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SIMBA-N: Modeling nitrogen dynamics in banana populations in wet tropical climate. Application to fertilization management in the Caribbean

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ABSTRACT

In banana plantations of the Caribbean, nitrogen (N) fertilization widely exceeds nutrient outputs after harvest. Under wet tropical climate, leaching results in considerable waste of N. Fertilization management aims at maintaining soil mineral N at the optimal level for banana nutrition throughout the year but it does not take into account variations in crop N demand or N supply through mineralization of crop residues. The dynamics of crop N demand and crop residue supply depend on the structure of banana populations, which become asynchronous with time. We designed the SIMBA-N model to simulate N dynamics in successive crop cycles of banana. The model calculates the N balance weekly, including N uptake by banana, N leaching, and N supply by organic matter mineralization. We validated the model using data from a field experiment comparing five levels of fertilization. Results showed SIMBA-N provides reliable indicators to support banana fertilization management taking into account N flows in the soil and change in N demand related to banana population structure.

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1. Introduction

In the Caribbean, bananas are grown under a wet tropical climate with heavy rainfall (2000–6000 mm annually) and harvested throughout the year. Godefroy and Dormoy (1983) determined the frequency of fertilizer applications as a function of rainfall with the aim of maintaining soil mineral nitrogen (N) above a critical threshold for banana nutrition. This method, however, does not take into account the dynamics of plant demand and crop residue supply. Hence, the amounts of N fertilizers applied widely exceed N outputs after harvest. In intensive banana plantations, 400 kg ha^{-1} year^{-1} of N are generally applied while N exports at harvest rarely exceed 100 kg ha^{-1} year^{-1}. It thus appears that large amounts of the mineral N are lost by leaching or run-off. To reduce N wastes in the Caribbean, N crop supply must be adjusted to plant demand for environmental and economic reasons.

Bananas are rhizomatous herbs whose terminal bud produces the inflorescence. Each plant successively produces a series of bunches, each from a lateral shoot. Banana crops represent a collection of individual plants derived from vegetative propagules. They develop at their own rhythm and do not follow a synchronous cycle. At any given time, a banana crop consists of a population of individual plants at various developmental stages. The dynamics of banana biomass production reveal peaks whose amplitudes tend to be wider over time, until biomass production is continuous after five to seven cropping cycles.

The SIMBA-POP model (Tixier et al., 2004) was designed to simulate the population structure, and fruit and biomass production for bananas. Generic crop simulation models such as STICS (Brisson et al., 2003), CROPSYST (Stöckle et al., 2003), or APSIM (Keating et al., 2003) simulate mechanisms involved in production and transfer of mineral N. These models were designed for annual crops with homogeneous plant populations. Such models can be used for the first banana crop cycle (Brisson et al., 1998) but are not adapted as soon as the plant population structure becomes heterogeneous. Indeed, those models cannot properly simulate the dynamics of crop residue return and N uptake in perennial plant populations whose development stages become asynchronous with time.

Models specifically designed to manage N fertilization in annual crops under temperate climate and based on balance-sheet method such as Azobil (Machet et al., 1990) or Azodyn (Jeuffroy and Recous, 1999) do not take into account N leaching during crop growth. Thus they cannot operate properly in the case of over-fertilized perennial crops under heavy rainfall such as intensive banana crops in the Caribbean.

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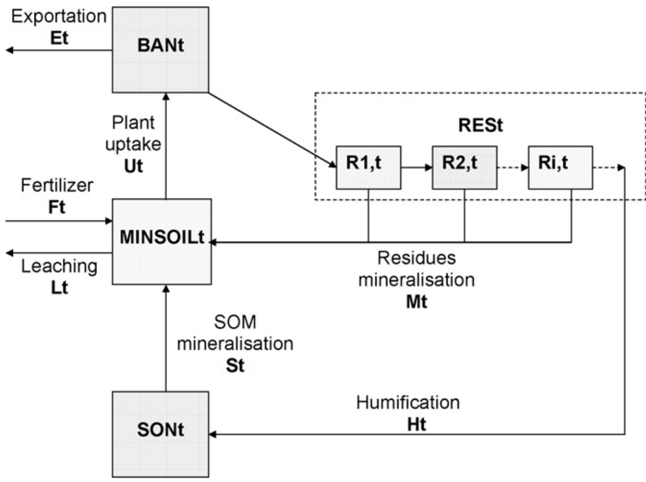

Fig. 1. General structure of SIMBA-N model.

We present here the SIMBA-N model designed to simulate crop requirements and soil N dynamics under banana cultivation. The model was validated by comparing observed and simulated soil mineral N dynamics in a fertilization experiment. Observed indicators of plant growth and plant N nutrition were also compared to N Stress Index computed by the model. We used the model to investigate the effect of soil-climate conditions and fertilization practices in volcanic ash soil of Guadeloupe on N leaching and availability.

