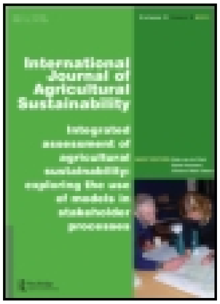

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Social institutional dynamics of seed system reliability: the case of oil palm in Benin

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Seed system reliability is of major importance in farming. Whereas earlier studies analysed mainly annuals, this study focuses on a perennial. Oil palm in Benin was chosen as a case study because farmers complained about non-hybrids (*dura* and *pisifera*) in plots allegedly planted with 100% hybrid (*tenera*). This study assessed the reliability of the oil palm seedling supply system over past decades and its main drivers. An event ecology approach was used to identify causal mechanisms accounting for the observed variation in oil palm types on smallholder plots. A total of 378 plots belonging to 248 farmers that were allegedly planted with *tenera* between 1969 and 2009 were sampled, and shell thickness of fruits was assessed to determine whether palms were *tenera*, *pisifera,* or *dura*. The proportion of *tenera* varied with seedling supply source, farmers' geographic position, seedling purchase price, and year of planting. The proportion of *tenera* decreased with year of planting. Socio-institutional mechanisms associated with the observed variation in smallholder plots were national policy change, local arrangements for seedling supply to smallholder farmers, and farmers' personal characteristics. The implications of the observed decrease in the reliability of the seedling supply system are discussed.

Keywords: event ecology; institutions; seedling quality; smallholders; oil palm; policy change; West Africa

1. Introduction

Improving farm-level oil palm (*Elaeis guineensis* Jacq.) productivity requires smallholder farmers to have access to high-quality seeds through a reliable seed system (Zen *et al*. 2005, Dimelu and Anyaiwe 2011). A reliable seed system delivers high-quality, affordable, and readily available seeds to smallholder farmers in a timely fashion (Reddy *et al*. 2007). In developing countries, the reliability of most crops' seed systems is a major problem for smallholders (Barbier 1989, Lipper *et al*. 2010, Guei *et al*. 2011). Reliability in a seed system for perennials is particularly important because perennials often take a long time to produce their first harvest, and they have a long productive life span. Oil palm, for example, takes about four years before the first bunches are produced, and palm stands are kept in production for 25–30 years. Financial loss due to poor quality or failure of oil palm seedlings is estimated at about 40% of expected

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revenue from hybrid material (Ngoko *et al*. 2004). Consequently, failure to plant the most productive perennial material has long-term negative effects on farm income, and thus on livelihood sustainability. This indicates the need for research to understand mechanisms that shape seed quality and seed system reliability.

Factors that affect seed systems in annual food crops are well documented in the literature: supply sources (Asiedu *et al*. 2008, CIP 2011), seed availability in farmers' vicinity, limited distribution (Akulumuka *et al*. 2002, Guei *et al*. 2011), past events, purchase price, inadequate information about availability of high-quality seed (Badstue 2006), lack of technical knowledge (Soyebo *et al*. 2005), education level (Alfredo 2004), membership of farmers' organizations (Ntege-Nayeenya *et al*. 1997; Rashid and Singh 2000), and regulatory frameworks (Tripp and Louwaars 1997, Tripp and Rohrbach 2001). However, such knowledge is limited for perennial crop seed systems, and very few records are available for oil palm. Bakoume (2005) and Bakoume *et al*. (2006) have reported fraudulent practices in seedling supply to smallholder farmers in Cameroon. Nurseries often claim to sell hybrid seedlings while part or all of their seedlings are non-hybrid (Durand-Gasselin and Cochard 2005). These studies, however, do not report on dynamics over time or the precise drivers of reliability, the documentation and analysis of which will enable more effective interventions to improve the seed system and thus farmers' livelihoods.

Oil palm is a major crop in Southern Benin (Adje and Adjadi 2001, MAEP 2009). It is a multifunctional crop well embedded in the everyday life of smallholders. In the mid-1990s, the government undertook an initiative to develop the oil palm sector by supplying high-quality planting material to smallholder oil palm plantations (Adje and Adjadi 2001, MAEP 2009). However, the initiative had little impact (Akpo *et al*. 2012). In a recent diagnostic study in Southern Benin, farmers claimed to see non-hybrid material in plots assumed to be composed of only hybrids (Akpo *et al*. 2012). Where and how non-hybrid enters the oil palm seed system (OPSS) and what factors contribute to it is unclear. Starting from the premise that a reliable OPSS would deliver 100% hybrid palms, this study was initiated to provide an empirical analysis of factors that undermine OPSS reliability.

2. Conceptual framework

The research design for this study draws on an event ecology approach (Vayda and Walters 1999, Walters and Vayda 2009) in order to establish causality between events in the seed system and changes in its observed reliability over time. The oil palm's long-life span allows for historical analysis of causal mechanisms that may have affected the reliability of the OPSS. Event ecology, contrary to common research approaches, proceeds from effect to cause to test plausible historical mechanisms that lead to observed outcomes. Working backwards in time (revisiting past events) and outwards in space (searching for information on socio-institutional processes outside the initial study area), event ecology enables the testing of candidate mechanisms to see how well they explain observed changes. The approach has been used in a range of studies to explain human-induced environmental changes (Carr 2002, Walters 2003, 2008).

Using the event ecology approach, we surveyed smallholder farmer plots to determine the genetic quality of seedlings they bought somewhere in time. We recorded candidate mechanisms that might have affected the genetic quality of seedlings planted. The recorded candidate mechanisms were organized in time series per study village. We made critical judgements of recorded candidate mechanisms by examining counterfactuals, i.e. asking what the genetic quality would have been if the candidate mechanism had been absent.

We surveyed the genetic quality of smallholder plots using variables including supply source, farmers' distance from supply source, and year of planting. Seedling supply sources varied depending on whether farmers obtained seedlings from official or from unofficial suppliers. Farmers' distance from supply sources was framed in terms of the geographical position of farmers' villages and of seedling purchase price.

We recorded candidate mechanisms as any historical event, decision, or initiative to increase national production of oil palm, but also farmers' personal characteristics. Past initiatives included implementation of policies, public, and private interventions (Tripp and Rohrbach 2001), or the construction/destruction of physical infrastructures or facilities. Personal characteristics of farmers included membership of a farmers' organization, reliance on informal intermediaries to buy seedlings, and education level (Ntege-Nayeenya *et al*. 1997).

