper zone. However, the N_{ef} (>0.96) and *RMSE* (<10%) values were very satisfactory at 71 and 100 DAS, when the root profile was deeper than 1 m (Table 4).

Effect of pig slurry application on the spatial variability in the root length density

Marked initial differences, to the benefit of the *PS* treatment, were noted as a result of the faster and more uniform spatial occupation of the soil profile by the root system (Fig. 2). Conversely, at 71 DAS, the mean *RLD*s became lower in the PS treatment and the soil occupation pattern also became more heterogeneous in the 0.2-0.8 m horizon (Table 6). The standard deviation of the *RLD* population was higher in the *PS* treatment, for slightly lower or equivalent means.

Table 4. Parameters of the exponential decay function of depth fitted on the experimental values of the root length density (*RLD*). Statistics of the length root density and mean root distances (RD)

		Pig slurry plot				Control plot			
DAS		43	59	71	100	43	59	71	100
Number of values (depths)		6	7	11	15	4	5	11	15
Decay Function	β (m^{-1})	7	5.7	4.5	3.8	11.7	7.2	4.4	3.2
of *RLD*	RLD_0 (m m^{-3})	3400	5200	8700	9300	2600	4900	9300	10100
Statistics *RLD*	N_{ef}	0.99	0.99	0.99	0.95	0.99	0.98	0.99	0.96
	RMSE (%)	2.9	8.5	5.1	22	10	14	5.4	14
Statistics *RD*	N_{ef}	0.75	0.31	0.99	0.98	0.45	0.70	0.96	0.97
	RMSE (%)	40	54	3.4	5.9	65	37	8.1	6.6

DAS is day after sowing, N_{ef} is the Nash efficiency coefficient and *RMSE* is the root mean square error.

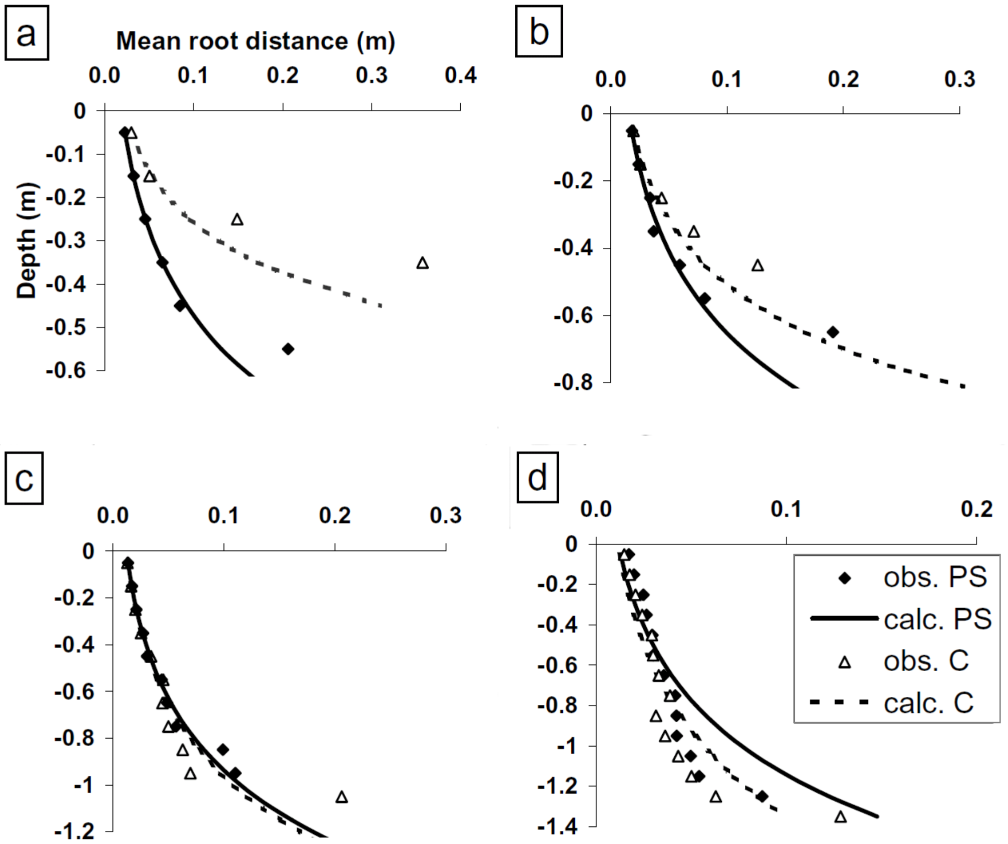

Fig. 4. Mean distances between roots (*RD*, m) in the pig slurry (*PS*) and control (*C*) plots at four dates after sowing (DAS): 43 (a), 59 (b), 71 (c) and 100 (d).

