Analysing seed systems performance

The case of oil palm in Bénin

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To Irène Kodjia

&

My late mother Monyidé Akpo

&

My late father Agongnonvi Laga Akpo

ABSTRACT

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The seed supply system used by smallholder farmers is characterised by many dysfunctions. For perennials, including oil palm, there is a knowledge gap regarding these dysfunctions. In this thesis, we used oil palm as a case to analyse the performance of seed systems. We conducted social surveys, sampled farmers' oil palm plots, ran field experiments and documented the social learning process of stakeholders involved.

To identify major constraints in the seed system, we conducted a diagnostic study using farmers' perspective. Jointly with stakeholders the following major constraints were identified (in order of importance): poor geographic distribution of official nurseries, poor genetic quality of palms in smallholder plots, high costs of hybrid seedlings, and poor seedling care in nurseries leading to poor physiological quality. The poor care was specifically mentioned in the eastern part of the study area.

We investigated the reliability of genetic quality of seedlings supplied to smallholder farmers as one of the constraints that emerged from the diagnostic study. Main drivers of reliability in genetic quality over the past decades were analysed. Using event ecology approach, we document the historical events that may have affected the oil palm seed system. Proportions of hybrid palms varied with seedling supply source, farmers' geographic position, seedling purchase price and year of planting. Socio-institutional mechanisms associated with observed variation in smallholder plantations were national policy change, local arrangements for seedling supply to smallholder farmers, and farmers' personal characteristics. Local arrangements improved genetic quality in villages located far away from official supply sources. Villages where local seedling supply initiatives withdrew showed reduced genetic quality with farmers having fewer *tenera* in their fields than before. Membership of farmers' organisation correlated positively with proportion of *tenera*. Farmer's use of informal intermediaries showed negative effects on genetic quality they received.

To evaluate the efficacy of on-going nursery management practices on the seedling phenotype at planting we conducted joint learning experiments. In two full 3 × 4 × 3 factorial experiments, bag size (small, medium, large), type of soil substrate ("forest" soil, household waste substrate, arable soil, and arable soil with animal manure) and fertiliser supply (no fertilisation, split dose every 15 days, and full dose every 30 days) were tested for their effects on seedling phenotype. Bag size proved the main factor determining oil palm seedling phenotype in both the 2011 and 2012 experiment. Although large-sized bags produced largest seedlings, medium-sized bags filled with a mixture of arable soil and animal manure without any fertiliser supply sustained seedling growth well and seemed the best balance between physiological quality and production cost. Growth variables were highly correlated. Height and root-collar diameter constituted good proxies to estimate seedling biomass differences between objects in a non-destructive way.

To gain insight into temporal patterns of effects of bag size, substrate, fertiliser supply, and their interactions on seedling growth, we analysed the dynamics of oil palm seedling growth using monthly observations. Overall, in both experiments, bag size explained the largest proportion of experimental error and started to deviate earlier than substrate, fertiliser supply or their two and three way interactions. Curve fitting showed different growth models for height, root-collar diameter and number of leaves. The analysis of growth rates showed that (relative and absolute) growth rates were mainly affected by bag size in both years with larger F-values than for substrate, fertiliser supply, and interactions. Experimental findings indicated that pot size matters and cannot be compensated by fertiliser addition and should therefore be considered carefully for tree seedling production in nurseries.

We analysed the joint experiment as a multi-stakeholder process and contributed to understand how the way of organising social learning affects stakeholders' ownership of process outcomes. Stakeholders' perceptions of seedling quality and their appreciation of treatment performance varied with the use they make of planting material. While farmers, as end-users, put forward seedling vigour when describing quality seedlings, nursery holders underlined production costs and reported that seedling quality is a compromise with production costs. Field observations further to the joint experiment indicated changes in practices among nursery holders, research, and farmers. The level of stakeholders' involvement increased their participation, ownership of the learning process, and could lead to sustainable practices.

The research approach developed in this thesis to analyse seed systems performance contributed to the methodology for seed systems analysis. It also contributed to knowledge of dysfunctions of seed systems for perennials, tree nursery seedling production and social learning processes.

Key words: Bénin, genetic quality, growth dynamics, innovation, institutions, multi-stakeholders process, oil palm, perennials, physiological quality, pot size, seed quality, seed systems, smallholders, social learning.

CONTENTS

CHAPTER 1

General introduction

INTRODUCTION

This thesis analyses the oil palm seed system (OPSS) in Bénin. In line with the rationale behind the Convergence of Sciences for Strengthening Agricultural Innovation Systems research programme (see http://www.cos-sis.org/) under which the study was undertaken, I developed a research approach that sought to induce multi-level change that would benefit smallholders. In this introductory chapter, I provide background information on oil palm (*Elaeis guineensis* Jacq.) importance across the world and roles of quality seeds in agricultural development with emphasis on oil palm. I further describe the problem being investigated, an overview of the theoretical underpinnings, and the overall research design. I end with a brief description of the thesis content.

Importance of oil palm across the world

Adapted to humid tropical areas, oil palm is grown in this belt of the globe covering Africa, South East Asia and Latin America (Corley and Tinker, 2003). Unlike its production area, oil palm is used across the world for different purposes including human diet and health (Benadé, 2013; Kok et al., 2011; Logan and D'Andrea, 2012; Wahid et al., 2005), cosmetics (Fontanel, 2012; Keng et al., 2009; Vermaak et al., 2011), bio-energy (Tan et al., 2009), animal feed (Abubakr et al., 2013; Prabhakaran, 2010), input material for concrete (Alengaram et al., 2013; Shafigh et al., 2013), paper production (Henderson and Osborne, 2000), fertiliser (Chiew and Shimada, 2013), etc. In less than a century, the crop emerged as major commodity (Sayer et al., 2012) that proved more efficient in oil production and carbon sequestration than any other oil crop (Basiron, 2007; Caliman, 2011; Lamade and Bouillet, 2005). While world demand for edible oils is projected to double today's consumption by 2050, palm oil is expected to have significant contributions (Corley, 2009). Even though many records point out that oil palm reduces biodiversity in tropical areas (Aratrakorn et al., 2006; Fitzherbert et al., 2008; Koh and Wilcove, 2008), the acreage of the crop is still growing. The increasing areas planted to oil palm are an obvious response to increasing world demand (Carter et al., 2007; Curran et al., 2004; Omont, 2010; Sumathi et al., 2008; Turner et al., 2008).

In most production countries, smallholders account for an important share of oil palm plantations. In the largest supply countries like Malaysia, Indonesia and Thailand, smallholder farmers represent about 40% of land cropped with oil palm (Nagiah and Azmi, 2012; Von Geibler, 2012; Wangrakdiskul and Yodpijit, 2012). In African production countries, the crop is also still part of daily livelihoods of smallholders. In Nigeria, Ghana and Côte d'Ivoire for

Figure 1.1. Oil palm, a multifunctional crop for smallholders in Bénin (Photos, E. Akpo, 2009).

example, smallholders supply up to 80% of national production (Afrane, 2012; Jannot, 2010; Ohimain et al., 2013; Olangunju, 2008).

In Bénin, smallholders are main players who deliver the bulk part of national production. Currently, oil palm production in Bénin mainly serves for local use or export to Nigeria. For smallholders in Bénin (see Figure 1.1), oil palm provides next to oils, wood for cooking, wine for alcohol production, material for various domestic equipment, input for traditional soap making, income and employment, etc. (Ade et al., 2010; Hyman et al., 1990). Like in other West African countries (e.g., Nigeria, Ishola et al., 2013; or Ghana, Afrane, 2012), oil palm production in Bénin is also intended for biofuel (Mekhilef et al., 2011). Yet, no real achievements regarding biofuel can be reported so far. Emphasis has been placed, however, on smallholder farmer production to improve their livelihoods. The governmental initiative in mid-1990s that aimed at increasing national production of palm oil strongly supported smallholder farmers. To meet this government goal, the quality of planting material is a key aspect (Durand-Gasselin and Cochard, 2005).

Importance of seed quality in agriculture

The importance of seed quality in agriculture and its contributions to improving production performance of smallholder farmers has been widely reported (Louwaars, 2002; McGuire, 2005; McGuire and Sperling, 2013). Seed constitutes basic agricultural input (Dubreucq et al., 2010) and good quality seed of varieties that fit local context is critical to farmers' capacity to improve productivity (Marfo et al., 2008; Rubyogo and Sperling, 2009). In the hands of resources-limited farmers, who strive to maintain and improve their livelihoods under uncertain conditions, seed is the most precious of resources (Tripp, 1997). Planting material bears knowledge passed on through generations (Richards, 2009), and is the result of continuous adaptation and innovation in face of ever greater challenges for survival (Richards et al., 2009). Among the main factors that prevent smallholder farmers from having high yield, seed quality appears among the top ones (Bryan et al., 2013; Hounkonnou et al., 2012; Jayne et al., 2010; Lipton, 2010; Nordhagen and Pascual, 2013). The criticality of quality planting material is even more important with tree crops where several years are needed before first harvest of produce and planted material may be maintained for decades.

Quality of planting material and oil palm production

For oil palm, high productivity requires that pure hybrid planting material is used. Oil palm yield, like other allogamous crops (e.g., Batugal et al., 2009; El Hadrami and El Hadrami, 2009), heavily depends on genetic quality of seedlings (Durand-Gasselin and Cochard, 2005). Genetic quality of oil palm seedlings accounts for more than 59% of plantation outputs (Ngoko et al., 2004). Cochard et al. (2001) estimated up to 61% production loss due to use of non-hybrid seedlings. In fact, oil palm is composed of different types of material, and of these, only the hybrid produces high yield, and is therefore expected in commercial plantations. All these support the argument that supply of high genetic quality seedlings goes hand in hand with development of oil palm plantations (Durand-Gassselin et al., 2000).

PROBLEM STATEMENT AND OVERALL RESEARCH OBJECTIVES

Production of oil palm seed, a step beyond smallholder farmers

Unlike many other crops, having productive oil palm seed requires specific skills and facilities. This makes the use of *tout venant* (uncertain source) planting material more risky for four reasons.

First, the biology of oil palm reproduction indicates strict allogamy. This makes the use of collected seedlings more risky for smallholder farmers who are accustomed to collect planting material in previous harvests (Foti et al., 2008; Mekbib, 2007; Monyo et al., 2004; Tripp, 2006).

Second, production of hybrid palm seed is knowledge intensive. Oil palm is composed of three types: the *dura* type is thick-shelled with 35 to 70% of pulp, although most local palm populations have far lower proportion of pulp than 70%; the *pisifera* type is shell-less with 90% pulp and is usually female sterile; the *tenera* type (hybrid between *dura* and *pisifera*) is thin-shelled with 80% pulp and most productive of the three types, *tenera* occurs in natural stands but at a very low rate. Improved *tenera* is produced in dedicated institutes through selecting high-profile trees of *dura* (female parent) and *pisifera* (male parent) and careful implementation of appropriate crosses avoiding any contamination by external pollen material. Skills needed for the job make it almost impossible for untrained people to implement successfully. Consequently, smallholder farmers could not produce *tenera* seeds themselves. In Bénin, only the national research station in Pobé can make it available.

Third, the process of *tenera* production requires large investments in time. To obtain *tenera* from high-profile *dura* and *pisifera* parents, it takes about 20 to 30 years. Also, from on-farm inflorescence isolation (on parents) to production of planting seedlings, about 24 months are needed.

Lastly, oil palm takes a long time to produce its first bunches after planting on farm. In Bénin agro-ecological conditions, 3 to 4 years are needed for a hybrid palm to produce its first bunches. The local *dura* type palm even takes longer than hybrid palms to produce the first bunches. Local palms produce first bunches about 7 years after transplanting with yields representing between 10 to 30% of the yield of hybrid palm (Jalani et al., 1997; Noiret et al., 1985). It appears that any failure to buy *tenera* seedlings means waste of time and resources for smallholder farmers.

Problem description

Oil palm is the most important industrial crop in Southern Bénin. The crop has a long history in the country with strong contributions to foreign exchange up to early 1970s. Production statistics indicate, however, that the national production of palm oil (35,000 MT) is by far insufficient to meet the domestic demand (75,000 MT) (Adje and Adjadi, 2001). In such a context, developing the oil palm sector to improve national production is among national priorities of Bénin (MAEP, 2009). In the mid-1990s, a governmental programme for oil palm sector revival was initiated. This governmental initiative favoured smallholder farmers’ access to hybrid planting material (Adje and Adjadi, 2001). Mainly dominated by state cooperatives since the 1960s (Dissou, 1972), the acreage of smallholder grown oil palm significantly increased and smallholders became by far the main contributors to national production during the last ten years. Smallholder land cropped with oil palm was estimated to about 50,000 ha in 2010. Nevertheless, smallholders' contribution to the bulk part of national production was made under many production constraints that were not well documented.

Aware of the challenges to increase national palm oil production, the government's support to the oil palm sector is relentless. In its strategic plan for development of the agricultural sector, the Bénin government targeted oil palm as one of its priority crops (MAEP, 2009). In line with government policy, an exploratory study was conducted within the Convergence of Sciences for Strengthening Agricultural Innovation Systems programme (CoS-SIS, see for further details, http://www.cos-sis.org/) in Southern Bénin in 2009. The study reported institutional and technical constraints that smallholder oil palm farmers experienced. Among the main issues constraining farmers was the quality of planting material they purchased. The oil palm seed system (OPSS) was then suspected of not performing adequately.

In Bénin, the OPSS is organised in such a way that smallholder farmers are not allowed to raise *tenera* seedlings themselves. Nationwide producer of hybrid seed, the oil palm research centre "Centre de Recherche Agricole Plantes Perennes (CRA-PP)", provides germinated seeds to officially established nursery holders who are the only private people authorised to raise hybrid seedlings. For field planting, smallholder farmers are then forced to purchase *tenera* seedlings with official nursery holders or CRA-PP. Up to now, little is known about the functioning of the OPSS with reference to dynamics in the system and reliability of seedling quality for smallholder farmers.

In fact, the OPSS in Bénin consists of an informal sector and a formal system for seedling delivery to farmers. In the informal sector (also called traditional or local or farmers' seed system (Almekinders and Louwaars, 2002; Longley, 2001)) one way for smallholder farmers to collect seedlings is from existing plantations. Another way for smallholder farmers is to get seedlings from informal networks that involve non-official nurseries. The existence of non-official nurseries selling seedlings to smallholder farmers was reported earlier (Aoudji et al. 2012; Séhouéto, 2012). In the formal seed system, official private nursery holders are formally trained and established and they are assumed to provide only hybrid seedlings to farmers (Adje and Adjadi, 2001). In this OPSS chain of actors for seedling delivery, it occurs that smallholder farmers unwittingly get poor quality seedlings. This general picture of the OPSS needs further analysis to map out dynamics in the system and possible interrelationships between formal and informal systems to provide full insight. This insight could then lead to further studies that would contribute to better understanding of functioning of the current OPSS for quality seedling delivery to smallholder farmers.

Nowadays, oil palm production has often been associated with environmental controversies. Many authors associated responsible oil palm production to use of high-quality planting material. Durand-Gasselin et al. (2010), in this respect, argued that use of hybrid planting material promotes sustainable oil palm as it contributes to reduced forest clearance and at the same time increases the amount of palm oil produced per unit of land. The increase of palm oil production in Bénin should also be sustainable. This partly justifies the relevance of investigating major problems of seedling quality that main contributors to national production are facing. Consequently, the poor quality of planting material in the current OPSS was taken as entry point to this thesis.

Research objectives

The overall objective of this research was to analyse the performance of the oil palm seed system across Southern Bénin. Such an analysis would provide better understanding of dynamics in the seed system for further improvement for smallholder farmers. Specifically, this thesis aims to:

- identify major constraints in the oil palm seed system from a farmers' perspective;
- assess reliability of genetic quality of seedlings that farmers purchased;
- evaluate nursery management practices to address physiological quality issues;
- analyse the social learning process through which nursery management practices were evaluated.

The first objective was set beforehand by the researcher whereas the other three came in during the research process.

THEORETICAL UNDERPINNINGS

Seed systems (SS) can be analysed from different perspectives. The market perspective, often used to analyse SS, places much emphasis on farmers' uptake of new varieties (Marfo et al., 2008; Tripp, 1997). SS analysis from regulatory frameworks' perspective cares more about formal arrangements and processes leading to seed release (Muhhuku, 2008). Another way of analysing SS is to focus on characteristics that differentiate between informal and formal SS, public vs. private actors' involvement and achievements (Almekinders et al., 1994; Etwire et al., 2013). Little attention is often given to perceptions of end-users of seeds. Furthermore, studies of SS often limit themselves to describing the state of a SS but hardly take on initiatives to address them effectively (e.g., Etwire et al., 2013; Hirpa et al., 2010). In this thesis, a different research approach was used.

First, a farmers' perspective for analysing a SS as described by (Weltzien and vom Brocke, 2001) was used. From a farmers' perspective, a SS fulfils a series of functions namely: (1) seed quality, (2) appropriateness of variety traits, (3) timeliness of seed availability, (4) conditions under which planting material can be obtained. A better understanding of dynamics in current SS requires clear identification of levels at which identified major constraints can be solved. To reach this, the multi-level perspective of Geels (2002) was adapted. According to Geels (2002), change happens from interactions of different processes at different levels. These include niche level (localised change where institutional and socio-technical experiments can take place); regime level (signifying relative stability in institutions across multiple locations); and landscape level (signifying larger institutional context that cannot be readily changed by niche experiments or regime-level 'rules of the game').

Second, the perennial characteristic of oil palm allows an in-depth analysis of historical events that may have affected reliability of genetic quality of seedlings. To document connections between events and performance of OPSS over time, a timeline study of causal mechanisms was considered relevant. I used an event ecology approach, as framed by Vayda and Walters (1999) and Walters and Vayda (2009). Event ecology starts from effects to reach underlying causes through exploring plausible historical mechanisms that led to observed outcomes. The approach was earlier used to explain human-induced environmental changes (e.g., Carr, 2002).

Third, to effectively address issues that hinder smallholder farmers from using appropriate seedlings they pay for, this thesis integrates approaches that favour communications and mutual understanding among main actors of the OPSS. Social learning around the material appeared to be one of the best ways to achieve this. Field experimentation with non-academics was considered then. Experimentation is reported to significantly crystallize and shape social learning (Bos et al., 2013). Social learning allows stakeholders to engage in active collaboration that generates knowledge, skills and relationships. As social learning is complex, appropriate steps need to be undertaken for successful implementation. Addressing issues around the OPSS performance might be ineffective if the research approach omits some of the main players. Creating a multi-stakeholder platform was considered as it allows to address effectively issues requiring contributions from several stakeholders (GIZ, 2011).

In the end, studying the complex realities of the SS requires integrative analysis of interconnected elements, processes, and emerging properties from these connections. The SS reflects complex interactions between biological, economic, and social processes. Since isolated components cannot fully explain all interactions between practices and processes within the SS. A separate study of each or either of them might deprive of mapping out their interrelationships and linkages that might show patterns to be used for further improvement. Moreover, the SS is built upon a set of organizations, institutions and farmers that shape and contribute to its performance. The latter have to be considered as interconnected key elements, supporting the system, to be analysed altogether, including indigenous knowledge. The research approach used in this study shows how far the current OPSS meets needs of smallholder farmers, and moved further to test ways to effectively address them. The approach has the advantage of helping to bridge gaps between stakeholders to improve performance of the current OPSS for smallholder farmers.

In this thesis, I use the terms “seed” and “seedling” but both have the meaning of planting material. I also use the term “genetic quality” of oil palm. I restrict the meaning of “genetic quality” of oil palm to proportions of *tenera*, *dura* and *pisifera* types. Higher genetic quality implies a larger proportion of trees or planting material is *tenera*. The OPSS is understood as combination of official and non-official supply sources, including various actors and institutions involved in planting material delivery to farmers.

RESEARCH DESIGN

This study is trans-disciplinary research involving academics and non-academics: researchers, extension agents, nursery holders, and oil palm farmers; and as such, it distinguishes itself from merely social or biophysical research. The research design drew on the Convergence of Sciences (CoS-SIS) research programme design. In the CoS-SIS research design a number of research steps were planned starting with an exploratory study that would lead to a diagnostic study. The diagnostic study would identify socio-institutional and technical issues that are critical for smallholders to improve their production and livelihoods. The exploratory study was conducted within the oil palm sector in 2009. The objective was to identify major areas of concerns for smallholder farmers and possible opportunities to address them. Among identified constraints, the quality of planting material was top ranked. To gain further insights into seedling quality problems, an in-depth analysis was needed. This triggered the

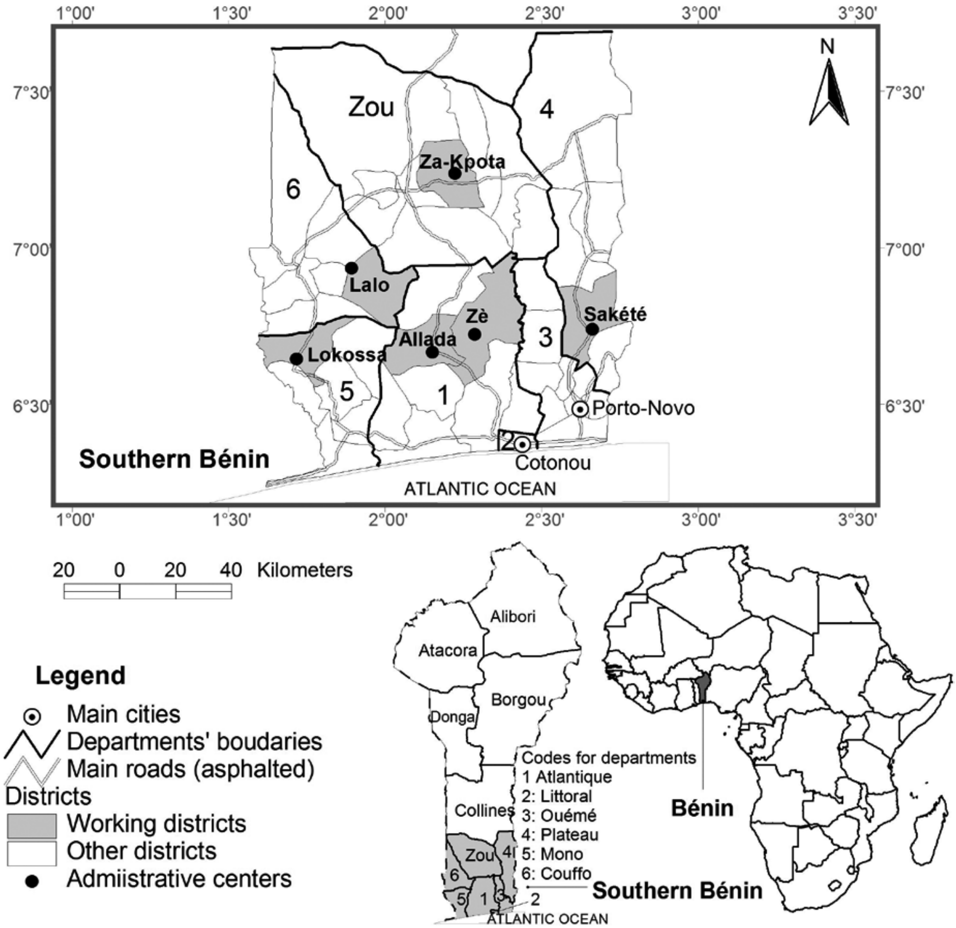

Figure 1.2. Map of Southern Bénin showing the studied districts, at the bottom a map of Africa and of Bénin for general reference.

participatory diagnostic study conducted in 2010 (reported in Chapter 2, see also Akpo et al. (2012)). The objective was to identify, jointly with key actors, constraints in the OPSS and to assess its performance from a farmers' perspective. Identified constraints were shared with stakeholders via a validation workshop. The workshop ended with a joint research agenda that was set and further implemented. The research agenda suggested the need for further research to understand the historical context of OPSS development, and joint experimentation with stakeholders to learn about nursery management practices that sustain physiological seedling quality.

BRIEF INTRODUCTION TO THE STUDY AREA

The research project was carried out, from July 2009 to December 2012, in the oil palm growing belt in Southern Bénin covering agro-ecological zones VI to VIII (MEPN, 2008) ranging from the coast (6°30’ N) to 7°30’ N. In this area, oil palm takes an important part in smallholder farmers’ livelihoods. The climate is transitional equatorial with two rainy seasons, from March to July and September to November, and two dry seasons, from August to September and from November through March. The rainfall decreases from east to west with an annual rainfall of 1400 mm in Sakété and of 950 mm in Grand-Popo. For oil palm to express its full potential, an average annual rainfall of 1800 mm evenly distributed over the year is required (with a minimum higher than 1300 mm) (Jacquemard, 1995). The annual average temperature fluctuates between 23 to 32 °C (MEPN, 2008; Tchibozo et al., 2005) compared to 18 °C (minimum) and 28 to 34 °C (maximum) required (Jacquemard, 1995). Main types of soil encountered in the region are ferralitic soils mainly composed of deep soil known as *terre de barre*, vertisols in the depression of Lama, and hydromorphic soils. Deep soils or soils with temporary hydromorphy are the most suitable ones for oil palm production. In Southern Bénin, farming is the main activity for local communities. The agricultural landscape is mainly featured by oil palm plantations, pineapple [*Ananas comosus* (L.) Merr.] farms and food crop farms (with maize [*Zea mays* L.], cassava [*Manihot esculenta* Crantz], cowpea [*Vigna unguiculata* (L.) Walp.]).

The study covered 6 of the main districts of oil palm production in Bénin from west to east: Lokossa, Lalo, Allada, Zè, Za-Kpota and Sakété (Figure 1.2). In the eastern part of the study area, the main purpose of oil palm production is oils. The western part, however, is the area where oil palm use for alcohol production is more important than elsewhere in the country. An important aspect of selected districts is their representativeness of the situation of the seed system in their respective regions.

THESIS OUTLINE

The research approach developed and used to analyse the oil palm seed system (OPSS) performance led to a number of studies that compose this thesis (Figure 1.3). The lead study, the diagnostic study, is reported in C**hapter 2**. In this Chapter, OPSS characteristics are presented from a farmers’ perspective. Major constraints are presented and included poor geographic distribution of official nurseries, poor genetic quality of palms in smallholder plots, high cost of hybrid seedlings, and poor seedling care in nurseries leading to poor physiological quality. These constraints led to further studies to understand the historical

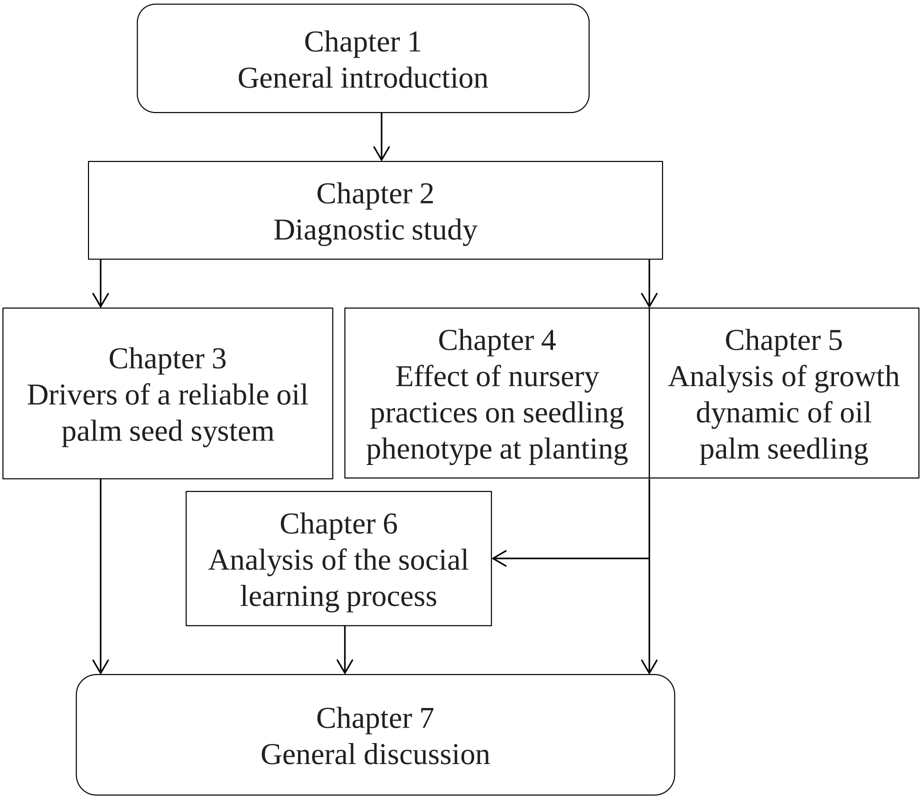

Figure 1.3. Thesis structure indicating connections between studies and chapters.

context of OPSS development regarding genetic quality, and ways to handle poor seedling management practices in nurseries.

