Understanding soil factors limiting the potential yield of yam (Dioscorea spp.)

Lucien N Diby[1, 2], Robert Carsky[3], Ay?mou Assa[1], Ti? B Tra[4], Olivier Girardin[2] and Emmanuel Frossard[5]

[1] University of Cocody, Abidjan, Ivory Coast. Email: lucien.diby@ipw.agrl.ethz.ch
[2] Swiss centre for scientific research, 01 BP 1303, Abidjan, Ivory Coast. Email: olivier.girardin@csrs.ci
[3] The Africa Rice Center (WARDA). Email: r.carsky@cgiar.org
[4] National institute of technology FHB, Yamoussoukro, Ivory Coast
[5] Group of plant nutrition, swiss federal institute of technology, Zurich, Eschikon 33, CH-8315 Lindau. Email :emmanuel.frossard@ipw.agrl.ethz.ch

Abstract

The influence of soil properties on yam growth and tuber production is discussed. Two species were grown with or without fertilization in two agro-ecological zones (forest and savannah) in Ivory Coast. Leaf area index (LAI), and dry matter (DM) accumulation and partitioning among plant parts were measured during plant growth. These data were tested against a model describing the growth of *D. alata*. DM production of all plant parts of *D. alata* was always higher than those of *D. cayenensis-rotundata* for all sampling dates and for both zones. This was explained by the higher LAI of *D. alata* which intercepted a higher amount of radiation. Fertilizer application increased DM production of both species in the savannah site only. A good agreement between measured and simulated DM was noticed only for *D. alata* in the forest zone site, and for all other treatments in both sites the DM pattern was similar and with overestimations. The overestimations were attributed to the differences in soil fertility (e.g. higher pH, higher clay and organic matter in forest) between zones and to genetic differences between species.

Media summary

An investigation of the growth curves of yam using a simulation model revealed how soil factors limit the potential yield of two main yam species in West Africa.

Key Words

Crop physiology, Ivory Coast, modeling, YamSim.

Introduction

Yam *(Dioscorea spp.)* is a tuber crop widely cultivated in the humid and sub-humid lowland regions of West Africa and the Caribbean (Onwueme and Haverkort 1991). More than 90% of the worldwide production (40 Mt fresh tubers/year) is being produced in West Africa (FAOSTAT 2004). Yam is grown in traditional cropping systems as the first crop after virgin forest or after a long period of fallow yielding about 10 t of fresh tuber/ha/year (Carsky et al. 2001). The potential yield of one of the most important species, *D. alata*, is estimated between 60 and 75t/ha year (Zinsou 1998**)**. The potential yields of other *Dioscorea* species have not been published. Further, very little research has been conducted on the crop physiology of yam. Research is therefore needed to assess the factors that limit the yield of yam. Onwueme and Haverkort (1991) recommended a modeling approach to achieve a greater understanding of the processes influencing yield formation in yam. YamSim (Yam Simulator) is the only published model developed and calibrated with actual data sets to describe the growth of yam (Rodriguez 1997). This work was undertaken (i) to evaluate the effect of soil properties on the growth and tuber dry matter production of two main yam species and (ii) to test YamSim against field data recorded in the Centre of Ivory Coast.

Materials and methods

Location

The field experiments were conducted at the Swiss Centre for Scientific Research Field Station, Bringakro in the Centre of Ivory Coast. The station is situated 150 m above mean sea level at 6?40’ N and 5?09’ W. The experiments were carried out from May to December 2001. The area is located at the borderline of two agro ecological zones: the Guinea savannah in the north and the tropical moist forest in the south. One site was chosen from each zone and the sites were seven kilometres apart from each other. Soil surveys were made in each site by sampling the top soil (0-20 cm) and routine soil analysis was made (Table 1).

Table 1: Soil properties for 0-20 cm layer in the experimental fields. Samples were collected and analysed in 2003.

Soil chara cter	Units	Forest site	Savannah site
pH (H_2O)	1:2.5[a]	6.4	5.1
Exchangeable Ca	meq/100g	4.2	1.5
Exchangeable Mg	meq/100g	1.7	1.2
Exchangeable K	meq/100g	0.3	0.1
Cation Exchange Capacity (CEC)	meq/100g	8	3
Assimilable P (Olsen method modified by Dabin)	mg/kg	11	10
Total N (Kjeldhal method)	g/kg	0.73	0.67
Total C (Walkley-Black Method)	g/kg	11.5	7.3

[a]Ratio soil : water

Plant materials

The cultivars 95/00010 and 89/02461 belong respectively to the species *D. alata* and *D. cayenensis-rotundata* and are the main edible species in West Africa. These are the improved cultivars selected by the International Institute of Tropical Agriculture in Ibadan, Nigeria for their aptitude to be produced with “minisett” technique and without staking. Setts were obtained by cutting the whole tuber up into seeds weighing 100g. They were finally treated with a mixture of 13% Oxamyl 240g/L (nematicide), 2.5% Imazalil sulfate 40g/L (fungicide) and 2.7% Deltamethrine 12.5g/L (insecticide) two hours before planting.