2. Material and methods

2.1. Model description

SIMBA-N was developed using the STELLA® software environment from High Performance System® (Lebanon, NH, USA). The general structure of the SIMBA-N model is presented in Fig. 1. SIMBA-N computes at a weekly step a dynamic soil N balance under banana cultivation as shown in Eq. (1).

$$\mathrm{MINSOIL}_t = \mathrm{MINSOIL}_{t-1} + F_t + S_t + M_t - U_t - L_t \tag{1}$$

Stock and flow variables involved in N balance are presented in Table 1.

We assumed that N volatilization and denitrification were low in Caribbean volcanic ash soils (Sierra et al., 2001; Thieuleux, 2006) and balanced by N deposition from the atmosphere (Jeuffroy and Recous, 1999). For this reason, these N flows were not considered in the model. We considered that only mineral fertilizers were applied and that N from fertilizers was transferred to soil mineral N stock as soon as applied. SIMBA-N calculates N outputs related to leaching and plant uptake and N inputs related to crop residues and soil organic matter mineralization.

2.1.1. Leaching

Mineral N leaching L_t is calculated at a weekly step using the equation of the NLEAP model designed by Shaffer et al. (1994):

$$L_t = \mathrm{MINSOIL}_t\left(1 - \exp\left(-K_{\mathrm{lea}}\frac{(R_t - \mathrm{PET}_t)}{\mathrm{SW}}\right)\right) \tag{2}$$

with R_t = rainfall at step t (mm); PET_t = potential evapotranspiration (mm); SW = soil water stock at saturation (mm); K_{lea} = leaching coefficient depending on physical soil characteristics.

According to Dorel et al. (2000) and Sansoulay (2006), SW and K_{lea} are respectively equivalent to 200 mm and 0.7 for the andosols of Guadeloupe.

2.1.2. Nitrogen crop uptake

We assumed that N crop uptake was driven by crop dry matter production. The SIMBA-POP model (Tixier et al., 2004) was used to calculate crop dry matter. This model enables one to simulate the evolution of banana population structure and the dynamics of crop dry matter throughout the successive production cycles of a banana plot (Fig. 2). For each production cycle, crop dry matter increases until harvest. At harvest, the mother plant is cut and the crop dry matter is reduced to the dry matter of the sucker selected for the following production cycle. The passage from one production cycle to the next does not induce discontinuity in the dry matter curve because the model takes into account the heterogeneity of developmental stages in the banana population.

The plant N concentration at step t (NC_t) is calculated as a function of crop dry matter amount (DM_t) according to the reference critical dilution curve proposed by Greenwood et al. (1990) for C3 plants as presented in Eq. (3).

$$\begin{cases} \text{If} & \mathrm{DM}_t < 2(\text{tons/ha}) \\ \text{Then} & \mathrm{NC}_t = 4\% \\ \text{Else} & \mathrm{NC}_t = 5.7\mathrm{DM}_t{}^{-0.5} \end{cases} \tag{3}$$

NC_t serves to determine crop N demand. The actual crop uptake is equal to the minimum of mineral N available in the soil and crop demand.

2.1.3. Crop residue mineralization

Crop residues return to soil following the harvest dynamics pattern simulated with the SIMBA-POP model with peaks that tend to spread over time (Tixier et al., 2004). We considered that a residual fraction K_1 of N of crop residues remains in organic form and

Table 1
Stock and flow variables of SIMBA-N (expressed in kg ha^{-1} of N)

Stock variables	
$\mathrm{MINSOIL}_t$	Soil Mineral N at step t
SON_t	Soil Organic N at step t
BAN_t	Banana N content at step t
RES_t	Crop Residue N at step t
$R_{i,t}$	Mineral N of crop residues aged of i weeks at step t
Flow variables	
F_t	Mineral N fertilized at step t
L_t	Mineral N leached at step t
U_t	Mineral N plant uptake at step t
E_t	Mineral N exported (bunch) at step t
M_t	N mineralized from residues at step t
S_t	N mineralized from soil organic matter at step t
H_t	N humification from residues at step t

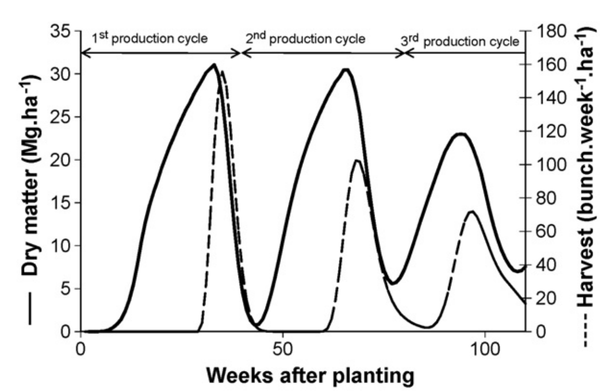

Fig. 2. Dry matter dynamics and harvest dynamics in a bananas population simulated at the plot scale with the SIMBA-POP model.

is transferred to soil organic N pool (H_t). The other part mineralizes directly. According to Thieuleux (2006), the mineralization rate (M_i) of this fraction varies with time as a decreasing exponential function (Eq. (4)).

$$M_i = \exp(K_{deg1} + K_{deg2} i) \quad (4)$$

where i is the number of weeks since crop residue return and K_{deg1}, K_{deg2} two parameters characterizing the mineralization dynamics of organic N respectively equal to 3.2 and −0.19 for banana crop residues.