In **Chapter 3**, the reliability of the OPSS is documented as one of the studies that emerged from the diagnostic study. Main drivers of the OPSS reliability over the past decades are analysed. This chapter presents how proportions of hybrid palms vary with seedling supply source, farmers' geographic position, seedling purchase price and year of planting. It also elaborates on socio-institutional mechanisms associated with observed variation in smallholder plantations over time, i.e., national policy change, local arrangements for seedling supply to smallholder farmers, and farmers' personal characteristics.

In **Chapter 4**, efficacy of on-going nursery management practices is evaluated on seedling phenotype at planting. This chapter highlights the relative importance of nursery practices on seedling growth. Chapter 4 also reports an analysis of the economic balance between seedling quality and production costs for both nursery holders and farmers. The level of correlation between growth variables is shown as well as best candidate proxies to estimate seedling biomass production non-destructively. Consistency of treatment effects on total dry weight produced over the two years was reported as well. In Chapter 4 the core message regarding the importance of nursery management practices and their consideration for tree seedling production in nurseries was drawn.

Chapter 5 analyses dynamics of seedling growth to understand expression patterns of nursery practice effects on seedling growth over time. Bag size effects from seedling transplanting to the end of nursery were compared with substrate, fertiliser and interaction effects. This chapter also shows that growth parameters follow different growth models. Seedling growth rates for different growth variables were examined. In Chapter 5, one of the main contributions of this thesis to scientific knowledge was highlighted.

Chapter 6 analyses the social learning among stakeholders in the joint experiment to improve seedling management practices. This chapter documents how the joint experiment served as means to co-innovate the OPSS. New production practices that participants, mainly nursery holders, learned from their peers are presented. Sketches of changes in practices mainly with nursery holders and research centre are reported. The layout of methodological steps taken in this research process and observed positive feedback mechanisms are discussed.

Chapter 7 binds together the findings of the implemented research approach. Important issues that could not be covered in previous chapters are discussed in the general discussion. It concludes this thesis and provides further lines of policy development and thinking.

CHAPTER 2

A participatory diagnostic study of oil palm (*Elaeis guineensis*) seed system in Bénin

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ABSTRACT

A participatory diagnostic study of the oil palm (*Elaeis guineensis* Jacq.) seed system (OPSS) was conducted along a gradient of rainfall and distance to the oil palm research centre across the oil palm growing belt of Bénin. The objective was to assess the performance of the OPSS from a farmers' perspective and to identify, jointly with key actors, the constraints in the OPSS. The methodology included introductory community meetings, group discussions, individual in-depth interviews, field visits and a validation workshop with the key actors. Farmers indicated that the current OPSS does not perform well. Major constraints include the poor geographic distribution of official nurseries, poor genetic quality of the material in plantations, high cost of hybrid planting material, and poor seedling care in nurseries, leading to poor physiological quality. The poor physiological quality was specifically mentioned in relation to official nurseries in the east of our study area, whereas farmers in the west and centre were more concerned about the uncertain genetic quality of planting material. The constraints indicate the need for further research to understand the historical context of OPSS development, joint experimentation to improve seedling management practices in official nurseries and joint identification of the (genetic) quality of oil palm seedlings using morphological and molecular characteristics and tools. The study also identified potential opportunities for institutional intervention.

Key words: Bénin, institutional change, oil palm, planting material, seed quality, seed systems.

INTRODUCTION

An initial exploratory study was carried out within the Convergence of Sciences for Strengthening Agricultural Innovation Systems programme (CoS-SIS, see http://www.cos-sis.org/) in Bénin in 2009 to obtain a general view of the major researchable socioeconomic, institutional and technical constraints experienced by smallholder oil palm (*Elaeis guineensis* Jacq.) farmers and the existing opportunities to deal with such constraints (Vissoh et al., 2010). Among the constraints mentioned by farmers was the functioning of the oil palm seed system (OPSS), mainly in relation to the genetic and physiological quality of the purchased planting material, indicating that neither the formal nor the informal seed system were performing adequately. The diagnostic study of the OPSS reported here was undertaken to deepen the initial constraints analysis.

Researchers have identified many instances of dysfunction in food crop seed systems for reasons that include inability to meet the annual demand for seeds; limitations of the regulatory frameworks (Gemeda et al., 2001); high prices and inappropriateness of hybrid varieties (Thiele, 1999); the level of inputs needed to make use of improved varieties, that many small farmers cannot afford (Kessy and Laub, 2006); and the release of only a few varieties that in turn fail to meet small farmers' needs (Almekinders and Louwaars, 2002). No such studies seem to have been made on perennial crops. If seed systems are to benefit many farmers, these setbacks need to be adequately addressed (Kessy and Laub, 2006), also for perennial crops. This requires a thorough understanding of the particularities of the seed system, even more so for seed systems of perennials where heavy investments are needed before the production of the first produce.

In principle, oil palm farmers in our study area either can use the traditional and locally available oil palm seedlings of the so-called *dura* type or they can plant hybrid material of the *tenera* type (Adje and Adjadi, 2001). *Tenera* produces higher yield than *dura* owing to the heterosis effect. A small percentage of *Elaeis guineensis* palms are naturally of a different fruit type, the so-called *pisifera* palms. Since around 1970 (Durand-Gasselin and Cochard, 2005), the oil palm research system in Bénin has produced the more productive hybrid or *tenera*, obtained through a cross of *pisifera* (male) and *dura* (female) parents (Adje and Adjadi, 2001). Breeding has further progressed by producing improved lines of both parents and crossing these. Farmers start any planting event, whether of hybrids or traditional *dura* palms, by using established seedlings because controlled germination of seed is a tedious and knowledge intensive step. Farmers are prepared to purchase only the hybrid seedlings because these otherwise are difficult to obtain and can be accessed only from the research system, either directly or through nurseries. *Dura* type seedlings are obtained without financial cost through uprooting volunteer seedlings in existing plantations or in wild groves.

The production of hybrid planting material requires many technical steps including the selection of parents, inflorescence isolation, checking the inflorescence at maturity and artificial pollination. The hybrid seeds that are harvested six months later then undergo a controlled germination process. These steps are normally conducted under the surveillance of a breeder in order to control the quality. The germinated seeds are delivered to specially trained and official nurseries that raise the seedlings and sell them on to farmers.

The supply of hybrid planting material to farmers is arranged through a network of actors. A farmer who buys oil palm seedlings has no means to directly check the genetic quality of the material and may unwittingly buy non-hybrid material or a mix of non-hybrid and hybrid material. It is currently possible to distinguish hybrid oil palms from non-hybrids only through the dissection of their nuts, and the first of these are produced only when palms are around 3-4 years old. The economic impact on rural livelihoods of this delay is important. According to Ngoko et al. (2004), the supply of non-hybrid material to farmers in Cameroon reduces production from 77% down to 59% of its potential. The seedling quality delivered in any country is closely linked to the way the seed system is organised and functions. Durand-Gassselin et al. (2000) argue that the supply of hybrid oil palm planting material, especially to smallholders in developing countries, needs more attention but that the reform of existing systems should be carried out cautiously. Smallholder farmers who want to increase oil production on their farm through the use of improved material are, to a large extent, exposed to poor quality material from multiple sources. This chapter analyses the relevance of earlier findings on the seed systems of annual crops and OPSS for the specific case of oil palm in Bénin.

In this chapter we use the definition of seed system framed by Maredia et al. (1999): "the complex of organizations, institutions and individuals associated with the development, multiplication, processing, storage, distribution and marketing of seeds of any specific crop in a country" (Maredia et al., 1999, page 3).

In this definition an organisation is understood as any social unit of people that is structured and managed to reach a need or a set goal. Institutions are defined as the rules of the game, i.e. norms, values, regulations in which organisations are grounded (North, 1990). A seed system may include an informal seed system, also known as the local (Gemeda et al., 2001; Mekbib, 2007) or farmers' seed system (Almekinders and Louwaars, 2002), and a formal seed system. All activities in an informal seed system that are connected to seed development and production are performed without any external control of seed quality. A formal seed system typically involves a number of formal organisations, each with specific tasks. Strict quality control protocols regulate the development of new varieties and production of the seeds that are released to farmers. The main difference between informal and formal seed systems lies in the formalisation in the latter case of control over seed quality during development and production.

The formal seed system in this study refers to the oil palm research system where the control over the quality of seedlings from hybrid seeds is formally assured. Hybrid seeds are obtained from controlled pollination. The term, informal seed system, refers here to seedling production and distribution in which there is no formal control of the genetic quality. The term, official nursery, is used for nurseries that officially obtain germinated seeds from the research system and where the nursery holder has received formal training to ensure seedlings are of both genetic and physiological high-quality. The term, non-official nursery, applies to any other nursery that obtains seedlings unofficially from the research system or any other source, and where the nursery holder may not have received training on how to deliver quality seedlings. A special case is the planting by farmers of seedlings collected by uprooting volunteer seedlings from existing plantations or wild groves. We thus take the OPSS to include the various supply sources, the involved actors, their respective activities and the interrelations among the actors from seedling production to delivery to end users.

The study focuses on the following questions: (1) What are the components of the OPSS? (2) How can the OPSS be characterised? (3) What are the major issues hindering smallholder farmers from getting quality planting material in a timely fashion? (4) What are actors' perspectives on the possibilities for improvement? Based on these four key questions, this study identifies the relevant actors involved in the OPSS and their respective roles, as well as research issues and key institutional factors constraining smallholder farmers from getting access to good quality planting material

The next section outlines the importance of the oil palm crop and presents the study area. Data collection and data analysis methods and tools are described in the methodology. The findings section presents the components, organisational arrangements and characteristics of the OPSS from the farmers' perspective, identifies the constraints, and explores farmers' knowledge and practices in the OPSS. The extent to which the OPSS fits farmers' goals and needs and the institutional level at which solutions to the major constraints might be found then are analysed and discussed. The chapter concludes by indicating the way forward in terms of further research and possible institutional interventions to improve seeds system functioning.

STUDY CONTEXT

Oil palm is an important crop for farmers in Southern Bénin (Adje and Adjadi, 2001) and for the rural economy of this region (MAEP, 2009). It is a multifunctional crop well-embedded in everyday life of the local people. Its uses include food consumption (local dishes, palm wine), traditional soap making, customary ceremonial practices and as an organic fertiliser. Some of the main by-products obtained from milled processing, such as palm kernel and cattle cake, are valued as animal feed (Bamikole and Ikhatua, 2009; Nyanjou, 2008; Tan, 2006). Palm oil is also used for industrial processing: to make cooking oil (known as whitened oil), for valuable compounds like the oleochemicals used in cosmetics, for energy (as a solid fuel and biofuel) and paper (Corley and Tinker, 2003; Rupilius and Ahmad, 2007). Kernel oil is used in margarine, and the cake and chocolate industries (Corley and Tinker, 2003).

In the past, oil palm was a crop with a strong positive influence on the national economy of Bénin (Dissou, 1988). It was the prime export cash crop until the early 1970s; the export value share was 73.9% in 1965 (Sedjro, 1980). By the mid-1990s oil palm represented more than 50% of the total production of vegetable oil in Bénin (Djegui and Daniel, 1996) and covered 43% of the national demand for fats (Adje and Adjadi, 2001). However, national production of palm oil (35,000 MT) today covers only about half of total domestic consumption (75,000 MT) (Adje and Adjadi, 2001; SNV, 2008). A government programme initiated in 1995 for the development of the oil palm sector, had little impact (MAEP, 2009). The initiative emphasised the development of smallholder oil palm plantations to improve smallholder livelihoods while also increasing national palm oil production for industrial purposes (MAEP, 2009). A good first step was made through the establishment of nurseries run by trained nursery holders and that were provided with a foundation stock of good quality seedlings. In this way, planting material of assured quality became more readily available to farmers in the agro-ecological zones most suited for oil palm production.

Agro-ecological zones suitable for oil palm growing are located in the southern part of the country, between the coast (6° N) and 7° N inland. The climate is transitional equatorial with two rainy seasons, from March to July and from September to November, and two dry seasons, from August to September and from November through March. The annual rainfall decreases from 1400 mm in Sakété (east) to 950 mm in Grand-Popo (west) (MEPN, 2008). For oil palm to express its yield potential, an average annual rainfall of 1800 mm which is evenly distributed over the year, is required (with a minimum higher than 1300 mm) (Jacquemard, 1995). The observed annual average temperature ranges from 23 to 32 °C (MEPN, 2008; Tchibozo et al., 2005) as compared to the reported minimum of 18 °C and maximum between 28 and 34 °C (Jacquemard, 1995).

The oil palm research centre (Centre de Recherche Agricole Plantes Pérennes: CRA-PP) develops planting material of assured quality to meet farmers' needs. The CRA-PP, located in the district of Pobè (Figure 2.1), produces and sells hybrid seeds to both national and international buyers. At the country level, nursery holders, the extension service and oil palm farmers' organisations are part of the seed supply system of the CRA-PP. Both hybrid and non-hybrid types are used in farmers' plantations. Up to the early 2000s *dura* palm farms dominated; the current oil palm landscape indicates that planting of oil palms sold as hybrids has become common (MAEP, 2009), implying that there has been a great change in the seed

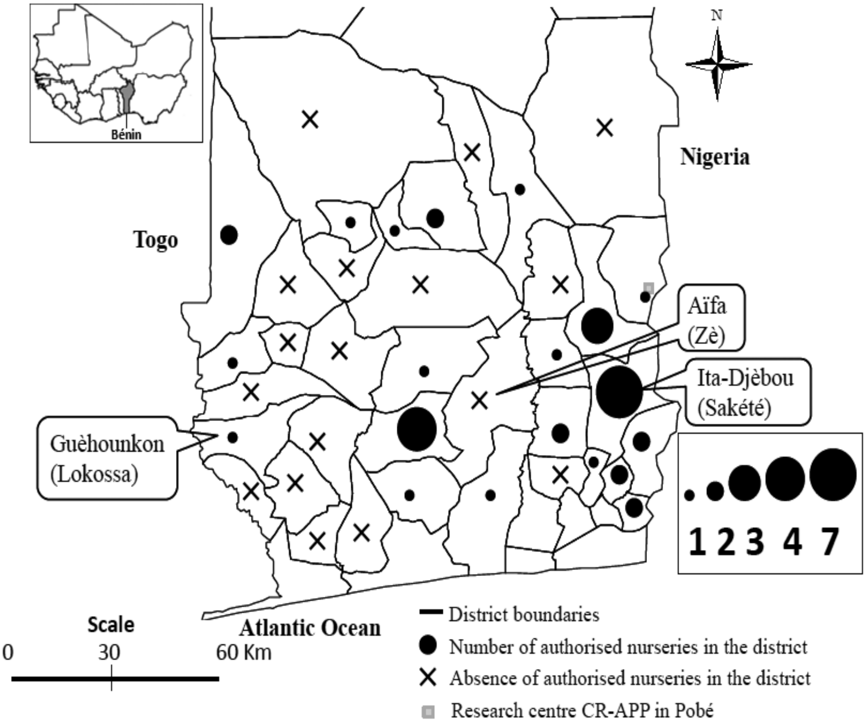

Figure 2.1. Map of Southern Bénin. The selected villages (districts) are indicated in balloons; the research station site and the absence or number of official nurseries in each district are indicated by symbols explained in the legend.

system, especially for farmers, and that a new effort to guarantee the quality of the planting material is needed.

Planting material constitutes the first input in the agricultural cycle (Dubreucq et al., 2010) to improve farm outputs (Rubyogo and Sperling, 2009). In the establishment of an oil palm plantation the genetic and physiological quality of the planting material is of crucial importance to farmers because it endures in their plantations for more than 30 years (Durand-Gasselin and Cochard, 2005). Durand-Gassselin et al. (2000) argue that the development of oil palm plantations is closely connected to a successful supply of hybrid planting material. Hybrid planting material ensures higher productivity and thereby secures planters' investment.

An exploratory study carried out within the CoS-SIS programme on the constraints to smallholder oil palm production suggested that the OPSS is not working adequately for farmers and constitutes a major bottleneck. Farmers complained mainly about the poor

Table 2.1. Characteristics of the selected villages.

Criteria	Villages (District)		
	Ita-Djèbou (Sakété)	Aïfa (Zè)	Guèhounkon (Lokossa)
Dominant ethnic group	Nago	Aïzo	Kotafon
Main purpose of oil palm production	Palm oil	Palm oil	Alcohol and palm oil
District proximity to CRA-PP centre (km)	30	150	200
Age of hybrid oil palm plantations (years)	More than 10	More than 10	Less than 10
Annual rainfall (mm)	1400	1200	1000

Source: District extension services of Lokossa, Zè and Sakété.

genetic and physiological quality of the planting material supplied to them (Vissoh et al., 2010). The diagnostic study reported here was carried out to obtain further insight into the seed system and to identify appropriate remedial actions. The diagnostic study was conducted in three districts, Lokossa, Zè and Sakété (Figure 2.1), selected along a transect from east to west of the southern oil palm growing belt, along a rainfall gradient and a gradient of distance from the oil palm research centre. The criteria for the selection of the three districts along the gradients included the importance of oil palm production in the district, the distance from the research centre, the main reasons for growing oil palm and the age of the plantations. The selection of the three districts was carried out with the help of the extension service because secondary data on oil palm are scarce.

In each district a village (Guèhounkon in Lokossa, Aïfa in Zè and Ita-Djèbou in Sakété) (Figure 2.1) was jointly selected by using information gathered from key informants, together with representatives of oil palm farmer organizations and the local extension service. Table 2.1 presents the characteristics of the selected villages. The main selection criterion was the presence of both hybrid and non-hybrid oil palm plantations.

RESEARCH METHODOLOGY

To assess the performance of the seed system across the study area data were gathered about the components of the OPSS, the characteristics of the OPSS based on farmers' perspectives, the major issues constraining farmers, and farmers' knowledge of and practices in the OPSS. Data were collected through introductory community meetings, group discussions, open and semi-structured interviews, field visits and a validation workshop with actors. For a list of all meetings and the number of participants, see Table 2.2.

Table 2.2. Summary of tools used for data collection and number of participants.

Tools	Number of participants per selected site		
	Guèhounkon	Aïfa	Ita-Djèbou
Introductory community meetings	27	37	33
Group discussions with farmers	28	25	31
Open discussions with representatives of organisations	11	10	9
Semi-structured interviews with farmers	136	102	148
Field visits	2	4	1
Validation workshop with actors from the three sites	15		

Introductory community meetings and preliminary data gathering

In each of the selected villages an introductory meeting was held. In addition to oil palm farmers the meetings gathered together the representatives of the oil palm farmer organisation at the village level, and a representative of the extension service who facilitated the introduction of the main researcher (and author of this thesis). The objective was to inform the oil palm farmers about the purpose of the study and to announce that the researcher was ready to work on the many constraints that had been documented related to the quality of the oil palm planting material, jointly with all actors in order to find appropriate solutions. The farmers then were asked to confirm that working on the quality of the planting material was worthwhile. The participants approved the opportunity offered to discuss such a question that they qualified as being of high importance. Many of the participants talked about their experience of poor quality planting material.

Data gathering about the components of the OPSS

The study used snowball sampling to identify the actors playing a role in the OPSS (Wasserman et al., 2005). The starting nodes were individual farmers. Each actor was asked who his or her partners were and how they related to each other in the system. Group discussions were used to collect further data about the components of the seed system and its internal organisation. Key informant interviews provided further details about the issues discussed in the groups.

Data gathering on farmers' perceptions of OPSS characteristics, constraints, knowledge and practices

Methods were chosen to stimulate open discussion so as to reveal the actors' perceptions of the OPSS' characteristics (Weltzien and Vom Brocke, 2001), the major constraints, and the endogenous knowledge and practices in the OPSS. The farmers first were sorted into three groups based on the type of oil palm material they grew: (i) oil palm farmers growing only local material, (ii) oil palm farmers growing only hybrid material, and (iii) oil palm farmers growing both materials. The hypothesis behind this typology was that farmers in the different categories might have different strategies for accessing planting material. A group discussion was held with each category of oil palm farmers. The number of attendees varied from 6 to 12 people. The same issues that emerged in the group discussions were pursued in follow-up semi-structured interviews with the individual participants in order to obtain more specific information. Field visits subsequently were conducted with one to four key informants to check in the field setting some of the issues raised such as the inappropriate genetic composition of stands, variation in the characteristics of local oil palm, less productive hybrid oil palms, and the nurseries.

Validation workshop

A workshop was organised with 15 representatives of the oil palm farmers, nursery holders, oil palm farmer organizations, the extension service, and the research centre in order to discuss and validate the findings of the study and to identify the need for further research and possible institutional interventions. The workshop was held in the conference room of the municipality of Sakété. Two invited representatives of the official nursery holders did not attend for private reasons.

Data analysis

The identified constraints regarding the OPSS were prioritised by participatory ranking and weighting using a seven-point scale indicating little importance (1) to very great importance (7) (Kilchling et al., 2009). The mean was calculated based on the total number of participants. With respect to the organisations (farmer organisations, extension service, SNV NGO, research service), the raised constraints were simply ranked by priority. Matrix tables were constructed on the constraints and the data across the three studied villages were compared to find similarities and specificities connected to a given study village. The constructed tables allowed reading through the different actors' perceptions of the constraints in the seed system. The participants' framing of the constraints and facts were reported. To characterise the target farmers' profile, percentages were also calculated based on the number of respondents who answered the questions. Local names of different local oil palm types were recorded and compared to their known botanical names.

The farmers' perspective is used in the analysis, as described by Weltzien and Vom Brocke (2001), because farmers are the end users of seedlings. From a farmers' perspective a seed system has a number of characteristics: (i) seed quality, (ii) appropriateness of the variety traits, (iii) timeliness of the seed availability, (iv) conditions under which planting material can be obtained. Seed quality is closely connected to the health status of the seed. It is concerned with the capability of the seedling to tolerate various ecophysiological and biological stresses and to be vigorous. Weltzien and Vom Brocke (2001) named these aspects physical qualities but in this chapter the term physiological qualities is preferred because the performance of parts or the whole seedling is concerned. The appropriateness of the varietal traits refers to the genetic purity and suitability of oil palm traits for local uses, and includes whether the sold seedlings are hybrid or non-hybrid and whether the available oil palm varieties allow farmers to make their own choice in order to fulfil their needs. The timeliness of seedling availability underlines the capacity of the supply system to meet farmers' demand at planting time. For this third characteristic, the phrase fine-tuning of supply and demand is used. The conditions under which seedlings are available refer to financial and physical accessibility, i.e., the price in the market as well as facilities (equipment, infrastructure, location). These characteristics are interdependent and analysis of them will help to develop a good understanding of the functioning of the whole seed system.

The hierarchical, multi-level framework of Geels (2002) has also been used in the analyses in this chapter. Innovation arises, according to Geels (2002), from the interactions of distinctive processes at a range of levels: the niche level, of localised change where institutional and socio-technical experiments can take place; the regime level, signifying relative stability in institutions across multiple locations, and the landscape level, signifying the larger institutional context that cannot be readily changed by niche experiments or regime-level ‘rules of the game’. In this chapter, a simplified two-level framework is used in order to classify constraints as either constraints at farm level, understood as issues that could be solved by innovations developed and carried out by local actors, including farmers, and constraints above the farm level, and that need contributions from higher level actors to resolve.

Some limitations to the study

The oil palm sector is very dynamic and then, the identified constraints in this study may change slightly, few times later, for their order of priority or be phrased differently by the same interviewed people.

Besides the production phase, the oil palm value chain also includes processing and marketing. This study only looked at the production phase with focus on seedling quality supplied to farmers. For oil palm production in Bénin, men are those mainly involved. This justified the fact that most people interviewed during this study were men. Women are seen mainly at the processing and marketing phases.

RESULTS

Components and organization of the OPSS

The two components of the OPSS (informal and formal seed systems) and their interrelations are presented.

Informal oil palm seed system

Two main supply sources were distinguished in the informal seed system: volunteer seedlings and the non-official supply sources.

Farmers collected volunteer seedlings in both local oil palm plantations and existing hybrid oil palm plantations. The collection of seedlings did not include any selection practice. Most concerned farmers acknowledged picking the planting material around a place with many seedlings. The seedlings collected were directly transplanted on farm without rearing in a pot.

Non-official supply sources are composed of:

- Non-official suppliers of germinated seeds of oil palm: the interviewed individuals indicated they supplied germinated hybrid seeds to non-official nursery holders. The seed was allegedly collected from bunches that had been controlled pollinated and thus should lead to hybrid seedlings as indicated by the research centre workers from whom they obtained the seeds. We have not been able to trace these workers to check the source further. The material collected by the workers of the research service was delivered to their clients either by themselves or through intermediaries. These intermediaries were people who knew the research centre workers, or had an acquaintance with the research centre, or formerly worked on the research centre. The price of a germinated seed from a non-official source was 100 FCFA[1] against 150 to 250 FCFA in the formal system.
- Non-official nursery holders: non-official nurseries existed across the oil palm growing belt. They provided planting material allegedly raised from hybrid seeds to smallholder oil palm farmers. All non-official nursery holders interviewed during the study were male. The price of the germinated seed was as cited above. They raised the seedlings in the same way as the official nurseries did. The selling price of an allegedly hybrid seedling varied from 200 to 600

[1] The exchange rate during the study was fixed at 655 FCFA for 1 €.

FCFA. All non-official nursery holders interviewed expressed their willingness to operate in the formal seed system if there would be a possibility to acquire authorisation from the CRA-PP and certified germinated hybrid seeds.

- Oil palm farmers relying on the non-official nurseries: farmers used the informal channel to obtain hybrid oil palm planting material. They testified that their suppliers insured them that the material they were selling was from hybrid seeds they got from the research centre. Farmers also acknowledged that they relied on the informal nursery as this was the one easily accessible to them. They reported that they bought the planting material for 200 to 600 FCFA.

Formal oil palm seed system

The formal seed system included:

- Oil palm research centre: nationwide, the "Centre de Recherche Agricole Plantes Pérennes" (CRA-PP), the oil palm research service, was the only organisation that produces the certified hybrid oil palm seeds. These were delivered to farmers via the official nursery holders or directly to state cooperatives. CRA-PP authorised the establishment of new official nurseries in collaboration with the extension service. It trained the extension agents and oil palm farmer organizations on growing practices. CRA-PP provided technical support to official nurseries at their operating sites for them to raise good quality (well-developed) pure hybrid planting material. Just on need expressed by farmer, the researchers visited oil palm farms for technical intervention. CRA-PP supplied the official nurseries with germinated seeds that were either tolerant or that were not tolerant to *Fusarium* wilt, a disease endemic to Africa that develops mostly during the replanting[2] phase. The certified material was produced by CRA-PP in collaboration with the oil palm programme of CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement). To protect the material, many controls under a representative of CRA-PP, were organized to check on possible cheating (introduction of non-hybrid seedlings) by the nursery holders. A nursery holder who would be found to be cheating would be withdrawn from the list of the official nursery holders and was no longer provided with germinated seeds from the research centre.

The research centre fought against the non-official nurseries as well. Any case of non-official nursery discovered across the oil palm growing belt was systematically destroyed with the help of the local security officers. The research service acknowledged that these actions were illegal as no formal regulation existed to give them the right to act in such a way.

[2] The replanting is understood as the replacement of an old plantation by a new one.

- Official nursery holders: they conducted their activities under the control of CRA-PP. They raised the germinated seeds until the stage plants were ready to be transplanted on farm. They provided farmers with seedlings at planting time. Many of the nursery holders helped the less skilled farmers in planting techniques. The selling price of the planting material to farmers varied from one nursery holder to another and depended on the agronomic characteristics of the material being sold. The price varied from 600 FCFA for the "material non-tolerant to *Fusarium* wilt" to 900 FCFA for the "material tolerant to *Fusarium* wilt". However, the official prices for the different hybrid seedlings were 600 and 700 FCFA respectively.
- State cooperatives of oil palm: state cooperatives were spread over the oil palm growing belt and owned large oil palm plantations that were all planted to hybrid *tenera*. The germinated seeds raised by state cooperatives were purchased directly from the research centre.

Farmers reported that they bought planting material from representatives of state cooperatives. State cooperative representatives acknowledged that they sold the leftover of planting material to other cooperatives or private planters.