Table 5. Effect of pig slurry on root length density (m m^{-3}) at different dates (DAS) and depths (m)

Soil depth	Plot	43 DAS	59 DAS	71 DAS	100 DAS
0-0.4 m	*C*	500± 95	1560± 280	4320± 660	5510± 650
	PS	1150± 130	2040± 560	3970± 910	4520± 720
0.4-0.8 m	*C*		80±30	720± 240	1570± 330
	PS		150± 50	740± 330	1440± 290
0.8-1.6 m	*C*			80± 40	590± 180
	PS			30± 20	410± 210

Mean and standard deviation of four profiles

Discussion and Conclusion

The increase in total root length over a time course followed a sigmoid curve, with a growth rate that accelerated up to earing and declined thereafter until harvest. These results closely agreed with those obtained by Anderson (1987). In our study, the total root length (*TRL*) in the unfertilized control peaked at 3 300 m m^{-2} at the end of flowering in a relatively low yielding variety. This *TRL* was higher than that obtained in Côte d'Ivoire (Chopart 1985), in a dry infertile environment that limited the root growth of a maize variety with a very short cycle. In contrast, with highly productive hybrid maize varieties and high mineral fertilization, the *TRL* sometimes reached 24 000 m m^{-2} (Baligar et al. 1998), with quite similar plant numbers per m² at both sites. The *RLD* profiles of maize are adequately represented by an exponential decay function of depth, as reported by Canadell et al. (1996) for most vegetation types and used in a number of models (Feddes et al. 1978, Vanclooster et al. 1994, Li et al. 2001).

High pig slurry application 2-3 weeks before maize sowing had a positive effect on maize shoot biomass which is in agreement with most previous studies on this topic. This slurry had a spectacular beneficial effect on the root system during the first third of the cycle, when the crop was becoming established. This was likely associated with the much higher available mineral element storage (especially nitrogen) in the *PS* plot as compared to the *C* plot. But the root growth rate in the PS treatment dropped below that of the control by 43 to 71 DAS. At the beginning of the grain filling phase (100 DAS), the total length of the root system in the PS treatment was around 18% lower than that of the control, while the difference was clearly in favour of *PS* (around + 50% at harvest, 120 DAS) with respect to shoot biomass. This root growth slowdown was not spectacular but it did seem to be a clear trend. Moreover, in the second half of cycle duration, spatial variability of root distribution also became more heterogeneous in the *PS* treatment.

However no final conclusions could be drawn since this was just a preliminary study − this is why the title is in question form. But it is highly probable that the positive effect of pig slurry on maize shoots did not have involved a proportional effect on the root system.

Different hypotheses may be put forward to explain root system behaviour. Among them, two were expected to be the most probable. The first could be a simple negative effect of soil nitrogen content on the root system as reported by some authors. Oikeh et al. (1999) observed a positive effect (30 kg ha-1 mineral nitrogen supply), but also a negative effect (120 kg ha-1 nitrogen supply) on the root system. As in the example above, the high-level nitrogen supply in the PS plot may have slowed down root growth compared with the *C* plot. As the plants were able to access nutrients to fulfil their needs with shorter roots, they may have adjusted their root growth. However, other authors have obtained different results at the same growing stage as in our experiment (Baligar et al. 1998).

Table 6. Effect of pig slurry (*PS*) on the spatial variability in the root length density (m m^{-3}) observed 71 days after sowing on *Ns* soil samples (3x10^{-4} m^3) measured at different depths

Depth	*Ns*	Statistics	*C* plot	*PS* plot
0.05 0.2 m	120	Mean	5420	4960
		SD	1810	1900
		% of void samples	0	0
0.2 0.4 m	160	Mean	2560	2405
		SD	1010	1300
		% of void samples	3	11
0.4 0.8 m	320	Mean	1030	1070
		SD	540	650
		% of void samples	32	33

Mean and standard deviation (SD) were calculated on log-transformed data in compliance with their skewed probability density function. A void sample is a soil sample without roots

The second possible explanation is that soil acidification at the beginning of cycle, associated with nitrification of high quantities of ammonia supplied by pig slurry, gave rise to rhizotoxic exchangeable Al in the rhizosphere, in this soil that has an initial pHwater < 5.5, thus causing a slight lag in maize root growth relative to the nitrification peak, since measured values reflect the root system history, from root emission at soil surface until the measurement date. The negative effect of exchangeable aluminium on maize root growth has been documented in several papers (Horst 1995, Diatloff et al. 1998, Sivaguru and Horst 1998, Sivaguru et al. 1999, Sierra et al. 2003, Eticha et al. 2005).

Further studies would be worthwhile to assess the effects of pig slurry on the maize root system in order to confirm (or not) these initial results with other *PS* doses and under different environmental field conditions. If confirmed, the biophysicochemical mechanisms involved in this root growth inhibition should be more clearly documented.

The challenge is substantial since pig slurry applications on crop fields should become increasingly common and regulated. As nitrates are mobile in the soil, especially under tropical climatic conditions with heavy rainfall and often permeable soils, the root system must be able to intercept a maximum amount of nitrates before they are transported by convection to deeper horizons where they can no longer be utilized by crops but instead become a potential source of groundwater pollution. A reduction in soil occupation by the root system, associated with *PS* application, would thus reduce the efficiency and even usefulness of this application in soils cropped with maize under such tropical conditions.

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