2.1.4. Soil organic matter mineralization

In the Caribbean, bananas are grown in volcanic ash soil under wet tropical climate where soil temperature and water content changes throughout the year are small. In such conditions we assumed that mineral N produced weekly by soil organic matter mineralization (S_t) is only related to soil organic N content (SON_t) and can be calculated according to Eq. (5).

$$S_t = K_{\text{som1}}\text{SON}_t + K_{\text{som2}} \quad (5)$$

where K_{som1} and K_{som2} are two parameters depending on soil characteristics.

2.1.5. Nitrogen Stress Index

According to Godefroy and Dormoy (1983), N nutrition stress occurs in banana plantations if soil mineral N falls below 40 kg ha^{-1}. We defined an N Stress Index at step t (NSI_t) as follows:

$$\begin{cases} \text{If} & \text{NMINSOIL}_t > 40\,\text{Kg ha}^{-1} \\ \text{Then} & \text{NSI}_t = 1 \\ \text{Else} & \text{NSI}_t = \dfrac{\text{NMINSOIL}_t}{40} \end{cases} \quad (6)$$

2.2. Model sensitivity analysis

A sensitivity test was performed to assess the effect on model outputs (N leaching and NSI) of the variation in soil-climate characteristics and fertilization practices encountered in the banana plantations of Guadeloupe. In Guadeloupe, banana plantations are mainly located on volcanic ash where soil and climate characteristics change in accordance with altitude (Dorel et al., 2005). Three sites located at different altitudes on a soil-topo sequence of the east side of the volcanic island of Basse-Terre and equipped with automatic meteorological stations were selected. Simulations were performed using mean daily rainfall, temperature and radiation calculated from data recorded on these sites between 2000 and 2005. Soil parameters used for simulations were determined according to the results of Dorel et al. (2006) obtained on the same soil-topo sequence. Main soil-climate characteristics of the three sites are presented in Table 2. Simulations were also performed to test the effects on model outputs of the amount of nitrogen fertilizer applied each year and the effect of different frequency of fertilizer application.

Table 3
Soil characteristics of the experimental plot, in the ploughed layer (0–30 cm).

Soil characteristics	Value
Soil organic N (kg ha^{-1})	6400
Soil mineral N (kg ha^{-1})	20
Bulk density (Mg m^{-3})	0.8
Water content at field capacity (g g^{-1})	0.75
Clay (%)	62
Silt (%)	32
Sand (%)	6

2.3. Experiment

2.3.1. Experimental design

An experiment was carried out to evaluate the effect of different levels of N fertilization on soil N availability and banana growth. The experimental plot was at the CIRAD research station of Neuchâteau (Guadeloupe, 16°13′ N, 61° 36′ W, altitude 250 m). The soil, developed on recent volcanic deposits, was classified as andosol. The average annual rainfall recorded on Neuchâteau site is 3500 mm.

Before the beginning of the experiment, the plot was left for two years under a sanitation fallow; weeds were controlled by scheduled applications of herbicide to prevent plant-parasitic nematode conservation. Soil characteristics at the beginning of the experiment are presented in Table 3.

After planting with banana plants from tissue culture (*Musa* spp., AAA group, cv. Cavendish Grande Naine; Vitropic SA, Saint Mathieu de Tréviers, France), five distinct fertilization treatments were applied on separate plots: 20, 120, 220, 320, and 420 kg ha^{-1} year^{-1} of N (T0, T1, T2, T3, and T4, respectively). For each treatment, yearly fertilization was split into 12 applications monthly. Each treatment was randomly replicated on five 500 m^2 elementary plots of 90 banana plants each. The experiment was monitored from the planting (February 2005) to the flowering stage of the third production cycle (January–April 2007).

2.3.2. Measurements

- Rainfall and temperature were recorded hourly on the site during the experiment.
- Basal girth of banana pseudo-stem was measured monthly till flower emergence for each of the three production cycles. At the flower emergence stage, the number of fruits per bunch was recorded.
- Mineral N content of the 0–30 cm soil layer was determined every month. The day before fertilizer application, 30 core sam-

Table 2
Soil parameters and climate characteristics of three sites of the eastern coast of Basse-Terre (Guadeloupe)

	Location		
	Site 1 Monrepos	Site 2 Neuchateau	Site 3 Bois Rouge
Altitude (m)	80 m	250 m	420 m
Soil classification	Nitisol	Andosol	Perhydrated andosol
Mean annual rainfall (mm)	2000	3000	4500
Mean temperature (°C)	25.5	24.4	22.7
Soil organic matter content (%)	3	8	19
SOM mineralization parameters of SIMBA[a]			
K_{som1}	0.001	0.002	0.002
K_{som2}	20.841	−6.112	−6.112

[a] According to Dorel et al. (2006).

ples were taken in each elementary plot with a 60 mm diameter auger and mixed to obtain a composite sample. Mineral N was colorimetrically measured after extraction with a 1 N KCl solution.
- Chlorophyll content of the last unfolded leaf was measured each month with a light transmittance chlorophyll meter (SPAD-502, Minolta).