- Extension service: the extension agents inform the farmers about the official nursery holders for seedling purchase. The latter were not well known amongst most new planters of hybrid oil palm. When it was considered time to open a new nursery, they looked for new applicants who filled in an application form that was sent to CRA-PP via the headquarters of the regional extension services. They also checked on the non-official nurseries to stop their activities. They sold specific inputs such as KCl fertilizer to farmers and nursery holders.
- Dutch development organization (SNV NGO): the SNV NGO supported farmers' organisations, extension agents and CRA-PP to preserve the quality of seedlings. It provided the research centre with financial support to train extension agents and representatives of oil palm farmer organization on growing practices. It played the role of broker that tried to gather the different actors for joint and coordinated actions. The SNV NGO initiated a memorandum of agreement in 2010, between itself (SNV NGO), CRA-PP, the headquarters of the regional extension services (CeRPA: Centre Régionale de Promotion Agricole) and the oil palm farmers' organization (FNPPH: Fédération Nationale des Planteurs de Palmier à Huile). The role of CRA-PP in the memorandum focused entirely on arrangements that contributed to deliver quality hybrid planting material to farmers. The memorandum was valid until December 2011.
- Oil palm farmers' organizations: the oil palm farmers' organizations guided farmers to the official nursery holders to avoid the purchase of non-hybrid seedlings. They helped their peers to get access to specific fertilizers by collecting their demands for grouped orders.

- Oil palm farmers: they were the ‘end consumers’ of the planting material. They helped their peers to buy hybrid planting material by indicating sources they trusted themselves.

It is essential to mention that the CRA-PP had formal links only to official nursery holders and state cooperatives; there were no legally established or formalised links to any of the other actors in the OPSS that have been noted above.

Links between the formal and the informal seed systems

The research showed that the informal and the formal seed systems are interrelated. One example in this respect was seedling flow. Hybrid oil palm seedlings were found in both seed systems. Actors operating in the informal seed system obtained hybrid seedlings from their peers in the formal system. Furthermore, many oil palm farmers operated in both systems through acquiring seedlings from the informal seed system in one year and from the formal seed system in another year.

Another way in which the informal and the formal seed systems could be considered to be complementary was the reliance of farmers on the informal seed system whenever the formal seed system was found to be deficient or not able to supply the required material. An illustration of the role of the informal seed system as the default option is provided by the case of Zè district, where official nurseries do not exist, obliging most farmers to rely on the non-official seedling suppliers. Moreover, farmers who fail to find enough planting material in the official nursery turned to the non-official nursery holders. In these ways, the informal seed system could be said to complement the formal seed system, even though the non-official nursery holders were pressed by local authorities, under the lead of CRA-PP, to cease their activities.

Characteristics of the OPSS, based on farmers’ understanding of a seed system

First, the four characteristics are presented of a seed system from the farmers’ perspective (mentioned in the conceptual framework i.e. physiological quality of the planting material, genetic quality and suitability of oil palm materials to local uses, fine-tuning of supply and demand and physical and financial accessibility of seedlings). The extent to which the current OPSS fulfils these characteristics is then highlighted.

Physiological quality of the planting material

Farmers in Ita-Djèbou stated that the care of the planting material in nurseries had to improve. Farmers assessed the physiological quality of the planting material by checking on the seedling vigour, how disease free it was, and size of the collar diameter. The interviewed farmers in Ita-Djèbou, the study site closest to CRA-PP, stated that when they compared the planting material of the official nursery holders to the one they bought at the nursery of CRA-PP, seedlings they got from the official nurseries looked stunted. They presumed the seedling management practices to be the main cause. Farmers also noticed that the nursery holders did not sort out their planting material and obliged them to buy even the least vigorous plants. Finally, farmers acknowledged that they observed many cases of mortality after transplanting on farm.

Genetic quality and suitability of oil palm materials to local uses

Farmers indicated that the genetic quality of the planting material was problematic. The purchased seedlings, all presumed to be *tenera*, included non-hybrid material. Unfortunately, the determination of the composition in palm types of the plantation (*dura*, *tenera* or *pisifera)* is possible only at the seed production age of 3-4 years old.

All farmers interviewed across the three sites acknowledged that they did not have any possibility to choose within the available material the varieties that would suit their needs. Farmers reported for example that they did not have the opportunity to choose a hybrid cultivar that gave palm oil with a redder colour and good conservation traits. The palm oil from the local material, that was redder in colour compared to that from the hybrid material, was acknowledged to have better conservation traits.

Another issue raised by farmers was that the hybrid oil palm material did not fulfil many of the needs covered by the local material. One example of these needs raised by farmers was the use of the local material for wine tapping in the case of an urgent need for cash. Farmers also reported that the bunch production of the local oil palm seemed to be better distributed over the year than that of the hybrid material. This allowed them to collect products from their oil palm farms over the whole year, creating financial flows which allowed them to solve their everyday problems.

Fine-tuning of supply and demand

Farmers attested that they lacked planting material at planting time. The official nursery holders in this regard reported that farmers failed to express their demand in time. Consequently, the amount of seedlings raised per planting season by the nurserymen was often below the demand, in order to avoid a seedling surplus. When farmers lacked planting material at planting time in a given year, they postponed planting to the following year.

Physical and financial accessibility of seedlings

Farmers reported that the planting material was not easily accessible, because the official nurseries were located far away from their locations. Physical accessibility was described also in terms of the road infrastructure, as the roads to some nursery places were in a bad state and the nurseries were located in muddy areas. With respect to financial accessibility, farmers indicated that the purchase price (600 FCFA to 900 FCFA per single plant) of the hybrid seedling was too high.

The next section presents the farmers' and other actors' framing of the constraints in the seed system. The analysis provides suggestions for follow up research priorities and institutional interventions.

Perceptions and analysis of the constraints around the OPSS

The constraints were listed, prioritised and weighted (Table 2.3) by adding the weightage scores provided by individual participants during group discussions. The mean was obtained by the ratio of the total weight and the number of participants.

Oil palm farmers

The distance of the official nurseries to farmers, the poor genetic quality (pure *dura* or a mix of *dura*, *pisifera* and *tenera*), the high cost of the hybrid planting material, the high number of non-official nurseries, the poor physiological quality (the poor care) of seedlings and the palm oil colour and conservation appeared to be the major constraints of the OPSS based on farmers' prioritisation (Table 2.3). The identified constraints were technical, socio-economic or institutional, or all at the same time.

The ranking of the constraints differed slightly between the farmers using hybrid material and farmers growing both materials. For the latter, the less reddish colour of the hybrid material's palm oil was a more important issue than for farmers growing only hybrid material. In contrast, the oil palm farmers growing only local material specifically pointed to the inappropriateness of hybrid oil palm for local uses.

The main difference between the selected sites was the absence of official nursery holders in the district of Zè. The genetic quality constraints appeared to be more important for farmers in the centre (Aïfa, Zè district) and the west (Guèhounkon) compared to the east (Ita-Djèbou). For distribution of official nurseries holders per district see Figure 2.1. The west and the centre of the oil palm growing area appeared to be characterised by a low number of official nurseries.

Table 2.3. Farmers' weighting of the constraints in the oil palm seed system, based on criteria developed in group interviews with oil palm farmers.

Constraints	Local oil palm farmers			Hybrid oil palm farmers			Farmers using both materials		
	Ita-Djèbou (n=8)	Aïfa (n=6)	Guèhoun-kon (n=12)	Ita-Djèbou (n=11)	Aïfa (n=9)	Guèhoun-kon (n=8)	Ita-Djèbou (n=12)	Aïfa (n=10)	Guèhoun-kon (n=8)
Poor care of seedlings by official nursery holders	.	.	.	5.7	.	.	4.4	.	.
Distribution of less productive oil palms with nerves coloured in red	.	.	.	2.3	.	.	2.3	.	.
Death of palms after planting	.	.	.	3.0	2.3	.	3.4	2.8	.
Poor genetic materials	.	.	.	4.7	5.9	5.9	5.4	6.1	5.6
Less reddish colour and conservation of palm oil of hybrid material	4.0	4.3	4.5	4.5	3.4	5.0	4.9	4.7	5.8
Lack of a strong communication system for farmer orientation	.	.	.	.	.	4.9	.	.	.
Use of CRA-PP [d] name to provide non hybrid material	.	.	.	.	.	4.3	.	.	3.9
Absence of official nurseries	.	.	.	.	7.0	.	.	7.0	.
High number of non-official nurseries	.	.	.		6.6	6.8	.	5.9	6.6
Refusal of CRA-PP to establish official nursery	.	.	.	.	4.3	.	.	4.5	.
Lack of regulation and enforcement	.	.	.	.	3.9	.	.	.	.
Official nursery location far from/to farms / High transportation cost from nursery to farm	.	.	.	6.5	4.6	5.3	6.2	5.6	5.4
Existence of intermediary reselling planting material produced by CRA-PP	.	.	.	2.2	.	.	.	.	.
Requirement of fertilizer use for hybrid oil palm	.	.	3.1	.	.	.	.	.	.
Former regulation that hybrid material is planted only by state cooperatives	.	.	3.3	.	.	.	.	.	.
Inappropriateness of hybrid oil palm to local uses (early wine tapping)	.	3.5	5.3	.	.	.	.	.	.
High cost of hybrid planting material	5.1	5.7	5.0	5.5	4.8	6.1	5.7	5.4	6.5
Lack of credit system to support farmers	3.1	2.3	2.8	1.8	1.4	2.6	2.0	2.7	2.4

Notes: Figures in the table are averages of weights attributed by the indicated number of farmers in each village (n). The study used a 7-point scale, where higher values indicate more important constraints. OPSS: Oil palm seed system; Cell with "dot" means no constraint. CRA-PP: Centre de Recherche Agricole Plantes Pérennes.

Table 2.4. Ranking and weighting of the constraints around the OPSS by representatives of farmer organizations, nursery holders, NGO, extension and research services.

Constraints	Farmers' organizations			Holders of informal nurseries			Holders of formal nurseries			Local extension service representative			SNV NGO	Research centre
	Ita-Djèbou (n=3)	Aïfa (n=2)	Guèhounkon (n=2)	Ita-Djèbou (n=1)	Aïfa (n=4)	Guèhounkon (n=3)	Ita-Djèbou (n=3)	Aïfa (n=2)	Guèhounkon (n=3)	Ita-Djèbou (n=2)	Aïfa (n=2)	Guèhounkon (n=3)	(n=1)	(n=2)
Lack of regulation and enforcement	3	5	3	.	.	.	.	.	.	2	3	3	4	2
Lack of specific inputs	5	8	4	.	.	.	5.3	4.5	5.7	4	5	4	.	.
Absence of authorised nurseries	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Poor genetic materials	2	3	2	.	.	.	.	.	.	.	.	.	.	.
Poor distribution of authorised nurseries by CRA-PP [a]	.	7	.	.	.	.	.	.	.	.	.	.	.	.
High number of non-authorised nurseries	1	2	1	.	.	.	6.3	7.0	7.0	1	1	1	1	1
Lack of credit system to support farmers	6	.	5	.	.	.	4.3	5.0	4.0	.	.	.	.	.
Refusal of CRA-PP to establish authorised nursery	.	4	.	.	.	.	.	.	.	.	.	.	.	.
Lack of a good communication system for farmer orientation	4	6	.	.	.	.	.	.	.	3	4	2	3	.
Difficulties to get authorization	.	.	.	6.0	6.3	6.0	.	.	.	.	.	.	.	.
Lack of trust of the clients	.	.	.	.	4.0	4.7	.	.	.	.	.	.	.	.
Weak functioning of farmer organization	.	.	.	.	.	.	.	.	.	.	2	.	2	3

Notes: Columns without decimal are rankings from most important (1) to least important (the highest number). Columns with decimal are average weights on a seven-point scale as attributed by the indicated number of participants (n); the higher the value, the more important the constraint. OPSS: oil palm seed system. n: number of participants. Cell with "dot" means the indicated constraint was not mentioned. CRA-PP: Centre de Recherche Agricole Plantes Pérennes.

Other actors

Table 2.4 shows the ranking and weighing of the constraints regarding the OPSS by farmer organizations, official nursery holders, non-official nursery holders, SNV NGO, the extension service and CRA-PP. The high number of non-official nurseries, the lack of regulation and enforcement and the lack of specific fertilisers were the major constraints raised by most actors. For the non-official nurseries, the refusal of CRA-PP to authorise the opening of more hybrid oil palm nurseries is the top constraint. The genetic quality issue was a concern for farmers' organisations across the sites. All identified constraints proved to be at least partially institutional. Because official nursery holders were shown to play a key role in the seed system, a cause-effect relationship analysis was conducted of the constraints leading to the poor care of seedlings in nurseries. The institutional constraints, and in particular those related to the lack of specific inputs, seemed to be one of the roots of the technical constraint, poor care of the seedlings.

When reading through the constraints from all actors' perspectives (Tables 2.3 and 2.4 pooled together), it appeared that farmers and their organisations were concerned about many constraints, with particular emphasis on the genetic quality of available seedlings and the poor distribution of the formal nurseries. The other actors, on the other hand, perceived few constraints in the seed system but were concerned about issues like the weak functioning of farmers' organisations.

Famers' knowledge and practices in the OPSS

Categorisation of farmers, gender, age, education and growing purposes

A higher proportion of the interviewed farmers grew only hybrid oil palm at Ita-Djèbou (50.0%) compared to Aïfa where the farmers combined both materials (59.8%) (Table 2.5). In contrast, the local oil palm material was the most used in Guèhounkon (74.2%). Oil palm farmers in this area relied mainly on the informal seed system.

The demographic characteristics used in the study to describe the profile of the target farmers were sex, age and education level. Most interviewed oil palm farmers were men across the study area (95.3, 92.2 and 88.2% in Ita-Djèbou, Aïfa and Guèhounkon, respectively). Most interviewed oil palm farm owners (about 60% at least) were at least 40 years old across the three sites. Farmers in the study area had a low education level (more than 60% of them were illiterate across the study area). In Ita-Djèbou and Aïfa, the oil palm growing purpose was entirely for bunches, i.e. palm oil (100% of the interviewees). However in Guèhounkon, where the local oil palm was still predominant, wine tapping was the main purpose of oil palm production for about 14% of the interviewees. All farmers who grew oil palm for wine tapping purpose were "only local oil palm" farmers.

Table 2.5. Profile of oil palm farmer respondents.

		Ita-Djèbou (n=148)	Aïfa (n=102)	Guèhounkon (n=136)
Category of farmers[a]	Farmers growing only local material (%)	50.0	26.5	74.2
	Farmers growing only hybrid material (%)	17.6	13.7	11.8
	Farmers growing both materials (%)	32.4	59.8	14.0
Sex[a]	Male (%)	95.3	92.2	88.2
	Female (%)	4.7	07.8	11.8
Age[b]	29 years and under (%)	4.2	12.5	11.9
	30-39 years (%)	11.2	29.1	18.6
	40-49 years (%)	20.8	25.0	30.5
	50-59 years (%)	31.9	16.7	25.4
	60 years and over (%)	31.9	16.7	13.6
Education[b]	Illiterate (%)	63.6	70.0	64.4
	Primary school (%)	13.0	28.0	22.0
	High school (%)	11.7	2.0	11.9
	Senior secondary school (%)	10.4	0	1.7
	University degree (%)	1.3	0	0
Growing[b] purposes	Oil palm (%)	100	100	86.4
	Wine tapping (%)	0	0	13.6

Source: Oil palm farmer interviews.
[a] Percentages in these rows were calculated with the total number of farmers registered per site. [b] Percentages in these rows were calculated with the number of farmers who answered the question.

Farmers' knowledge of the existing variation of the material in the OPSS

Farmers growing the hybrid oil palm, across the sites of study, reported that they did not see any variation in the material supplied to them. In contrast, the farmers relying on the local oil palm or both materials recognized a variation within the local material. They attributed different names to the different material and based the differentiation on the thickness of the shell and the nut colour. Table 2.6 compiles farmers' knowledge of the local oil palms. Farmers specified that apart from the natural *dura*, the other palm types they identified were rare in the natural oil palm populations (two to four per ha). When the farmers growing local oil palms were asked whether they linked the variation in the local material to different areas of the country, they answered that there was no clear relation that could be pointed out.

Farmers' practices in seedling acquisition

Across the study sites, oil palm farmers put forward three main considerations in the acquisition of hybrid planting material: trust, nursery proximity, and purchase price. For the farmers supplied by official nurseries, trust was the first consideration. Farmers tended to get planting material from the nursery closest to their place of residence. Farmers supplied by non-official nurseries also cited the proximity of the nursery when choosing their source of

Table 2.6. Summary of farmers' knowledge of the variation in the local oil palm.

Names of local oil palms in local languages			Corresponding botanical names	Uses	Endogenous criteria of recognition
Nago (Ita-Djèbou)	Aïzo (Aïfa)	Kotafon (Guèhounkon)			
Tchanka	*Houédé* or *Goudé*	*Bénindé*	Natural *dura* palms	Bunches, palm oil and wine tapping	Thick shell, high kernel number after processing
Okpèifa	*Fadé*	*Afadé*	*Idolatrica* palms	Traditional ceremonies in *Fâ* divinity	Leaflets packed together lifelong
Okpèimoko	*Sèdé*	*Sèdé*	*Virescens* palms	Treatment of illness oil, not good for consumption	Green fruits at early stage and yellow-orange at maturity
Ouma	*Dougbakoun* or *Dévotchi*	*Adéfotin*	Natural *pisifera* palms	Palm oil	Shell-less
Imofo	*Déhla*	-	Natural *tenera* palms	Palm oil	Small/thin shell

Source: Interviews with oil palm farmers.

seedling supply. According to the farmers, proximity helped to reduce the transportation hassle and saved time. The lower price of non-hybrid seedlings compared to the price of the hybrid ones was the other criterion used by the farmers supplied by non-official nurseries.

DISCUSSION

Complementarity of the formal and informal oil palm seed systems

The informal and formal OPSS appear to be evolving together across the oil palm growing belt, under the control of different categories of actors. The formal seed system, where the CRA-PP has a monopoly over the production of certified material, gives a key role to official nursery holders, relying on them to deliver quality hybrid planting material to farmers. The informal seed system, however, continues to operate as an important part of the OPSS. It delivers both hybrid and non-hybrid material to farmers. The informal seed system fills in many shortcomings of the formal seed system's material, namely, higher quality palm oil, a more even distribution of bunch production over the year and fitness for wine tapping, i.e. traits that effectively tally with smallholders' needs. With respect to bunch production of the hybrid oil palm, the peak month often produces 40% of the annual production, with less than 1% in the least productive months (Nouy et al., 1996). The complementarity of the two seed

Table 2.7. Identified constraints in the oil palm seed system (OPSS), indicating the level at which institutional action could be taken to improve the workings of the system.

Indicative level for action	
Farm level	Above the farm level
- Poor quality of palm oil from hybrid *tenera*	- Poor care of seedlings - Poor quality of palm oil from hybrid *tenera*
- High number of non-official nurseries	- Poor geographic distribution of official nurseries across the oil palm growing belt - High price of hybrid planting material - Poor genetic materials in plantations - High number of non-official nurseries - Lack of regulation in OPSS

Source: Adapted from Geels (2002)

systems also relates to the failure of the formal seed system to supply the entire demand by farmers' for seedlings.

Identified constraints and the institutional levels at which solutions might be developed

The identified constraints indicate that the formal OPSS does not currently fulfil farmers' needs, as has been observed for other seeds systems (Weltzien and Vom Brocke, 2001). Farmers and the other actors raised many constraints that affect the quality of the supplied planting material, with emphasis on the poor geographic distribution of the official nurseries, the observed poor genetic material in the plantations, the high number of non-official nurseries, the high cost of hybrid planting material, the poor care of seedlings in nurseries, the poor quality of hybrid palm oil and the lack of specific inputs.

The poor geographic distribution of the official nurseries provides space for the non-official nurseries to enter the market. In areas where official nurseries are lacking, non-official nursery holders are the unique source of supply of (allegedly) improved planting material for resource-limited farmers. The west and the centre of the study area are characterised by a low number of official nurseries and these are the areas where farmers are more concerned with the issues of genetic quality of planting material. The poor distribution of official oil palm nurseries clearly requires a redefinition of the process of authorising nursery establishment. In terms of the multi-level perspective of (Geels, 2002), this is an institutional issue that needs to be discussed by actors at a higher level than the farm (Table 2.7).

The poor genetic quality of the planting material is primarily a matter of the mixture of oil palm materials, i.e. *dura*, *pisifera* and *tenera* found in the plantations. This suggests that some of the seedlings might have been collected from existing hybrid oil palm plantations[3]. A common reasoning used by many of the nursery holders and farmers we interviewed is that seedlings collected from hybrid oil palm plantations do generate hybrid oil palms. This reasoning would be valid if the oil palm crop were an autogamous species (Baudoin et al., 2002; Corley and Tinker, 2003), but the fact that oil palm is strictly allogamous (cross-pollinated) means that the collection of seedlings from hybrid plantations a very unreliable approach to genetic improvement. Obviously, an improved understanding by the actors in the OPSS of what hybrid material is, is essential. The report by farmers that their plantations have a mixture of oil palm types makes visible the failure of the whole supply system. Genetic quality control so far has been the job of the CRA-PP, that has tried to protect the quality of its own material by conducting periodic visits to the official nursery holders to provide technical support and check their trustworthiness. Despite this, non-hybrid material is still somehow sold to farmers as hybrid plants. The main questions remain, where and how the non-hybrid material enters the seed system. Further studies to assess the reliability of the current OPSS are needed to develop a better understanding. By establishing the extent of non-hybrid materials in smallholder plantations in relation to the seedling supply sources and practices, the performance of the seed system could be assessed more accurately.

Another question is whether the genetic quality control of planting material should still be the job of CRA-PP. The involvement of other actors, such as forestry officers, might offer some advantages because the forestry officers, unlike CRA-PP, are represented in all districts across the country. They are closer to the operating sites of the nursery holders. Quality control might be more effective also if it were carried out jointly with the official nursery holders and representatives of farmers' organisations, in a participatory way that allowed joint learning across the system. Furthermore, since we found that most of the interviewed non-official nursery holders wished to operate in the formal seed system, a review of the procedures for the establishment of official nurseries might significantly reduce the flow of non-hybrid material to farmers. Additional steps for controlling genetic quality might include regulation and enforcement of standards, mass sensitisation, and further research to find out which characteristics might allow early differentiation between hybrid

[3] A hybrid oil palm plantation consists of only *tenera* material (Durand-Gassselin et al., 2000; Gascon et al., 1981). The seedlings collected from a hybrid oil palm plantation will contain around ¼ dura, ½ *tenera* and ¼ *pisifera* due to the monogenic inheritance of the shell thickness (Corley and Tinker, 2003; Soh et al., 2009). As the *pisifera* palms are female sterile (abortion of the female flower before the maturity of the bunch) the resulting plantation contains many sterile oil palms (about ¼ of the total palm trees), a frequency far higher than in natural groves.

and non-hybrid material. However, bringing these propositions into reality seems to be the task of actors above the farm level (Geels, 2002).

Farmers attested that the purchase price (600 FCFA to 900 FCFA) of the hybrid planting material was too high. The high prices of planting material in the formal seed systems hindered the resource-constrained farmers from using hybrid material, as in other seed systems (Muthoni and Nyamongo, 2008; Thiele, 1999). Reducing the purchase price of the oil palm planting material is an option that could materialise through government intervention. An alternative option would be to allow farmers to postpone payment until the farms became productive (up to five years) but this might create problems of collection of the final payment. Getting one or another option into reality obviously requires action above the farm level (Geels, 2002).

The other issues relating to planting material quality were found to be the care of seedlings in nurseries, hybrid palm oil colour and conservation. Good nursery management involves more attention but is one of the first prerequisites to guarantee a good plantation (Tiong, 2005). A closer analysis of practices in the official oil palm nurseries would be a promising field of research that could lead to an improvement in the physiological quality of seedlings. Further actions to ensure the physiological quality of seedlings could include the development of procedures for ISO certification of the official nurseries. With respect to the quality of the palm oil from the hybrid material, research studies suggest that, apart from poor processing practices, options are available within the existing oil palm germplasm to improve palm oil quality in terms of the desired colour of the palm oil (Kaur and Sambanthamurthi, 2008; Trujillo-Cuijano et al., 1990). These issues could be solved by investing in research (by agricultural research institutes, universities, and NGOs operating in the research domain) i.e. by institutional developments above the farm level (Geels, 2002).

Our analysis shows that the OPSS displays many of the weaknesses already identified by research on other seed systems (e.g. Gemeda et al., 2001; Thiele, 1999). Even though oil palm is a perennial crop, the OPSS is performing dysfunctionally in ways observed already in seed systems for annual staple foods (Gemeda et al., 2001; Weltzien and vom Brocke, 2001). The formal seed systems in many developing countries often fails to ensure seedling supply to farmers, especially smallholders (Almekinders and Louwaars, 2002; Wiggins and Cromwell, 1995). Almekinders et al. (1994) and Daniel and Adetumbi (2004) advocate official support for the complementarity of the informal and the formal seed systems because one seed system alone cannot fulfil the different needs of users. They further consider it might be useless to treat the seed systems independently in policy as well as in seed supply studies. However, an important respect in which the oil palm seed system differs from that of annual crops is the near impracticability of breeding by farmers themselves, given the 20-30 year life cycle of the oil palm, and the necessity to sustain a direct link between the farmers and the formal breeding programme over this long period. Overall our findings and analysis suggests that improving the productivity of oil palm for smallholder farmers, in such a constraining seed system environment, will be challenging without the effective support of actors from local to the national level (e.g. policy makers) working together, as proposed also by (Kessy and Laub, 2006).

Farmers' knowledge of oil palm variation in relation to their seedling acquisition practices

Farmers were found to have a good knowledge of their material. The main traits they use to characterize the diversity within their material are the thickness of the shell and nut colour, which are the same criteria used by research scientists. These shared reference points for varietal identification provide a good foundation for cooperation between farmers and scientists to develop additional indicators.

Trust and nursery proximity were found to be important considerations used by farmers to select seedling suppliers. One trust factor used by farmers to select a nursery was how often their peers bought seedlings in the nursery. To some extent, this might be a misleading indicator because it does not avoid the purchase of non-hybrid material that is sold as hybrid, a problem that is compounded by the long period of time that elapses between purchase and the evidence of actual performance of the material.

CONCLUSIONS AND IMPLICATIONS FOR FURTHER STUDIES

The study indicates that the major issues constraining smallholder farmers in the OPSS were the poor geographic distribution of the official nurseries and related presence of non-official ones, the inability of most actors to check the genetic quality of material at purchase, the high price of hybrid planting material, the poor care of seedlings in nurseries, the poor quality of hybrid palm oil and the low availability of specific inputs. Farmers in the west and centre (located far away from the research centre) were more concerned about the genetic quality of seedlings.

The study, based on farmers' perceptions of the seed system, provides insight into the degree to which the OPSS meets smallholder farmers' expectations. It shows that the OPSS includes a formal and an informal seed system that are interrelated and that the current OPSS is not performing adequately from farmers' perspective, a finding shown also for seed systems in other developing countries. However, the particularities of the OPSS as a tree-based system also were shown to be consequential, i.e. the tedious seed germination process and cross-pollination necessary for seed development, obliges hybrid oil palm farmers to rely entirely on seedling suppliers (in contrast to seed development or improvement for most annual food grains, where the technical requirements can be more easily performed by farmers themselves).

This study provides baseline information that indicates that few of the identified constraints could be solved by institutional and technical developments at the farm level. The issues identified in this study, that would seem to require action at higher levels, include a review of procedures of authorising oil palm nursery establishment, regulation of the informal seed system, an improved mechanism for controlling the sale of quality hybrid seedlings, research into traits that would allow farmers to distinguish *tenera* seedlings from *dura* ones, and improvement to the circulation of information regarding seedling quality issues.

Follow-up research that seems indicated on the basis of this study includes: the analysis of factors (seedling supply sources, distance to research centre and historical changes) affecting the genetic quality of the material in the smallholder oil palm plantations to check on the reliability of the OPSS so far;

- a study of characteristics of quality (genetic) oil palm seedlings using morphological markers that could help in early and independent detection of any cheating in the OPSS;
- an improvement of seedling management practices in the official nurseries and the optimisation of the current protocols to improve the physiological quality of seedlings.

