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Research article

Unexpected N and K nutrition diagnosis in oil palm smallholdings using references of high-yielding industrial plantations

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Abstract – The rising demand for vegetable oil is inducing an expansion of oil palm cultivation in the tropics. In southern Cameroon oil palm smallholdings have been growing fast since the mid-1990s. Now, industrial plantations and smallholdings exist side by side. The current technical advice given to smallholders originates from agroindustrial practices. However, industrial plantations were created by planting on previous forest cover with no food intercrops, whereas for smallholdings food crops are a common previous cover and an intercrop during the juvenile phase. Technical advice used for industrial plantations may therefore not apply to smallholdings. Huge yield differences are observed in oil palm smallholdings, ranging from 2 to 14 $t \cdot ha^{-1}$ of fresh fruit bunches, while in industrial plantations yields average 14-16 $t \cdot ha^{-1}$. As no agronomic evaluation to date had explained those variations, we carried out a regional agronomic diagnosis of N and K nutrition on smallholder plots planted with selected oil palms. To prepare leaf samples and determine mineral contents, we used the same standardised method and the same laboratory as the regional industrial plantations. We compared smallholder leaf N and K contents with reference models of critical mineral contents, previously built with data from the high-yielding industrial plantations. Statistical links were also established between nutritional status and practices. Our results showed two groups of oil palm plantations: a group with N deficiencies ranging between 80 and 90% of the reference and K deficiencies ranging from 45 to 90% of the reference, and another group with satisfactory N and K status. The N deficiency was statistically linked to food cropping as the previous cover or as an intercrop, whilst K deficiency was qualitatively linked to an absence of K fertilisation. N deficiency is a specificity of oil palm smallholdings that had never been encountered in African industrial plantations. To conclude, the current technical advice given to smallholders is not well adapted.

mineral nutrition / regional agronomic diagnosis / oil palm smallholdings / *Elaeis guineensis* / Cameroon / nitrogen / potassium / nutritional status trends in oil palm plantations

1. INTRODUCTION

The world oilseed market is characterised by rising demand for vegetable oils and fats for human consumption, the cosmetics industry and, recently, for use as agrofuel (Oil World, 2008). As oil palm (*Elaeis guineensis* Jacq.) produces five to seven times more oil per hectare than all other oil crops, new oil palm planting is currently booming in the humid tropics (Sheil et al., 2009). Plantations are being set up as much by large companies as by smallholders, after forest clearance or on previous fallow or savannah. This expansion is already raising environmental and social issues that cannot be solved without tackling the sustainability of agricultural efficiency (Phalan et al., 2009).

In Cameroon, and more generally in Africa, oil palm plantations are managed both by agroindustrial companies, which have their own oil mills, and by smallholders, who deliver their fresh fruit bunches to an industrial mill, or process their own production on a small scale. Oil palm smallholdings have been booming since the mid-1990s, notably since 1993 with a trebling of selected oil palm areas (Hirsch, 2000; Bakoumé et al., 2002). The increase in areas has led to a surge in national production and rural development (Fèvre, 2003), though without being able to meet ever-increasing national demand for edible oil. As a result, the total area of smallholdings planted with selected oil palms exclusively of the *tenera* type is estimated at 40 000 ha (Rafflegeau, 2008), but the area of unselected oil palm smallholdings, planted with open-pollinated progenies of selected palms, remains unknown as it has never been evaluated.

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However, a survey by Bakoumé et al. (2002) uncovered differences in yields within oil palm smallholdings, ranging from 2 to 14 t·ha^{-1} of fresh fruit bunches, while the three private agroindustries in Cameroon average from 14 to 16 t·ha^{-1} fresh fruit bunches for their industrial plantations. Another survey also revealed considerable diversity in farmer practices in terms of the previous crop cover, the type of planting material, intercropping, legume cover crop and fertiliser applications (Cheyns and Rafflegeau, 2005).

Among smallholder practices, the choice of planting material is the most decisive element for productivity per hectare in oil palm plantations. Indeed, given the segregation of traits and inbreeding, unselected oil palms produce oil yields not exceeding 40% of those produced by selected oil palms grown under the same conditions (Cochard et al., 2001). All the other cited practices can affect the mineral nutrition of palms, which is a second decisive element (Hartley, 1988; Corley and Tinker, 2003; Turner and Gillbanks, 2003): in particular, satisfactory mineral nutrition enables selected oil palms to fulfil their genetic potential under the local pedoclimatic conditions of a plantation. In order to monitor mineral nutrition in mature oil palm plantations, agroindustrial companies carry out leaf analyses in accordance with a standardised international procedure, acknowledged to be an efficient tool for annual monitoring of mineral nutrition per plot (Caliman et al., 2003; Foster, 2003).

However, such monitoring does not exist for smallholdings, and to date no agronomic evaluation has been able to explain the large differences in the yields of oil palms grown under the agricultural conditions in smallholdings. In order to uncover the factors determining yield differences (Valantin-Morison and Meynard, 2008), we sought to establish a regional agronomic diagnosis of mineral nutrition in mature oil palm smallholdings planted with selected palms in the Edea oil palm-growing area of southern Cameroon, where agroindustrial and smallholder production exist side by side. Using the on-farm regional agronomic diagnosis method (Doré et al., 2008), we assessed the agronomic sustainability of smallholder cropping systems, without reference to their agri-environmental sustainability, which would have required us to construct indicators (Bockstaller et al, 2009).

We diagnosed mineral nutrition by carrying out leaf analyses in smallholder plots using the methodology applied in industrial plantations, and we compared them with reference models of critical contents for mineral nutrients depending on palm age, which are internationally used by agroindustrial companies. We set out to check whether the mineral nutrition of palms was a yield-limiting factor in smallholdings.