2.4. Statistical methods

We used the normalized root mean square error (RMSE) to analyze the accuracy of model predictions. Normalized RMSE (expressed in percent) was calculated according to Loague and Green (1991) as follows:

$$\text{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{(P_i - O_i)^2}{n}} \times \frac{100}{M} \quad (7)$$

where P_i and O_i are predicted and observed values and M the mean of the observed variable.

Results of fertilization experiments were analyzed through ANOVA. Mean values were compared using Newman–Keuls test (threshold 5%).

3. Results

3.1. Model calibration

3.1.1. Crop residue mineralization – K_1 parameter determination

The decomposition of banana crop residues produced high amounts of residual organic matter which incorporate into soil organic matter pool. Godefroy (1974) reported that the residual fraction of organic N represented about 60% of the initial N content of banana crop residues. Furthermore, the basal part of the harvested banana, which contains 35% of the N crop residues (Marchal and Malessard, 1979), does not decompose immediately. In fact, the corm of the harvested plant can remain alive for several months (sometimes several years) before decomposition occurs. Factors determining corm decomposition after harvest are not well known but seem related to soil biology. Consequently we assumed that only 25% of the N of crop residues was directly mineralized and that K_1 could be assessed at 75%.

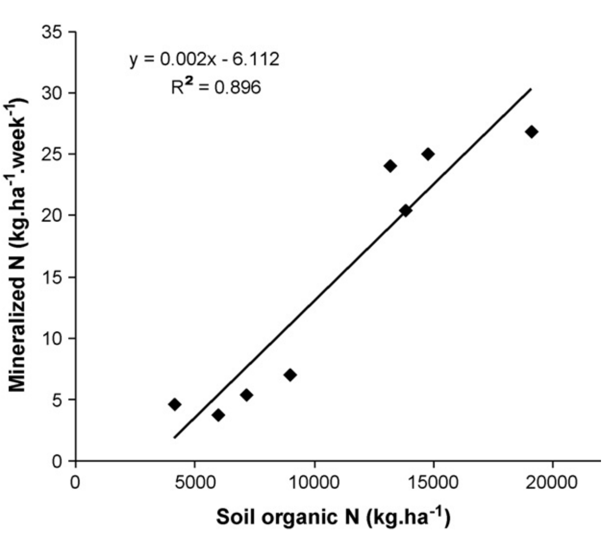

Fig. 3. Nitrogen mineralized as a function of the soil organic N in andosols of Guadeloupe.

Table 4
Normalized RMSE for Log(MINSOIL) and correlation (R^2) between observed and simulated values for the five treatments of the experiment

Treatments	T0	T1	T2	T3	T4
Normalized RMSE (%)	26.12	22.98	24.32	24.11	15.46
R^2	0.69	0.91	0.61	0.72	0.67

3.1.2. Soil organic matter – mineralization rate determination

Test incubation carried out with andosols from Guadeloupe (Dorel et al., 2006) showed a linear relation between amounts of N mineralized and soil organic N content (Fig. 3). According to these results, K_{som1} and K_{som2} were estimated to be 0.002 and −6.112 respectively for andosols.

3.2. Comparison of simulation and experimental results

3.2.1. Model validation

Model validation was achieved by comparing observed and simulated soil mineral N dynamics for the three crop cycles in the five treatments of the fertilization experiment (Fig. 4). Simulations were performed with initial soil characteristics presented in Table 3. As shown in Table 3, the correlation coefficients between observed and simulated data in the five experimental treatments ranged from 0.61 to 0.91 After Log transformation of observed and simulated values of the NMINSOIL variable to reduce amplitude variations, normalized RMSE (Loague and Green, 1991) was calculated to evaluate the accuracy of SIMBA-N (Table 4). According to Jamieson et al. (1991), the accuracy in the prediction can be considered fair for T0, T1, T2, T3, and good for T4. However, despite a better accuracy in the prediction for the highest fertilization level, our results do not allow a clear correlation between model accuracy and fertilization level.

3.2.2. Simulated Nitrogen Stress Index and observed indicator of nitrogen nutrition

Chlorophyll meter readings (CHLr) can be used as an indicator of N nutrition, provided that readings can be related to a reference reading carried out at the same time on well-fertilized plants (Piekielek et al., 1995; Spaner et al., 2005; Arregui et al., 2006). We assumed that the T4 treatment of fertilization experiment (420 kg ha^{-1} year^{-1} of N) enabled optimal N nutrition conditions for bananas and could be a reference for chlorophyll meter readings. We investigated the relationship between CHLr, taken as indicator of N nutrition observed in the field and NSI computed with the model. NSI can be computed from soil mineral N stock weekly or from the mean value of soil mineral N during a longer period. NSI calculated from soil mineral N stock weekly was correlated with CHLr (R^2 = 0.49). However, the best correlation between CHLr and NSI (R^2 = 0.61) was observed when NSI was computed from the mean values of soil mineral N recorded for the four weeks preceding the measurement date (Fig. 5).