Fertilizers

One dose of fertilizer was applied and compared with a control without fertilizer. The dose consisted of 240-11-269-8.5-11-66 kg/ha of N-P-K-Ca-Mg-S respectively, and was applied with an aim of obtaining yield of about 60 tons of fresh tubers per hectare (Carsky et al. 1998). Fertilizer was applied in two equal splits on the opposite side of each ridge at emergence (approximately 47 days after planting) and one month before maximum biomass growth (approximately 75 days after planting).

Experimental design and cultural practices

In each site, two factors (fertilizers and yam species) with two levels each arranged in a completely randomised design with four replicated blocks were established. A block was 14m x 12m and contained four sub-plots 2m apart. The size of the subplot was 5m x 6m. Ridges were made in each sub-plot with hoes at the density of 2 per m^2, and then one sett was planted per ridge. Plants were sampled in an effective sub-plot area of 4m x 2m which contained 16 plants. Four plants were randomly sampled at four different physiological stages: the first at around 90% germination occurring at 47 days after planting (DAP), the second at maximum biomass growth occurring at 107 DAP, the third at maximum tuber growth occurring at 160 DAP, and the fourth at harvest time at 190 DAP.

Data collection and analysis

Plant samples were separated into vines, leaves and tubers, and their dry matter content was measured. Dry matter was determined by drying samples in an oven at 70?C till obtaining constant weights (72 hours for tubers and 48 hours for other parts). Leaf area index (LAI) was measured with a scanner linked to a computer program (*WinRHIZO regular version)* giving direct results. Data were analysed with the SAS programme, version 8.02. The analysis of variance (ANOVA) of fresh tuber at harvest was performed using the GLM procedure. The MEANS procedure was used to calculate the means of the four blocks for each treatment.

Model

Data sets obtained were compared with results computed by YamSim (Rodriguez 1997). YamSim has been adapted from SUCROS (Simple and Universal CROp growth Simulator) (Spitter et al. 1989) and it estimates potential crop growth assuming no limitations. YamSim calculates the carbohydrates as a function of the CO_2 assimilated by single leaves, the radiation absorbed by the canopy and the crop leaf area. YamSim has been calibrated with *D. alata* grown in Costa Rica (Gu?piles) under optimal hydric and nutrient conditions using daily total solar radiation, daily average air temperature and humidity recorded from day 152 to 336 in 1993. Growth rates, LAI, development and partitioning rates were based on weekly growth analyses carried out in 1992. The data sets of DM for validation consisted of 10 samples replicated 12 times from experiments conducted in Gu?piles in 1992.

Results

Leaf area index

In all the treatments and in both sites, a similar growth pattern was observed for the LAI (Figure 1), which increased slowly until 50 DAP, and then increased rapidly until 107 DAP. The LAI achieved its maximum value from 107 to 160 DAP, which then declined in the last month of growth. Significant differences were noticed between LAI in both species, with a higher LAI in *D. alata.* Only LAI of *D. alata* in the forest site was well estimated by the model, and that of *D. cayenensis-rotundata* was always overestimated after 47 DAP in both sites. In the savannah site a good trend was observed only for *D. alata* with fertilizer at 47, 160 and 190 DAP.

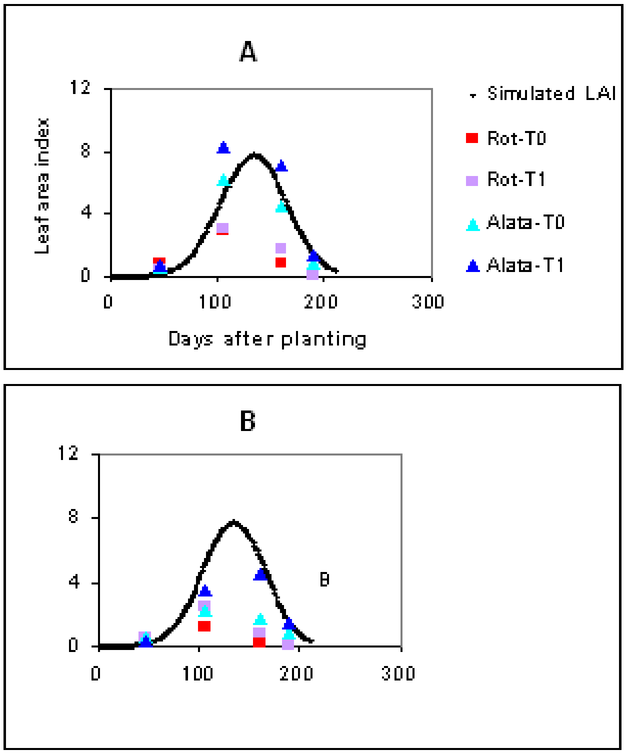

Figure 1: Observed and simulated LAI over the growing season of two yam species with and without fertilizer in a forest site (A) and a savannah site (B). Rot-T0 = *D. cayenensis-rotundata* without fertilizer, Rot-T1 = *D. cayenensis-rotundata* with fertilizer, Alata-T0 = *D. alata* without fertilizer, Alata-T1 = *D. alata* with fertilizer.