2. MATERIALS AND METHODS

2.1. Regional agronomic diagnosis methodology

In order to assess mineral nutrition in oil palm smallholdings, we adapted the regional agronomic diagnosis method proposed by Doré et al. (1997) to the case of a perennial crop. The method is based on a conceptual model of crop yield build-up, linking the status of the cultivated stand at key moments of yield build-up, the environmental status, and the practices used. We focused on the nutritional status of mature oil palms and on the environmental status and practices likely to explain it (Rafflegeau, 2008). As a perennial crop was involved, the practices considered were planting, management during the juvenile phase and management during the production phase, for which the key stages were identified through surveys. We performed a variance analysis with XLSTAT 2009 1.01 software to establish statistical relations between the different variables considered, in order to afford a degree of robustness to the relations revealed (Doré et al., 2008).

This agronomic diagnosis led to the discovery of relations between leaf mineral content levels in mature oil palm plantations and certain practices, particularly planting and management during the juvenile phase. Once the sequence of different technical operations over time since planting was established for each of the analysed plots, it was possible to reconstruct hypothetically the nutritional status trends that resulted from major types of technical management since planting. The concept of nutritional status trends in oil palm plantations is similar to that proposed by Le Bissonnais and Martin (2004) for trends in soil surface condition which constitute the assumed evolution of erosion risks in plots over time: it refers to environmental status in plots with annual plant stands following on from each other in time. The concept of nutritional status trends in oil palm plantations is also similar to that proposed by Lamanda et al. (2006) to reconstruct the temporal dynamics of the structure of agroforest stands: this case is nearer to our situation since it involves changes in the status of a perennial plant stand, albeit multispecies and over a long time period.

2.2. Study region

Given its small size (Fig. 1), the Edea region in southern Cameroon can be considered climatically uniform. As the oil palm, *Elaeis guineensis* Jacq., originates from the Gulf of Guinea, pedoclimatic conditions in southern Cameroon are the most suitable for it in the country. The Edea region has a hot, pseudo-humid tropical climate, according to the classification by Génieux in 1958 (Barral et al., 2004), with an average annual water deficit under 200 mm. As in the other oil palm-growing regions of Africa, the main climatic limiting factor is insufficient sunlight at the height of the wet season (Quencez, 1996). The soils are of the yellow ferralitic type, rather poor in organic matter, with a sandy texture southwest of the town of Edea and loamy sand southeast of the town (Barral et al., 2004).

Today, the Edea region is a major palm oil production area (Bakoumé et al., 2002) (Fig. 1). Numerous oil palm smallholdings exist alongside three of the five agroindustrial companies operating in Cameroon: *Société Africaine Forestière et Agricole du Cameroun* (SAFACAM), *Société des Palmeraies de la Ferme Suisse* (SPFS) and *Société Camerounaise de Palmeraies* (SOCAPALM). These three private agroindustries establish contractual relations with small farmers, in a radius of about 30 km around oil mills, to collect their production

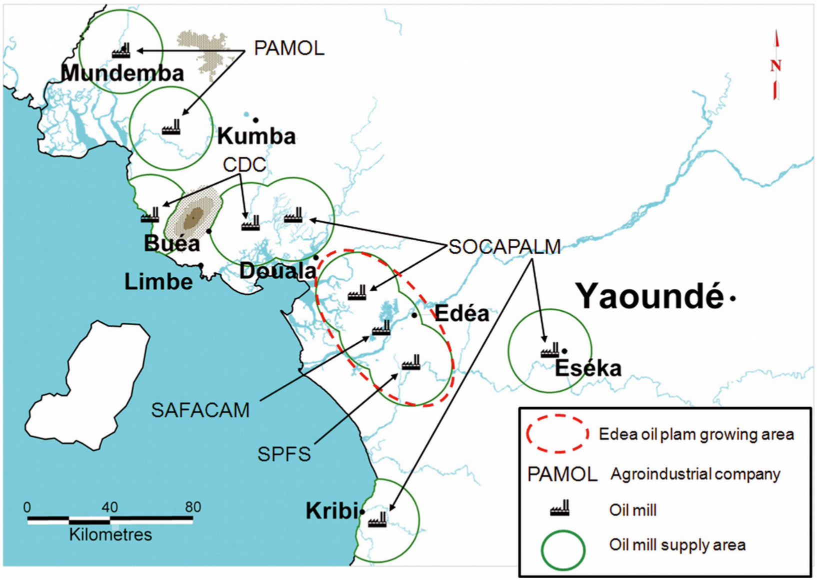

Figure 1. The existence of oil palm smallholdings and industrial plantations in a small, relatively uniform region in terms of physical and human environment (Bassa people) justified the choice of the Edea oil palm-growing area for this study.

and offer them opportunities for technical advice and purchases of fertiliser and selected planting material (Cheyns and Rafflegeau, 2005). From 1978 to 1991, funds from the national rural development fund (FONADER) enabled the development of selected oil palm smallholdings (Hirsch, 2000), backed up by know-how from SOCAPALM, which was a State-owned oil palm development company at the time. At the beginning of the 1990s, small-scale processing of smallholder fresh fruit bunches also developed under the impetus of non-governmental organisations, thereby offering growers a further outlet opportunity. At the same time SPFS and SAFACAM also began buying fresh fruit bunches from the nearest farmers for processing in their oil mills.