3.2.3. Simulated Nitrogen Stress Index and banana growth and development

Fig. 6 presents the increase in banana pseudo-stem girth during three crop cycles. During the first crop cycle, banana growth was equivalent for the different treatments. From the second cycle, banana girth in treatment T0 became significantly lower than in the other treatments. However, due to slower development, the growth period was longer for T0, and the pseudo-stem girths reached at flowering time were not significantly different for the five fertilization treatments. The number of fruits per bunch, which

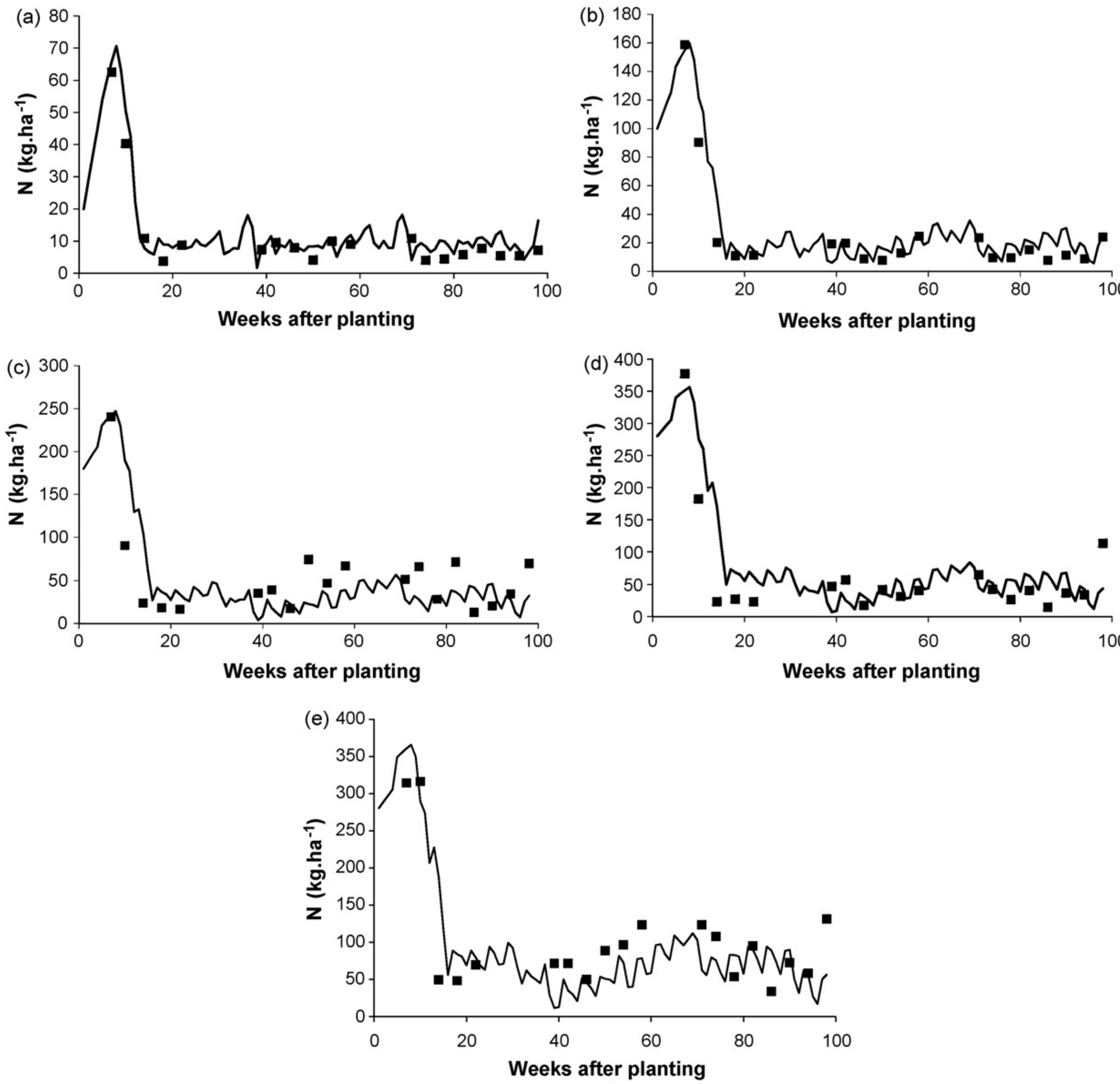

Fig. 4. Soil mineral N observed (■) and simulated (–) for treatments T0 (a), T1 (b), T2 (c), T3 (d), and T4 (e) with 20, 120, 220, 320, and 420 kg ha^{-1} year^{-1} of N, respectively.

can be considered as an indicator of the expected yield, was not significantly different either.