CHAPTER 3

Drivers of a reliable seed system: the case of oil palm in Bénin

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ABSTRACT

Seed system reliability is of major importance in farming. Earlier studies mainly analysed annuals and this study focusses on a perennial. Oil palm in Bénin was used as case study because farmers complained about non-hybrids (*dura*, *pisifera*) in plots allegedly planted to 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 observed variation in oil palm types in smallholder plots. A total of 378 plots belonging to 248 farmers and allegedly planted to *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. Proportion of *tenera* decreased with year of planting. Socio-institutional mechanisms associated with observed variation in smallholder plots were national policy change, local arrangements for seedling supply to smallholder farmers and personal characteristics of farmers. Implications of observed decrease in reliability of the seedling supply system are discussed.

Key words

Distance, event ecology, institutions, policy change, seedling quality, smallholders.

INTRODUCTION

Improving farm level productivity in oil palm (*Elaeis guineensis* Jacq.) requires that smallholder farmers have access to high-quality seeds through a reliable seed system (Dimelu and Anyaiwe, 2011; Zen et al., 2005). 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; Guei et al., 2011; Lipper et al., 2010). Reliability in a seed system for perennials is particularly important because perennials often take a long time to produce the first harvest and they have a long productive life span. Oil palm, for example, takes about four years before 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%, compared to expected 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., 2001; 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' organisations (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. Nursery holders often claim to sell hybrid seedlings while part or all sold seedlings are non-hybrid (Durand-Gasselin and Cochard, 2005). These studies, however, do not report on dynamics over time nor the precise drivers of reliability, the documentation and analysis of which will enable more effective interventions in improving the seed system and thus farmers' livelihoods.

Oil palm is a major crop in Southern Bénin, (Adje and Adjadi, 2001; MAEP, 2009). It is a multifunctional crop well-embedded in 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 Bénin, 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 was unclear. Starting with the premise that a reliable OPSS would deliver 100% hybrid palms, the current study was initiated to provide an empirical analysis of factors that undermine the reliability of the OPSS.

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. 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 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).

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

We surveyed genetic quality of smallholder farmer plots using variables including supply source, farmer distance to supply source, and year of planting. Seedling supply sources varied according farmers' collection of seedlings from official or non-official suppliers. Farmers' distance to supply sources was framed according to geographical position of farmers' villages as well as the purchase price for seedlings.

We recorded candidate mechanisms as any historical event, decision or initiative to increase national production of oil palm, but also farmer 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 to farmers' organisation, reliance on informal intermediaries to buy seedlings, and education level (Ntege-Nayeenya et al., 1997).

RESEARCH METHODOLOGY

This study was conducted from February 2011 to December 2012 in two stages. The first stage was the analysis of genetic quality of palm trees in smallholder plots with the objective of assessing performance of the oil palm seed system (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 (see Figure 3.1) (Corley and Tinker 2003, Soh et al. 2009). First, *dura* type is thick-shelled with 35 to 70% of pulp over fruit and is the main naturally available type. Second, *pisifera* type is shell-less, with 90% pulp; usually female sterile, its bunches often do

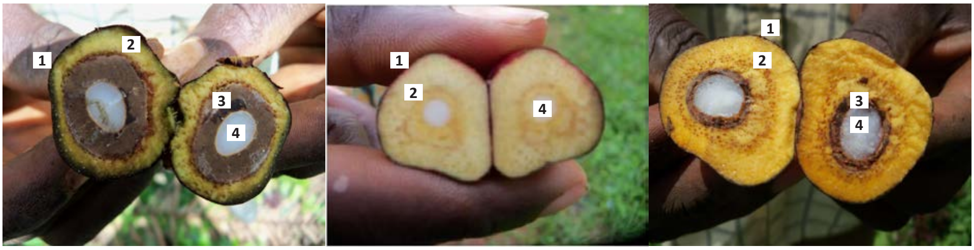

Figure 3.1. Examples of fruits of the three distinct oil palm types. Numbers 1-4 are explained below photos with botanical terms in parentheses (Photo: E. Akpo, 2012).

not reach maturity. *Pisifera* is non-productive in terms of oil (Sambanthamurthi et al., 2009). Third, *tenera* type, resulting from the cross *dura* by *pisifera*, is thin-shelled with 80% pulp, and is the most productive of the three. 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* in their plots (Cochard et al., 2001). In this study, we defined the term "genetic quality" of oil palm on a plot as proportions 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 in the sampled plots.

Analysis of genetic quality of oil palm in smallholder plantations

Study area and site selection

The study was carried out in the oil palm growing belt in Southern Bénin. 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 3.1 presents characteristics of selected villages.

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

Table 3.1. General characteristics of selected villages.

Characteristics	Villages (Districts)					
	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 owe	1 to 2	1 to 2	1 to 4	1 to 5	1 to 3	1 to 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 farmers' organisation of Lokossa, Lalo, Allada, Zè, Za-Kpota, and Sakété.

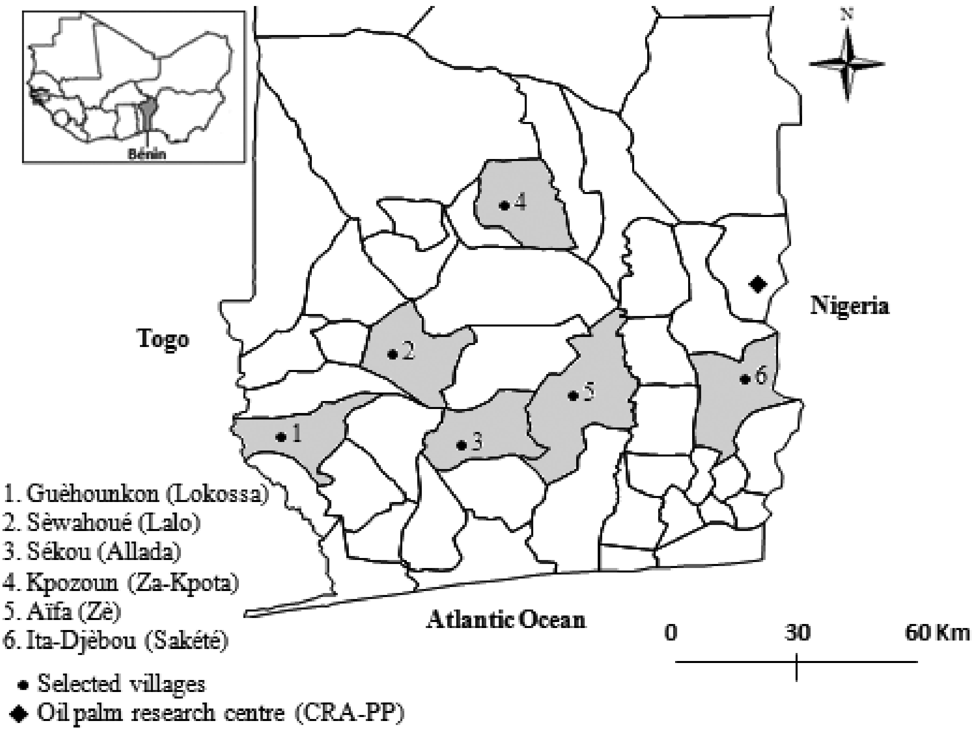

Figure 3.2. Map of Southern Bénin showing the selected villages (districts).

District selection: The three main oil palm production districts where an earlier diagnostic study was conducted (Chapter 2) were selected: Lokossa, Zè and Sakété (Figure 3.2). Three additional main districts were selected purposefully based on reported complaints about genetic quality during the diagnostic study. In Ouémé-Plateau region, where few complaints were registered, we selected no districts other than Sakété. In Mono-Couffo region, where many complaints were registered, one additional district (Lalo) was selected. In Atlantique region, where farmers expressed many concerns about genetic quality, one additional district (Allada) was selected. In 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 organisations and respective district extension services because secondary data were not available to allow researchers to independently select villages.

Description of 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 (3 years and 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 Bénin. 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 to oil palm bought from one particular supply source in a given year. Parts of a land planted to seedlings bought from different sources in the same year were treated as separate plots. Likewise, parts of a land planted to 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.

Determination of composition of plots: Composition of smallholder plots was quantified through recording for individual palms its fruit type: *dura*, *pisifera*, *or tenera*. Per sampled

> Box 3.1. Monogenic inheritance of shell thickness
> Beirnart and Vanderweyer (1941) explained monogenic nature of shell thickness which fits simple Mendel laws. In principle, controlled cross between *dura* palms will lead to 100% *dura*. Controlled cross between *dura* and *pisifera* will lead to 100% *tenera*, i.e., commercial material. Controlled cross between *tenera* and *tenera* leads to about 25% *dura*, 50% *tenera* and 25% *pisifera*. Observed percentages in established palms may slightly differ from mentioned ones because of various factors effecting seed germination and seedling establishment.

plot, all palm trees were checked to best verify fits to Mendel's laws (Box 3.1). Per palm tree, two to three fruits were cross-sectioned to determine its type (Ngoko et al., 2004) (Figure 3.1). If particular palms were not carrying bunches during a visit, the plot was visited at later stage to sample these palms. If after four visits still no bunches were present, we recorded it as palm without bunch.

Gathered data per sampled plots

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 diagnostic study (Chapter 2) were used: (1) Oil palm research centre (CRA-PP), the nationwide producer of hybrid seeds; (2) State cooperatives that sell their surplus of seedlings grown from germinated seeds from CRA-PP; (3) official private nurseries that CRA-PP provided with germinated seeds; (4) non-official private nurseries, that have no formal access to CRA-PP seeds and obtain germinated seeds from various sources.

Furthermore information was also 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 holder after seedling purchase, and the first year of bunch production.

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

During the same visits when genetic composition of plots was being checked, we also interviewed farmers and nursery holders about any events that in their view had had major impact on the OPSS over the past 50 years. For example, we asked interviewees whether the Bénin government or any NGO helped them in getting access to seedlings. In addition to individual interviews during plot check, we held group discussions with farmers, nursery holders, 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, national library of Bénin, documentation centres of Ministry of Agriculture, CRA-PP research centre, and other target organisations. Collected data included objectives, way of implementation, achievements and lessons that could be learned from interviewees' perspective. These data later helped to explain *why* a particular event affected the OPSS as observed through proportions of palm types.

For better understanding of effects of historical events on genetic quality, we surveyed plots installed before 1994, when smallholder farmer access to hybrids was not official policy in Bénin. 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 of Agamé, Koudo, Koundokpoe, and Obékè-Ouèrè that sold leftover seedlings to smallholder farmers.

We also gathered data on farmers' personal characteristics and practices including education level, membership of farmer organisation, and their reliance on intermediaries for acquisition of seedlings. We recorded educational level as number of school years; membership of oil palm farmers' organisation as member or non-member; 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 relationship between farmers and informal intermediaries. An informal intermediary is understood as personal contact – other than a formal nursery holder, CRA-PP, extension agent or NGO – who helped farmers to buy seedlings.

Data synthesis and analysis

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

Mendel's laws (Box 3.1) of phenotype distribution for a single gene trait were used to categorise sampled plots into plots planted to seedlings of hybrid seeds and plots planted to seedlings from 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. Most plausible candidate mechanisms were selected through 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 installed before 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 correlation, but claims for causality are based upon subsequent analysis of the likelihood of those observed outcomes occurring in the absence of the documented historical events.

RESULTS

General characteristics of sampled plots

The average acreage of sampled plots across six villages was 0.9 ha (Table 3.2). Few sampled plots were larger than 1.8 ha. Chi-Square test for equality of distribution showed significant variation of plot sizes in sampled villages ($\chi^2 = 51.328$, $p<0.001$). Oil palm of sampled plots produced first bunch after 3 to 4 years. More than three quarters of all sampled plots had been planted to 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 FCFA and 700 FCFA per unit and 70% of plots were planted to seedlings purchased at these prices. In Ita-Djèbou and Sékou, plots were planted to seedlings purchased for more than 700 FCFA, while in Sèwahoué and Guèhounkon seedlings were partly purchased for less than 600 FCFA. The six villages differed in nature of seedling supply sources (Table 3.2). In Sèwahoué, non-officially established nurseries were the main supply source with over 80% of total purchase. In contrast to other sampled villages, plots in Ita-Djèbou and Kpozoun had most of their seedlings from either the research centre (CRA-PP) or official nurseries.

In recent years, 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 difference between total number of planted seedlings and number of hybrid palms (Figure 3.3).

Table 3.2. Characteristics of smallholder plots sample. Values expressed as percentage of each variable per village. Numbers below villages indicate sample size.

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						
≤ 600FCFA [a]	14.3	28.6	7.5	7.9	2.3	1.0
600-700FCFA	85.7	71.4	74.6	92.1	95.4	73.0
≥ 700FCFA	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
Non-officially 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

[a]: The exchange rate during the study was fixed at 655 FCFA for 1 €

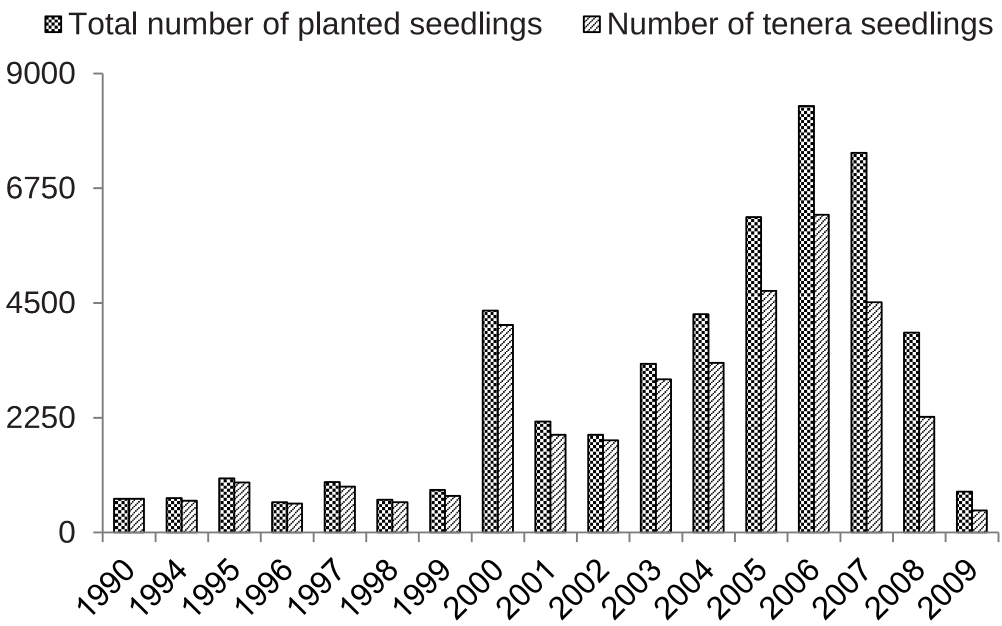

Figure 3.3. Evolution of number of planted seedlings and number of *tenera* in sampled plots between 1990 and 2009. Plots planted between 2008 and 2009 were not always carrying bunches. Differences between bars indicate *dura* and *pisifera*.

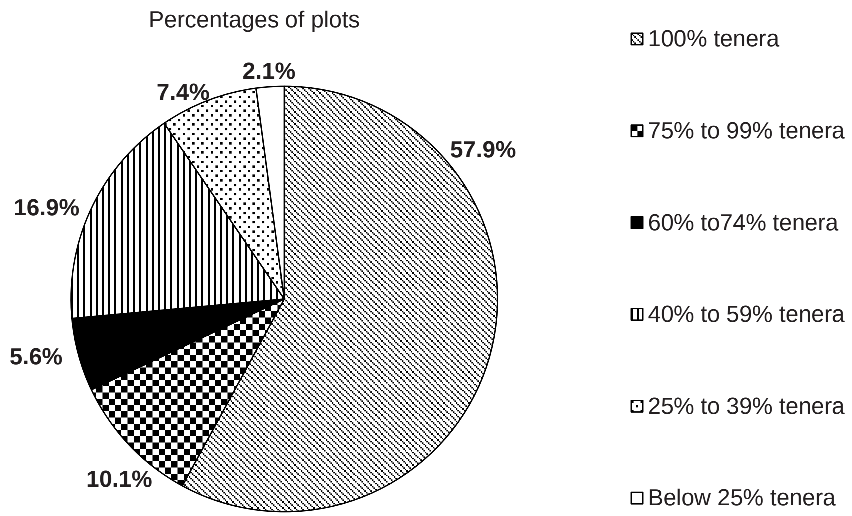

Figure 3.4. Percentages of sampled plots composed of *tenera* across all villages.

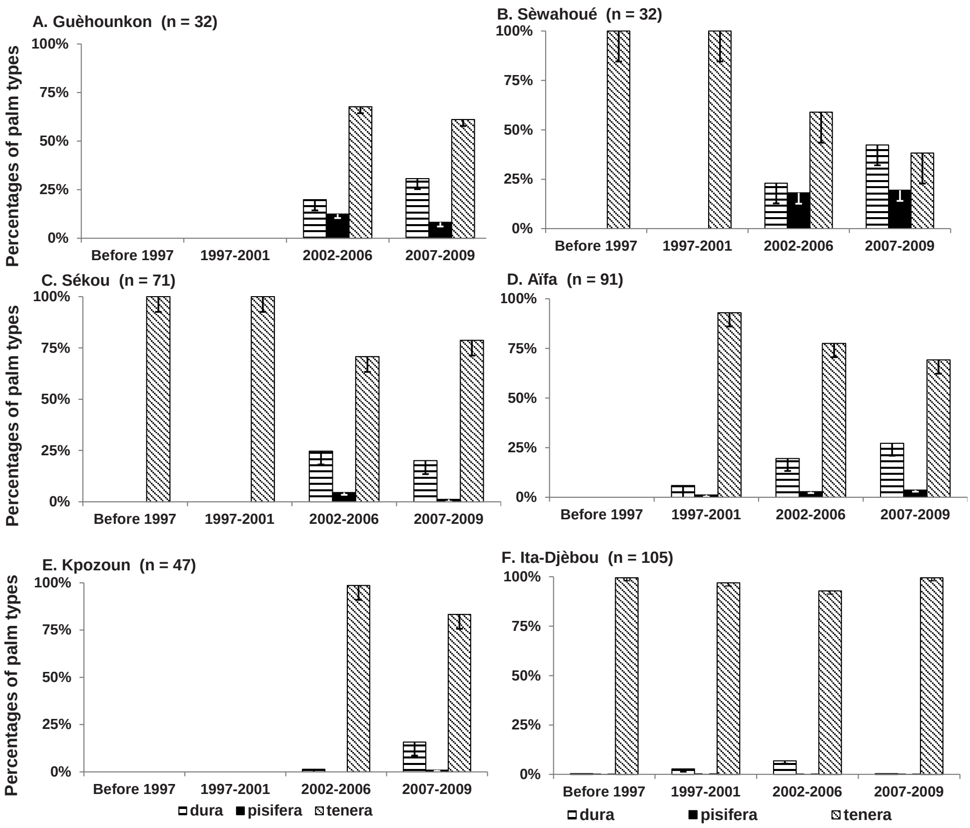

Figure 3.5. Observed percentages of oil palm types for 4 distinguished planting year classes and per selected village. Numbers in brackets indicate sample sizes. Bars indicate standard errors of means.

Variation of genetic quality of palm trees in sampled plots

Across all sites and eras, only 58% of all sampled plots were entirely composed of *tenera* (Figure 3.4). Genetic quality of sampled plots varied according to seedling supply source, geographical position, year of planting and seedling purchase price.

Variation of proportions of oil palm types per selected village and evolution over time

Proportions of palm types differed from one village to another (Figure 3.5). 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

Table 3.3. On-plot and within-village analysis of variation of 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

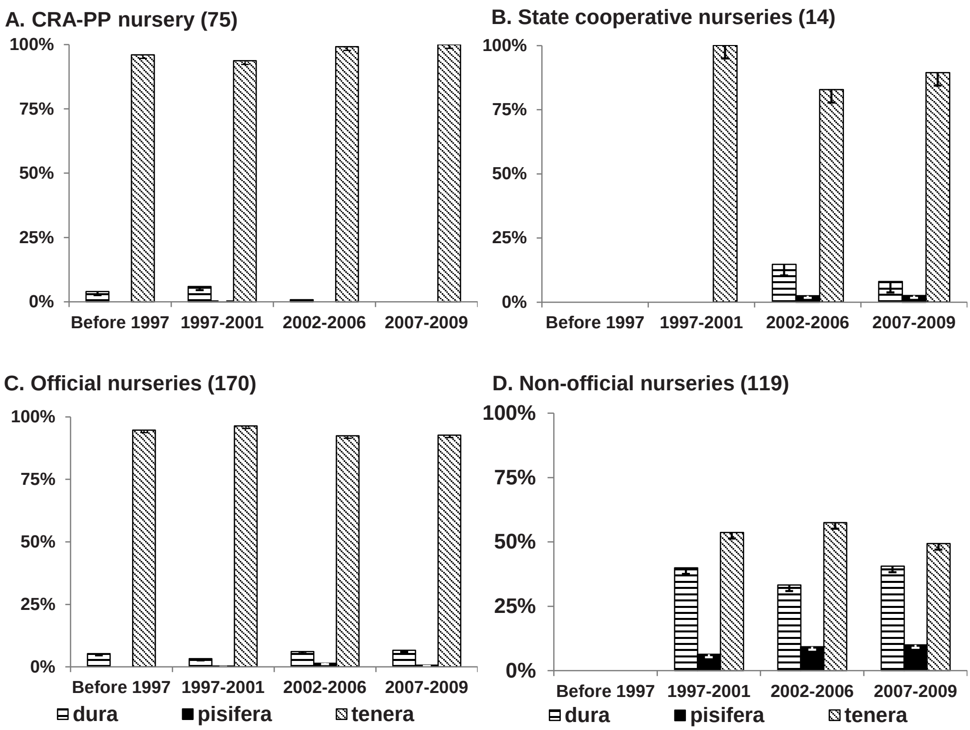

Figure 3.6. Observed percentages of oil palm types for 4 distinguished planting year classes and four supply sources: CRA-PP nursery (A), Official nurseries (B), State cooperative nurseries (C) or Non-official nurseries (D). Numbers in brackets indicate sample sizes. Bars indicate standard errors of means.

selected villages, younger oil palm plots consistently had a lower proportion of *tenera* (Figure 3.5), except Ita-Djèbou. In Guèhounkon, the drop in proportion of *tenera* was slight with 6% points (2002-2006 to 2007-2009 plots). Between the periods from 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 proportions 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* for 1997-2001 plots against 99% *tenera* for 2007-2009 plots. Analyses of genetic variation on-plots and within-villages exhibited the same trends (Table 3.3).

Seedling supply source-related variation of proportions of oil palm types

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

Over time, proportions of *tenera* that individual supply source delivered differed little (Figure 3.6) compared to differences observed between sources. Non-official nurseries have all the time supplied higher proportions of non-hybrid palms to smallholder farmers than official nurseries. It is worth noting that, not all categories of supply sources were available to farmers in each village. While seedlings supplied from CRA-PP were observed mainly in Ita-Djèbou, those from state cooperative nurseries were present in Guèhounkon, Sékou and Aïfa (Table 3.4). In contrast, official and non-official nurseries served farmers across all sampled villages. Proportions of palm types varied across supply sources and per village. Higher proportion of *tenera* was observed for plots planted to CRA-PP seedlings (98%), followed by official nurseries (93%) and state cooperatives (88%). Plots planted to CRA-PP purchased seedlings were found to have as low as 73% *tenera*. Plots planted to 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%).

Seedling purchase price-related variation of proportions of oil palm types

The proportion of *tenera* in sampled plots increased with an increase in seedling purchase price (Table 3.5). Seedlings purchased for 600 to 700 FCFA showed a proportion of *tenera* from 62% to 97% in Guèhounkon and Ita-Djèbou, respectively. Nearly 100% of seedlings purchased for more than 700 FCFA were *tenera*, except in Sékou where we observed one plot composed of 80% *tenera*.

Having characterised the genetic quality of oil palm in smallholder plots, it is relevant to explore possible explanatory mechanisms of observed variation.

Table 3.4. Variation in percentages of tenera, dura, pisifera as affected by seedling supply source.

	CRA-PP nursery	Officially established nurseries	State cooperative nurseries	Non-officially established nurseries
Guèhounkon				
Dura	-[a]	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

[a]: A dash means that this supply source was not represented

Table 3.5. 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	-[a]
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

[a]: A dash means that this purchase price was not represented

Historical events associated with observed genetic quality

This section presents events that happened within or outside the oil palm seed system (OPSS) that had positive or negative impacts on proportions of *tenera* farmers received.

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 private-owned nursery existed to sell seedlings to farmers. Smallholders who wished to plant *tenera* palms had to travel to CRA-PP nursery at Pobè. In 1994, a policy change led to training and installation 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 grew to 40 by 2012. Until 2012, the number of official nurseries established per oil palm production region were 4 in Mono-Couffo, 8 in Atlantique, 4 in Zou, and 24 in Ouémé-Plateau.

Although the 1994 policy change led to the installation of official nurseries, it also led to less control over genetic quality. This is shown through 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, CRA-PP continued to deliver near optimal quality seedlings when selling directly to farmers (Figure 3.6A). In other words, the CRA-PP does not seem to be the source of observed poor quality since 1994.

Recorded mechanisms associated with reliability of local seedling supply systems

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

Our data show that local arrangements through NGOs and public agency activities had often improved proportion of *tenera* 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 installation 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 returned to non-official nurseries, resulting in low proportions of *tenera* (Figure 3.5D).

Like in 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 purchase subsidy. Figure 3.5E shows that the Bornefonden NGO initiative initially provided higher proportion of *tenera* than in later time. More recently purchased seedlings in Kpozoun were not fully subsidised. 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 3.5B 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 3.5F).

Not all interventions by intermediaries improved the reliability of the OPSS for farmers. In Guèhounkon, where the reliability of the OPSS went from bad to worse (Figure 3.5A), two former state cooperative nursery workers had been selling seedlings to farmers on behalf of state cooperative. In the same vein, a former official nursery holder 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 showed also negative impact on genetic quality in Guèhounkon. For example, the state cooperative of Agamé 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 planted to the same seedlings, we observed comparable proportions of non-hybrids.

Looking beyond the effect of formal intermediaries, farmer's 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 pots in Sékou, 11 of 33 plots in Aïfa, and 4 of 10 plots in Ita-Djèbou, that were planted to seedlings obtained through informal intermediaries, were fully composed of *tenera* (Table 3.6). In terms of farmers' personal characteristics, education level did not correlate positively with proportion of *tenera* on their plots (Table 3.6). In Guèhounkon and Sékou, farmers who attended secondary school had equal or lower proportion of *tenera* than those who attended only primary school; in Sèwahoué and Kpozoun, farmers who did not attend school at all showed 12% and 9% points higher proportions of *tenera* than those who attended primary school, respectively; in Ita-Djèbou,

Table 3.6. Variation in percentages of oil palm types for classes of farmer education level, belonging to farmer organisation and use of intermediary for seedling purchase per study village.

	Education level			Belongs to farmer organisation		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	-[a]	-
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.*[b]			
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.*	

[a]: A dash means that this parameter was not represented enough to calculate percentages.

[b]: n.a. = not applicable as test conditions were not fulfilled.

farmers who only attended primary school had higher proportion of *tenera* in their plots than their peers who attended secondary school. Local arrangements and joint seedling purchase with peers members of farmers' organisation could have favoured low-education farmers who sometimes received better quality seedlings than higher educated farmers. Membership of farmers' organisation correlated positively with proportion of *tenera*. In comparison to non-members, farmers who were members of farmer organisation showed an increase in proportion of *tenera* by 39% in Guèhounkon, 15% in Sèwahoué, 22% in Aïfa, 90% in Kpozoun, and 4% in Ita-Djèbou. Field records indicate that members of farmers' organisations often purchased seedlings together from official sources.

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 genetic quality of seedlings is a critical step for success of plantation outputs (Hasnah et al., 2004). The analysis of smallholder plot composition of oil palm types showed that plots allegedly planted to *tenera* contained non-hybrids. Drawing on event ecology approach, we found that socio-institutional mechanisms of past contributed to observed variation in proportions of oil palm types.

Genetic quality of oil palm in smallholder plantations

Proportions of palm types of sampled plots in six villages varied with seedling supply sources. Non-official nurseries were by far the least reliable seedling source. Official nurseries, CRA-PP centre and state cooperative nurseries were also shown less than 100% reliable. Observed high proportions of non-hybrid within material non-official nursery holders supplied 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 existence of fraudulent practices in the supply system to smallholder farmers (Durand-Gasselin and Cochard, 2005). For seedlings originating from 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 also seedling suppliers' trustworthiness is an important determinant of reliability in an OPSS (Durand-Gasselin and Cochard, 2005).