3. Research methodology

This study was conducted from February 2011 to December 2012 in two stages. The first stage was the analysis of the genetic quality of palm trees on smallholder plots with the objective of assessing the performance of the OPSS. Analysing the distribution of *dura*, *pisifera*, and *tenera* oil palms in stands of various ages in a variety of sites creates an empirical reference point for OPSS performance in space and time. Unlike most cross-pollinated crops (e.g. maize), oil palm consists of three genetic types. The three types differ in thickness of shell (Figure 1) (Corley and Tinker 2003, Soh *et al*. 2009). The *dura* type is thick-shelled with 35–70% of pulp over fruit and is the main naturally available type. The *pisifera* type is shell-less, with 90% pulp; usually female sterile, its bunches often do not reach maturity. *Pisifera* is non-productive in terms of oil (Sambanthamurthi *et al*. 2009). The *tenera* type, resulting from crossing *dura* with *pisifera*, is thin-shelled with 80% pulp, and is the most productive of the three. The occurrence of *tenera* in natural stands is very low. Given these characteristics of oil palm types, smallholder farmers who buy hybrid seedlings wish to have only *tenera* on their plots (Cochard *et al*. 2001). In this study, we defined the term 'genetic quality' of oil palm on a plot as the relative proportion of *dura*, *pisifera*, and *tenera* types. Higher genetic quality implies a larger proportion of *tenera*.

In terms of the event ecology approach, the results of the genetic quality analysis establish an observable outcome that can then be explained. The second stage of the research investigated various potential mechanisms within or outside the OPSS that help explain the temporal and spatial variations in genetic quality observed on the sampled plots.

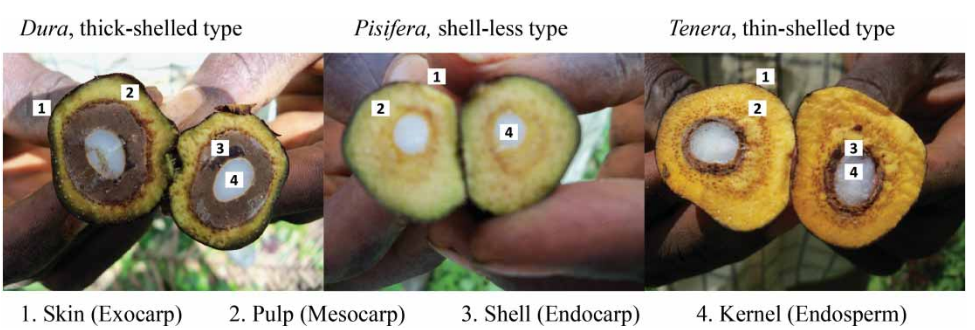

Figure 1. Examples of fruits of the three distinct oil palm types. Numbers 1–4 are explained below photos with botanical terms in parentheses.
Photo: E. Akpo, 2012.

3.1. *Analysis of genetic quality of oil palm in smallholder plantations*

3.1.1. *Study area and site selection*

The study was carried out in the oil palm growing belt in Southern Benin. Stratified sampling was used to select six villages covering the main growing area. Region, district, and village were the first, second, and third stratum, respectively. At each stratum, the main criterion for site selection was the importance of oil palm production. Table 1 presents the characteristics of the selected villages.

Region selection: The following four main regions of oil palm production in Benin were selected: Ouémé-Plateau, Atlantique, Mono-Couffo, and Zou.

District selection: The three main oil palm production districts where an earlier diagnostic study was conducted (Akpo *et al*. 2012) were selected: Lokossa, Zè, and Sakété (Figure 2). Three additional main districts were selected purposefully on the basis of reported complaints about genetic quality during the diagnostic study. In the Ouémé-Plateau region, where few complaints were registered, we selected no district other than Sakété. In the Mono-Couffo region, where many complaints were registered, one additional district (Lalo) was selected. In the Atlantique region, where farmers expressed many concerns about genetic quality, one additional district (Allada) was selected. In the Zou region, where oil palm production is less important than in other regions, one district (Za-Kpota) was selected. The Zou region was not covered during the diagnostic study.

Village selection: In each district, the village with the largest acreage of oil palm stands was selected, i.e. six villages in total. Selection was performed jointly with representatives of farmer organizations and respective district extension services because secondary data were not available to allow researchers to independently select villages.

3.1.2. *Description of the sampling strategy for farmers and plots, and determination of oil palm types*

In each selected village, all farmers who grew hybrid oil palm were registered and numbered. From among all farmers who had hybrid palm stands at production age (three years and

Table 1. General characteristics of selected villages.

	Villages (districts)					
Characteristics	Guèhounkon (Lokossa)	Sèwahoué (Lalo)	Sékou (Allada)	Aïfa (Zè)	Kpozoun (Za-Kpota)	Ita-Djèbou (Sakété)
Main purpose of oil palm production	Alcohol and palm oil	Alcohol and palm oil	Palm oil	Palm oil	Palm oil	Palm oil
Number of planters of hybrid oil palm at production age	22	27	42	58	32	67
Number of palm plots farmers generally own	1– 2	1–2	1–4	1–5	1–3	1–5
Predominant land tenure	Purchase	Purchase	Purchase	Purchase	Purchase	Purchase
Village proximity to CRA-PP centre (km)	215	195	130	165	120	18
Proximity to official nursery (km)	18	35	5	25	20	5

Source: District extension services and representatives of farmer organizations in Lokossa, Lalo, Allada, Zè, Za-Kpota, and Sakété.

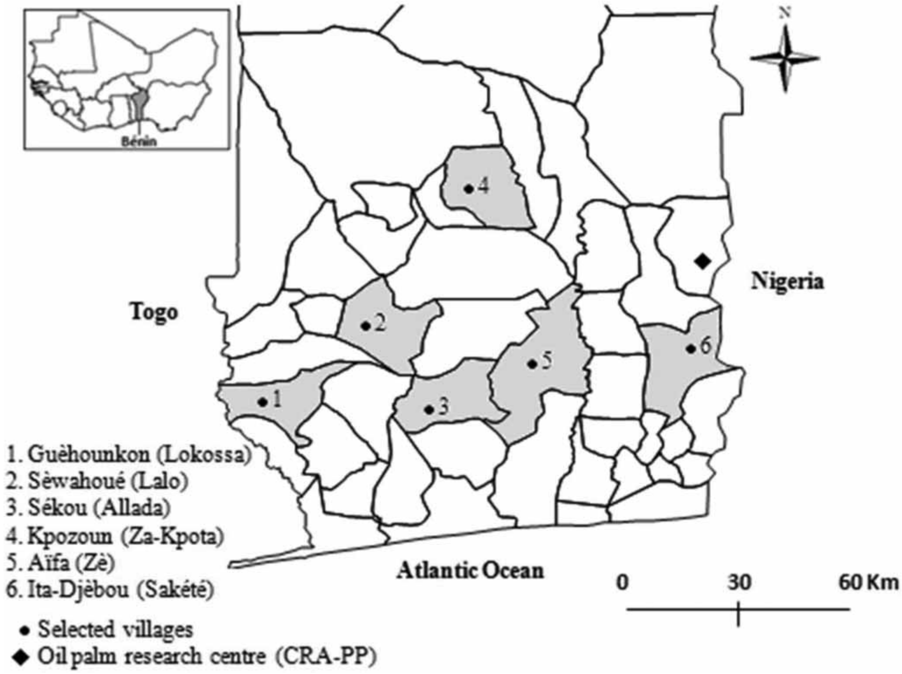

Figure 2. Map of Southern Benin showing selected villages (districts).

above), a minimum of 20 farmers were drawn per village for plot checking. Hybrid oil palm was not largely produced in all districts across Southern Benin. In Lokossa and Lalo districts, where fewer than 20 farmers were registered in a village, additional farmers were selected in neighbouring villages to make up the minimum sample size of 20 farmers.