Simulated NSI values for treatments T0, T1, T2, T3, and T4 (Fig. 7) are ordered according to the fertilization level. In T0 treatment, strong N stress held on three months after planting. In T1 and T2 treatments, despite NSI values indicating moderate nutritional stress, plant growth and development were not significantly affected. These results suggest that N nutritional stress significantly reduces plant growth and slows down plant development only in case of heavy stress (T0 treatment). Effects of moderate stress on plant growth and development are only slight.

3.3. Model sensitivity to soil-climate conditions and fertilization practices

We tested model sensitivity to soil-climate variations using three sets of soil-climate data corresponding to the three sites presented in Table 3. The simulations were operated with a standard N fertilization of 400 kg ha^{-1} year^{-1} split into 12 monthly applications. Simulated soil mineral N and NSI dynamics for the three sites are shown on Fig. 8a–c and can be correlated to rainfall (Fig. 8d). Table 5 presents the mean value of NSI and the cumulated N leaching over the simulation period. In the site 3 located at the

Table 5
Mean Nitrogen Stress Index (NSI) and cumulated N leaching calculated from SIMBA-N simulation for three production cycles

	Site 1	Site 2	Site 3
Mean NSI	0.64	0.99	0.99
Cumulated N leaching (kg ha^{-1})	372	1196	2235

Table 6
Cumulated N Leaching and mean NSI calculated with SIMBA-N for three production cycles

Treatments	T0	T1	T2	T3	T4
N leaching (kg ha^{-1})	104	274	554	729	1067
NSI	0.21	0.54	0.82	0.95	0.98

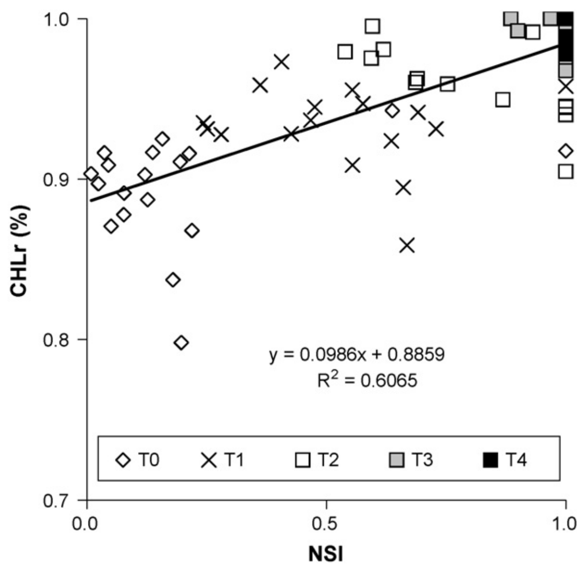

Fig. 5. CHLr as a function of NSI calculated from mean soil mineral N of the four weeks preceding the measurement.

highest altitude (420 m), despite very high levels of N leaching, N availability was suitable and allowed proper plant nutrition (NSI keep value closed to 1). In the site 2 (altitude 250 m), N availability was suitable too, but N leaching was much lower than in site 3. In site 1 (altitude 80 m), in spite of N fertilization exceeding plant uptake, high NSI variations indicate that N availability was not sufficient to maintain proper plant nutrition throughout the year. In this site, simulated N leaching was lower than in the other sites but remained relatively high. Soil organic matter stock was low and N supply through mineralization was not sufficient to maintain the N balance. These simulations show that with the same fertilization level, soil-climate variations at production basin scale result in high differences in N availability and N leaching. N availability variation can be related to N supply through mineralization of variable stocks of soil organic matter.

We also tested the effect of annual N fertilizer amount on N leaching and NSI. We used the dataset corresponding to the five treatments of the fertilization experiment. As shown on Table 6, N leaching varied widely with fertilization level. With the highest fertilization level T4, N leaching exceeded 1000 kg ha^{-1} and was 10 time higher than with T0. NSI also varied widely with fertilization level. NSI values close to 1, indicating proper N nutrition, were found with T3 and T4 treatment for which leaching was very high. N leaching was much lower with T0 and T1 but the model simulated N stress in this case. According to model simulation, none of the five fertilization treatments enables proper N nutrition and low N leaching.

The effect of increasing fertilization splitting from monthly to weekly applications was simulated with SIMBA-N for a standard annual N fertilization of 400 kg ha^{-1}. NSI and N leaching dynamics are shown on Fig. 9a and b. Increasing fertilization splitting led to only slightly modified NSI and N leaching. These simulations indicate that increasing fertilizer application frequency does not greatly improve N fertilizer efficacy.

4. Discussion

We have shown that SIMBA-N allows proper simulation of the effect of fertilization level on soil mineral N dynamics under banana cropping in volcanic ash soil of Guadeloupe. Simulations showed that, whatever the fertilizer amount applied each month, it is difficult to match proper N availability and low N leaching in banana plantations. Proper N availability for banana nutrition was obtained for fertilization levels above 300 kg ha^{-1} year^{-1}, but these fertilization levels lead to high N leaching. For a given fertilization level, increasing application frequency only slightly changes N leaching and N availability. In most soil-climate conditions of Guadeloupe, the implementation of the critical rainfall threshold method (Godefroy and Dormoy, 1983) led to advise monthly applications of fertilizer. In most cases, this standard fertilizer application frequency seems to be a good compromise between fertilizer efficiency and labor cost for application.