Our findings show that genetic quality of seedlings supplied to farmers varied highly from one village to another. This raises the issue of density and uniform coverage of the oil palm growing belt in official nurseries. 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 avoid farmers' misfortune, smallholders need to be well-organised and technically supported to benefit from their oil palm production. In Indonesia for example, scholars found that supported smallholders achieved higher yields than independent ones (Vermeulen and Goad, 2006). Whether district authorities or smallholder cooperatives (Hardjano et al., 2003; Rist et al., 2010), or extension service guiding farmers through reliable supply sources (Nangoti et al., 2004; Neate and Guei, 2010), support to smallholder farmers increases their income. Furthermore, the high geographic variability in the OPSS reliability emphasises the importance of understanding seed systems as complex and heterogeneous networks of relationships rather than as single, monolithic entities.

Causal mechanisms accounting for observed variation in palm types over time

Using event ecology approach, we identified mechanisms that accounted for observed variation in sampled plots over time. Event ecology approach allowed us to explain *why* in certain places and times, farmers got plots with high or low proportion of *tenera*. Those mechanisms included policy change, changes in local distribution system, local arrangements for seedling supply to farmers, and farmers' personal characteristics. About farmers' characteristics, membership of farmer organisation had strong positive correlation with quality seedling supply. Use of informal intermediaries to purchase seedlings had negative effects on seedling quality.

The policy change in 1994 aimed to increase smallholders' access to *tenera* seedlings through decentralising seedling distribution away from CRA-PP centre to newly established official nurseries in the major oil palm growing regions (Adje and Adjadi, 2001). While implementation of the policy did bring seedling production and distribution closer to part of the smallholder farmers, the supply chain has not been managed to adequately meet all farmers' demand. Data suggest that the mismatch between supply and demand, combined with a newly decentralised distribution system with weak oversight and accountability, appears to have created adequate opportunity and motive for various actors to introduce poor quality material into the OPSS. Field observations indicated presence of such misbehaviour in many instances. State cooperative workers who produced seedlings on their own, suspended official nursery holders 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. We expect that people's motives are most likely profit through fraud, but cannot entirely rule out ignorance of genetic quality maintenance (Chapter 2). To some extent, understanding of the genetics of oil palm (Box 3.1) seems relevant for all players. This could be an important step to improving the OPSS performance.

Local arrangements connecting farmers directly to official seedling supply sources greatly increased the proportion of *tenera* in smallholder plots. Even in villages located at greater distance to official supply sources, local arrangements enabled farmers to overcome the negative effects of distance. In Kpozoun where local arrangement for *tenera* seedling supply existed, smallholder farmers had high proportions of *tenera*. Unlike, Guèhounkon where no local initiatives existed to support farmers to acquire *tenera* seedlings, 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 observation that when they withdrew, smallholder farmers experienced negative impacts. In Aïfa, for example, withdrawal of Catholic Church project led to significant reduction in genetic quality. A relevant question, then, is how to sustain local initiatives that fill the gaps left by inadequate functioning of formal seed system.

Farmers' personal characteristics also correlated with the proportion of *tenera* farmers received. Most cases where farmers used informal intermediaries ended with reduced genetic quality. In Ita-Djèbou for example, while average *tenera* proportion was 97%, cases were observed with farmers receiving substantially lower *tenera* because of informal intermediaries. The main reason of lower quality with informal intermediaries is that farmers do not collect seedlings themselves from official sources. Membership of farmers' organisation increased proportion of *tenera*. Field interviews revealed that members of farmer organisation often ordered seedlings together and that practice limited the chances of being cheated. Because informal intermediaries had negative effect, and membership of farmers' organisation positive effect on seedling quality, the social organisation of seedling acquisition becomes an important aspect of seed system reliability. Farmer education level had not shown clear effects on farmers' access to quality seedlings. Social organisation of seedling acquisition could also explain such findings. Local initiatives and joint seedling purchase with peer members of farmers' organisation favoured low-education 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 drivers and dynamics of unreliability of the OPSS in Bénin over past decades. The approach helped to identify causes of observed variation in smallholder plantations while avoiding 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. After establishing clear correlations between social phenomenon and 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 have not 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 situations 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 its 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 sold seedlings that fail to be optimal. Further research would then reveal whether it is simple cheating or lack of knowledge.

CONCLUSION

The OPSS in Bénin is not reliable and smallholder farmers are exposed to important flows of non-hybrids that jeopardise plantation outputs. Sampling of plots allegedly planted to 100% *tenera* across the oil palm growing belt showed only 58% sampled plots composed of 100% *tenera*. Quality of seedling supply has on average decreased between 1994 and 2012. Local seedling acquisition arrangements and personal characteristics of farmers influenced proportion of *tenera* seedlings farmers received. Success of formal intermediaries like NGO’s or extension service in OPSS to connect farmers to official seedling suppliers implies that current problems can be solved when relevant organisations (CRA-PP, the extension service, NGO's, FBO's) 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 support smallholder farmers’ acquisition of quality *tenera* seedlings. This may take the form of better organisation of the formal state seed system to more effectively reach farmers, or it could take the form of better organisation by farmers to reach the producers of quality seedlings. Either way, improving the oil palm seed system in Bénin will go a long way toward achieving farmers’ objectives of better livelihoods as well as the state’s objectives of increasing smallholder production of oil palm.

CHAPTER 4

Effects of nursery management practices on oil palm seedling phenotype at planting

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This chapter is submitted

ABSTRACT

Official nurseries established in Bénin to produce oil palm seedlings for planting in fields of smallholder farmers fell short to follow the recommended practices and developed their own. To evaluate the efficacy of their nursery management practices in terms of seedling growth, two experiments were conducted, in Sakété district, from March to November 2011 and from April to October 2012. Three bag sizes in combination with four types of soil substrates and three fertiliser treatments were implemented in both experiments in a factorial design. Allometric variables including seedling height, number of leaves, length of most developed leaf, root-collar diameter and biomass production were measured 8 (2011) or 6 (2012) months after transplanting.

Bag size was the main factor determining oil palm seedling growth in both experiments. Applying 10 g fertiliser once a month was harmful to seedling survival with lethal effects in small-sized bags. Arable soil with animal manure in medium-sized bags without any fertiliser supply sustained seedling growth well; this practice seemed to be the best balance between quality and production cost although large-sized bags produced the best seedlings. Growth variables were highly correlated. Height and root-collar diameter constitute good candidates to estimate seedling biomass production non-destructively. The treatment effects on total dry weight produced were similar for the two experiments.

From the observed large effects of bag size on seedling growth, our findings suggest that fertiliser addition or substrate selection cannot compensate bag size effects; the latter should be considered carefully for tree seedling production in nurseries.

Key words: Nursery, oil palm, physiological quality, pot size, seedling growth.

INTRODUCTION

The oil palm is an important perennial crop in South East Asia, South America and Africa (Cao et al., 2011). Its oil is valued in human diet and body care, animal feed, detergents, and bio-energy (Foo and Hameed, 2010; Palatty et al., 2013; Russo et al., 2012). Known as efficient competitor with other oil crops in terms of production per acreage (Fairhurst and Mutert, 1999), oil palm is a potential carbon sink (Wicke et al., 2008), largely produced in tropical countries and smallholder farmers own an important part of the plantations. For smallholder farmers to establish a successful plantation with early fruiting, the use of vigorous planting material is required (Bah and Rahman, 2004; Ibrahim et al., 2010). Many factors are known to influence the growth of seedlings during nursery stage. These include water, nutrients, shading, soil substrates, age of transplanting, weeds, pests and diseases (Bah and Rahman, 2004; Jacquemard, 1995; Poorter et al., 2012a; Witt et al., 2006). Some of these factors (e.g., nutrients, soil substrates) can be controlled by nursery holders during seedling production.

In Bénin, smallholder farmers own the largest part of planted oil palm stands and some nursery holders are officially established to supply them with seedlings for field planting. The seedling supply system is organised in such a way that farmers are forced to purchase planting material from the officially established nurseries. The oil palm research centre (CRA-PP) developed a protocol of seedling production which consists of a number of recommendations to ensure good quality seedling delivery. For instance, it is recommended to nursery holders to use forest soil preferentially, or household waste substrate. These substrates are transported at high cost, or are not available at all as forest is scarce in the southern Bénin where land pressure is high (Koudokpon et al., 1994). Recommendations also include the use of a polythene bag of 40 cm × 40 cm, but nursery holders consider that too huge requiring too much substrate and labour to fill. Yet, based on such a protocol, the nursery holders were trained and authorised to install themselves for seedling production. While producing seedlings in their own nurseries, nursery holders deviated from the recommended practices, as they found the recommendations very constraining to optimise their seedling production enterprise. During a diagnostic study carried out in 2010 in South Bénin by (Chapter 2; Akpo et al., 2012), farmers complained about the physiological quality of the seedlings they purchased. Nursery holders readapted the recommended practices and developed alternative ways of seedling production. The observed nursery holders' deviations from recommended practices included substrate, bag size and fertiliser supply. Nursery holders for instance used soil substrate found around the nursery place alone or in combination with animal manure. They used smaller-sized bags than recommended. Unfortunately, some of these practices did not fully guarantee the physiological quality of seedling at planting time for smallholder farmers. This justifies this research devoted to evaluate which nursery holders' developed practices sustain seedling quality at planting.

The influence of nursery management practices on the physiological quality of seedlings has been partially studied on a range of plant species including *Eucalyptus* (Close et al., 2010; Teixeira et al., 2008), date palm (Aisueni et al., 2009), pine (South et al., 2005), passion fruit (Da Silva et al., 2010) and oil palm (Aya, 1974; Teixeira et al., 2009). These studies tried to explain the way fertiliser supply, bag type and size, and soil substrate affect physiological quality of seedlings. These studies drew on few aspects of seedling growth at the same time and most of them were conducted in research station settings and far from the nursery production conditions and constraints. In the particular case of oil palm, the existing literature on seedling behaviour vis-à-vis nursery management practices is limited and this calls for more research on the subject.

Size of nursery containers have been reported as one of the main factors affecting the successful growth of tree plants (Krizek and Dubik, 1987). Nesmith and Duval (1998) observed that smaller-sized containers increase restrictions to root growth. Poorter et al., (2012b) pinpoint the reduction of photosynthesis efficacy of plants grown in smaller pots. On annuals, Ray and Sinclair (1998) reported important reduction of shoot dry weight and total transpiration with smaller-sized pots in soybean and maize. The growing substrate also influences plant growth and development as reported by Ahmad et al. (2012a) for rose species, Radhouani et al. (2011) for muskmelon, and Lazcano et al. (2009) for tomato. The growing media could also affect seedling survival (Lazcano et al., 2009). The substrate itself or through addition of (chemical) fertilisers, might impose salinity which is reported to decrease plant (root) growth (Javid et al., 2011; Saint Pierre, 2012).

This general knowledge of effects of nursery practices on seedling growth coupled with the context of the seedling supply system in Bénin raises the following issues that deserve to be investigated in the current study: (1) the forest soil substrate used at current land pressure may be sub-optimal compared to the intended forest soil and so alternative substrates nursery holders developed may be better alternatives; (2) smaller-sized bags may have an effect on available nutrients and on rooting space that will compromise seedling size at transplanting, but may provide a realistic cost reduction; (3) inorganic fertiliser application in smaller-sized bags may compromise seedling survival while it is unknown whether this can be avoided through splitting the amount throughout the nursery phase; (4) it is also not documented whether bag size, fertiliser supply or substrate will show the largest effects on seedling growth, and what their interactions are. To get a good understanding of these agronomic issues and contribute to the knowledge of nursery seedling production, a full factorial experiment with three factors was carried out twice; we were specifically interested in treatment interactions and also examined financial indicators.

A secondary aspect in this study was to find best ways to non-destructively determine physiological seedling quality differences. Farmers and nursery holders negotiate prices based on quality assessment, and while seedling weight after the nursery phase would be a good indication of physiological quality, a non-destructive proxy for this weight is sought. Lucas (1980) reported high correlations between some growth parameters of oil palm seedlings.

Specifically, this research evaluated the effects of bag size, substrate type and fertiliser supply on growth and development variables of oil palm seedlings, the correlations between these variables and the best proxy to estimate dry weight in a non-destructive way, and the financial implications. The common planting age of oil palm seedling lies between 6 and 8 months (8 months as recommendation and 6 months as often used by nursery holders). For this reason, treatment effects on seedling growth were measured at 8 months during the first experimental year (2011) and at 6 months in the second experimental year (2012).

MATERIAL AND METHODS

The study was conducted under typical nursery holder conditions and as a joint learning experience at the site of an officially established oil palm nursery in Sakété district, Bénin, the district where recently problems in quality of oil palm seedlings have been reported (Chapter 2; Akpo et al., 2012). The joint learning aspect is reported in Chapter 6. Here the findings on management effects on seedling quality are reported. The study was carried out in 2011 from March 4th to November 4th (8 months period) and in 2012 from April 6th to October 6th (6 months period). The total monthly rainfall, and monthly average minimum and maximum temperature and average relative humidity during the study periods are presented in Figure 4.1.

Experimental design

A full 3 × 4 × 3 factorial experiment with 36 treatments was conducted and carried out in 5 replications. Factors and levels were: bag size with 3 levels (small: 25 cm diameter × 30 cm deep, medium: 31 cm × 31 cm and large: 40 cm × 40 cm); type of soil substrate with four levels ("forest" soil, household waste substrate, arable soil, and arable soil with animal manure) and fertiliser supply with three levels (no fertilisation, split dose: 5 g per seedling every 15 days, and full dose: 10 g per seedling every 30 days). "Forest" soil was the top 20 cm of soil collected under a plantation of *Eucalyptus camadulensis* Dehnh, the most readily available forest soil type. Household waste substrate was collected from a pile of decomposed waste and sieved to 8 mm. Arable soil was collected from a field near the experimental site that had never been planted to oil palm or oil palm seedlings. Animal manure was collected as the top 5 cm from an area where cattle stayed overnight. The arable soil and animal manure were mixed in a volume proportion of 2:1.

Each experimental unit consisted of six bags arranged in two rows with one seedling per bag. In both years a single batch of genetically identical seedlings of 4 months old was

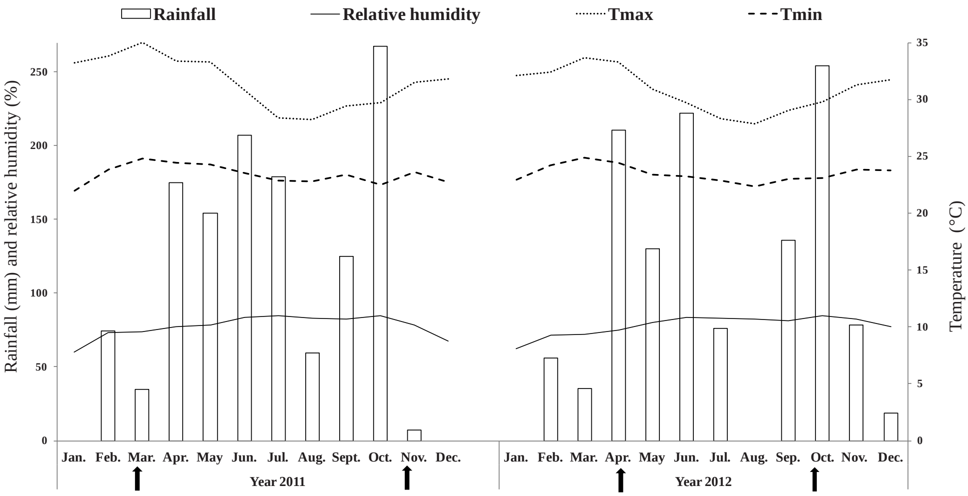

Figure 4.1. Rainfall, temperature and relative humidity in the study area in 2011 and 2012. Rainfall and relative humidity on the left vertical axis; temperatures on the right axis. Arrows indicate the study periods.

collected from the oil palm research centre. The batch of seedlings was raised in the CRA-PP research centre in a single pre-nursery under shade in 10 cm × 15 cm bags filled with forest soil around CRA-PP, and watered three times a week until the age of 4 months when they were brought to the experimental site. Fibrous waste of processed palm nuts was used to mulch seedlings (Von Uexkull and Fairhurst, 1991) two weeks after transplanting. Three months after seedling transplanting to the experimental site, the pesticide Dursban (chlorpyrifos; 0.4 ml per 20 seedlings) was used once preventive pest control. For treatments in which fertilisers were applied, urea (46% N) and NPK (10%, 20%, 20%) was used alternatively. Fertiliser application started with urea two weeks after transplanting. Seedlings were spaced and arranged in a 60 cm × 60 cm grid. Throughout the experiment, 1 litre of water was supplied per seedling three times a week.

At the time bags were filled, two samples of 500 g of each of the different substrates were collected and air dried for later chemical analyses. Samples were analysed using classical methods for soil nutrient analysis in the laboratory (Pansu and Gautheyrou, 2006). The pH was determined using glass electrodes. Further methods were: the Walkley and Black method for organic carbon, the Kjeldahl method for total nitrogen, the Bray (I) method for phosphorus, and the ammonium acetate method for potassium, calcium, magnesium and exchangeable cations (Table 4.1). The mentioned nutrients were those that mattered most for physiological quality of oil palm seedlings (Corley and Tinker, 2003; Turner, 2003).

Table 4.1. Results of chemical analysis of the substrates used in the experiments.

Soil substrates	pH	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (ppm)	Available cations (meq/100g)			Cation exchange capacity (CEC) (meq/100g)
					K+	Mg2+	Ca2+	
2011								
Arable soil	6.55	1.48	0.10	62.9	0.88	1.53	1.03	6.0
Mixture arable soil and manure	7.00	4.46	0.29	53.8	2.75	12.36	6.32	23.0
Household waste substrate	7.53	3.73	0.21	46.4	3.88	8.50	8.50	23.0
"Forest" soil top layer	7.48	1.65	0.08	8.4	0.62	1.18	1.26	7.5
2012								
Arable soil	7.36	2.34	0.14	67.9	1.82	1.5	2.80	10.6
Mixture arable soil and manure	7.05	4.33	0.26	60.1	2.24	11.4	5.60	20.6
Household waste substrate	7.82	4.98	0.30	33.5	4.81	1.6	1.64	8.6
"Forest" soil top layer	8.06	2.95	0.18	24.0	1.02	1.8	2.04	11.9

Data collection

At 8 (2011) or 6 (2012) months after seedling transplanting to full nursery (henceforth referred to as nursery) the seedling number per experimental unit was recorded and for surviving seedlings the following variables were determined: seedling height, total number of leaves, length of most developed leaf, root-collar diameter, sanitary state, root and shoot dry weight.

Seedling height was measured from the plant base to the apical level of the leaves, by straightening the leaves upwards. The total number of newly formed leaves was recorded through counting all leaves that appeared since the time seedlings were transplanted. The length of the most developed leaf was determined as the largest distance between the insertion node and the tip of the longest leaf on a plant. The root-collar diameter was taken as the mean of two measures taken at perpendicular angle at the stem base where the roots originate from the shoot. The height, the number of leaves, the length of the most developed leaf, and the root-collar diameter were measured on four randomly selected seedlings out of the six in an experimental unit.

For the check of the sanitary state of the seedlings three of the six seedlings were selected at random and examined thoroughly to check for any hole in its basal part. Then it was sectioned longitudinally in four parts and scrutinised whether it hosted any insects. Examined seedlings were recorded as healthy if no hole or insects were observed. In case of presence of insects, plants were scored as attacked and the number of insects was recorded. Further to sanitary state check, the dry weight was assessed by drying and weighing these same three seedlings. The roots were separated from the above ground parts. The drying was conducted in an oven at 70 ºC for 72 hours.

The total financial costs related to the different nursery practices were evaluated in the local currency and based on labour and material costs in the area.

Data analysis

Seedling survival was determined as the seedlings alive as percentage of seedlings at transplanting. Total dry matter was calculated as the total of root and shoot dry matter per individual plant. The shoot to root ratio was determined as another important variable connected to seedling quality (Harris, 1992). Data were analysed with Statistical Analysis System (SAS, v. 9.2) software using the general linear model procedure for a randomised complete block design. In case of significant difference between treatments, means were separated using the Tukey honestly significant difference (Tukey-HSD) comparison test ($p<0.05$).

The correlation between growth parameters was investigated through plotting one variable against another and determining the correlation coefficient (R^2) and its level of significance. The consistency of the trends of treatment effects between the two years was determined through plotting the average dry weight produced per treatment in 2011 and 2012.

Costs involved in each nursery practice were evaluated. The calculations are reported per 1000 seedlings.

RESULTS

Seedling survival under tested nursery practices

There was an interaction between bag size and fertiliser supply in their effect on seedling survival (Table 4.2), substrate itself or in interaction with bag size and fertiliser supply did not affect survival. Survival was near 100% when plants were grown in large-sized bags irrespective of fertiliser supply. In 2011, 7 to 17% dead seedlings were observed in medium-sized bags when fertilisers were applied at 10 g per seedling per month, while in 2012 survival was 100% for this bag size. In small-sized bags, both fertiliser supply doses reduced

Table 4.2. Survival of transplanted seedlings under nursery practices, expressed as percentage (%) surviving seedlings over the number of transplanted ones.

	Year 2011			Year 2012		
	Fertiliser supply			Fertiliser supply		
	0 dose	Split dose	Full dose	0 dose	Split dose	Full dose
Large-sized bags filled with arable soil	100	100	100	100	100	100
Large-sized bags filled with mixture arable soil + manure	100	100	96	100	100	100
Large-sized bags filled with "forest" soil	100	97	100	100	100	100
Large-sized bags filled with household waste	100	100	97	100	100	100
Medium-sized bags filled with arable soil	100	97	93	100	100	100
Medium-sized bags filled with mixture arable soil + manure	100	100	93	100	100	100
Medium-sized bags filled with "forest" soil	100	97	83	100	100	100
Medium-sized bags filled with household waste	100	100	93	100	100	100
Small-sized bags filled with arable soil	97	87	20	100	97	27
Small-sized bags filled with mixture arable soil + manure	100	77	17	100	93	30
Small-sized bags filled with "forest" soil	100	80	13	100	90	23
Small-sized bags filled with household waste	100	83	17	100	97	33

Percentages calculated over 30 transplanted seedlings per treatment.

survival of seedlings. At 10 g per seedling once per month as much as 80 to 87% and 67 to 77% dead seedlings were recorded in 2011 and 2012, respectively.

In general, the percentages of dead seedlings were higher in the 2011 experiment than in the 2012 one. Across the two years, only one third of seedlings raised in small-sized bags (all substrates included) survived. For the rest of the paper, treatments including small-sized bags and full dose fertiliser supply (10 g per seedling once a month) are discarded and only the remaining 32 treatments are analysed.

Effects of nursery practices on seedling growth after 8 (2011) and 6 (2012) months

The three-way interaction between substrate, bag size and fertiliser supply was not significant for root-collar diameter, height, number of leaves and length of the most developed leaf of seedlings in either year (Table 4.3). On the other hand, the three-way interaction was significant on seedling biomass variables except shoot to root ratio (for both years) and root dry weight in 2011. The two-way interactions of substrate and fertiliser supply significantly affected all allometric variables of seedling growth in both years. The two-way interaction

Table 4.3. F-values and probability levels from the GLM analysis of allometric variables and biomass production of oil palm seedlings

	df	Height (cm)	Root-collar diameter (cm)	Number of leaves	Length of largest leaf (cm)	Root dry weight (g)	Shoot dry weight (g)	Shoot to root ratio	Total dry weight (g)
2011									
Bag (Ba)	2	159***	131***	119***	171***	190***	189***	2.69ns	208***
Substrate (Su)	3	3.75*	4.66**	4.03**	4.53**	4.55**	3.45*	1.88ns	3.76*
Ba × Su	6	1.63ns	0.95ns	0.86ns	1.24ns	1.07ns	0.85ns	0.73ns	0.84ns
Fertiliser supply (Fe)	2	1.28ns	3.68*	9.85	4.01*	2.48ns	6.49**	2.06ns	6.17**
Ba × Fe	3	4.21**	3.50*	2.72*	4.66**	3.20*	7.62***	2.97*	7.39***
Su × Fe	6	6.24***	3.79**	3.99*	7.06***	6.25***	4.41***	2.19*	4.99***
Ba × Su × Fe	9	1.00ns	0.96ns	0.62ns	1.00ns	0.81ns	1.84*	1.45ns	1.74*
2012									
Bag (Ba)	2	550***	162***	277***	437***	481***	529***	2.54ns	582***
Substrate (Su)	3	24.0***	10.0***	15.5***	19.7***	16.1***	20.6***	18.4***	20.43***
Ba × Su	6	0.70ns	0.71ns	1.48ns	0.23ns	1.82ns	3.10**	0.43ns	2.96**
Fertiliser supply (Fe)	2	1.86ns	4.31*	11.6***	4.13*	6.21**	7.64***	38.3***	5.07**
Ba × Fe	3	1.05ns	2.15ns	0.88ns	0.91ns	1.52ns	3.95**	1.57ns	3.74*
Su × Fe	6	10.2***	6.43***	6.32***	5.85***	4.12***	11.9***	3.60**	11.2***
Ba × Su × Fe	9	0.55ns	0.21ns	0.37ns	0.23ns	3.26**	3.50***	0.83ns	3.78***

*, ** and *** indicate significant effects at $p < 0.05$, $p < 0.01$, $p < 0.001$, respectively. Fe: fertiliser supply; Ba: Bag size; Su: Substrate; The symbol × indicates a factor interaction; df: degrees of freedom.

between bag size and fertiliser supply significantly affected allometric variables of seedling growth only in 2011. F-values in Table 4.3 indicate that among the main factors, bag size was the one that most strongly affected seedling growth.

Interaction effect of substrate, bag size and fertiliser supply on biomass production

In both years, the top ranking treatments for dry weight all included large-sized bags (Table 4.4). Among these any substrate amended with fertiliser or arable soil amended with manure and either or not with fertiliser tended to yield higher dry weights. Arable soil without manure, *Eucalyptus* soil and household waste without fertiliser tended to yield seedlings of lower dry weight ($p < 0.05$). Combinations that included medium-sized bags in almost all cases produced significantly lower-weight seedlings than identical combinations with large-sized bags and comparisons between treatments within medium-sized bags showed mostly similar trends to the same treatments within large-sized bags for both years. As observed for large-sized bags, household waste and arable soil without any fertiliser supply were the treatments that produced the lowest dry weights in medium-sized bags, for both years. Apart from the earlier mentioned higher seedling death in small-sized bags, all lower dry weights

Table 4.4. Treatment effects on seedling dry weight production in 2011 and 2012, treatments have been sorted on total dry weight for each year.