Sampling of plots: All plots belonging to each selected farmer were included and sampled. In this study, a plot was defined as a piece of land planted with oil palm bought from one particular supply source in a given year. Parts of land that were planted with seedlings bought from different sources in the same year were treated as separate plots. Likewise, parts of land that were planted with seedlings from the same source but bought in different years were sampled as different plots. To establish effects of temporal dynamics in the OPSS, plots of all ages were sampled per village.

3.1.3. *Gathered data per sampled plots*

The composition of smallholder plots was quantified by recording the fruit type – *dura*, *pisifera*, or *tenera* – of each individual palm. Per sampled plot, all palm trees were checked to best verify fits to Mendel's laws (Box 1, Supplementary Material). Per palm tree, two to three fruits were cross-sectioned to determine their type (Ngoko *et al*. 2004) (Figure 1). If particular palms were not carrying bunches during a visit, the plot was visited at a later stage to sample these palms. If after four visits there were still no bunches, we recorded it as a palm without a bunch.

In addition to plot composition, data were gathered on supply source, geographical position, year of planting, and purchase price of seedlings. Four sources of hybrid seedling supply identified during the diagnostic study (Akpo *et al*. 2012) were used: (1) the oil palm research centre (CRA-PP), the nationwide producer of hybrid seeds; (2) state cooperatives that sell their surplus seedlings grown from germinated seeds from CRA-PP; (3) official private nurseries that CRA-PP provides with germinated seeds; (4) unofficial private nurseries that have no formal access to CRA-PP seeds and obtain germinated seeds from various sources.

Furthermore, information was collected for every plot: total number of seedlings purchased, farmer's own appreciation of genetic quality of palms (hybrid or non-hybrid), receipt obtained from nursery after seedling purchase, and the first year of bunch production.

3.2. *Documentation of socio-institutional mechanisms associated with observed genetic quality of oil palm over time*

While the genetic composition of plots was being checked, we interviewed farmers and nursery managers about any events that in their view had had a major impact on the OPSS over the past 50 years. For example, we asked interviewees whether the Benin government or any non-government organization (NGO) helped them to access seedlings. In addition to these individual interviews, we held group discussions with farmers, nursery managers, and representatives of implementers of any supportive initiatives. We also recorded key informants' narrative descriptions and explanations of events.

Desk study provided additional independent data about how those historical events impacted the OPSS. We visited national archives, the national library of Benin, documentation centres of the Ministry of Agriculture, the CRA-PP research centre, and other target organizations. Collected data included objectives, way of implementation, achievements, and lessons that could be learned from the interviewees' perspective. These data later helped to explain *why* a particular event affected the OPSS as observed in proportions of palm types.

To better understand the effects of historical events on genetic quality, we surveyed plots established before 1994, when smallholder access to hybrids was not an official policy in Benin. We used snowball sampling to identify holders of plots planted before 1994. Plots differing in age were sampled drawing two samples of 100 palms with fruit bunches. We also surveyed state cooperatives in Agamé, Koudo, Koundokpoe, and Obékè-Ouèrè that sold leftover seedlings to smallholder farmers.

We gathered data on farmers' personal characteristics and practices including education level, membership of farmer organization, and their reliance on intermediaries to acquire seedlings. We recorded the educational level as number of school years; membership of oil palm farmers' organization as member or non-member; the use of informal intermediary to buy seedlings as whether or not one or more informal people were involved in seedling transactions between nursery and farmer; and the relationship between farmers and informal intermediaries. An informal intermediary is understood as a personal contact – other than a formal nursery manager, CRA-PP, extension agent, or NGO – who helped farmers to buy seedlings.

3.3. *Data synthesis and analysis*

We quantified the genetic quality by determining proportions of *dura*, *pisifera*, and *tenera* per plot. Beyond analysing the nuts, we also clustered plots according to the variables: supply sources, farmers' geographical distance, purchase price, and planting year. When χ^2 test assumptions were met, the significance of counts of different palm types was tested across variables. On-plot and within-village variation in genetic quality was also analysed.

Mendel's laws (Box 1, Supplementary Material) of phenotype distribution for a single gene trait were used to categorize sampled plots into plots that were planted with seedlings of hybrid seeds and plots that were planted with seedlings of mixed origin (Beirnart and Vanderweyer 1941). Such an analysis provides additional information about where suppliers might have collected their material.

Following the event ecology approach, we integrated information collected about genetic quality and recorded historical events in an effort to best explain observed patterns. The most plausible candidate mechanisms were selected by asking whether the OPSS would have been different in the absence of a particular mechanism (counterfactual analysis) (Walters and Vayda 2009). For example, to test whether policy change led to less control over seedling quality, we sampled plots established before the policy change in 1994. In the same vein, to find out whether local initiatives improved farmers' access to quality seedlings, we compared genetic quality before and after significant local events. This establishes a correlation, but claims in relation to causality are based upon subsequent analysis of the likelihood of those observed outcomes occurring in the absence of the documented historical events.

4. Results

4.1. *General characteristics of sampled plots*

The average acreage of sampled plots across the six villages was 0.9 ha (Table 2). Few sampled plots were larger than 1.8 ha. The χ^2 test for equality of distribution showed a significant variation in plot sizes in the sampled villages ($\chi^2 = 51.328, p < 0.001$). Oil palms from sampled plots produced their first bunch after three to four years. More than three-quarters of all sampled plots had been planted with hybrids since 2001. Even in Sèwahoué, Sékou, and Ita-Djèbou, only few plots planted before 1997 were registered (less than 10%). The official seedling purchase price was between 600 and 700 FCFA per unit, and 70% of plots were planted with seedlings purchased at these prices. In Ita-Djèbou and Sékou, plots were planted with seedlings purchased for more than 700 FCFA, whereas in Sèwahoué and Guèhounkon, some seedlings were purchased for less than 600 FCFA. The six villages differed in nature of seedling supply sources (Table 2). In Sèwahoué, unofficially established nurseries were the main supply source, with over 80% of total purchases. In contrast to other sampled villages, the plots in Ita-Djèbou and Kpozoun had obtained most of their seedlings from either the research centre (CRA-PP) or official nurseries.