Soil and climate change with altitude can be taken into account with SIMBA-N. The simulations performed with different soil-climate conditions showed that the high soil organic N contents at high altitudes improve N availability, in spite of high rainfall, without increasing fertilizer supply. Simulation results are in agreement with results of Godefroy and Dormoy (1983) on volcanic ash soil of Martinique. Indeed, those authors reported marked change with altitude in N availability related to soil organic matter content. They suggested to take into account N from soil organic matter mineralization in banana fertilization of high altitude banana plantations. Increasing soil organic matter content may thus be a way to improve the sustainability of banana cropping systems.

Our experimental results showed that moderate N nutrition stress had no appreciable effect on plant growth and develop-

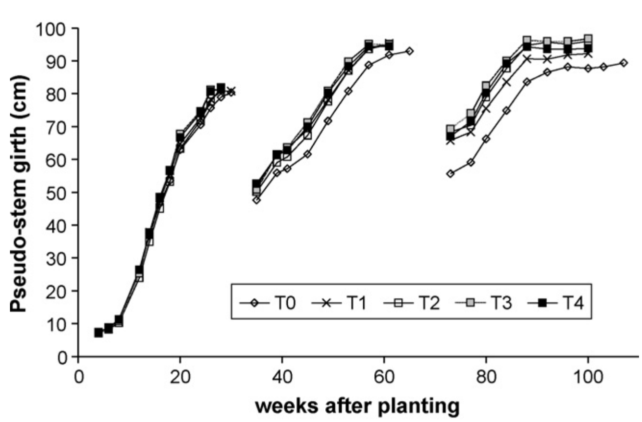

Fig. 6. Pseudo-stem girth variation for three production cycles ($n = 10$) for treatments T0, T1, T2, T3, and T4 with 20, 120, 220, 320, and 420 kg ha^{-1} year^{-1} of N, respectively (the last point of each growth curve corresponds to flowering stage).

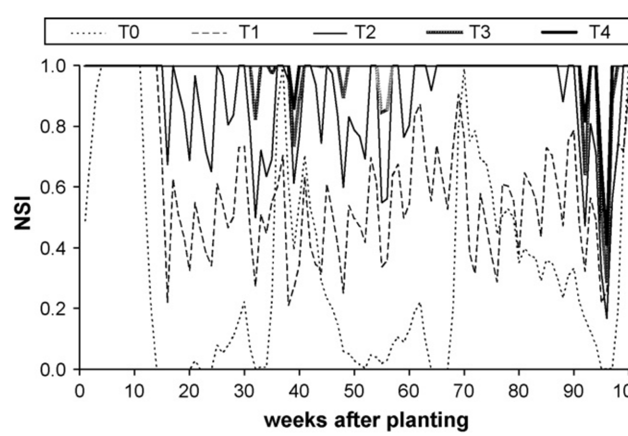

Fig. 7. Nitrogen Stress Index simulated with SIMBA-N for treatments T0, T1, T2, T3, and T4 with 20, 120, 220, 320, and 420 kg ha^{-1} year^{-1} of N, respectively,.