2011							2012						
Treatments	Root dry weight (g)		Shoot dry weight (g)		Total dry weight (g)		Treatments	Root dry weight (g)		Shoot dry weight (g)		Total dry weight (g)	
LSHoSD	42.2	A	178	AB	220	A	LSArm0D	14.5	A	66.5	A	81.1	A
LSFoSD	35.5	ABCD	182	A	218	AB	LSFoFD	13.4	ABC	61.0	AB	74.4	AB
LSHoFD	39.1	AB	176	AB	215	AB	LSHoFD	13.8	AB	57.5	ABC	71.3	ABC
LSArm0D	38.1	ABC	176	AB	214	AB	LSFoSD	13.2	ABC	55.0	ABCD	68.2	ABCD
LSArFD	38.2	ABC	174	AB	212	AB	LSHoSD	12.4	ABCD	50.3	BCDE	62.7	BCDE
LSArSD	35.4	ABCDE	174	AB	210	AB	LSArmFD	10.9	BCDEF	50.4	BCDE	61.2	BCDE
LSArmSD	33.5	ABCDEF	161	ABCD	195	ABC	LSArmSD	10.5	CDEF	50.4	BCDE	60.8	BCDE
LSArmFD	31.0	ABCDEFG	162	ABC	193	ABC	LSArFD	11.1	BCDE	46.6	CDEF	57.7	CDEF
LSFoFD	31.0	ABCDEFG	148	ABCDE	179	ABCD	LSHo0D	13.0	ABC	43.7	DEFG	56.8	CDEF
LSFo0D	29.2	BCDEFGH	132	ABCDEF	162	ABCDE	LSArSD	10.3	CDEFG	43.9	DEFG	54.1	DEFG
LSAr0D	31.4	ABCDEFG	118	BCDEFG	149	BCDEF	LSFo0D	11.1	BCDE	37.6	EFGH	48.7	EFGH
MSArmFD	21.7	FGHIJKLM	113	CDEFGH	134	CDEFG	LSAr0D	9.8	DEFGH	33.9	FGHI	43.7	FGHI
MSArm0D	28.0	BCDEFGHI	106	CDEFGH	134	CDEFG	MSArm0D	7.3	GHIJK	33.2	GHIJ	40.4	GHIJ
MSHoFD	24.0	DEFGHIJK	109	CDEFGH	133	CDEFG	MSHoFD	7.8	FGHIJ	29.8	HIJ	37.6	HIJ
MSFoSD	22.9	DEFGHIJKL	106	CDEFGH	129	CDEFG	MSHoSD	8.3	EFGHI	29.1	HIJ	37.4	HIJ
MSArmSD	25.9	CDEFGHIJ	103	CDEFGH	129	CDEFG	MSArmSD	6.5	IJKL	28.4	HIJK	34.9	HIJK
LSHo0D	26.0	CDEFGHI	101	DEFGH	127	CDEFG	MSArmFD	6.5	IJKLM	28.0	HIJK	34.4	HIJK
MSHoSD	23.4	DEFGHIJKL	98	EFGH	121	DEFG	MSHo0D	6.9	HIJKL	23.0	IJKL	29.8	IJKL
MSAr0D	22.8	EFGHIJKL	98	EFGH	120	DEFG	MSFoFD	5.7	IJKLMN	23.9	IJKL	29.6	IJKL
MSArSD	21.1	FGHIJKLM	89	EFGHI	110	DEFGH	MSFoSD	5.7	IJKLMN	23.7	IJKL	29.3	IJKL
MSFoFD	19.3	GHIJKLM	79	FGHI	99	EFGH	SSArm0D	5.7	IJKLMN	22.9	IJKL	28.6	IJKL
MSArFD	20.9	FGHIJKLM	76	FGHI	97	EFGH	MSArFD	5.1	JKLMN	22.6	IJKL	27.7	JKL
SSArm0D	18.2	HIJKLM	75	FGHI	93	EFGH	MSAr0D	6.6	HIJKL	20.6	JKL	27.2	JKL
MSFo0D	16.9	HIJKLM	76	FGHI	93	EFGH	MSFo0D	6.7	HIJKL	20.2	JKL	26.8	JKL
MSHo0D	16.6	HIJKLM	69	GHI	86	FGH	MSArSD	4.5	KLMN	20.8	JKL	25.3	JKL
SSHoSD	15.6	IJKLM	67	GHI	83	FGH	SSHoSD	4.2	KLMN	16.0	KL	20.2	KL
SSAr0D	15.4	IJKLM	65	GHI	80	FGH	SSHo0D	4.8	JKLMN	14.9	L	19.7	KL
SSArmSD	12.6	KLM	58	GHI	70	GH	SSArmSD	3.3	MN	15.8	KL	19.1	L
SSFo0D	11.0	LM	59	GHI	70	GH	SSAr0D	4.2	KLMN	13.3	L	17.5	L
SSArSD	13.3	JKLM	57	HI	70	GH	SSFoSD	3.1	N	13.3	L	16.4	L
SSHo0D	12.4	KLM	54	HI	66	GH	SSFo0D	4.1	LMN	11.6	L	15.7	L
SSFoSD	10.0	M	36	I	45	H	SSArSD	2.8	N	12.3	L	15.1	L
SE	0.8		3.9		4.6			0.3		1.3		1.6	

LS: large-sized bags; MS: medium-sized bags; SS: small-sized bags. Fo: "forest" soil; Ho: household waste; Ar: arable soil without manure; Arm: arable soil + manure. 0D: 0 dose fertiliser supply; FD: full dose fertiliser supply; SD: split dose fertiliser supply.

Values followed by the same letter in the same column are not significantly different as established by the Tukey-HSD test ($p < 0.05$).

SE: Average standard error of the means

Table 4.5. Two way-interaction effects between substrate and fertiliser on seedling height, root-collar diameter, number of leaves and length of most developed leaf in 2011 and 2012 averaged over large and medium-sized bags. Small-sized bags were excluded given their effect on seedling survival.

2011					2012				
Treatments	Height (cm)	Root-collar diameter (cm)	Number of leaves (cm)	Length of largest leaf (cm)	Treatments	Height (cm)	Root-collar diameter (cm)	Number of leaves (cm)	Length of largest leaf (cm)
Arm0D	82.7 A	5.77 A	18.7 A	67.9 A	Arm0D	54.2 A	3.59 A	13.1 A	42.3 A
ArmFD	73.5 AB	5.29 A	18.2 A	58.9 AB	ArmFD	48.2 A	3.31 AB	12.7 AB	38.1 A
ArmSD	73.9 AB	5.66 A	18.4 A	58.6 AB	ArmSD	47.4 A	3.32 AB	12.7 AB	37.1 A
Ho0D	67.1 B	4.82 A	15.9 B	54.3 B	Ho0D	47.0 A	2.97 AB	11.8 AB	38.0 A
HoFD	75.1 AB	5.53 A	18.3 A	59.7 AB	HoFD	50.1 A	3.41 AB	12.9 AB	40.0 A
HoSD	77.2 AB	5.59 A	18.5 A	61.9 AB	HoSD	49.9 A	3.59 A	12.9 AB	39.2 A
Ar0D	74.1 AB	5.30 A	17.5 AB	59.8 AB	Ar0D	45.0 A	2.95 AB	11.5 B	35.8 A
ArFD	73.7 AB	5.38 A	18.3 A	58.2 AB	ArFD	44.4 A	3.16 AB	12.3 AB	34.7 A
ArSD	73.0 AB	5.54 A	18.5 A	58.2 AB	ArSD	43.2 A	3.02 AB	12.2 AB	34.2 A
Fo0D	73.1 AB	4.82 A	17.0 AB	58.7 AB	Fo0D	44.0 A	2.75 B	11.6 B	35.1 A
FoFD	70.4 AB	5.31 A	17.8 AB	55.8 B	FoFD	48.9 A	3.28 AB	12.6 AB	38.4 A
FoSD	76.1 AB	5.58 A	18.5 A	60.4 AB	FoSD	48.3 A	3.31 AB	12.6 AB	36.6 A
SE	0.9	0.07	0.2	0.7		0.7	0.05	0.1	0.6

Fo: "forest" soil; Ho: household waste; Ar: arable soil without manure; Arm: arable soil + manure. 0D: 0 dose fertiliser supply; FD: full dose fertiliser supply; SD: split dose fertiliser supply.

Values followed by the same letter in the same column are not significantly different as established by the Tukey-HSD test ($p < 0.05$).

were observed on small-sized bags, yet differences between identical combinations of substrate and fertiliser supply were generally not significant, indicating that on average the step from small to medium-sized bags influence dry weight less than the step from medium to large-sized bags. The addition of 5 g fertiliser per seedling every 15 days tended to have no or a positive effect on large-sized bags but no or at times a negative effect on small-sized bags.

Two-way interaction effects between substrate type and method of fertiliser supply, and between bag size and method of fertiliser supply

For most growth variables in both years, the two way-interactions between substrate type and fertiliser supply indicated significantly better seedling performance on arable soil with manure without any inorganic fertiliser supply than when inorganic fertiliser was added while seedling performance on household waste with no inorganic amendment tended to be worse than when inorganic fertiliser was added (Table 4.5). The other two substrates tended to follow the same logics as for household waste but with generally smaller fertiliser effects.

Table 4.6. Two way-interaction effects between bag size and fertiliser on seedling height, root-collar diameter number of leaves and length of most developed leaf in 2011.

2011								
Treatments [1]	Height (cm)		Root-collar diameter (cm)		Number of leaves (cm)		Length of largest leaf (cm)	
LS0D	78.7	A	5.55	AB	18.0	B	63.3	A
LSFD	81.1	A	6.00	A	19.3	A	64.2	A
LSSD	82.1	A	6.07	A	19.5	A	65.5	A
MS0D	69.8	B	4.81	C	16.5	CD	57.0	B
MSFD	65.2	BC	4.76	C	17.0	BC	52.1	BC
MSSD	68.0	B	5.11	BC	17.4	BC	54.0	B
SS0D	60.5	CD	4.18	D	15.2	E	48.5	CD
SSSD	55.4	D	4.12	D	15.3	DE	43.6	D
SE	0.9		0.07		0.2		0.7	

LS: large-sized bags; MS: medium-sized bags; SS: small-sized bags. 0D: 0 dose fertiliser supply; FD: full dose fertiliser supply; SD: split dose fertiliser supply.
Values followed by the same letter in the same column are not significantly different as established by the Tukey-HSD test ($p < 0.05$).

Table 4.7. Correlation matrix of growth variables in both years.

	Root-collar diameter	Height	Number of leaves	Length most developed leaf	Root dry weight	Shoot dry weight
2011						
Root-collar diameter	-					
Height	0.762***	-				
Number of leaves	0.791***	0.723***	-			
Length of most developed leaf	0.725***	0.984***	0.687***	-		
Root dry weight	0.700***	0.734***	0.687***	0.728***	-	
Shoot dry weight	0.661***	0.805***	0.712***	0.788***	0.827***	-
Total dry weight	0.685***	0.813***	0.727***	0.798***	0.878***	0.995***
2012						
Root-collar diameter	-					
Height	0.719***	-				
Number of leaves	0.771***	0.790***	-			
Length of most developed leaf	0.628***	0.965***	0.740***	-		
Root dry weight	0.569***	0.856***	0.642***	0.831***	-	
Shoot dry weight	0.626***	0.884***	0.762***	0.856***	0.869***	-
Total dry weight	0.628***	0.897***	0.754***	0.869***	0.911***	0.995***

*** indicate significant correlation between variables at $p < 0.001$.

The two way-interaction effects for objects with normal seedling survival between bag size and fertiliser supply showed that large-sized bags with split or full dose fertiliser supply produced the largest seedling growth, all variables included (Table 4.6). Except for the

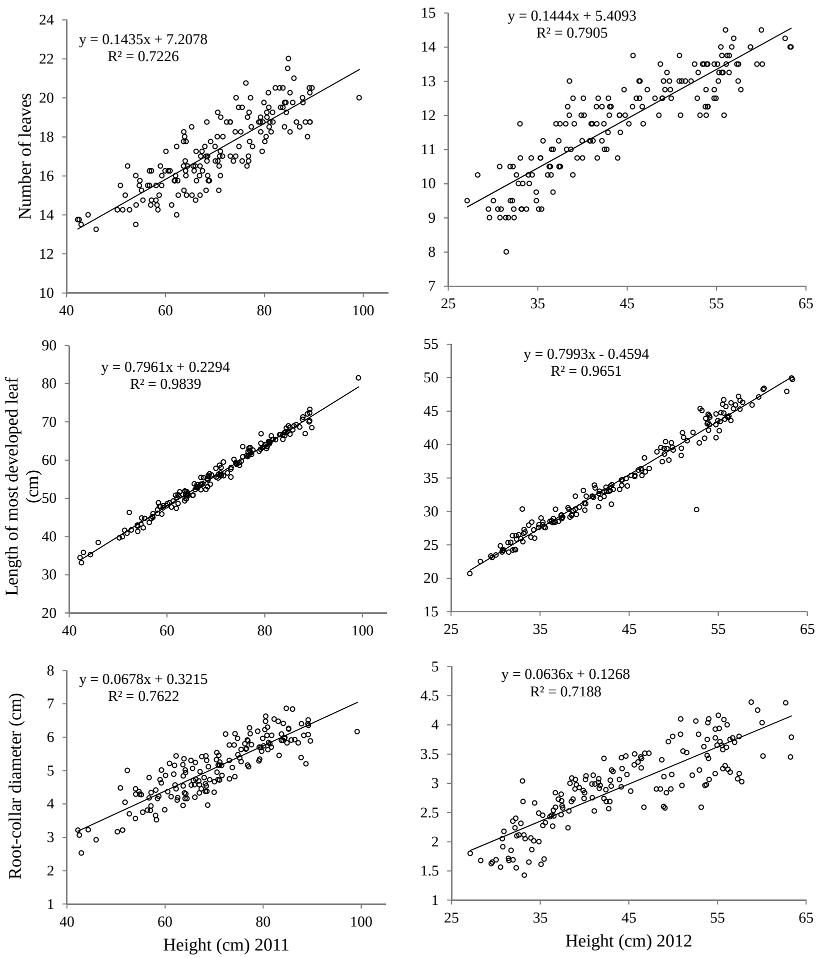

Figure 4.2. Correlation between allometric variables.

number of leaves, the lowest seedling growth was registered on small-sized bags with split dose fertiliser supply.

Correlations between growth parameters of seedlings as observed in 2011 and 2012

Correlations between allometric variables

Allometric variables of 8- and 6-months seedlings were highly correlated in both years ($p < 0.001$) (Table 4.7). The highest correlations between variables were observed for plant height and length of the most developed leaf (R^2 = 0.98 and 0.97 for 2011 and 2012, respectively). The lowest correlation coefficients between allometric variables were observed between

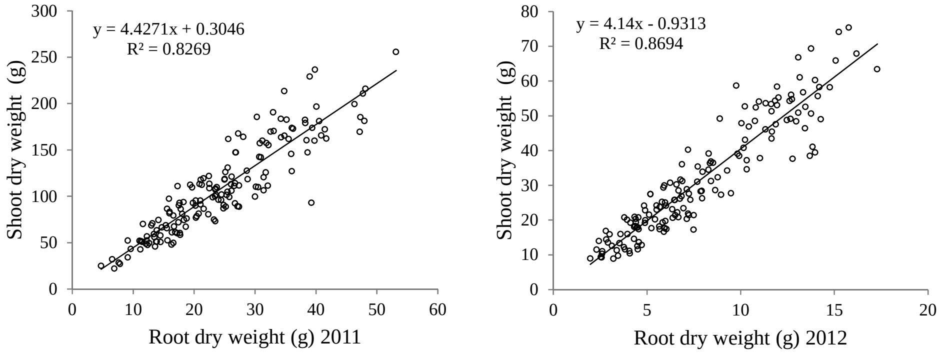

Figure 4.3. Correlation between biomass variables.

length of the most developed leaf and root-collar diameter ($R^2 = 0.73$ in 2011 and $R^2 = 0.63$ in 2012). Figure 4.2 provides some indication of the scatter of observed values around the 1:1 lines relating height and other variables.

Correlations between biomass variables

The biomass variables were highly correlated in 2011 and 2012 ($p < 0.001$) (Table 4.7). The distribution of observed values for root and shoot biomasses (that showed correlation coefficients $R^2 = 0.83$ in 2011 and $R^2 = 0.87$ in 2012) is shown in Figure 4.3.

Estimating dry weight using allometric variables

The relationships between dry weight and allometric variables were curvilinear. Correlation of biomass was highest with seedling height (R^2 = 0.85 and 0.91 in 2011 and 2012, respectively). The weakest correlation was observed with root-collar diameter (0.74 in 2011 and 0.71 in 2012) but still with $p < 0.001$. The correlation between dry weight and the product height × root-collar diameter was high ($R^2 = 0.84$ in 2011 and $R^2 = 0.86$ in 2012) (Figure 4.4).

Treatment effects over the two experimental years: consistency of findings

We used dry weight to analyse the similarity of treatment effects between the two years. The regression plot between produced average total dry weight of treatments in 2011 and 2012 is presented in Figure 4.5. The correlation coefficient indicated that observed treatment trends in 2011 were closely associated with trends in 2012 ($R^2 = 0.86$, $p < 0.001$). At 8 months or 6 months of nursery, tested nursery practices showed comparable pattern of effects on seedling

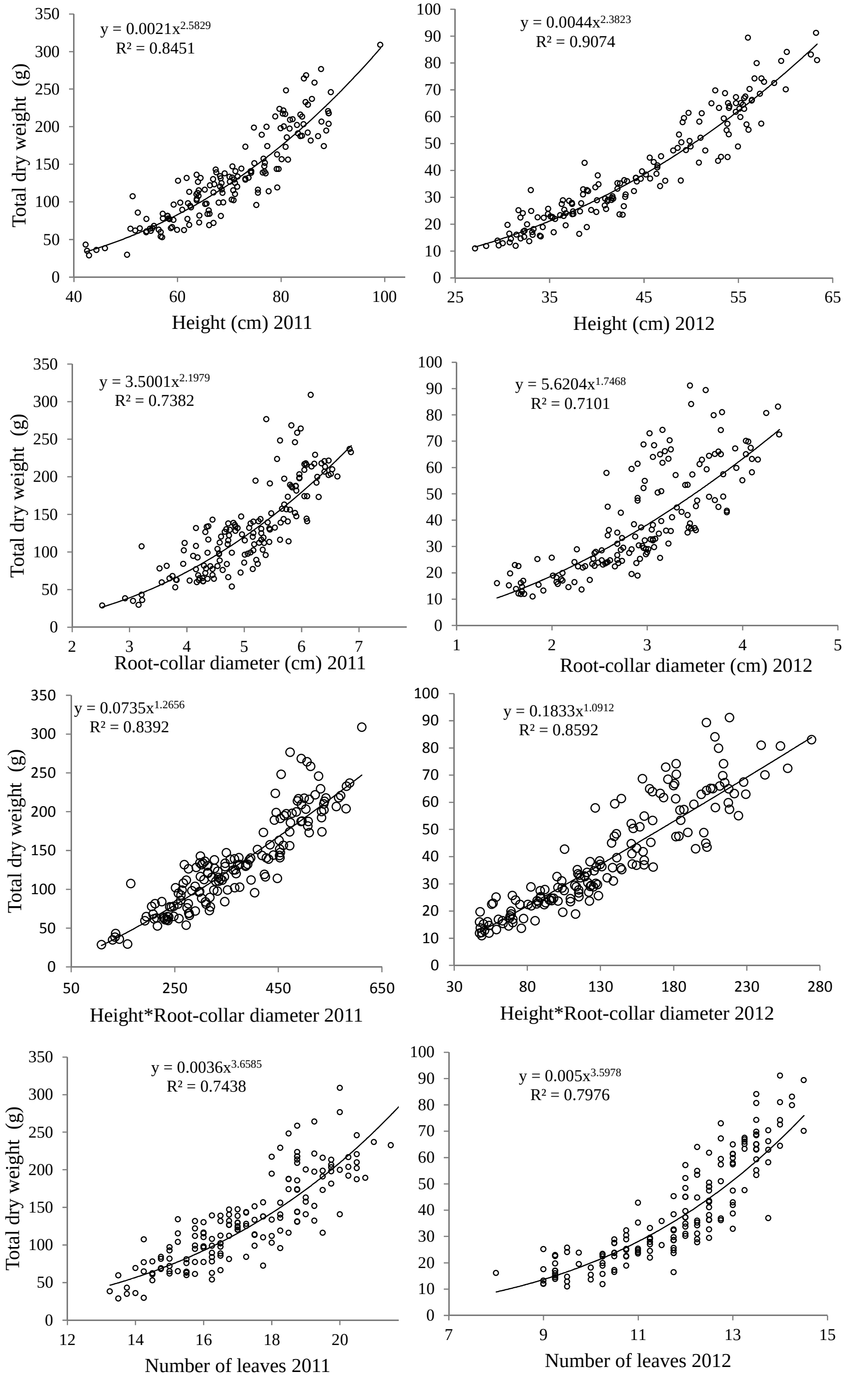

Figure 4.4. Correlation between allometric and total biomass variables.

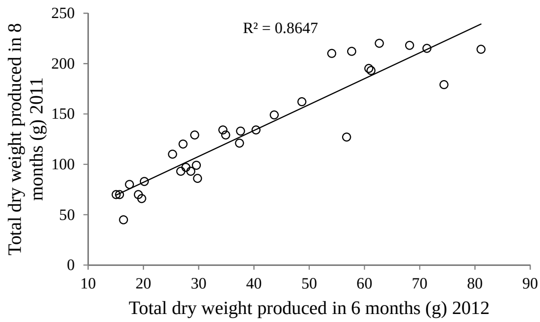

Figure 4.5. Consistency of treatment effects between the two years.

Table 4.8. Overall treatment rank over the two experimental years.

Treatments	Treatment rank in year 2011	Treatment rank in year 2012	Overall treatment rank
LSArm0D	4	1	1
LSFoSD	2	4	2
LSHoFD	3	3	2
LSHoSD	1	5	2
LSFoFD	9	2	5
LSArFD	5	8	6
LSArmFD	8	6	7
LSArmSD	7	7	7
LSArSD	6	10	9
LSFo0D	10	11	10
LSAr0D	11	12	11
MSArm0D	13	13	12
LSHo0D	17	9	12
MSHoFD	14	14	14
MSArmFD	12	17	15
MSArmSD	16	16	16
MSHoSD	18	15	17
MSFoSD	15	20	18
MSFoFD	21	19	19
MSAr0D	19	23	20
MSHo0D	25	18	21
MSArFD	22	22	22
SSArm0D	23	21	22
MSArSD	20	25	24
MSFo0D	24	24	25
SSHoSD	26	26	26
SSArmSD	28	28	27
SSAr0D	27	29	27
SSHo0D	31	27	29
SSFo0D	29	31	30
SSArSD	30	32	31
SSFoSD	32	30	31

LS: large-sized bags; MS: medium-sized bags; SS: small-sized bags. Fo: "forest" soil; Ho: household waste; Ar: arable soil without manure; Arm: arable soil + manure. 0D: 0 dose fertiliser supply; FD: full dose fertiliser supply; SD: split dose fertiliser supply.
The lower the value the best the treatment rank.

growth. Table 4.8 details the overall rank of treatment performance across the two experiments with highest dry weight having the value 1.

Sanitary analysis of seedlings under tested nursery management practices

The seedlings raised were dissected for presence of insects, mainly *Oryctes* spp. that damage seedling hearts. None of the seedlings was attacked by any insect species so no treatment differences were established in any of the experiments.

Financial implications of the different nursery practices

Across all treatments plant dry weight increased linearly with an increase in costs made by nursery holders (Figure 4.6). Details on costs of different practices are provided in the supplementary data (Table A 4.1). On average the best practices were as cost effective in terms of dry weight per invested FCFA as the least performing treatments within a year or duration of nursery, as shown by the linear relations (Figure 4.6). The horizontal distance between the broken line and related points (seedling production costs) and the dashed vertical line (current selling price) indicates the profit made by nursery holders. If the current fixed price would be replaced by a variable price where a standard profit of 20% return on investment is assumed (this margin represents almost the average margin across all management practices), the broken line moves to the right as indicated by the dotted line and related points. This indicates that selling 8 months old seedlings in medium or large-sized bags becomes uninteresting for nursery holders unless farmers would pay for the higher quality associated with these practices. In addition to the purchase price farmers have to pay transport costs to get the purchased seedlings on their farms. The drawn line and corresponding points indicate actual costs of seedlings for farmers assuming they would pay actual production costs, a 20% profit margin of nursery holders and transportation costs.

Overall, a nursery holder who follows the recommended practices would spend 646 FCFA to produce one seedling leaving a benefit of 54 FCFA per unit after 8 months. With the current official selling price set to 700,000 FCFA for 1000 seedlings, nursery holders stay below this price by 17 to 29% and 8 to 20% if seedlings were raised for 6 and 8 months, respectively. The reduction of bag size, the collection of arable soil around the nursery place, the supply of fertiliser once a month rather than split to twice a month and the shortening of the nursery phase duration from 8 to 6 months, increased the benefit for nursery holders over the recommended practice.

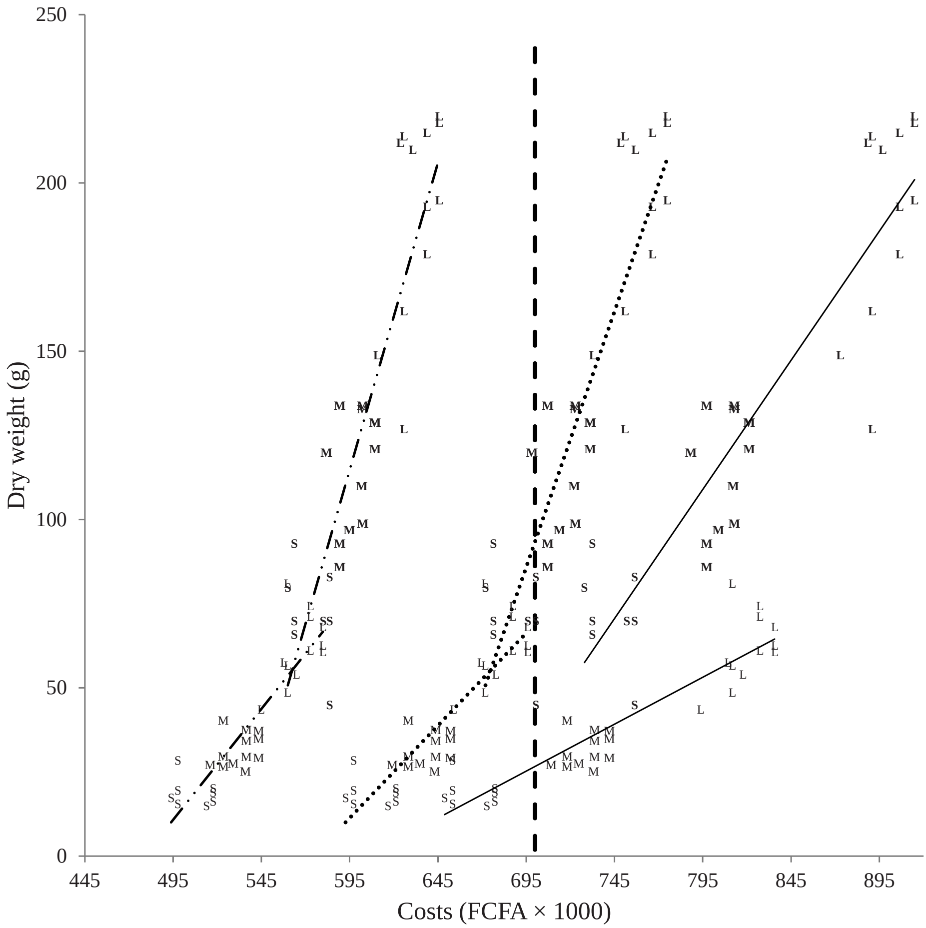

Figure 4.6. Seedling dry weight production as function of invested costs. For background information on costs see supplementary data (Table A 4.1).

L: large-sized bags; medium-sized bags; S: small-sized bags. Larger-sized font letters indicate data from the 8 months nursery (2011); small-sized font letters refer to data from the 6 month nursery (2012). Broken regression lines indicate production costs for nursery holders; dotted regression lines indicate production costs for nursery holders including 20% profit margin; drawn regression lines indicate costs for farmers based on their transport costs plus the production costs and 20% profit margin for nursery holders. The vertical broken line indicates current formal selling price of 1000 seedlings.

DISCUSSION

This study provided an understanding of the way the different management practices that oil palm nursery holders in Bénin use affected seedling growth and shed light onto their financial implications for nursery holders and physiological quality for smallholder farmers. The recommended protocol of seedling production that included the use of large-sized bags, "forest" soil and fertiliser supply, was not workable for nursery holders who developed alternative production practices. This experiment examined whether good quality seedlings can be produced with the nursery holders' developed management practices that combined smaller-sized bags, various substrates and fertilisation.

Seedling phenotype as affected by nursery holders' developed management practices

The standard recommended substrate, i.e. forest soil, as applied by nursery holders, did not meet expectations. Even though trees in general are known to maintain and regenerate soil fertility (Schroth and Sinclair, 2003), soils under eucalyptus have been reported to have relatively poor biological and chemical characteristics (Baber et al., 2006). It has to be reconsidered whether recommending the use of good forest soil under current land pressure in Southern Bénin is still a good option, and whether the notion of 'good forest soil' is a transferable one. Alternative substrates nursery holders developed sustained seedling growth better in fact. Especially the mix of arable soil and animal manure showed good seedling performance, while this mixture did not need additional inorganic fertilisers. Laboratory analysis of arable soil with animal manure (Table 4.1) indicated that this was the substrate with better nutrient characteristics. The results clearly support a choice of nursery holders to simply add organic manure to arable soil and abstain from the use of inorganic fertilisers during the nursery phase to cut costs. The higher efficacy of animal manure in comparison to inorganic fertilisers has earlier been reported on cocoa seedling growth (Ndubuaku and Kassim, 2003). Óskarsson (2010) reported that biological and chemical substrate characteristics during nursery phase improve field performance for tree seedlings.