Oil palm is the main tree crop in the Edea region (Barral et al., 2004). It exists alongside food intercrops, which are intended for home consumption and the surplus for sale. The most widespread food crop system consists of several short-cycle crops, e.g. maize, groundnut, pistachio, marrows, etc., sown with a combination of tubers such as cassava, new cocoyam and taro, or with cassava alone. The short-cycle crops are harvested three months after the tubers are planted, which then occupy the space completely until they are harvested, 10 to 18 months after planting. This widespread food crop system is also reproduced entirely in the interrows of juvenile oil palms, or partially with no tubers.

2.3. Crop management sequence in oil palm smallholdings

The selected oil palm grown in Africa is a hybrid of the *tenera* type, obtained by crossing the *dura* and *pisifera* types, whose biological characteristics and management in plantations have been described in several books (Hartley, 1988; Corley and Tinker, 2003; Turner and Gillbanks, 2003). In the Edea region, SOCAPALM disseminated a crop management sequence among smallholders who benefited from funds provided by the FONADER project from 1978 to 1991. At the time, the three agroindustries disseminated the same crop management sequence among the growers in their respective supply areas. This normative advice was derived from the results of on-station research and from the knowledge acquired in industrial plantations (Tab. I). It is very similar to agroindustrial practices: planting on forest with manual felling and windrowing techniques, a legume cover crop (*Pueraria javanica*), annual nitrogen fertilisation in the juvenile phase, then potassium or potassium and magnesium in the production phase. In the initial phases of the FONADER project, the farmers followed that advice. Thereafter, they sought to adapt it to their own constraints, opportunities and planting rates. At the same time, certain beneficiaries of the FONADER project started to set up oil palm plantations without planting funds, whilst new growers followed their example outside the zones covered by the FONADER project, and outside the supply areas of the industrial oil mills. This gave rise to substantial variability in practices, notably planting on previous long-cycle food crops (tubers) and intercropping with those crops during the juvenile phase (Cheyns and Rafflegeau, 2005).

2.4. Experimental design

We characterised the variability in mineral nutrition in oil palm smallholdings by sampling 30 mature plots planted with selected planting material. The plot was defined as a unit of space, planting year and type of planting material. Enquiries about the supplier of the planting material made it possible in theory to discard plots planted with unselected material. The

Table I. Crop management sequence recommended in 1978 for oil palm smallholdings planted with selected palms (Rafflegeau, 2008).

Setting up	– Previous forest cover – Felling and chopping up with a chainsaw – Manual windrowing – 9-m equilateral triangle planting design – Planting at the start of the wet season (May to July) with selected *tenera* plants 1.20-m tall in 40 × 40 cm polybags after 12 months in the nursery – Installation of wire guards against rodents – Sowing of a legume cover crop, *Pueraria javanica*
Juvenile phase (years 1, 2, 3)	– Regular weeding of the circle around each palm – Slashing of the legume cover crop – Elimination of invasive weeds – Urea: 200 g/palm/year in year 1, 400 g/palm/year in years 2 and 3 – Intercrops forbidden
Production (⩾year 4)	– KCl: 500 g/palm/year – Crown upkeep (pruning of dry fronds, cutting of epiphytic ferns) – Weeded circle upkeep – Harvest path maintenance – Interrow slashing – Harvesting every 10 to 15 days: fresh fruit bunch cutting, transport to edge of field and collection of loose fruits
Replanting	– Felling of the oil palm plantation once the palms are too tall for harvesting with a 12-m pole, or earlier if mortality exceeds 25% – Replanting

plots were chosen in such a way as to cover the most contrasting range possible of agronomic situations and ages (4 to 27 years) for mature oil palm smallholdings in the Edea region.

Planting material conformity was checked by cutting fruits twice, in April–May 2005 and October–November 2005, to discard plantations containing unselected palms (Cochard et al., 2001). In each plot, a smaller plot of 30 palms (2 rows of 15 palms or 3 rows of 10 palms) was marked out in a uniform zone without any missing palms for leaf sampling in January and February 2005 using the standardised sampling, preparation and analysis method (Martin, 1977; Ochs and Olivin, 1977; Bonvalet, 1981). Leaf analyses focused on nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca) and chlorine (Cl).

2.5. Choice of variables

A scheme for determining oil palm standing bunch yields constructed by several agronomists specialising in the oil palm as part of a thesis (Rafflegeau, 2008) links the mineral nutrition level of oil palms in a mature oil palm smallholding in Cameroon with key practices of the crop management sequence (Tab. II): location and previous cover (soil type, topography, cropping history of the plot prior to planting), management in the juvenile phase (*Pueraria* cover crop, food intercrops, N fertilisation), and management in the production phase (P fertilisation). It also specifies that leaf mineral nutrient contents depend on genetic type (*tenera* obtained by Deli × La Mé crossing) and age.

We considered that food crops, notably tubers, grown as the previous crop cover or intercropped with palms during the juvenile phase had the same effect on mineral fertility in the plot. Given that food crops do not receive any fertilisation, we relied on experimental results showing the negative effect of tubers on soil mineral fertility (Ollivier et al., 1994) to distinguish between two types of food crop. We therefore adopted two categories of previous cover and food crops (Tab. II):

- "forest + few or no food crops", corresponding either to previous forest without food intercrops during the juvenile phase, or previous forest followed by 1 or 2 short cycles of food crops (maize, groundnut, marrow, etc.) before or after planting the oil palms;
- "many food crops", corresponding either to previous forest then intercropping in years 1 and 2 of the oil palm plantation with long-cycle crops (tubers), or previous food crops over several years, including a dense stand of tubers.