In recent years, the demand for hybrid seedlings has increased across all six villages, with a simultaneous increase in the proportion of non-hybrid palms among sold seedlings, as indicated by the difference between the total number of planted seedlings and the number of hybrid palms (Figure 3).

4.2. *Variation in genetic quality of palm trees in sampled plots*

Across all sites and periods, only 58% of all sampled plots were entirely composed of *tenera* (Figure 4). The genetic quality of sampled plots varied according to the seedling supply source, geographical position, year of planting, and seedling purchase price.

4.2.1. *Variation in proportions of oil palm types per selected village and evolution over time*

Proportions of palm types differed from one village to another (Figure 5). Ita-Djèbou farmers benefitted from higher genetic quality palms (97%), followed by Kpozoun (92%), Aïfa and Sékou (78%). Sèwahoué presented the lowest proportion of *tenera* with only 49% hybrid type. In Guèhounkon, the proportion of *tenera* was 64%.

The proportions of non-hybrid palms increased for more recently planted plots across most selected villages. Even though not all planting year categories were represented in all selected villages, younger oil palm plots consistently had a lower proportion of *tenera* (Figure 5), except Ita-Djèbou. In Guèhounkon, the drop in the proportion of *tenera* was slight at 6 percentage points (from 2002–2006 to 2007–2009 plots). Between the periods 1997–2001 and 2007–2009, the proportion of *tenera* dropped from 100% to 38%, 100% to 79%, and 93% to 68% in Sèwahoué, Sékou, and Aïfa, respectively. In the period between 2002–2006 and 2007–2009, the proportion

Table 2. Characteristics of smallholder plots sample.

Plot characteristics	Villages					
	Guèhounkon (32)	Sèwahoué (32)	Sékou (71)	Aïfa (91)	Kpozoun (47)	Ita-Djèbou (105)
Size of sampled plots						
< 0.9 ha	87.5	46.9	40.8	75.8	83.0	51.4
0.9–1.8 ha	12.5	37.5	40.8	18.7	17.0	39.0
> 1.8 ha	0	15.6	18.3	5.5	0	9.5
Years before bunch production						
3–4 years	96.9	100	100	98.9	97.9	99.0
5 years	3.1	0	0	1.1	2.1	1.0
Planting years of palm trees						
Before 1997	0	3.1	1.4	0	0	5.7
1997–2001	0	6.3	11.3	23.1	0	18.1
2002–2006	50.0	21.9	47.9	47.3	58.7	53.3
2007–2009	50.0	68.8	39.4	29.7	41.3	22.9
Purchase price of seedlings						
≤600 FCFA[a]	14.3	28.6	7.5	7.9	2.3	1.0
600–700 FCFA	85.7	71.4	74.6	92.1	95.4	73.0
≥700 FCFA	0	0	17.9	0	2.3	26.0
Seedling supply sources						
CRA-PP nursery	0	0	7.2	0	2.1	66.7
Officially established nurseries	40.6	15.6	39.1	48.3	95.8	31.4
State cooperative nurseries	15.6	0	4.3	6.7	0	0
Unofficially established nurseries	43.8	84.4	49.3	44.9	2.1	1.9
Farmers' assessment of the genetic quality of planted material on their plots						
Mixture of oil palm types	62.5	9.4	0	37.4	2.1	2.9
Hybrid oil palm	31.3	62.5	49.3	62.6	78.7	97.1
Did not know	6.3	28.1	50.7	0	19.2	0

Notes: Values expressed as percentage of each variable per village. Numbers below villages indicate sample size.
[a]The exchange rate during the study was fixed at 655 FCFA for €1.

of *tenera* palms dropped from 99% to 83% in Kpozoun. Only Ita-Djèbou did not follow the generally observed drop in genetic quality, with 94% *tenera* on 1997–2001 plots against 99% *tenera* on 2007–2009 plots. Analyses of genetic variation on-plots and within-villages exhibited the same trends (Table 3).

4.2.2. *Seedling supply source-related variation in proportions of oil palm types*

Compared to official supply sources, unofficial nurseries delivered material composed of the lowest proportion of *tenera* (53% on average). Only 6% of plots that were planted with unofficial nursery seedlings presented 100% *tenera*. In Guèhounkon, Sèwahoué, Sékou, and Aïfa, where unofficial nurseries supplied a significant proportion of seedlings (43%), only 40–60% seedlings were *tenera*.

Over time, proportions of *tenera* that individual supply sources delivered differed little (Figure 6) compared to differences observed between sources. Unofficial nurseries have always supplied higher proportions of non-hybrid palms to smallholder farmers than official

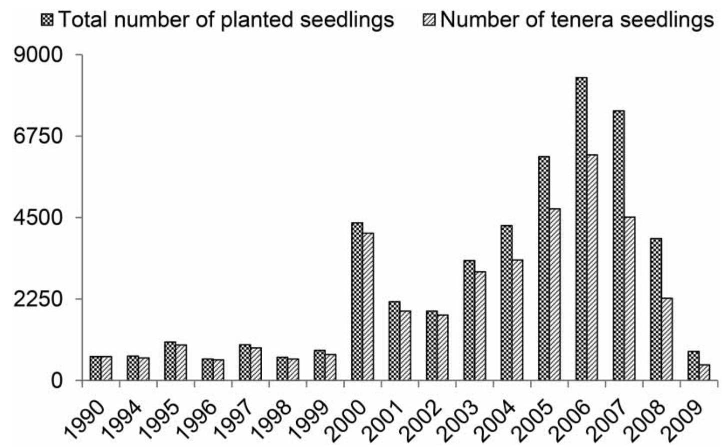

Figure 3. Evolution of the number of planted seedlings and the number of *tenera* in sampled plots between 1990 and 2009. Plots planted between 2008 and 2009 did not always have bunches. Differences between bars indicate *dura* and *pisifera*.