An important point is that the nursery holder developed practices included arable soil collection around the oil palm nursery. For the sake of seedling health, this should be carried out cautiously. If arable soil is collected from a place that had previously hosted seedlings, or if the substrate is collected under existing oil palm plantations, poor seedling health may be the consequence when the former nursery was infested with *Oryctes* spp or the plantation was infected with *Fusarium oxysporum f. sp. elaeidis*. *Oryctes* spp is a nursery insect that shelters in and feeds on the meristems of seedlings. When a seedling is infested with *Oryctes* spp, the insect continues its foraging after seedling planting on farm and plant death might follow. *F. oxysporum* is the most dangerous oil palm disease endemic to Africa (Flood and Lane, 2006). Currently, not all oil palm cultivars delivered to nursery holders are tolerant to *F. oxysporum*. If substrates in this case are not collected appropriately, farmers could receive infected seedlings and their plantation could fail later on. To avoid this, arable soil should be collected in places that have never been used for an oil palm nursery or plantation before.

The use of smaller-sized bags was part of the nursery management strategies. The research showed that bag size was the factor that had the greatest effect on seedling growth. Bigger-sized bags induced an increased performance of seedlings after 6 and 8 months nursery. The experiment also showed that at smaller than recommended bag size, i.e. medium-sized bags, reasonable seedling growth was observed. This finding supports that good quality seedlings can be produced with the nursery holders' developed management practices that used smaller than recommended bag size. Even though the largest seedlings were produced in largest-sized bags, end-users found medium-sized bag produced seedlings more suitable (Chapter 6) in comparison to recommended large-sized bags that are costly both for nursery holders and for farmers during transport (Fig. 4.8).

Inorganic fertiliser application in full dose throughout the nursery phase presented more risks than split amounts. The supply of full dose fertiliser to seedlings in smaller-sized bags than the medium-sized one showed to be depressive and seedlings did not survive. The supply of split amounts throughout the nursery phase in small-sized bags avoided seedling death. Even though Iremiren et al. (1986) reported the non-significant effect of split supply of fertiliser on oil palm seedling growth, their study did not include different bag sizes. The observation of (Iremiren et al., 1986) is challenged if small-sized bags are considered.

The observed larger effects of bag size than of fertiliser supply or substrate type suggest that bag size effects on oil palm seedling growth cannot not be mediated by adding fertiliser or selecting appropriate soil substrate. Consequently, the selection of bag size for seedling production should be considered carefully to fit the time in the nursery. The positive effect of increasing bag size on seedling growth was reported for many plant species. For pine (Dominguez-Lerena et al., 2006), eucalyptus (Vaknin et al., 2009), and acacia (Dumroese et al., 2011), it was observed that seedling height, stem diameter, leaf production and dry weight increased with increase in bag size. The greater effect of bag size on plant growth extends beyond perennials and includes annuals like tomato (Stevenson and Fisher, 1975), maize and sorghum (Yang et al., 2010). If the use of seedlings in bags as planting material improves productivity and allows better production organisation (Riviere et al., 1990), it matters to consider bag size. Poorter et al. (2012b) suspect pot size to influence seedling systems biology. In the same vein, Vaknin et al. (2009) reported that larger-sized bags increase essential oil concentration for *Eucalyptus citriodora* Hook. seedlings.

Relationships between growth variables and implications for the choice of allometric variables for non-destructive assessment of biomass seedling growth

The empirical observations showed a higher correlation between height and length of the most developed leaf but also between above ground biomass and total dry weight. The observed high correlation between length of most developed leaf and height could be explained by the fact that the length of the most developed leaf takes an important part of seedling height. The observed high correlations between height and length of most developed leaf on the one hand, and between above ground and total dry weight on the other have two implications while measuring oil palm seedling growth. First, it is unnecessary to consider both plant height and length of the most developed leaf to evaluate seedling growth. The researcher would come to the same conclusion by selecting one of these two allometric variables. Second, instead of measuring the total dry weight of oil palm seedling, the researcher should consider only the above ground biomass which is easier to collect and less time consuming.

At the age of 6 months or 8 months, among all allometric variables seedling height seemed to be the best non-destructive proxy to oil palm seedling dry weight. Although lower, root-collar diameter also showed a significant correlation with dry weight. In forestry, the correlation between biomass and height or stem diameter is well known and used as non-destructive method to estimate forest biomass (Brown et al., 1989; Vieilledent et al., 2012).

Financial implications and trade-off with physiological seedling quality

The financial analysis of seedling production under different nursery management practices showed that the reduction of bag size, the collection of arable soil around the nursery place, the supply of fertiliser once a month rather than split to twice a month and the shortening of the nursery phase duration from 8 to 6 months allowed nursery holders to reduce production costs over the recommended practice. At comparable dry weights, though, there were always a series of practices that required different investments, some optimisation of costs per seedling could be made which did not reduce seedling dry weight. As the dry weight gain of seedlings increased with the additional costs when seedlings were sold after 8 rather than 6 months, the rationale to sell early to safe costs is not supported by our findings. An essential point remains that farmers pay a fixed price, irrespective of the costs made by nursery holders and irrespective of seedling quality. For nursery holders, emphasis will be on lowering costs and selling lower weight seedlings, while for farmers the rationale will be to request more investments and buy the larger-sized seedlings. If nursery holders are to deliver good quality seedlings to smallholder farmers, it will require a trade-off between quality and the choice of nursery management practices. The trade-off would mainly target bag size selection and the duration of the nursery phase. This is supported by the understanding between farmers and nursery holders on medium-sized bags with 6 months old seedlings (Chapter 6). Even though nursery holders are not the end users of seedlings, such a trade-off is indispensable for the flow of high-quality seedlings for field planting to smallholder farmers. It is unfortunate that the current seedling market is imperfect. Producing a higher quality seedling does not lead to a higher seedling price *vice-versa*.

CONCLUSION

In the practical context of the nursery holders in Southern Bénin the theoretically perfect forest soil substrate is not to be recommended as nursery holders tend to use instead a "forest" soil substrate that performs clearly worse than other substrates at their disposal, e.g. arable soil amended with animal manure. Over the tested nursery period (6 to 8 months) the latter substrate did not need additional fertiliser.

Reducing bag size may for practical reasons seem appropriate but it has major effects on performance of oil palm seedlings. Research is recommended on the longer term effects of using medium rather than the large-sized bags for oil palm performance after transplanting to the field. Such a research would elucidate whether a short-term compromise between farmers and nursery holders (see also Chapter 6) has any negative long-term pay-off that is currently unknown and would be solely weighed on the farmers. Knowledge of such effects could feed the decision taking. Fertiliser supply does not counter the negative effects of using smaller-sized bags. Neither does the use of a richer substrate type. The smallest-sized bags combined with adding fertiliser potentially leads to salinity problems and seedling death making this a very undesirable combination. Ultimately, the production of quality seedlings to fit the growing season requires a careful choice that would mainly target bag size and the duration of the nursery.

To evaluate performance of oil palm seedlings without destructive harvesting, plant height and root-collar diameter are very good indicators. The appreciation of seedling growth does not require measuring both height and length of the most developed leaf. Estimating the above ground dry weight instead of the total dry weight would lead to meaningful conclusions on seedling biomass production, unless the researcher is specifically interested in root biomass-related attributes.

APPENDIX

Table A 4.1. Costs related to nursery management practices.

Treatments								
Bag size	Substrate type	Fertiliser use	Total cost if seedling raised for 6 months (FCFA)	Total cost if seedling raised for 8 months (FCFA)	Ratio incremental cost over recommended practice if seedling raised for 6 months	Ration incremental cost over recommended practice if seedling raised for 8 months	Benefit if seedling raised for 6 months (FCFA)	Benefit if seedling raised for 8 months (FCFA)
LS	Ar	0D	544800	610800	-15.64	-5.42	155200	89200
		FD	557800	623800	-13.63	-3.41	142200	76200
		SD	564800	630800	-12.54	-2.32	135200	69200
	Arm	0D	559800	625800	-13.32	-3.10	140200	74200
		FD	572800	638800	-11.30	-1.08	127200	61200
		SD	579800	645800	-10.22	0.00	120200	54200
	Fo	0D	559800	625800	-13.32	-3.10	140200	74200
		FD	572800	638800	-11.30	-1.08	127200	61200
		SD	579800	(1)645800	-10.22	0.00	120200	54200
	Ho	0D	559800	625800	-13.32	-3.10	140200	74200
		FD	572800	638800	-11.30	-1.08	127200	61200
		SD	579800	645800	-10.22	0.00	120200	54200
MS	Ar	0D	515900	581900	-20.11	-9.89	184100	118100
		FD	528900	594900	-18.10	-7.88	171100	105100
		SD	535900	601900	-17.02	-6.80	164100	98100
	Arm	0D	523400	589400	-18.95	-8.73	176600	110600
		FD	536400	602400	-16.94	-6.72	163600	97600
		SD	543400	609400	-15.86	-5.64	156600	90600
	Fo	0D	523400	589400	-18.95	-8.73	176600	110600
		FD	536400	602400	-16.94	-6.72	163600	97600
		SD	543400	609400	-15.86	-5.64	156600	90600
	Ho	0D	523400	589400	-18.95	-8.73	176600	110600
		FD	536400	602400	-16.94	-6.72	163600	97600
		SD	543400	609400	-15.86	-5.64	156600	90600
SS	Ar	0D	493950	559950	-23.51	-13.29	206050	140050
		SD	513950	579950	-20.42	-10.20	186050	120050
	Arm	0D	497700	563700	-22.93	-12.71	202300	136300
		SD	517700	583700	-19.84	-9.62	182300	116300
	Fo	0D	497700	563700	-22.93	-12.71	202300	136300
		SD	517700	583700	-19.84	-9.62	182300	116300
	Ho	0D	497700	563700	-22.93	-12.71	202300	136300
		SD	517700	583700	-19.84	-9.62	182300	116300

LS: large-sized bags; MS: medium-sized bags; SS: small-sized bags. Fo: "forest" soil; Ho: household waste; Ar: arable soil without manure; Arm: arable soil + manure. 0D: 0 dose fertiliser supply; FD: full dose fertiliser supply; SD: split dose fertiliser supply.

Calculations have been made for 1000 seedlings.

The exchange rate during the study was fixed at 655 FCFA for 1 €.

(1) Reference cost, recommended practice.

CHAPTER 5

Analysis of growth dynamics of oil palm seedlings

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This chapter is submitted

ABSTRACT

Tree seedling survival in the field partly depends on the management during seedling production. Insight in how nursery practices affect seedling growth dynamics would generate understanding in how to optimise tree seedling production. The objective of this study was to analyse dynamics of oil palm seedling growth to gain insight into expression patterns of effects of bag size, substrate type, fertiliser supply, and their interactions on plant growth. An experiment was run in 2011 (March to November 2011) and repeated in 2012 (April to October 2012) using three levels of bag sizes, four levels of substrate type, and three levels of fertiliser supply. A 3 × 4 × 3 factorial design was used. Seedling height, root-collar diameter and number of leaves were measured over time. Seedling growth was analysed through comparing treatment effects at monthly intervals. Data were also fitted to growth curves to analyse treatment effects on absolute and relative growth rates of seedling height, root-collar diameter and number of leaves.

While substrate and fertiliser supply effects were fairly constant over time, bag size effects increased with larger variance explained over time. We observed that bag size effects overtook substrate, fertiliser and interaction effects from about two months onwards. Seedling height and root-collar diameter followed an exponential growth while number of leaves increased linearly over time. Analysis of generated data with the different growth models indicated that seedling growth rates were mainly under the influence of bag size, followed by substrate. Interactions between nursery practices, although significant sometimes, did not account for a large part of experimental error. Implications for tree seedling management in general are further discussed.

Key words: Fertiliser, growth dynamics, growth model, growth rate, oil palm, pot size, substrate.

INTRODUCTION

For tree nurseries in general, seedlings are sorted using several criteria, including seedling provenance, physiological quality, pest and disease tolerance, etc. (Konnert and Ruetz, 2003). Among these, physiological quality criteria are prioritised for seedling establishment after planting (Villar-Salvador et al., 2004). The production of planting material that insures seedling survival under changing and sub-optimal biotic and abiotic field conditions requires good knowledge of nursery management practices during seedling development. Besides generally investigated environmental factors controlling plant growth (e.g., light, temperature, and water), management practices (e.g., pot size, substrate, fertiliser supply, and planting density) are reported to greatly affect physiological quality of tree nursery seedlings (Dominguez-Lerena et al., 2006). Effects of pot or bag size (Aya, 1974; Close et al., 2004; Krizek and Dubik, 1987; Nesmith and Duval, 1998; Poorter et al., 2012a), type of substrate (Ahmad et al., 2012a; Lazcano et al., 2009; Radhouani et al., 2011) and fertilisers applied (Javid et al., 2011; Saint Pierre, 2012) on seedling growth were underscored for both annual and perennial plant species.

Bag size, substrate type, and fertiliser supply are among the top most important management factors that influence tree seedling production (Oliet et al, 2004; Poorter et al., 2012a). An account of the way those effects occur throughout seedling growth is an important aspect; knowledge of this issue can contribute to optimising production of tree nursery seedlings. In the literature, much emphasis is placed on overall effects of management practices on seedling development. For tree nursery seedlings in particular, studies are still lacking regarding insight into the temporal dynamics of seedling growth as affected by bag size, type of substrate, fertiliser supply and their interactions. More specifically, it is often not well documented at what point in time, e.g., pot size, substrate or fertiliser effects manifest themselves and in what direction they evolve; whether those effects increase or decrease over time or remain more or less constant. This study addressed specifically these issues and thereby aimed to contribute to knowledge that could underpin options for improved management.

To investigate above mentioned issues, we used oil palm as an example of a tree nursery crop. We elaborate upon the former chapter on effects of nursery management practices on seedling phenotype. That chapter revealed large differences between treatment effects at the end of two experiments (8 months experiment in 2011 and 6 months experiment in 2012). In comparison to substrate and fertiliser supply, bag size was the factor that showed the largest effects on seedling growth. The chapter, however, did not report: (1) at what point in time the different treatments started to differ and how these differences developed over time; (2) which treatment combinations showed similar growth rates. To investigate them, this study analysed seedling growth dynamics of oil palm as a major crop.

Oil palm is a major crop with increasing demands for its products for human use worldwide (Henderson and Osborne, 2000; Koh, 2011; Mekhilef et al., 2011). Acreage cropped to oil palm is expected to increase in most production countries in years ahead (Castiblanco et al., 2013; Sayer et al., 2012; Wicke et al., 2011). In some oil palm growing countries (e.g., Bénin, Ghana, and Nigeria), smallholder farmers constitute the main players and produce the bulk part of national production (Carrère, 2010). Successful smallholder plantations - in a context where farmers rely on nursery holders to purchase seedlings - depend on availability of suitable seedlings at planting time. Like many tree nursery seedlings (e.g., Sullivan et. al., 2001; Sullivan and Sullivan, 2008), oil palm is sensitive to rodent pest damages at early phase of transplanting to the field (Buckle et al., 1997; Puan et al., 2011). Well raised nursery seedlings are more likely to survive field conditions than poorly raised ones.

To conduct a plant growth study of tree seedlings, a timeline collection of seedling dry weights constitute one of the ways of analysis. To monitor treatment effects and yet circumvent a high number of seedlings through destructive seedling sampling over time allometric variables seedling height, root-collar diameter and number of produced leaves were observed. For oil palm, these allometric variables were reported to highly correlate with total dry weight and are reliable proxies to evaluate oil palm seedling growth (Chapter 4; Lucas, 1980). Besides the importance of the correlation between dry weight, root-collar diameter and height, the relevance of height and root-collar diameter in characterising plant growth was reported and used in literature for several tree species (Asif et al., 2013; Bowman et al., 2013; Hari et al., 1977; Nyombi et al., 2009; Özel and Ertekin, 2011; Wang et al., 2012). For growth of tree species, Bowman et al. (2013) observed that height and diameter are the most commonly measured tree attributes to characterise growth because of their strong correlations with wood volume and biomass.

MATERIAL AND METHODS

The study was conducted in Sakété district, Bénin. The experiments were run in 2011 from March 4th to November 4th (8 months period) and in 2012 from April 6th to October 6th (6 months period). Total monthly rainfall, monthly average minimum and maximum temperatures, and average relative humidity during study periods are presented in Figure 5.1.

Experimental design

A full 3 × 4 × 3 factorial experiment with 36 treatments was conducted and carried out in 5 replications, each year. Factors and levels were: bag size with 3 levels (small: 25 cm × 30 cm [flat bag measures], medium: 31 cm × 31 cm and large: 40 cm × 40 cm); type of soil substrate with four levels ("forest" soil, household waste substrate, arable soil, and arable soil with animal manure) and fertiliser supply with three levels (no fertilisation: 0 g per seedling during experiment periods, split dose: 5 g per seedling every 15 days, and full dose: 10 g per seedling

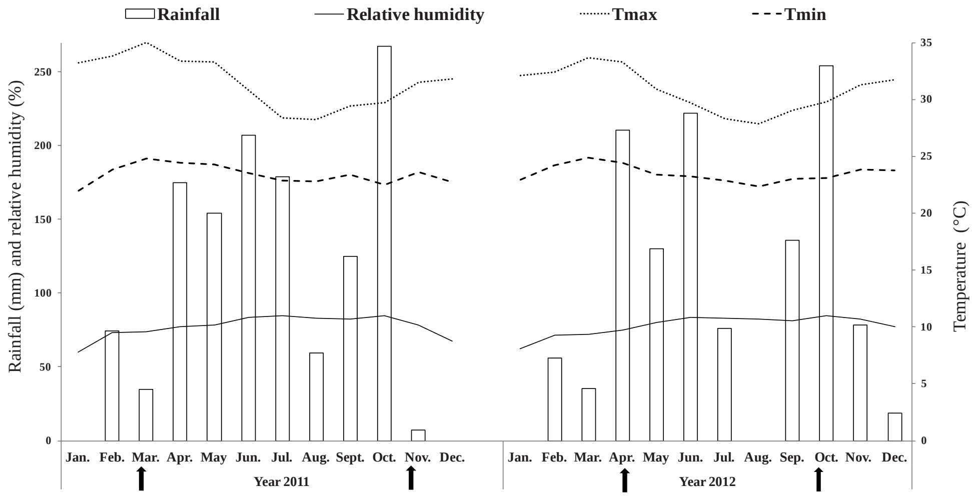

Figure 5.1. Rainfall, temperature and relative humidity in the study area in 2011 and 2012. Rainfall and relative humidity on the left vertical axis; temperatures on the right axis. Arrows indicate the study periods.

every 30 days). "Forest" soil was the top 20 cm of soil collected under a plantation of *Eucalyptus camadulensis* Dehnh. Household waste substrate was collected from a pile of decomposed waste and sieved to 8 mm. Arable soil was collected from a field near the experimental site that had never been planted to oil palm or had never held oil palm seedlings. Animal manure was collected as the top 5 cm from an area where cattle stayed overnight. Arable soil and animal manure were mixed in a volume proportion of 2:1.

Each experimental unit consisted of six bags with one seedling per bag per replication. Seedlings were arranged in two rows and spaced in a 60 cm × 60 cm grid. In both years, genetically identical seedlings of 4 months old were collected from the oil palm research centre (CRA-PP research centre in Pobè, Bénin). The batches of seedlings were raised in the same pre-nursery under shade in 10 cm × 15 cm bags and watered three times a week until the age of 4 months when they were brought to the experimental site. Fibrous waste of processed palm nuts was used as mulch around individual seedlings per bag (Von Uexkull and Fairhurst, 1991) two weeks after transplanting. Three months after seedling transplanting, the pesticide Dursban (chlorpyrifos; 0.4 ml per 20 seedlings) was used once to control foliage pests. For treatments in which fertilisers were applied, urea (46% N) and NPK (10%, 20%, 20%) was used alternatively. Fertiliser application started with urea two weeks after transplanting. Throughout the experiment, 1 litre of water was supplied per seedling three times a week. At

Table 5.1. Chemical characteristics of used substrates in 2011 and 2012 experiments

Soil substrates	pH	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (ppm)	Available cations (meq/100g)			Cation exchange capacity (CEC) (meq/100g)
					K+	Mg2+	Ca2+	
2011								
Arable soil	6.55	1.48	0.10	62.9	0.88	1.53	1.03	6.0
Mixture arable soil and manure	7.00	4.46	0.29	53.8	2.75	12.4	6.32	23.0
Household waste substrate	7.53	3.73	0.21	46.4	3.88	8.50	8.50	23.0
"Forest" soil top layer	7.48	1.65	0.08	8.4	0.62	1.18	1.26	7.5
2012								
Arable soil	7.36	2.34	0.14	67.9	1.82	1.50	2.80	10.6
Mixture arable soil and manure	7.05	4.33	0.26	60.1	2.24	11.4	5.60	20.6
Household waste substrate	7.82	4.98	0.30	33.5	4.81	1.60	1.64	8.6
"Forest" soil top layer	8.06	2.95	0.18	24.0	1.02	1.80	2.04	11.9

the time bags were filled, two samples of 500 g of each substrate were collected and air dried for later chemical analyses. Samples were analysed using classical methods of laboratory soil nutrient analysis (Pansu and Gautheyrou, 2006). The pH was determined using glass electrodes. Further methods were: the Walkley and Black method for organic carbon, the Kjeldahl method for total nitrogen, the Bray (I) method for phosphorus, and the ammonium acetate method for potassium, calcium, magnesium and exchangeable cations (Table 5.1). Analysed nutrients were the most important ones for physiological quality of oil palm seedlings (Turner, 2003; Corley and Tinker, 2003).

Due to lethal effects of full dose fertiliser in small-sized bags, data were reported on 32 treatments only, excluding all combinations of small-sized bags with full dose fertiliser.

Data collection

From the second (2011) or first (2012) month after seedling transplanting onwards, observations were made monthly on seedling height, root-collar diameter and number of leaves.

Seedling height was measured from the plant base to the apical level of leaves, by stretching leaves upward in the direction of the stem. Root-collar diameter was taken as the mean of two measures taken at perpendicular angle at the stem base where roots sprout from shoot. Number of leaves was recorded through counting all leaves that appeared since the

Table 5.2. Plant growth models considered in this study and selection criteria

Model name	Equation	Parameters	Parameter definition	Interpretability of model parameters
Linear	$b_1 + b_2.t$ (4)	b_1, b_2	b_1: Intercept (initial value) b_2: Absolute growth rate	Parameters are biologically interpretable
Exponential	$b_1.e^{b3.t}$ (5)	b_1, b_3	b_1: Initial value b_3: Relative growth rate	Parameters are biologically interpretable
Power	$b_1.t^{b4}$ (6)	b_1, b_4	b_1: Initial value b_4: "Relative growth rate"	B_4 is not biologically interpretable as relative growth rate
Expolinear (Yin, 2003)	$(b_2/b_3).\ln[1+e^{b3(t-b5)}]$ (7)	b_2, b_3, b_5	b_2: Growth rate during linear phase b_3: Relative growth rate during exponential phase b_5: Time before the linear phase starts	Parameters are biologically interpretable

time seedlings were transplanted. Growth variables were measured on four randomly selected seedlings out of six per experimental unit.

Data analysis

Determination of time treatments started to differ and way they developed with time: patterns of treatment effects over time

To determine time treatments started to differ from each other, we used monthly data to run an analysis of variance, under the general linear model procedure for a randomised complete block design using Statistical Analysis System (SAS, v. 9.2) software. The significance level used for F-tests was $p < 0.05$. To show the way treatment effects developed with time, we calculated monthly the variance explained by main factors and their interactions and drew a graph.

Determination of seedling growth rates: seedling growth model type selection and analysis

To select a model for oil palm seedling growth, data were examined to make sense of the shape of the growth curve they followed. Observed curve shapes were coupled with our biological understanding of the phenomenon studied and this allowed us to consider four possible growth models summarised in Table 5.2. In general terms the nonlinear regression model can be formulated as:

$\phi_i = f(t_i, b_j) + e_i$ (1)

Where ϕ_i is the i-th response variable (i.e., height, root-collar diameter, number of leaves); i (= 1, 2, ..., n) is the individual observation with n the number of observations; t_i is the time that i-th observation was made, expressed as month after seedling transplanting to nursery; b_j is j-th model parameter; j (= 1, 2, ..., k) is the number of model parameter with k the maximum number of model parameters; e_i represents the random error of i-th observation.

The estimates b_j were determined through minimising the sum of square error function (SS_{err}) for each model when fitting data, except, b_1 (initial value for each variable), which was set beforehand as all seedlings came from the same batch and had similar initial height, root-collar diameter and number of leaves.

The sum of square error (SS_{err}) (2) and Akaike's Information Criterion (AIC) (3) were calculated as one criterion for model selection. With this criterion, the model with smaller value of SS_{err} or AIC was assumed the best fit. The second criterion consisted of checking the outcomes of fitted models (generated parameters). This second criterion relates to interpretability of model parameters and general applicability of the models. On the one hand, interpretability of model parameters is concerned with its biological meaning. On the other hand, the general applicability of the model relates to whether generated parameter values can realistically reflect true values. The two criteria were used to finally decide which model to select per growth variable.

$SS_{err} = \sum_{i=1}^{n}[e_i]^2 = \sum_{i=1}^{n}[\phi_i - f(t_i, bj)]^2$ (2)

$AIC = n.\ln(SSerr/n) + 2.k$ (3) (Motulsky and Christopoulos, 2003, p. 143)

The regression model finally selected for each growth variable was used to build a data matrix of generated model parameter values per treatment by replication. Based on this data matrix, an analysis of variance was conducted and if significant, means were separated using Tukey honestly significant difference (Tukey-HSD) comparison test ($p < 0.05$). It was then determined which treatments showed significantly different growth rates in comparison to others.

Table 5.3. Timeline deviations of bag size, substrate, fertiliser supply, and interactions effects as expressed by P-values on seedling height, root-collar diameter and number of leaves for the 2011 and 2012 experiments

	df	P-values						
2011		2 MAT	3 MAT	4 MAT	5 MAT	6 MAT	7 MAT	8 MAT
Height								
Ba (Bag size)	2	0.566	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
Su (Substrate)	3	0.178	0.503	**0.039**	**<.001**	**0.006**	**0.008**	**0.013**
Ba×Su	6	0.778	0.961	0.674	0.424	0.208	0.121	0.145
Fe (Fertiliser supply)	2	0.105	0.113	0.272	**0.013**	**<.001**	**0.005**	0.281
Ba×Fe	3	0.338	0.531	0.352	**0.014**	**0.001**	**0.009**	**0.007**
Subs×Fe	6	0.105	0.047	0.116	**<.001**	**<.001**	**0.001**	**<.001**
Bag×Subs×Fe	9	0.451	0.403	0.658	0.419	0.617	0.543	0.442
Root-collar diameter								
Ba (Bag size)	2	0.324	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
Su (Substrate)	3	**0.023**	**<.001**	**0.005**	**<.001**	**0.001**	**0.006**	**0.004**
Ba×Su	6	0.906	0.463	0.910	0.631	0.745	0.204	0.463
Fe (Fertiliser supply)	2	0.147	0.074	0.266	0.248	0.185	**0.012**	**0.028**
Ba×Fe	3	0.329	0.224	0.290	**0.046**	**0.037**	**0.004**	**0.018**
Subs×Fe	6	0.468	0.102	0.258	**0.009**	**0.003**	**0.001**	**0.002**
Bag×Subs×Fe	9	0.892	0.393	0.286	0.647	0.707	0.308	0.474
Number of leaves								
Ba (Bag size)	2	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
Su (Substrate)	3	**0.010**	**<.001**	**<.001**	**<.001**	**<.001**	**0.001**	**0.009**
Ba×Su	6	0.675	0.749	0.108	0.310	0.077	0.098	0.526
Fe (Fertiliser supply)	2	0.140	**0.004**	**0.004**	**0.001**	**<.001**	**<.001**	**0.001**
Ba×Fe	3	0.444	0.309	0.842	0.055	**0.050**	0.096	**0.047**
Subs×Fe	6	0.461	0.057	**0.015**	**<.001**	**<.001**	**0.001**	**0.001**
Bag×Subs×Fe	9	0.777	0.317	0.743	0.913	0.998	0.614	0.778
2012		1 MAT	2 MAT	3 MAT	4 MAT	5 MAT	6 MAT	
Height								
Ba (Bag size)	2	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	
Su (Substrate)	3	0.544	0.393	**0.003**	**<.001**	**<.001**	**<.001**	
Ba×Su	6	0.330	0.499	0.497	0.452	0.776	0.653	
Fe (Fertiliser supply)	2	0.112	**0.043**	**0.022**	**<.001**	**0.010**	0.159	
Ba×Fe	3	0.310	0.711	0.872	0.320	0.269	0.372	
Subs×Fe	6	0.134	0.172	**0.012**	**<.001**	**<.001**	**<.001**	
Bag×Subs×Fe	9	0.903	0.195	**<.001**	**0.021**	0.212	0.837	
Root-collar diameter								
Ba (Bag size)	2	na	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	
Su (Substrate)	3	na	**0.001**	**0.029**	**0.009**	**0.036**	**<.001**	
Ba×Su	6	na	0.314	0.210	0.616	0.813	0.640	
Fe (Fertiliser supply)	2	na	0.251	0.311	0.230	0.093	**0.016**	
Ba×Fe	3	na	0.387	0.827	0.307	0.370	0.098	
Subs×Fe	6	na	0.159	0.115	**0.013**	**0.014**	**<.001**	
Bag×Subs×Fe	9	na	0.588	0.767	0.966	0.955	0.992	
Number of leaves								
Ba (Bag size)	2	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	
Su (Substrate)	3	0.120	**<.001**	**0.010**	**<.001**	**<.001**	**<.001**	
Ba×Su	6	0.954	0.979	0.739	0.115	0.211	0.199	
Fe (Fertiliser supply)	2	**0.004**	0.121	0.501	0.992	0.214	**<.001**	
Ba×Fe	3	0.430	0.473	**0.037**	0.947	0.440	0.452	
Subs×Fe	6	0.243	0.235	0.689	**0.001**	**<.001**	**<.001**	
Bag×Subs×Fe	9	0.807	0.830	0.920	0.989	0.917	0.947	

MAT: Month after transplanting; na: not available. Ba: bag size; Su: substrate; Fe: Fertiliser; ×: Interaction between two or three factors; df: degrees of freedom. Bold figures indicate significant difference ($p < 0.05$).