For the statistical analysis, we performed an ANOVA per element, as leaf contents are quantitative data, whereas the explicative variables are all qualitative data.

2.6. Interpretation of leaf contents measured in oil palm smallholdings

In mature industrial plantations, leaf analysis results are compared with the curves for yield responses to fertilisation from long-term trials, usually conducted in the actual industrial plantations. Relations are thus established between leaf contents, fertiliser applications and yields, with a view to determining the levels of any deficiencies in relation to a critical level (Hartley, 1988; Corley and Tinker, 2003) and drawing up fertiliser schedules. This critical level is defined as being the leaf content level of a given nutrient above which any further

Table II. List of variables included in the survey, analysis and observation of oil palm smallholdings in the Edea region, Cameroon (November 2004 to March 2006).

Variables	Modalities
Oil palm plantation age	Number of years from the planting year
Leaf contents	Leaf N, P, K, Mg, Ca, Cl contents expressed as a percentage of dry matter (% DM)
Soil texture	Sandy or loamy sand Clay soils
Topography: interpreted as soil depth and risk of erosion assessment	Ridge or slope: shallow soil with risk of erosion Plateau or bottom of slope: deep soil without risk of erosion
Previous cover + food crop	Forest + few or no food crops Many food crops
Pueraria cover crop in juvenile phase	With or without *Pueraria*
Juvenile phase: N application (urea)	Application or no application
Production phase: KCl application	Without KCl Irregular KCl (some years) Regular KCl (every year)

application of fertiliser is no longer economically compensated for by the additional production that might result from it (Caliman et al., 1994).

Leaf analyses, which have been used with success in most industrial plantations worldwide for several decades, are a reliable indicator for annual guidance of mineral fertilisation (Caliman et al., 2003). They can also be combined with mineral analyses of the rachis, which provide a more precise indication of potassium availability in the plant (Foster and Prabowo, 1996, 2002), but the three oil palm agroindustrial companies in the Edea region did not carry out rachis analyses in 2005. The three companies provided us with their leaf analysis results for N, P, K, Mg, Ca and Cl free of charge: 1993 to 2003 for SPFS (11 years), 1992 to 2004 for SAFACAM (13 years), and one year (2000) for SOCAPALM. The three companies grew the same selected planting material originating from the La Dibamba oil palm research centre (CEREPAH). We assumed that mineral fertilisation was properly managed and that the leaf contents measured were close to the critical levels. By comparing those figures with the critical levels given in the literature (Ng, 1977; Pacheco et al., 1985; Tampubolon et al., 1990; Caliman et al., 1994), we constructed regional models of critical levels per nutrient depending on the age of the oil palm plantation. The regional models were used to compare smallholder plots of different ages by expressing measured contents as a percentage of the model value for the same age. When a smallholder plot displayed a content that was more than 90% of the regional model, the nutrition level for the mineral nutrient in question was considered satisfactory.

3. RESULTS AND DISCUSSION

3.1. Limitations of the study

Of the initial sample of 30 smallholder plots, only 18 were planted with selected oil palms of the Deli × La Mé *tenera* type produced by CEREPAH, which are usually planted in industrial plantations. The results presented in this article therefore only concern those 18 smallholder plots, which nonetheless reflect the variability sought for in terms of palm age and contrasting agronomic situations.

In oil palm smallholdings, mineral deficiencies only involved the nutrients N, P and K. However, we postulated that the P deficiency was induced by N deficiency, for two reasons. Firstly, the literature reports that oil palm P nutrition closely depends on the leaf N/P balance, whatever the environment (Caliman et al., 1994). Secondly, in the industrial plantations of Edea, the absence of phosphate fertiliser applications does not lead to P deficiency. Moreover, N and K are known to be by far the two main minerals taken up by oil palm (Ng, 1977). We therefore chose, in this article, to focus on the results of leaf N and K contents.

Competition from weeds for mineral nutrients during the oil palm juvenile phase was not taken into consideration for lack of precise data. Competition from weeds in the mature phase can be considered secondary, since their growth under shade is much reduced.

3.2. Regional models of critical N and K levels depending on plantation age

For N, a regional critical leaf level model (Nc) was built by seeking the best regression of all spots for two industrial plantations, SAFACAM and SPFS, as there were not enough data from SOCAPALM to use them. Our model showed the classic decrease in leaf N content as oil palms age (Fig. 2):

$$Nc = 28924 - 0.0109\ n - 0.0007n^2$$

where Nc is the nitrogen critical level (% DM)
n is the age of the plantation (years)
$r^2 = 0.6466$ which is highly significant*** for 31 spots.

Our model was also very close to the Indonesian critical leaf N content model depending on age (Tampubolon et al., 1990). In fact, the average variance of the Indonesian model from 3 to 19 years old amounted to 1.75% of our model. We also observed that industrial plantations that had been set up

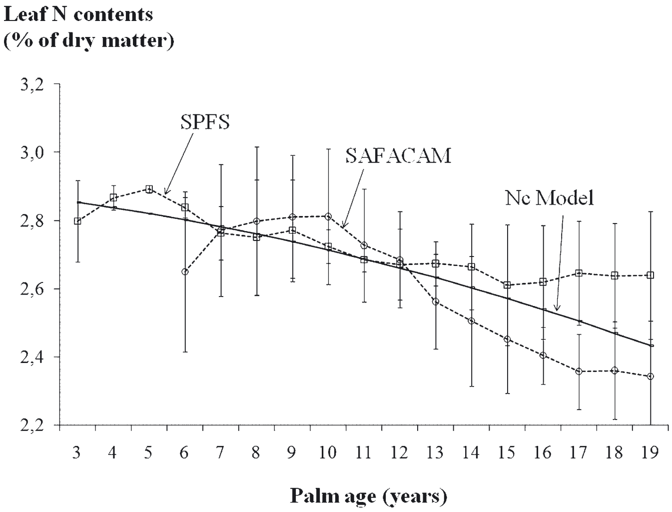

Figure 2. Leaf N content as a % of dry matter for industrial plantations depending on palm age (years); our regional model for the critical leaf N level (Nc model) shows the classic decrease in leaf N content as oil palms age. Our model was built by seeking the best regression of all spots for both industrial plantations.