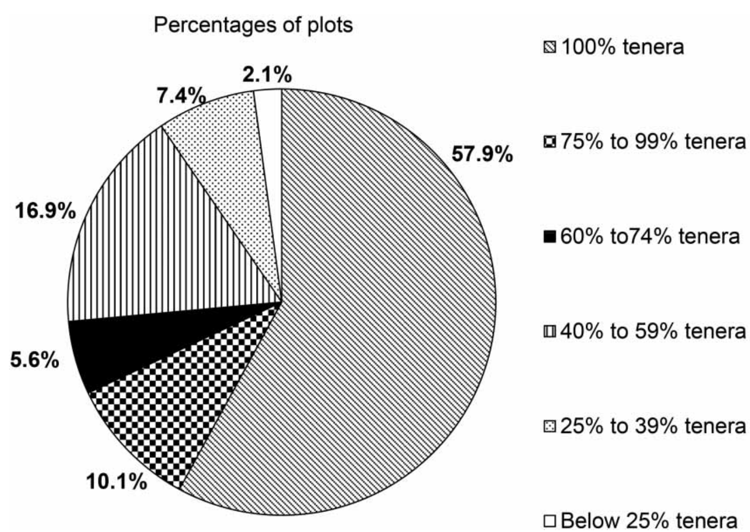

Figure 4. Percentages of sampled plots composed of *tenera* across all villages.

nurseries. It is worth noting that not all categories of supply sources were available to farmers in each village. Whereas seedlings supplied from CRA-PP were observed mainly in Ita-Djèbou, those from state cooperative nurseries were present in Guèhounkon, Sékou, and Aïfa (Table 4). In contrast, official and unofficial nurseries served farmers across all sampled villages. Proportions of palm types varied across supply sources and per village. A higher proportion of *tenera* was observed for plots planted with CRA-PP seedlings (98%), followed by official nurseries (93%), and state cooperatives (88%). Plots planted with CRA-PP-purchased seedlings were found to contain as low as 73% *tenera*. Plots that were planted with official nursery and state cooperative seedlings showed proportions of *tenera* as low as 34%. Guèhounkon was the village where official nurseries and state cooperatives delivered the lowest proportion of *tenera* (below 80%).

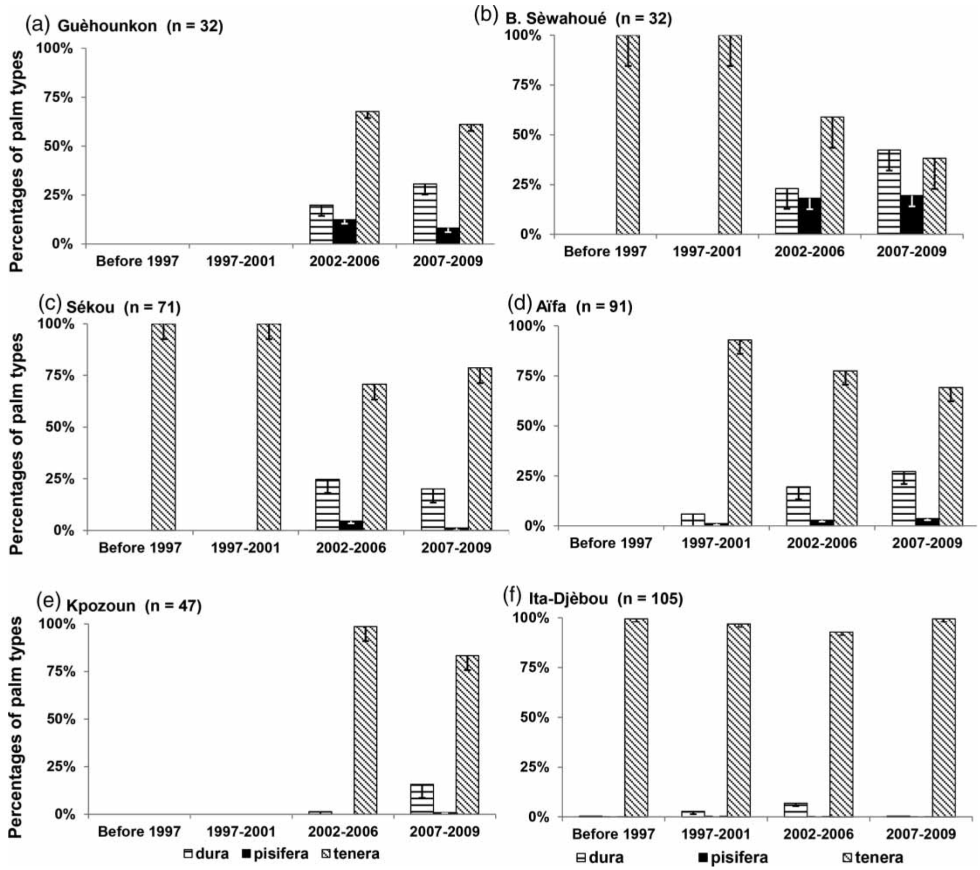

Figure 5. Observed percentages of oil palm types for four distinguished planting year classes and per selected village. Numbers in brackets indicate sample sizes. Bars indicate standard errors of means.

Table 3. On-plot and within-village analysis of variation in oil palm types.

Villages	Recorded lowest proportion of *tenera* per plots	Percentage of plots with less than 50% *tenera*	Percentage of plots with 100% *tenera*
Guèhounkon	23.9	37.5	28.1
Sèwahoué	20.5	71.9	12.5
Sékou	15.5	23.9	53.5
Aïfa	24.5	15.4	46.2
Kpozoun	3.8	2.1	72.3
Ita-Djèbou	47.8	1.0	86.7

4.2.3. *Seedling purchase price-related variation in proportions of oil palm types*

The proportion of *tenera* in sampled plots increased with an increase in the seedling purchase price (Table 5). Seedlings purchased for 600–700 FCFA showed a proportion of *tenera* from 62% to 97% in Guèhounkon and Ita-Djèbou, respectively. Nearly 100% of seedlings purchased