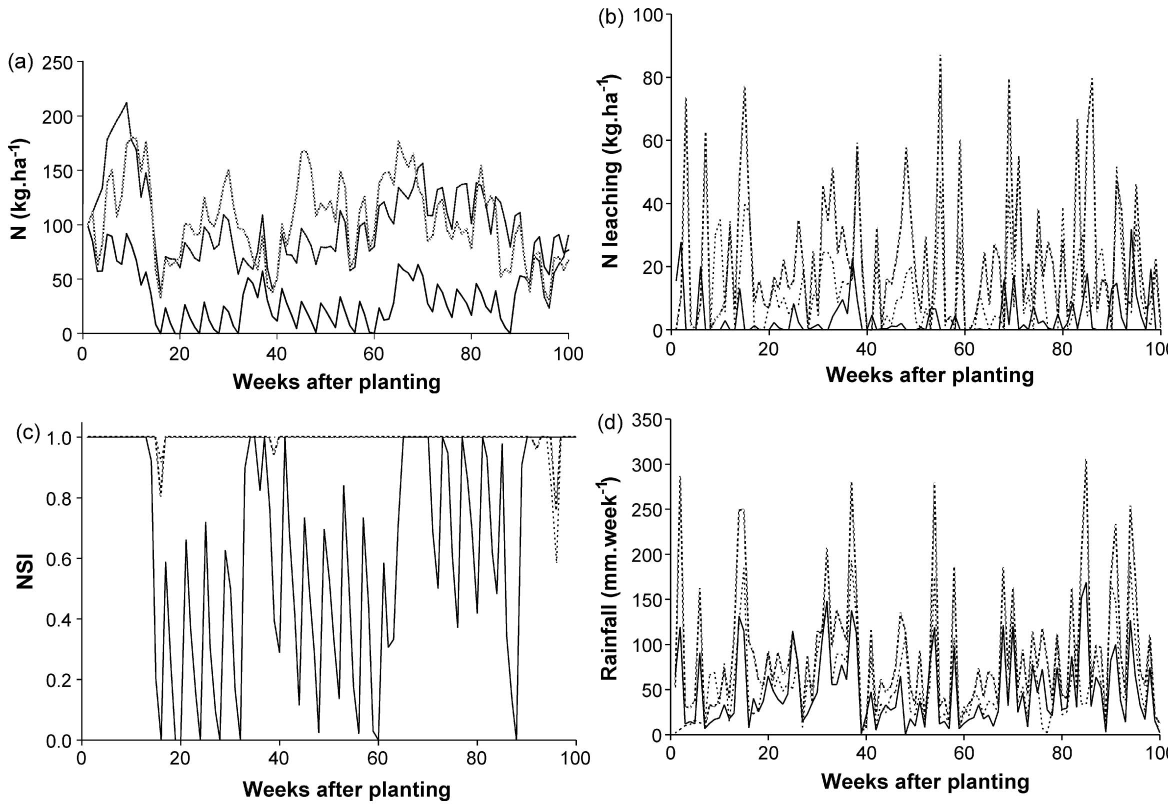

Fig. 8. Soil mineral N dynamics (a), N leaching (b), N Stress Index (c), and rainfall (d) for sites 1 (—), sites 2 (- - -), and site 3 (▬).

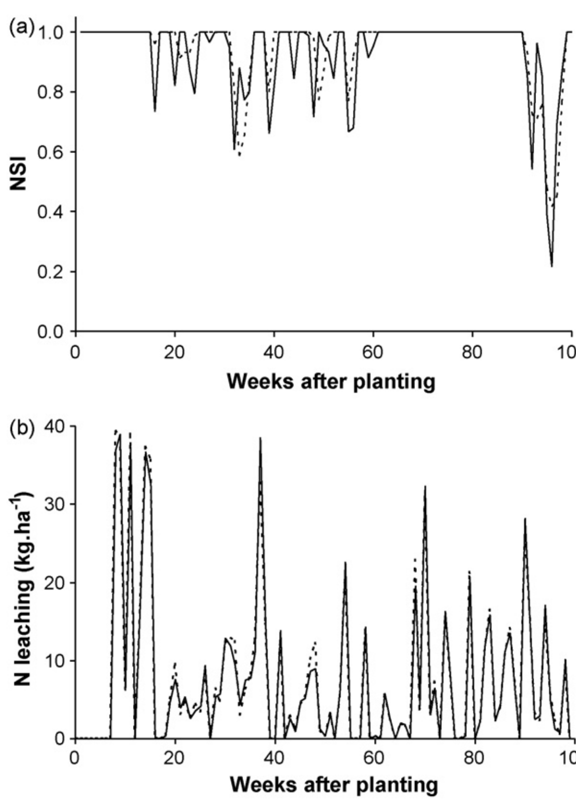

Fig. 9. Effect of splitting fertilization weekly (- - -) and monthly (—) on NSI (a) and N leaching (b), with a fertilization of 400 kg ha^{-1} year^{-1}.

ment. Only heavy stress, as observed in T0 treatment, slowed down plant growth and delayed development. Such stress conditions rarely occur in field conditions, particularly in intensive banana plantations of the Caribbean. As SIMBA-N does not simulate the effect of N stress on plant growth and development, this model could have limitations in case of poor fertility soil with low levels of fertilization.

We demonstrated that the relative chlorophyll content of leaves was sensitive to fertilization level. This indicator of plant N nutrition was correlated with the N Stress Index computed with SIMBA-N from soil available N. However, the chlorophyll content of leaves can depend on other factors such as water stress or temperature (Arregui et al., 2006). Chlorophyll content measurement and N Stress Index computed with SIMBA-N N Stress Index could be used together as fertilization management support to identify more reliably the period of N deficiency and decide on complementary fertilizer supply.

We assumed that a large part of the N from banana crop residues was directly transferred to soil organic N pool. In fact the fate of N of the harvested banana plant is poorly documented. The basal part of the harvested banana keeps vascular connections with the sucker. N from the harvested banana may be transferred directly to the sucker through these connections (Twyford and Walmsley, 1974) or enter the soil food web through decomposer activity. The decomposition rate of the basal part of the harvested banana (corm, pseudo-stem) seems to depend on biological factors (macro fauna, bacteria, fungi) that vary greatly with growth conditions. Model prediction accuracy could be improved by better knowledge of these processes.

5. Conclusion

SIMBA-N properly simulates the N dynamics in Caribbean volcanic ash soil under banana cropping. In wet tropical climate, the challenge with banana fertilization is not to balance N outputs globally but to keep the available N stock high enough throughout the year to meet plant requirements and low enough to avoid massive N leaching. SIMBA-N provides reliable indicators to support banana fertilization management taking into account soil N stock and change in N demand related to banana population structure. SIMBA-N is also used within the global cropping system model SIMBA (Tixier, 2004) and helps designing more sustainable cropping systems.

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