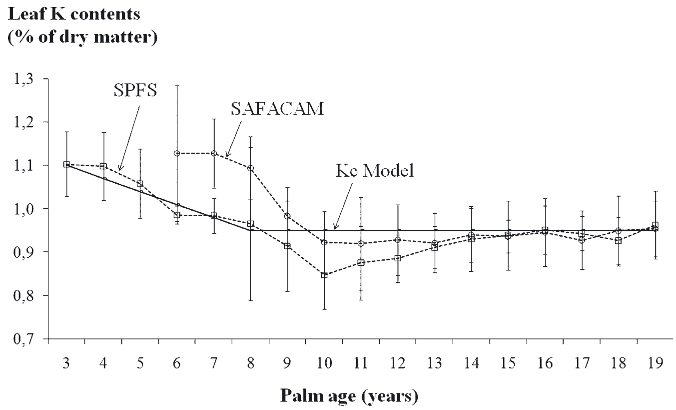

Figure 3. Leaf K contents as a % of dry matter for industrial plantations depending on palm age (years); our regional model for the critical leaf K level (Kc model) shows the classic decrease in leaf K contents from 3 to 8 years old and the following stabilisation at 0.95%. This model was constructed from the literature (Caliman et al., 1994) and from SPFS data.

on previous forest with *Pueraria* sowing and N fertilisation in the juvenile phase only, had a satisfactory N nutrition level where their leaf N contents were higher than 90% of the Indonesian Nc model. Nitrogen fertiliser applications in the production phase are not necessary to achieve sustainable satisfactory N nutrition levels for most industrial plantations in Africa (Caliman et al., 1994) and Brazil (Pacheco et al., 1985), unlike Asian oil palm plantations where they are usual (Ng, 1977).

For K, the critical leaf level (Kc) is 0.95% of dry matter in mature plantations in Cameroon and, more generally, in first-generation oil palm plantations (Caliman et al., 1994). In fact, such oil palm plantations planted on previous forest benefit from K being returned to the soil from forest debris, which ensures a satisfactory nutritional level for 6 to 11 years without fertiliser applications. The average leaf K contents at SAFACAM and SPFS tally with the literature (Caliman et al., 1994): they are high at the start of production, due to the systematic previous forest, then tend towards the critical level (Fig. 3). The regional critical K level model that we constructed to interpret the leaf analyses for oil palm smallholdings therefore resulted from the information provided by the literature (Kc = 0.95 starting from the mature phase) and also from SPFS data, which were the only ones available to show the Kc slope as production rises from 3 to 8 years. The SAFACAM curve suggested higher native K fertility in SAFACAM soils and/or better restitution from the forest. There were not enough data from SOCAPALM for use in constructing the following model:

$Kc = -0.03\,n + 1.19$ from 3 to 8 years
$Kc = 0.95$ from 9 years onwards
where Kc is the potassium critical level (% DM)
and n is the age of the oil palm plantation (years).

3.3. Variability in smallholder practices

The survey work undertaken to reconstruct the history of plots through the technical choices made by growers confirmed the greater variability of practices in oil palm smallholdings planted with selected palms, which tallied with the findings of Cheyns and Rafflegeau (2005) (Tab. III). Overall, the crop management sequence initially recommended by the agroindustrial field advisers was only fully applied in 2 of the 18 study plots.

3.4. Four mineral nutrition situations in mature oil palm smallholdings: satisfactory N and K, N deficiency, K deficiency, and N and K deficiency

Figure 4 shows the results of leaf N and K analyses as a percentage of the previously described Nc and Kc reference models (Figs. 2 and 3). In Figure 4, the recommended practices applied are presented to the right of each plot number: “F” symbolises the previous cover “Forest + few food crops”, “P” planting of a *Pueraria* cover in the juvenile phase, “N” application of urea during the juvenile phase and “K” regular applications of KCl in the production phase.

Of the typical crop management sequences in Table III, only the first (FPK) systematically led to satisfactory mineral nutrition for N and K. The first and the second typical management sequence with “Forest + few food crops”, e.g. FPK and F, guaranteed satisfactory N in the production phase whatever the other practices. Some agronomy trials (Caliman et al., 2002) show that good practices throughout the juvenile phase guarantee good levels of N nutrition when production begins. Lastly, of the eight plots which received regular K fertilisation during the production phase (FPK and NK), seven displayed a satisfactory level of K nutrition.

Table III. Four typical crop management sequences defined the variability of practices in oil palm smallholdings (Edea, Cameroon).

Variables				Typical crop management sequence		Plot numbers
Previous cover + food crop	*Pueraria* cover in juvenile phase	Urea in juvenile phase	KCl in production phase		Symbol	
Forest + few food crops (F)	with (P)	with (30, 31) without (27, 28, 33)	Regular (K)	Forest + few food crops, *Pueraria,* regular KCl	FPK	30, 31 27, 28, 33
Forest + few food crops (F)	without (except 45)	without (except 51)	Irregular or without	Forest + few food crops, little fertilisation	F	9, 25, 43, 45, 51
Many food crops	without	with (N)	Regular (K)	Many food crops, urea and regular KCl	NK	24, 26, 34
Many food crops	without	with (N) (except 20)	Irregular or without	Many food crops, little fertilisation	N	5, 20, 41, 49, 53

Shaded: practices corresponding to technical recommendations.