Dry matter production and partitioning

Total DM for all treatments increased until 160 DAP followed by a decrease at both sites (Figure 2). DM was higher for *D. alata* with fertilizer in both sites. Before 107 DAP, the major portion of DM production was allocated to the leaves and the vines (not shown). Tuber initiation began at 50 DAP and grew slowly till 100 DAP, with a linear increase in tuber DM production (not shown). A good agreement was achieved between DM predicted by the model and the measured in the forest site for *D. alata* with fertilizer at 107, 160 and 190 DAP. For all treatments at both sites, the model did not predict the LAI and DM well.

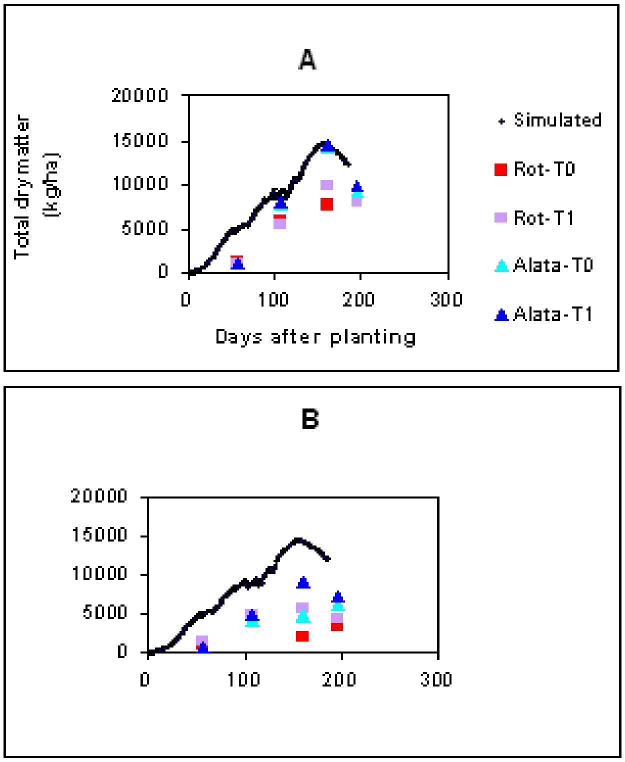

Figure 2. Observed and simulated total DM production over the growing season of two yam species with and without fertilizer in a forest site (A) and a savannah site (B). Rot-T0 = *D. cayenensis-rotundata* without fertilizer, Rot-T1 = *D. cayenensis-rotundata* with fertilizer, Alata-T0 = *D. alata* without fertilizer, Alata-T1 = *D. alata* with fertilizer.

Final yield

Table 2 shows differences between the mean yields of the two levels of fertilizers in each site for both species. Fertilizer did not have any effect on *D. alata cv. 95/00010* in the forest site; however it increased the yield significantly in the savannah site. For *D. cayenensis-rotundata*, the application of fertilizer enhanced yield only in the savannah site while lower yields were obtained in the forest site.

Table 2. Effect of fertilizer on the yield of two yam species cultivated in two agro-ecological sites.

	Mean yield t/ha [a]					
	D. alata cv 95/00010			*D. cayenensis-rotundata cv 89/02461*		
Site	With fertilizer	Without fertilizer	*Difference*	With fertilizer	Without fertilizer	*Difference*
Forest	51.53	50.72	0.81^{ns}	27.25	30.32	-3.07*
Savannah	30.21	23.76	6.45*	14.02	10.19	3.83*

Difference	21.32**	26.96**	13.23**	20.13**

[a] Average of four replications. ** = significant at 1% level, * = significant at 5% level, [ns] = non significant.

Discussion

Higher LAI in the forest site might have been due to the loose structure and the high organic matter content of the soil which allowed increased leaf production and leaf area duration. As a consequence, a high amount of radiation was intercepted contributing to an increase in total DM and yield. The yield difference between yam species could be attributed to genetic specificity explaining the variability of growth, C fixation and nutrient uptake between species. The model overestimated LAI and total DM for all treatments at both sites, except for *D. alata* at the forest site. The most obvious explanation for overestimations was that the model was calibrated with data recorded on *D. alata* under optimum growth conditions (Rodriguez 1997), in contrast to sub-optimal conditions found in our field experiments. Furthermore, differences in soil fertility between both sites as well as the genetic differences among species suggested the necessity to recalibrate and revalidate the model with data obtained from same experimental area and for each species.

Conclusions

LAI, tuber DM and final yield were influenced in both species by the soil characteristics. The values for these parameters were significantly increased in the most fertile soil (forest site), however the soil effect was more marked for *D. alata*. Fertilizer application enhanced the yield only in the savannah site, whereas in the forest site slight or even negative responses were observed. YamSim had a poor performance when tested against the experimental data sets recorded in our experiment, except for a good agreement for *D. alata* in the forest site for which and where it had been calibrated and validated. YamSim is therefore specific to the site and to the species. The model needs further improvement for better predictions of yam growth and productivity in different environments and for different species.

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