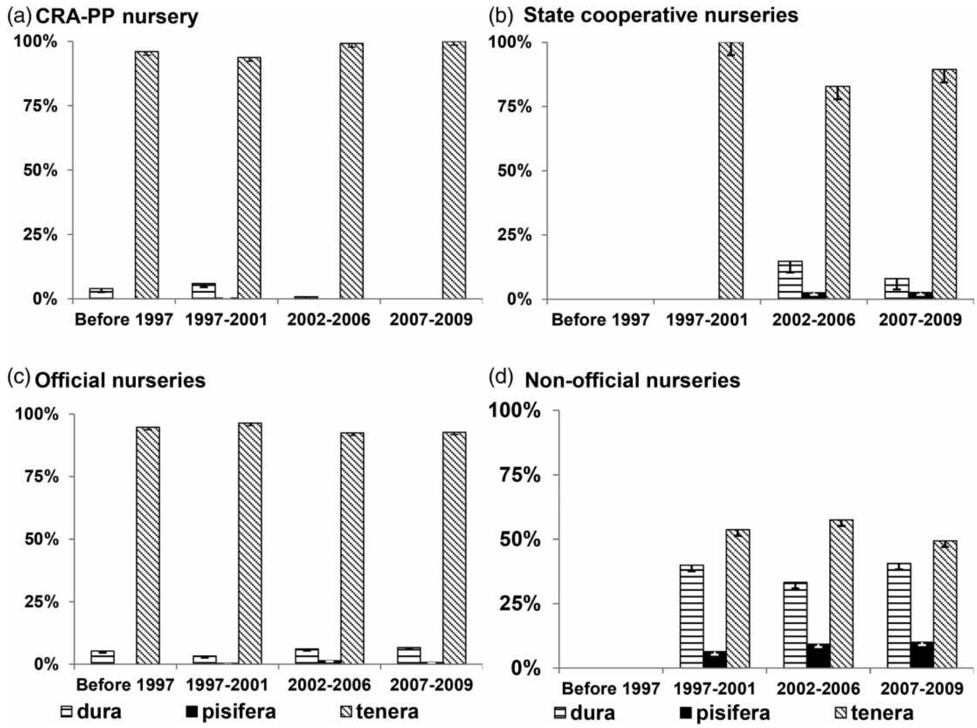

Figure 6. Observed percentages of oil palm types for four distinguished planting year classes and four supply sources: (a) CRA-PP nursery, (b) State cooperative nurseries, (c) Official nurseries, or (d) Unofficial nurseries. Numbers in brackets indicate sample sizes. Bars indicate standard errors of means.

for more than 700 FCFA were *tenera*, except in Sékou where we observed one plot composed of 80% *tenera*.

After characterization of the genetic quality of oil palm on smallholder plots, it is relevant to explore possible explanatory mechanisms of observed variations.

4.3. *Historical events associated with observed genetic quality*

This section presents events that happened within or outside the OPSS that had positive or negative impacts on the proportions of *tenera* that farmers received.

4.3.1. *Government policy change in 1994*

Before 1994, the CRA-PP was the only official seedling supply source, and it only supplied seedlings to state cooperatives. No official privately owned nursery existed to sell seedlings to farmers. Smallholders who wished to plant *tenera* palms had to travel to the CRA-PP nursery at Pobè. In 1994, a policy change led to training and the establishment of official nurseries in the oil palm growing belt, the main objective of which was to create reliable seedling supply sources closer to farmers. Ten official nurseries were established in 1994, and the number had grown to 40 by 2012. As at 2012, the number of official nurseries established per oil palm production region was 4 in Mono-Couffo, 8 in Atlantique, 4 in Zou, and 24 in Ouémé-Plateau.

Table 4. Variation in percentages of *tenera*, *dura*, and *pisifera* as affected by the seedling supply source.

	CRA-PP nursery	Officially established nurseries	State cooperative nurseries	Unofficially established nurseries
Guèhounkon				
Dura	–	13.7	17.7	38.7
Pisifera	–	6.8	4.7	15.7
Tenera	–	79.6	77.6	45.6
Séwahouè				
Dura	–	0	–	40.4
Pisifera	–	0	–	20.6
Tenera	–	100	–	39.0
Sékou				
Dura	0	0.6	4.6	43.0
Pisifera	0	0.1	0.1	5.8
Tenera	100	99.3	95.5	51.2
Aïfa				
Dura	–	8.0	5.6	30.8
Pisifera	–	1.0	1.1	4.4
Tenera	–	90.9	93.3	64.8
Kpozoun				
Dura	0	5.7	–	96.2
Pisifera	0	0.4	–	0
Tenera	100	93.9	–	3.8
Ita-Djèbou				
Dura	1.7	5.1	–	19.4
Pisifera	0.1	0.4	–	0.4
Tenera	98.2	94.5	–	80.2

Note: A dash means that this supply source was not represented.

Table 5. Variation in percentages of oil palm types per village and per class of seedling purchase price.

Purchase price	Guèhounkon	Sèwahoué	Sékou	Aïfa	Kpozoun	Ita-Djèbou
Below 600 FCFA						
Dura	47.1	32.0	45.2	34.6	7.5	–
Pisifera	11.8	26.0	4.4	5.1	2.5	–
Tenera	41.1	42.1	50.4	60.3	90.0	–
600–700 FCFA						
Dura	22.3	24.5	17.4	17.0	5.8	3.0
Pisifera	8.5	13.0	2.5	2.4	0.3	0.3
Tenera	69.3	62.5	80.1	80.6	93.8	96.7
Over 700 FCFA						
Dura	–	–	6.6	–	0	0
Pisifera	–	–	0.4	–	0	0
Tenera	–	–	93.0	–	100	100

Note: A dash means that this purchase price was not represented.

Although the 1994 policy change led to the establishment of official nurseries, it also led to less control over genetic quality. This is shown by the palm type determination of state cooperatives and farmers owning *tenera* in plots planted between 1969 and 1994. Before the policy change in 1994, the quality of seedlings provided to farms was optimal, leading to 100% *tenera* stands. After the policy change, the CRA-PP continued to deliver near optimal quality seedlings when selling directly to farmers (Figure 6(a)). In other words, the CRA-PP does not seem to be the source of the observed poor quality since 1994.

4.3.2. *Recorded mechanisms associated with the reliability of local seedling supply systems*

Change in national policy led to reconfiguration of the OPSS, but changes in local seedling distribution systems also affected the proportion of *tenera* that farmers received. Local mechanisms included NGO and public agency initiatives, activities of former official nursery workers, purchase of seedlings from informal sources in neighbouring countries, and farmers' personal characteristics.

Our data show that local arrangements through NGOs and public agency activities often improved the proportion of *tenera* that farmers received. For example, the Reforestation Project of the Cotonou Catholic Diocese, initiated by the late Monseigneur Isidore de Souza in Aïfa, led to the establishment of official nurseries between 1996 and 2002. Aïfa farmers had access to high genetic quality seedlings until 2001. In 2002, the project was stopped and, consequently, nurseries were no longer provided with seeds directly from the CRA-PP. Since then, farmers have returned to unofficial nurseries, resulting in low proportions of *tenera* (Figure 5(d)).

Like Aïfa, some other villages benefitted from interventions by NGOs or public agencies that facilitated the acquisition of quality seedlings. In 2003 in Kpozoun, the NGO Bornefonden implemented a project that connected farmers with official nurseries and provided financial support in the form of a purchase subsidy. Figure 5(e) shows that the Bornefonden NGO initiative initially provided a higher proportion of *tenera* than it did later. More recently, seedlings purchased in Kpozoun have not been fully subsidized. In Sèwahoué, the public extension service facilitated farmers' acquisition of seedlings until 2002, correlating with a high proportion of *tenera* in farmers' fields. Since 2002, however, there has not been an extension agent specifically assigned to oil palm. Figure 5(b) clearly shows a strong decline in the reliability of the seed system compared to the earlier period. In contrast, in Ita-Djèbou – which is located close to the CRA-PP and also has the highest number of official nurseries in its vicinity – the seedling supply system has remained highly, though not perfectly, reliable since 1994 (Figure 5(f)).