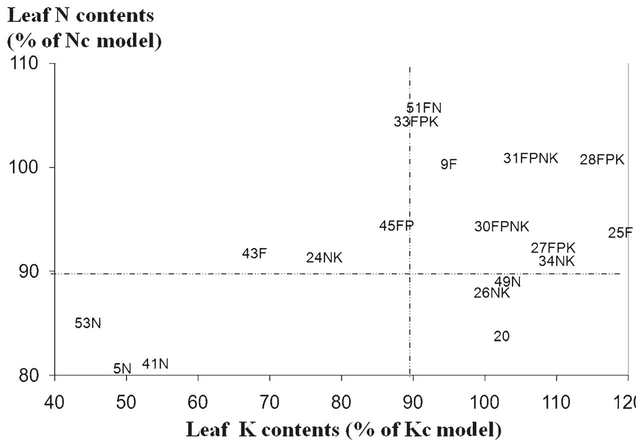

Figure 4. Leaf N and K contents in the 18 mature oil palm smallholdings surveyed, as a percentage of the Nc and Kc models. When the plot had a nutrient content over 90% of the model, the nutritional level for the mineral nutrient in question was considered satisfactory. Each of the 18 plots is positioned according to its N and K contents. All of the 10 plots with "Forest + few food crops" as previous cover (F) had a satisfactory N nutrition level and, of them, all the 5 plots also with *Pueraria* and regular KCl applications (FPK) had satisfactory N and K nutrition levels. Seven of the eight plots with regular KCl applications had a satisfactory K nutrition level. Of the seven plots with "Many food crops" as previous cover and the recommended applications of urea in the juvenile phase (N and NK), only two had a satisfactory N nutrition level.

3.5. Food crops in the juvenile phase: negative effect on oil palm nutrition

Of the seven plots with "many food crops" (long-cycle tuber crops before or during the juvenile phase) and "urea application" in the juvenile phase, plots 5, 41 and 53 displayed serious N deficiencies, and plots 26 and 49 had N contents approaching 90% of the reference, whereas nitrogen nutrition in plots 24 and 34 was satisfactory (Fig. 4). In plots 24, 26 and 34, application of the recommended urea and KCl fertilisation made it possible to partly compensate for the N and K deficiencies induced by tuber crops (Fig. 4). These results show ways of redressing the situation and encourage us to continue our investigations to gain a clearer understanding of the effects of food crops either as a previous cover or as intercrops.

The literature reports many trials of establishment intercropping in Africa and in Southeast Asia, usually showing earlier bearing where the soil has been tilled and has remained bare or with annual crops (Corley, 2003), but also lower subsequent yields than when a legume cover has been sown immediately (Chew and Khoo, 1977). In the juvenile oil palm plantations with cassava that we visited in Cameroon, there was not a minimum 2.3-m distance between the cassava plants and young palms, as in a trial in Nigeria (Okpala-Jose, 1995). Consequently, our results showed that a previous tuber crop, either at a high density or intercropped too close to oil palms, exported a large amount of N or N and K from the system, while *Pueraria* and previous forest cover returned a substantial amount of N and K to the system.

The first ANOVA confirmed the highly significant effect of the "Previous cover + food crops" variable on leaf N content in the production phase, with an estimated mean of 99% of the Nc model for the "Forest + few food crops" modality and of 84% for "Many food crops" (Tab. IV). Our data from only 18 plots, with many links between practice modalities, did not enable us to show a statistical effect of *Pueraria* cover and urea applications in the juvenile phase. For the same reason, the effects of all the practices were non-significant in the second ANOVA on leaf K contents, but practices concerning KCl applications in the production phase almost reached $P = 0.055$. There was no statistical link between the environmental status, soil depth and type of soil, and leaf N and K contents.

3.6. Two planting situations: without mineral deficiency, and with N or N and K deficiency

Consequently, with our knowledge of the way practices (planting, juvenile management, management in the production phase) affected N and K nutrition levels, we went back over the practices, after the event, to trace back hypothetically

Table IV. Results for both ANOVAs: leaf N content and leaf K content.

	Previous cover + food crop	*Pueraria* cover, juvenile phase	Urea, juvenile phase	KCl, production phase
Leaf N content as a % of the Nc model				
Estimated mean for recommended practice	99% A	89%	92%	94%
Estimated mean for non-recommended practice	84% B	94%	90%	89%
F probability and significance	0.001 ***	0.266 ns	0.509 ns	0.095 ns
Leaf K content as a % of the Kc model				
Estimated mean for recommended practice	97%	83%	83%	103%
Estimated mean for non-recommended practice	82%	96%	96%	76%
F probability and significance	0.316 ns	0.450 ns	0.287 ns	0.055 ns

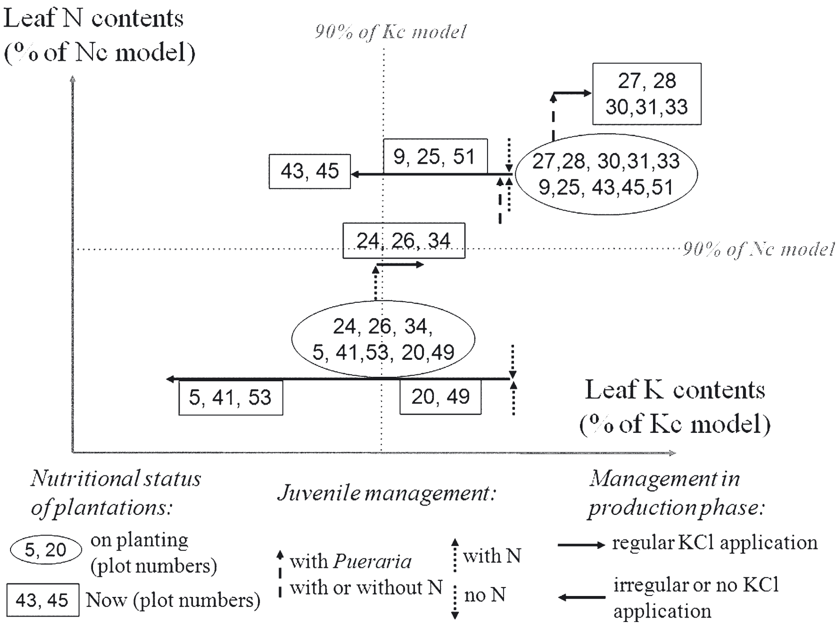

Figure 5. Qualitative reconstruction over time of the nutritional status of the oil palm plantations based on the known effect of the crop management sequences, and the current nutritional status defined by Figure 4. The following changes stand out: the recommended fertiliser applications (urea, KCl) only partly correct the nutritional status of plots planted with N or N and K deficiencies; regular KCl applications in the production phase maintain the satisfactory and sustainable nutritional status of plants planted without a deficiency. Two planting situations appeared for young oil palm plantations: satisfactory N and K nutrition, and deficient N or N and K nutrition.

the nutritional status trends for each of the plantations since planting (Fig. 5). We started from the four current situations defined in Figure 4: satisfactory N and K nutrition, N deficiency, K deficiency, and N and K deficiency. We considered that regular KCl applications in the production phase improved K nutrition. The same applied for N nutrition, improved by urea applications or by the existence of a *Pueraria javanica* cover crop in the juvenile phase. It turned out that two types of nutritional status must have existed at the time of planting and during the juvenile phase in the surveyed oil palm smallholdings, due to the previous crop cover or intercropping with food crops: (1) oil palm plantations with satisfactory N and K nutrition; (2) oil palm plantations with deficient mineral nutrition, without being able to specify whether the deficiency concerned only N or both N and K.

Native K soil fertility and the sum of K exports assessed by palm age can explain the K status scatter from 45 to 120% of the Kc model for the plots which did not receive regular KCl applications, whether their mineral nutrition status at the end of the juvenile phase was satisfactory; plots 43, 45, 9, 25 and 51, or deficient; plots 5, 41, 53, 20 and 49. For example, plots 5, 41 and 53 displayed a current severe K deficiency, but native K soil fertility should have been better at the time of planting for plots 41 and 53, which were 18 and 19 years old, respectively, than for plot 5, which was just 9 years old. In fact, plot 5 was located very close to the house so the old mother of the farmer had planted food crops each year for a long time before the oil palm plantation was set up. Two plots, 53 and 49, with the same type of soil and practices, were the same age but their current K status was different, which means that their native K soil fertility was different at the end of the juvenile phase. In fact, plot 49 was at the bottom of a slope with deep soil while plot 53 was on a ridge with shallow soil.

From N and K deficiency situations at planting time, it is possible to improve N nutritional status for three years, when urea applications are recommended in the juvenile phase,

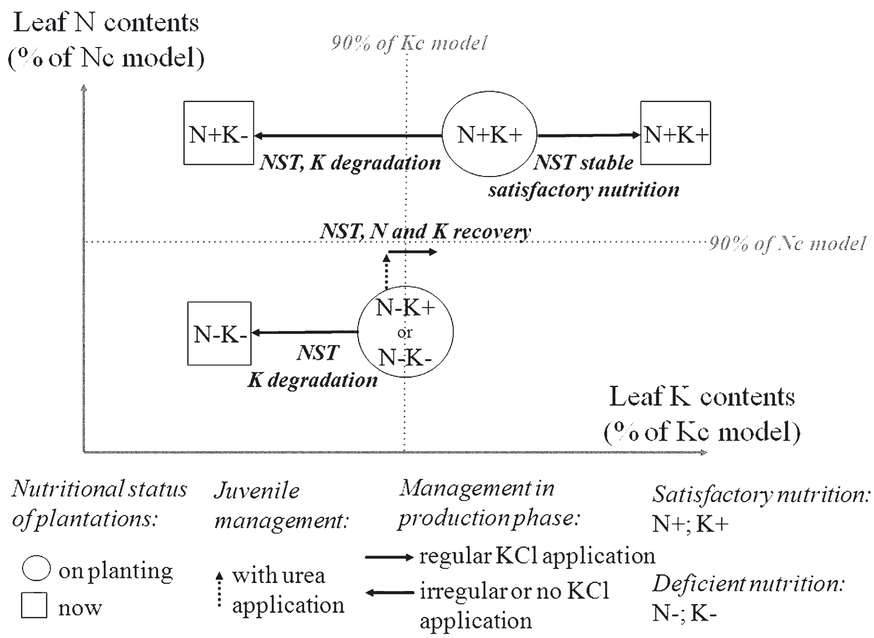

Figure 6. Nutritional status trends (NST) for the oil palm plantations based on the two planting situations. When mineral nutrition is satisfactory on planting (N+K+), either it remains durably satisfactory (*stable status, satisfactory nutrition*), or it gradually deteriorates towards a K deficiency (*K degradation*). The planting situations with a deficiency in N or N and K can be improved by urea then regular KCl applications (*N and K recovery*) or gradually deteriorate towards a K deficiency (*K degradation*).

whereas K is not limited in time but by the balance between K applications and K exports, as KCl applications are recommended during the production phase. So, with the current fertiliser recommendations, there is no chance of improving N status during the production phase and it might take a very long time to recover from severe K deficiencies.