Not all interventions by intermediaries improved the reliability of the OPSS for farmers. In Guèhounkon, where the OPSS reliability went from bad to worse (Figure 5(a)), two former state cooperative nursery workers had been selling seedlings to farmers on behalf of the state cooperative. In the same vein, a former official nursery manager maintained a network and continued to supply planting material to farmers in Guèhounkon. Furthermore, official suppliers purchasing germinated seeds from informal sources in neighbouring countries had a negative impact on the genetic quality in Guèhounkon. For example, the Agamé state cooperative purchased seeds from informal suppliers from Nigeria that the cooperative partly planted and sold to Guèhounkon farmers. Upon checking the plots of the state cooperative that were planted with these seedlings, we observed comparable proportions of non-hybrids.

Beyond the effect of formal intermediaries, farmers' use of informal intermediaries strongly correlates with decreased genetic quality. Only 1 of 2 plots in Guèhounkon, 1 of 5 plots in Sèwahoué, 3 of 8 plots in Sékou, 11 of 33 plots in Aïfa, and 4 of 10 plots in Ita-Djèbou were planted with seedlings obtained through informal intermediaries that were fully composed of *tenera* (Table 6). In terms of farmers' personal characteristics, the education level did not correlate positively with the proportion of *tenera* on their plots (Table 6). In Guèhounkon and Sékou, farmers who attended secondary school had proportions of *tenera* equal to, or lower than, those who attended only primary school; in Sèwahoué and Kpozoun, farmers who did not attend school at all had 12 and 9 percentage points higher proportions of *tenera,* respectively,

Table 6. Variation in percentages of oil palm types by farmer education level, belonging to farmer organization, and the use of intermediary for seedling purchase per study village.

	Education level			Belongs to farmer organization		Use of intermediary	
	Did not attend school	Attended primary school	Attended secondary school and beyond	No	Yes	Used informal intermediary	Did not use informal intermediary
Guèhounkon							
Dura	29.3	26.3	22.6	27.9	0	–	–
Pisifera	10.5	6.6	11.4	11.4	0	–	–
Tenera	60.2	67.2	65.9	60.7	100	–	–
χ^2-test	59.2 ($p < 0.001$)			n.a.			
Sèwahoué							
Dura	37.2	46.3	19.0	37.5	23.8	–	–
Pisifera	16.2	19.2	16.3	17.8	16.1	–	–
Tenera	46.6	34.5	64.7	44.7	60.1	–	–
χ^2-test	*342*.0 ($p < 0.001$)			93.7 ($p < 0.001$)			
Sékou							
Dura	29.7	9.9	12.2	19.8	–	31.4	18.3
Pisifera	1.8	4.9	3.1	2.7	–	4.3	2.5
Tenera	68.6	85.3	84.8	77.5	–	64.3	79.2
χ^2-test	750.5 ($p < 0.001$)					332.0 ($p < 0.001$)	
Aïfa							
Dura	22.6	14.9	15.9	28.9	9.3	25.1	14.5
Pisifera	3.1	2.5	1.5	4.2	1.3	3.9	1.9
Tenera	74.4	82.6	82.6	66.9	89.4	70.9	83.6
χ^2-test	239.5 ($p < 0.001$)			985.6 ($p < 0.001$)		138.7 ($p < 0.001$)	
Kpozoun							
Dura	5.2	14.3	9.8	96.2	5.6	–	5.7
Pisifera	0.5	0.5	0	0	0.4	–	0.4
Tenera	94.4	85.2	90.2	3.8	94.0	–	93.9
χ^2-test	n.a.			n.a.			
Ita-Djèbou							
Dura	5.0	1.3	3.5	3.9	0	15.9	1.9
Pisifera	0.1	0.4	0.1	0.2	0	0.4	0.2
Tenera	94.9	98.3	96.4	95.9	100	83.7	97.9
χ^2-test	n.a.			n.a.		n.a.	

Note: A dash means that this parameter was not represented enough to calculate percentages.
n.a., not applicable as test conditions were not fulfilled.

than those who attended primary school; in Ita-Djèbou, farmers who only attended primary school had a higher proportion of *tenera* on their plots than their peers who attended secondary school. Local arrangements and joint seedling purchase with peer farmers' organization members could have favoured less educated farmers who sometimes received better quality seedlings than more highly educated farmers. Membership of farmers' organization correlated positively with the proportion of *tenera*. In comparison to non-members, farmers who were members of a farmers' organization showed an increase in the proportion of *tenera* of 39 percentage points in Guèhounkon, 15 in Sèwahoué, 22 in Aïfa, 90 in Kpozoun, and 4 in Ita-Djèbou. Field records indicate that members of farmers' organizations often purchased seedlings together from official sources.

5. Discussion

The genetic quality of seedlings delivered to smallholder farmers is critical to improve both rural livelihoods and agricultural productivity. For long-term perennials like oil palm, ensuring the genetic quality of seedlings is critical for the success of plantation outputs (Hasnah *et al*. 2004). The analysis of smallholder plot composition by oil palm type showed that plots that were allegedly planted with *tenera* contained non-hybrids. Drawing on the event ecology approach, we found that past socio-institutional mechanisms contributed to the observed variation in proportions of oil palm types.

5.1. *Genetic quality of oil palm on smallholder plantations*

The proportions of palm types on sampled plots in the six villages varied by their seedling supply source. Unofficial nurseries were by far the least reliable source. Official nurseries, the CRA-PP centre, and state cooperative nurseries were also shown to be less than 100% reliable. Observed high proportions of non-hybrid in material supplied by unofficial nurseries matched our expectations because they gathered seedlings from unknown sources. In principle, 100% *tenera* is expected from reliable sources. If non-hybrids are found in material from these sources, it confirms the existence of fraudulent practices in the supply system to smallholder farmers (Durand-Gasselin and Cochard 2005). For seedlings originating from the CRA-PP, all cases with less than 100% *tenera* involved informal intermediaries. For state cooperatives and official nurseries, not all cases with less than 100% *tenera* were associated with informal intermediaries, confirming others' observations that seedling suppliers' trustworthiness is an important determinant of reliability in an OPSS (Durand-Gasselin and Cochard 2005).