The trends defined in this way for the 18 plots were grouped (Fig. 6) according to whether they had stabilised in a given nutritional status or were evolving from one status to another, e.g. deterioration or recovery. These deterioration or recovery trends for N and K nutritional levels led us to analyse the suitability of the recommended crop management sequence.

From the four typical crop management sequences, we reconstructed four nutritional status trends, which should correspond to four typical yield trends as yield and nutritional status are linked, as follows:

- FPK (Forest + few food crops, *Pueraria*, regular KCl) led to stable high yields;
- F (Forest + few food crops, little fertilisation) led to a yield degradation from high yields, more or less quickly depending on native K soil fertility;
- NK (many food crops, urea, regular KCl) led to a slow yield increase from low yields with more potential for improvement by the recommended KCl applications in the production phase, if N status was roughly satisfactory at the end of the juvenile phase;
- N (many food crops, little fertilisation) led to a yield degradation from low yields.

3.7. N deficiency in mature oil palm smallholdings: a specificity to be taken into account

The industrial plantations were all set up after previous forest cover without food intercrops, but with a legume cover crop and urea applications in the juvenile phase. They have never displayed any N deficiency, like most African industrial plantations (Caliman et al., 1994); the technical advice drawn up in 1978 (Tab. I) does not therefore include any N correction. However, our leaf analyses revealed a N deficiency specific to oil palm smallholdings, most probably linked to planting palms after or along with long-cycle food crops, notably tubers. Consequently, it appears necessary to modify the content of the technical recommendations made to smallholders.

Observation of the N deficiency specific to oil palm smallholdings leads us to a wider land-use challenge. In Cameroon, as in many tropical forest regions, conservation of forest biodiversity is a worldwide challenge. But, at the same time, the increasing national and international demand for edible oil, and the emerging demand for biofuels is encouraging growers to increase their oil palm areas and seek ways of increasing yields. Planting new oil palm plantations on diverse types of previous cover, such as food crops or bush fallow, is a strong likelihood. These dynamics confirm the need to propose technical management that is adapted to these new planting situations.

The diversity of farm situations, which results in a wide diversity of plots, leads us to propose different advice, based on a distinction between plots at the time of their planting, with or without a mineral deficiency. Diagnosis of the N and

K nutritional situation in plots must therefore be carried out before discussing with the farmer the solutions adapted to his farm situation. To do that, we recommend inventorying the diversity of agronomic situations in oil palm smallholdings based on how planting and juvenile management practices affect N and K nutritional deficiencies in the oil palms. In this way, specific advice could correspond to each type of typical management sequence. This recommendation is similar to that made by Nesme et al. (2003) for mature fruit orchards: these authors, after establishing statistical links between planting practices and agronomic performance, proposed ordering the diversity of cropping systems around the orchard design (variety, spacing, shape of the tree, etc.) to establish a regional agronomic diagnosis.

The solutions to be proposed to growers must therefore be participatory, along three lines: (i) how can deficiencies be identified easily without resorting to systematic costly leaf analyses in a multitude of small plots? (ii) what recovery solutions can be proposed for already existing plots? And (iii) what technical solutions can be proposed for farmers obliged to set up oil palm plantations after a previous tuber crop? Possible methods of recovery may include N applications in mature plantings, or in second-generation plantations, sowing a *Pueraria* cover crop and higher N applications in the juvenile phase. Establishing a *Pueraria*-based improved fallow before planting may, according to Caliman et al. (1994) and Wey et al. (2002), be more effective than mineral fertilisers in restoring soil mineral fertility. From that point of view, it may be useful working with farmers to identify food crop combinations that do not affect the production potential of selected oil palm plantations in the long term.

Lastly, with regard to understanding the effects of practices, it would be interesting to carry out some leaf analyses in a network of juvenile plots, in order to fine-tune the links between oil palm nutritional status and food crop systems, particularly the duration and number of crop cycles; it would probably be possible to explain why certain oil palm plots end up with a simple N deficiency, whereas others end up with a dual N and K deficiency.

4. CONCLUSION

In the Edea region of southern Cameroon, where oil palm smallholdings and industrial plantations exist side by side, we carried out a regional agronomic diagnosis of the mineral nutrition in smallholdings planted with selected material. An original application in smallholdings of leaf analyses combined with reference critical nutritional levels designed for managing fertilisation in industrial plantations revealed the effect of agricultural practices on the nutritional status of the oil palms. Statistical links were thus established between those practices and the leaf N and K contents in mature palms. We traced back nutritional status trends for the oil palm plantations from their planting to the present day. The oil palm smallholdings had mostly been set up without a legume cover crop, after a previous tuber crop and even with intercrops. This resulted in N and K deficiencies. N deficiency is a specificity of oil palm smallholdings that is never encountered in African industrial plantations. Such deficiencies persist when the plantations reach the production phase, especially without appropriate annual fertilisation. However, the technical advice given to smallholders is only adapted to situations with a previous forest cover and without food intercrops. The need of some farmers to grow food intercrops with young oil palms, along with the gradual disappearance of the previous forest cover, call for an expansion of the agronomic diagnosis methodology described in this article and for proposals providing technical advice adapted to these new situations.

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