Our findings show that the genetic quality of seedlings supplied to farmers varied greatly from one village to another. This raises the issue of the density and uniform coverage of official nurseries in the oil palm growing belt. For seed systems in general, Rohrbach *et al*. (2002) argue that, when the distance between buyers and sellers increases, seed quality control becomes a major issue. To help small farmers maximize their output and income, smallholders need to be well organized and technically supported. In Indonesia, for example, scholars found that supported smallholders achieved higher yields than independent ones (Vermeulen and Goad 2006). Whether district authorities, smallholder cooperatives (Hardjano *et al*. 2003, Rist *et al*. 2010), or extension services provide the requisite assistance (Nangoti *et al*. 2004, Neate and Guei 2010), support to smallholder farmers increases their income. Furthermore, the high geographic variability in OPSS reliability emphasizes the importance of understanding seed systems as complex and heterogeneous networks of relationships rather than as single, monolithic entities.

5.2. *Causal mechanisms accounting for the observed variation in palm types over time*

Using the event ecology approach, we identified mechanisms that accounted for the observed variation in sampled plots over time. The event ecology approach allowed us to explain *why*, in certain places and at certain times, farmers' plots had a high or a low proportion of *tenera.* Those mechanisms included policy change, changes in local distribution systems, local arrangements for seedling supply to farmers, and farmers' personal characteristics. In relation to farmers' characteristics, membership of a farmers' organization had a strong positive correlation with quality seedling supply. The use of informal intermediaries to purchase seedlings had negative effects on the seedling quality.

The policy change in 1994 aimed to increase smallholders' access to *tenera* seedlings by decentralizing seedling distribution away from the CRA-PP centre to newly established official nurseries in the major oil palm growing regions (Adje and Adjadi 2001). Although implementation of the policy did bring seedling production and distribution closer to some smallholder farmers, the supply chain has not been managed to adequately meet all farmers' demand. The data suggest that the mismatch between supply and demand, combined with a newly decentralized distribution system with weak oversight and accountability, appears to have created an adequate opportunity and motive for various actors to introduce poor quality material into the OPSS. Field observations indicated incidences of such misbehaviour in many cases. State cooperative workers who produced seedlings on their own behalf, suspended official nursery managers who continued selling seedlings, and a state cooperative that bought planting material from Nigeria through informal channels were observed cases of deviation from quality seedling production. The perpetrators' motive is most likely to be able to make a profit through fraud, but ignorance of genetic quality maintenance cannot be entirely ruled out. To some extent, understanding the genetics of oil palm (Box 1, Supplementary Material) seems relevant for all players. This could be an important step towards improving OPSS performance.

Local arrangements connecting farmers directly to official seedling supply sources greatly increased the proportion of *tenera* on smallholder plots. Even in villages located at greater distances from official supply sources, local arrangements enabled farmers to overcome the negative effects of distance. In Kpozoun, where there were local arrangements for *tenera* seedling supply, smallholder farmers had high proportions of *tenera*, unlike Guèhounkon where there were no local initiatives to support farmers to acquire *tenera* seedlings, and the proportions of non-hybrids were rather high. Support for the argument that local initiatives maintain good quality hybrid seedlings for small farmers comes from the observation that, when they ceased, smallholder farmers experienced negative impacts. In Aïfa, for example, withdrawal of the Catholic Church project led to a significant reduction in the genetic quality. A relevant question, then, is how to sustain local initiatives that fill the gaps left by the inadequate functioning of the formal seed system.

Farmers' personal characteristics also correlated with the proportion of *tenera* that farmers received. Most cases where farmers used informal intermediaries ended with reduced genetic quality. In Ita-Djèbou, for example, although the average *tenera* proportion was 97%, cases were observed of farmers receiving substantially less *tenera* because the seedlings were acquired from informal intermediaries. The main reason for lower quality with informal intermediaries is that farmers do not obtain the seedlings from official sources. Membership of a farmers' organization increased the proportion of *tenera*. Field interviews revealed that farmer organization members often ordered seedlings together and that practice limited the chances of being cheated. Because informal intermediaries have been shown to have a negative effect, and membership of a farmers' organization has a positive effect on seedling quality, the social organization of seedling acquisition becomes an important aspect of seed system reliability. Farmer education level did not show clear effects on farmers' access to quality seedlings. The social organization of seedling acquisition could also explain such findings. As discussed in Section 4.3, local initiatives and joint seedling purchase with peer farmer organization members favoured less educated farmers who sometimes received better quality seedlings than highly educated farmers.

By using the event ecology approach to connect biological analyses of existing oil palm stands with historical social phenomenon and practices, we have been able to clarify some of the drivers and dynamics of OPSS' unreliability in Benin over past decades. The approach helped to identify causes of the observed variation in smallholder plantations while avoiding the pitfalls of preconceived hypotheses. The use of counterfactuals was key to the methodological path that allowed us to draw causal links between social events and observed biophysical outcomes. Clear correlations having been established between social phenomena and the distribution of oil palm types in the plantations, the operation of causal mechanisms linking the two has been documented. Analysis of these mechanisms indicates that the observed biophysical outcomes would have been extremely unlikely to occur in their absence. For example, the positive effects of local arrangements for seedling delivery to farmers could not have been claimed without counterfactual analysis of the results of their withdrawal or absence. As a rigorous methodology for political ecology research, we have found event ecology to be a robust approach in any situation where counterfactuals can be used to critically examine causal claims. In this respect, the event ecology approach has great potential to be useful in studying supply systems of perennial crops, given that lasting proof of their functioning can be found and analysed independently.

Even though this research unveils the main drivers of reliability in the seedling supply system, it has still not documented the real motives of suppliers who sell seedlings that fail to be optimal. Further research might reveal whether it is simple cheating or lack of knowledge.

6. Conclusions

The OPSS in Benin is not reliable, and smallholder farmers are exposed to large flows of non-hybrids that jeopardize plantation outputs. Sampling of plots that were allegedly planted with 100% *tenera* across the oil palm growing belt showed only 58% of sampled plots composed of 100% *tenera*. The quality of seedling supply has on average decreased between 1994 and 2012. Local seedling acquisition arrangements and personal characteristics of farmers influenced the proportion of *tenera* seedlings that farmers received. The success of formal intermediaries like NGOs or extension services in OPSS to connect farmers to official seedling suppliers implies that current problems can be solved if relevant organizations (the CRA-PP, the extension service, NGOs, and farmer-based organizations [FBOs]) work to balance demand and supply of hybrid seedlings, restructuring the relationship between the formal research and extension network and farmers' modes of accessing it (Offei *et al*. 2010). Effective institutional support is then needed to help smallholder farmers to acquire quality *tenera* seedlings. This may take the form of better organization of the formal state seed system to more effectively reach farmers, or it could take the form of better organization by farmers to reach the producers of quality seedlings. Either way, improving the OPSS in Benin will go a long way towards achieving farmers' objective of a better livelihood as well as the state's objective of increasing smallholder production of oil palm.

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Supplementary material

Supplemental data for this article can be accessed at http:10.1080/14735903.2014.909634.

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