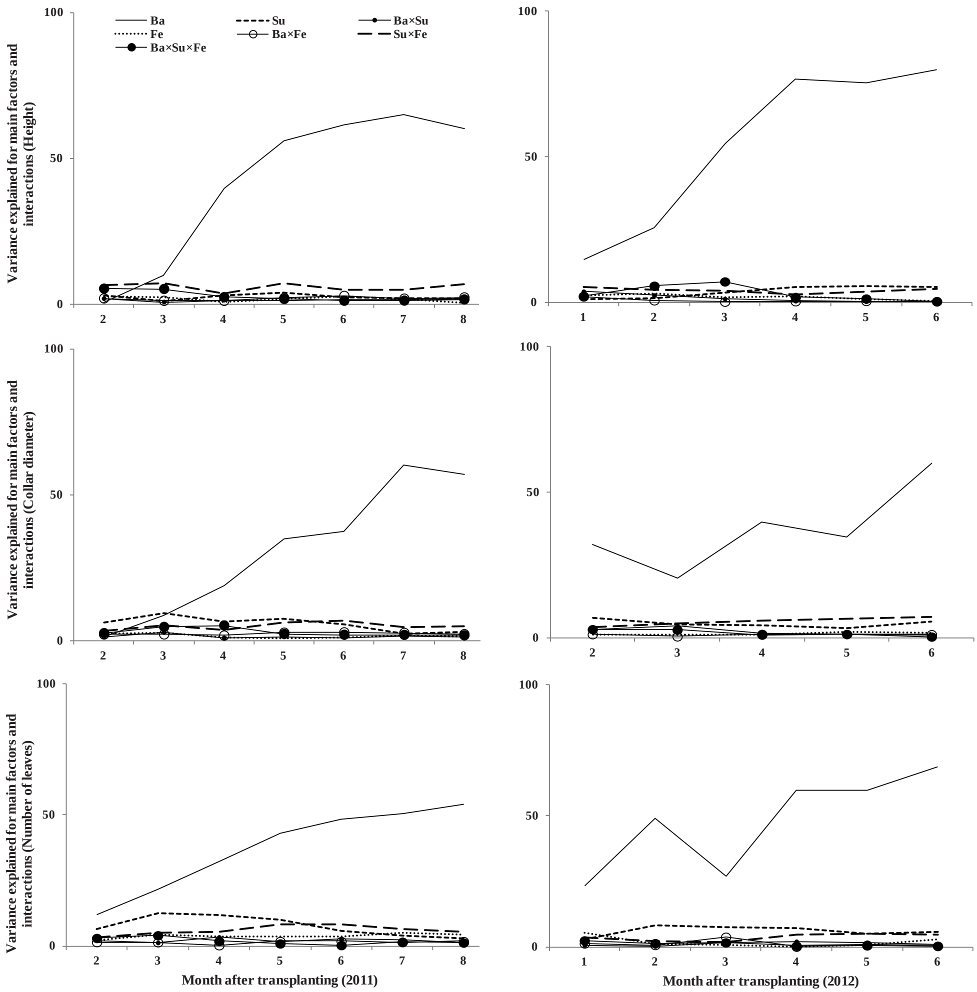

Figure 5.2. Patterns of bag size, substrate type, fertiliser supply and their interactions effects on seedling growth over time. Expressed as percentage of variance accounted for. Ba: bag size; Su: substrate; Fe: Fertiliser; ×: Interaction between indicated factors.

RESULTS

Patterns of bag size, substrate and fertiliser supply effects on seedling growth over time

The interactions and main effects of bag size, substrate and fertiliser supply on seedling growth in explaining experimental error developed differently over time (Table 5.3). Overall, in both experiments, bag size explained the largest proportion of experimental error and started to deviate earlier than substrate, fertiliser supply and their two and three way interactions. The second important factor after bag size was substrate. With longer time in nursery, interaction between fertiliser supply and substrate, fertiliser supply alone and

Table 5.4. Selection of growth model of height, root-collar diameter, and number of leaves based on error sum of square, Akaike information criterion, and model applicability. Formulas of tested model are given in Table 5.2.

Variables	Models	2011 Error sum of square	2011 Akaike information criterion (AIC)	2012 Error sum of square	2012 Akaike information criterion (AIC)	Selected model based on applicability
Height	Linear	28100	3615	5005	2056	
	Exponential	**8625**	**2288**	**3280**	**1582**	Selected
	Power	28902	3643	8659	2670	
	Expolinear	99347	5030	54232	4728	
Root-collar diameter	Linear	511	-873	71	-2711	
	Exponential	135	-2368	**37**	**-3441**	Selected
	Power	297	-1485	56	-2976	
	Expolinear	**49**	**-3499**	38	-3407	
Number of leaves	Linear	1443	290	**298**	**-1104**	Selected
	Exponential	2299	807	1369	604	
	Power	523	-851	1009	262	
	Expolinear	**309**	**-1436**	375	-843	

Bold figures indicated lowest error sum of squares and AIC among compared models

interaction between bag size and fertiliser supply started to influence growth variables. The interaction between bag size and substrate and the three way interaction were never significant with two exceptions: three way interaction at 3 and 4 months after transplanting for plant height in 2012.

Figure 5.2 shows the scope of importance and the way different factors and interaction effects evolved over time. It reveals that bag size, substrate and fertiliser supply during the first two months after seedling transplanting to nursery produced fairly small and similar effects on seedling growth (as expressed through the percentage of variance explained). Overall, bag size effects increased over time for different growth variables. In contrast to bag size, the effect of substrate and fertiliser supply remained fairly constant across the whole experimental phase, all explaining less than 10% of experimental error when significant.

Analysis of seedling growth

Model selection

Bag size was the factor that mainly affected seedling growth over time. For this reason, plots were constructed against time, for each variable, using different bag sizes as shown in Figure A 5.1. Observed curve shapes justify considering four regression models (i.e., exponential,

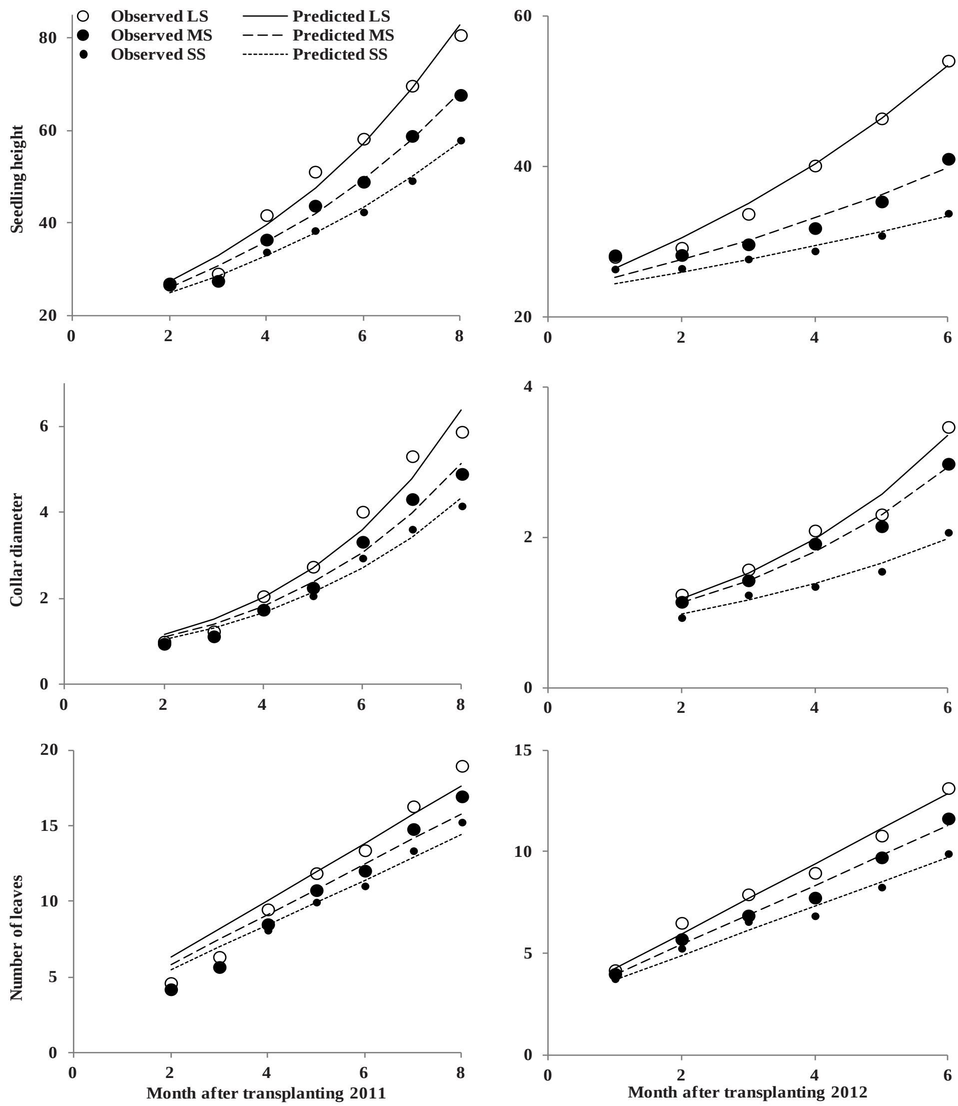

Figure 5.3. Observed averages across replications and fitted curves from 2011 and 2012 experiments. LS: large-sized bags; MS: Medium-sized bags; SS: Small-sized bags.

power, expolinear and linear). Using the first criterion of model selection, generated sum of squares and AIC indicated that height is best fitted with an exponential growth model in 2011 and 2012; root-collar diameter is best fitted with an expolinear growth model in 2011 and an exponential one in 2012; number of leaves is best fitted with an expolinear growth model in 2011 and a linear one in 2012, respectively (Table 5.4). Adding the second criterion for model

Table 5.5. F-values and significance from the GLM analysis of seedling growth variables: plant height, root-collar diameter and number of leaves in 2011 and 2012. Data were fitted to an exponential growth model for height and root-collar diameter and to a linear growth model for number of leaves (cf. Table 5.4). Model parameters are relative growth rate (b_3) for exponential model and absolute growth rate (b_2) for linear model (for full information on models see Table 5.2)

		2011			2012		
		Height	Root-collar diameter	Number of leaves	Height	Root-collar diameter	Number of leaves
Parameters	df	b_3	b_3	b_2	b_3	b_3	b_2
Bag size (Ba)	2	170***	108***	129***	486***	163***	251***
Substrate (Su)	3	5.01**	6.34***	8.85***	22.8***	10.6***	17.8***
Ba×Su	6	1.77 ns	1.4 ns	1.55 ns	0.82 ns	1.17 ns	1.50 ns
Fertiliser supply (Fe)	2	4.23*	2.28 ns	10.5***	5.40**	4.04*	2.89*
Ba×Fe	3	5.12**	3.48*	2.55*	1.82 ns	0.91 ns	1.37 ns
Su×Fe	6	5.15***	3.42**	5.39***	6.64***	6.03***	5.51***
Ba×Su×Fe	9	0.93 ns	0.99 ns	0.46 ns	1.02 ns	0.47 ns	0.24 ns

*, ** and *** indicate significant effects at $p < 0.05$, $p < 0.01$, $p < 0.001$, respectively. Fe: fertiliser supply; Ba: Bag size; Su: Substrate; The symbol × indicates a factor interaction; df: degrees of freedom

selection, generated parameter values with the different models were examined (Table A 5.1). The model applicability allowed to discard some models with smaller sum of squares or AIC. Based on the interpretability and applicability of four candidate models, the exponential growth model was selected for root-collar diameter and height; likewise, the linear model was the best fit for the number of leaves. Figure 5.3 shows observed values around prediction curves for the three bag sizes.

Model analysis

Model parameters analysed were relative growth rates (b_3) for seedling height and root-collar diameter (exponential model), absolute growth rate (b_2) for number of leaves (linear model). Absolute and relative growth rates were mainly affected by bag size, and substrate in both years with larger F-values than fertiliser supply and interactions (Table 5.5). The three way interaction between bag size, substrate and fertiliser supply was not significant in either year for any of growth variables. The two way interaction between substrate and fertiliser supply affected growth rates significantly for all variables in both years. The two way interaction between bag size and fertiliser supply was significant for the growth rates only in 2011. The two way interaction between bag size and substrate was not significant in either year for any of the growth variables.

Table 5.6. Two way-interaction effects between bag size and fertiliser on growth rates of seedling height, root-collar diameter and number of leaves. For full information on models see Table 5.2.

	2011					
	Height		Root-collar diameter		Number of leaves	
Treatments	b_3 (%)		b_3 (%)		b_2 (leaves/month)	
LS0D	18	A	28	AB	1.80	BC
LSFD	18	A	29	A	1.91	AB
LSSD	19	A	29	A	1.96	A
MS0D	16	B	26	C	1.61	DE
MSFD	15	BC	25	CD	1.64	DE
MSSD	16	B	26	BC	1.72	CD
SS0D	14	C	24	DE	1.47	F
SSSD	13	D	23	E	1.50	EF

Treatments are indicated as combination of bag size and fertiliser where: LS: large-sized bags; MS: medium-sized bags; SS: small-sized bags. 0D: 0 dose fertiliser supply; FD: full dose fertiliser supply; SD: split dose fertiliser supply.
Values followed by the same letter in the same column are not significantly different as established by the Tukey-HSD test ($p < 0.05$).

Table 5.7. Two way interaction effects between substrate and fertiliser on growth rates of seedling height, root-collar diameter and number of leaves. For full information on models see Table 5.2.

	2011						2012					
	Height		Root-collar diameter		Number of leaves		Height		Root-collar diameter		Number of leaves	
Treatments	b3 (%)		b3 (%)		b2 (leaves/month)		b3 (%)		b3 (%)		b2 (leaves/month)	
Am0D	18	A	27	A	1.80	A	12	A	25	A	1.64	A
AmFD	17	A	27	A	1.79	A	12	AB	25	A	1.62	AB
AmSD	16	A	26	A	1.74	A	10	AB	23	AB	1.53	AB
Ho0D	15	A	25	A	1.49	B	10	AB	21	AB	1.40	B
HoFD	17	A	28	A	1.80	A	13	AB	26	A	1.71	A
HoSD	16	A	27	A	1.73	A	10	AB	24	AB	1.51	AB
Ar0D	16	A	26	A	1.68	B	09	AB	21	AB	1.38	B
ArFD	17	A	27	A	1.77	A	10	AB	25	A	1.54	AB
ArSD	16	A	26	A	1.76	A	08	B	20	AB	1.41	AB
Fo0D	16	A	24	A	1.55	B	09	AB	19	B	1.33	B
FoFD	16	A	27	A	1.73	AB	12	AB	25	A	1.60	AB
FoSD	15	A	25	A	1.68	B	09	AB	22	AB	1.45	AB

Treatments are indicated as combination of substrate type and fertiliser where: Am: arable soil + manure; Ho: household waste; Ar: arable soil without manure; Fo: "forest" soil. 0D: 0 dose fertiliser supply; FD: full dose fertiliser supply; SD: split dose fertiliser supply.
Values followed by the same letter in the same column are not significantly different as established by the Tukey-HSD test ($p < 0.05$).

Two way interaction effects between bag size and fertiliser supply, substrate and fertiliser supply

The two way interaction between bag size and fertiliser supply showed that seedlings grown in the same-sized bags did not differ significantly in growth rates for different doses of fertiliser, except small-sized bags where split dose fertiliser supply produced a significantly lower relative growth rate for height in 2011 (Table 5.6). Overall, combinations including large-sized bags produced significantly higher growth rates than combinations including medium-sized bags, which also showed significantly higher growth rates in comparison to combinations including small-sized bags.

The two way interaction between substrate and fertiliser supply showed that seedlings grown in different substrates did not differ significantly in growth rates for different doses of fertiliser, except combinations including "forest" soil or arable soil or household waste and 0 dose fertiliser supply. These combinations showed lower growth rates than arable soil mixed with animal manure without fertiliser supply (Table 5.7).

DISCUSSION

This study analysed the response of oil palm seedlings to different nursery practices over time in terms of increase in height, root-collar diameter and number of leaves. It can be assumed these are indicative of trends in seedling biomass as well (see Chapter 4; Lucas, 1980). Findings indicate that valuable information can be obtained through examining the way differences in seedling growth evolve with time, in addition to what is observed at the end of the nursery phase. Following sections discuss observed temporal dynamics in growth and implications for optimisation of tree nursery seedling production.

Temporal patterns of bag size, substrate type and fertiliser supply effects on oil palm seedling growth

One of the aims of this study was to find out at what time treatments start to diverge and how great they are over time. The experiments showed that during the first two to three months after seedling transplanting, effects of bag size, substrate type and fertiliser supply were similar in terms of variance explained, while in total these treatments explained little variation. Overall, bag size started to affect growth variables earlier than other factors and interactions. Findings also revealed that substrates, fertiliser supply, and interactions accounted for a lower percentage of explained variance of seedling growth. Variance explained by bag size effects increased with time, explaining an increasing amount of total experimental error, unlike the observed almost constant percentages explained by substrates, fertiliser supply, and interactions.

Observed differential patterns of bag size, substrate type and fertiliser supply imply that they interfere in seedling growth through inflicting different intensity of stresses. It has been reported that plant growth is under the control of both internal regulations and environmental conditions. The intensity of environmental stresses, however, play an important role in plant growth (Rymen and Sugimoto, 2012; Walter and Schurr, 2005). The earlier deviation and increasingly larger proportion of explained variance by bag size indicate that most stress came from bag size among tested factors and their interactions. This stress could be regarded as available space for root development, but also as limitation of available water and nutrients (Lenzi et al., 2009). The low proportions of explained variance by factor interactions indicate few options are available to mitigate bag size effects. Literature on (tree) nursery seedling production provides rich documentation of pot size, growing media, and nutrient supply on plant growth and development (e.g., Jackson et al., 2012; Lazcano et al., 2009; Óskarsson, 2010; Teixeira et al., 2008; Vaknin et al., 2009). The missing aspects we documented in this study, are the comparative effects of pot size, substrate type and nutrient supply on nursery seedling growth and whether there is possibility to substitute pot size effects by another management factor. Findings support the lack of options to mediate pot size effects on oil palm seedlings. Adding a richer substrate or fertilising substrate are not optional. Remarks by Poorter et al. (2012a) about pot seedling production allowed to generalise to other nursery seedling plants that pot size could not be substituted with another management practice. One of the practical implications of increasing effects of pot size on seedling with time is that smaller pots can be used for short time nursery only whereas larger-sized pots should be preferred for longer time nursery.

Effects of bag size, substrate type and fertiliser supply on growth rates of seedling allometric variables

Growth rate is an important indicator of plant life history (McGraw and Garbutt, 1990) and it characterises to what extent different environmental factors impact plant growth. For tree nursery seedling production, growth rate determines the time planting material can be made available for field planting.

Curve fitting indicated different growth models for height, root-collar diameter and number of leaves. While the exponential model gave the best fit for height and root-collar diameter, a linear model gave the best fit for number of leaves. The fact that number of leaves increased rather linearly with time could be explained by the phenological character of leaf emergence. Unlike height and root-collar diameter, number of leaves is a phenological variable which under rather constant temperatures, typical of the research site, could be expected to increase linearly.

One of the main questions this study intended to answer was to find out what treatment combinations show significant effects on growth rates of height, root-collar diameter, and number of leaves. The experiments showed that (relative and absolute) growth rates were mainly affected by bag size in both years with larger F-values than substrate, fertiliser supply, and interactions. This result adds to findings of the former chapter where also larger effects were observed for bag size than for substrate, fertiliser and interactions on seedling phenotype at planting. One of nursery holders' objectives, when they use small-sized containers, is to reduce production cost (Chapters 4 and 6). The major bag size effects on seedling growth rates indicate that bag size reduction will not be made without affecting overall seedling growth and development.

CONCLUSION

Well-raised nursery seedlings are more likely to survive field conditions than poorly raised ones. For planters to secure tree crop plantations, nursery management practices that insure seedling growth and development would play important role. This timeline analysis of seedling growth provides valuable information that could have not been unveiled if seedlings were only analysed at the end of nursery (Chapter 4). Throughout the nursery phase, the factor affecting seedling growth most was bag size. Bag size effects showed up during the first months after seedling transplanting. In contrast to bag size, substrate, fertiliser supply, and interaction effects were less important throughout the whole nursery phase. On the one hand, increasing effects of bag size on seedling growth over time allow to conclude that small containers are good options for short time nursery seedling production. On the other hand, large-sized containers should be preferred for longer time nursery seedlings.

Further study should target a thorough and more nuanced analysis of bag size effects on seedling growth. Such studies would consist of testing not only three bag sizes but target a larger range of bag sizes to identify the minimum and critical bag size that does not lead to additional seedling growth for the oil palm crop. Also for other crops, such data do not seem available and thus would merit further investigation.

APPENDIX

Table A 5.1. Summary information for the assessment of model applicability: Range of generated model parameter values. For the meaning of model parameters, see Table 5.2.

			2011			2012			Decision
Variable	Models	Parameters	Mean	Minimum	Maximum	Mean	Minimum	Maximum	
Height	Linear	b2	5.62	2.47	8.43	3.15	0.47	6.29	
	Exponential	b3	0.16	0.10	0.21	0.10	0.02	0.17	Selected
	Power	b3	0.57	0.33	0.74	0.32	0.06	0.54	
	Expolinear	b2	0.76	0.05	53.1	0.82	0.03	52.5	
		b3	347	5	2E+4	8E+4	2	12E+7	
		b5	16.2	-3.08	152	48	-17.6	616	
Root-collar diameter	Linear	b2	0.47	0.20	0.69	0.31	0.08	0.59	
	Exponential	b3	0.26	0.17	0.31	0.23	0.09	0.32	Selected
	Power	b3	0.94	0.60	1.12	0.72	0.29	1.04	
	Expolinear	b2	1.03	-0.07	68.5	7	-0.17	120	
		b3	2.19	-12	174	5E+6	-112	8E+8	
		b5	3.14	-69.7	29.6	22.1	-33.2	124	
Number of leaves	Linear	b2	1.70	1.19	2.19	1.50	1.02	2.04	Selected
	Exponential	b3	0.25	0.22	0.28	0.27	0.22	0.31	
	Power	b3	0.91	0.77	1.03	0.86	0.69	1.01	
	Expolinear	b2	12.6	0.2	84.9	15.9	0.15	87.18	
		b3	66.4	1.2	104	44.2	0.7	2E+3	
		b5	0.73	-3.38	48	6.7	-5.07	35.7	

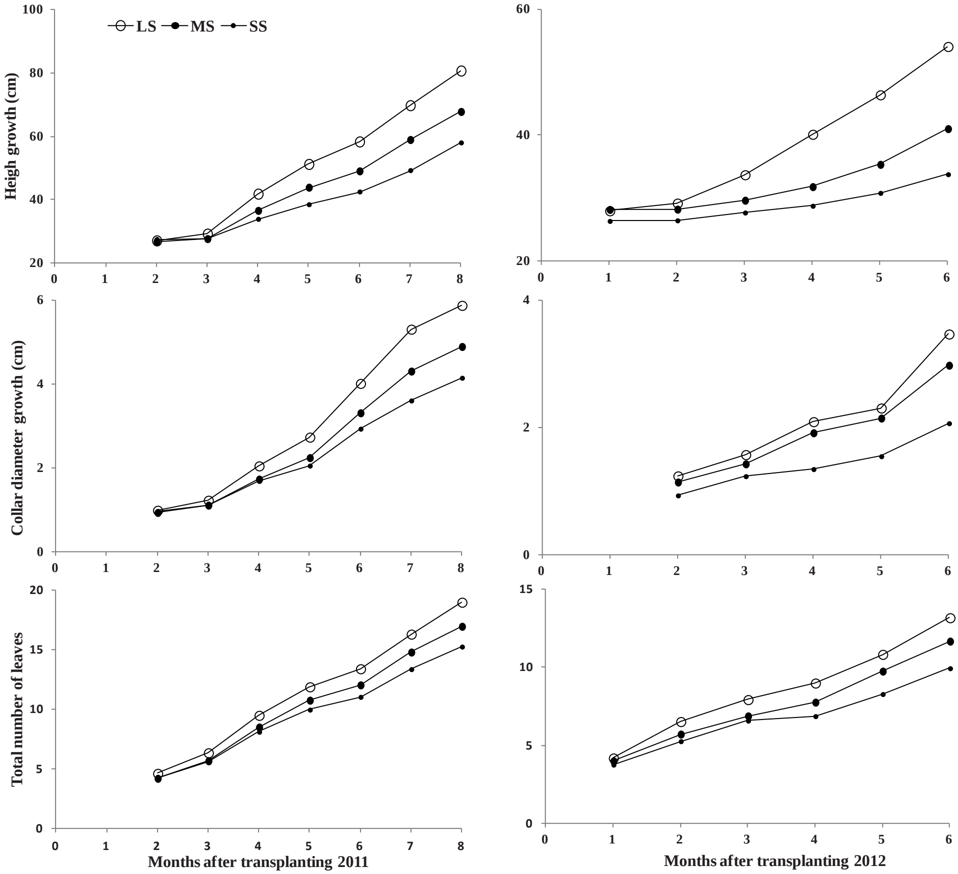

Figure A 5.1. Seedling height, root-collar diameter, and number of leaves as affected by bag size. LS: large-sized bags; MS: Medium-sized bags; SS: Small-sized bags. Individual data point represents the average value of 240 (LS, MS) or 160 (SS) seedlings.

CHAPTER 6

Co-production of knowledge in trans-disciplinary research: Analysing joint experimentation as social learning

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This chapter is submitted

ABSTRACT

Changing research design and methodologies regarding how researchers articulate with end-users of technology is an important consideration in developing sustainable agricultural practices. This chapter analyses a joint experiment as a multi-stakeholder process and contributes to understand how the way of organising social learning affects stakeholders' ownership of process outcomes. Through a detailed analysis of group dynamics, this chapter addresses an important knowledge gap in participatory agricultural development. We use quality oil palm seedling production as example to analyse how a joint experiment contributes to knowledge co-production and changes in practices. The joint experiment was documented through multi-method approach including informal and semi-structured interviews, analysis of meeting minutes and participant observations.

The design of this joint experiment served as means to co-innovate the seedling supply system. The setting of learning group contributed to bridge gaps between stakeholders and partly solved some institutional issues through connecting main players of the seedling supply system. Methodological steps taken in this research process showed its efficacy to produce quick and positive feedback mechanisms. Stakeholders' perspectives on what constitutes a quality oil palm seedling varied widely. Participants, mainly nursery holders, learned new production practices from their peers. Representative of research centre learned mismatch of recommendations with users' contexts. Field observations indicate changes in practices among nursery holders, researchers and farmers in response to the joint experiment. The level of stakeholders' involvement increased their participation and ownership of the learning process that would lead to sustainable practices.

Key words: Bénin, co-production of knowledge, innovation, joint experimentation, oil palm, social learning.

INTRODUCTION

The added value of multi-stakeholder collaboration in problem solving is increasingly well-recognized (Douthwaite and Gummert, 2010). As such, developing sustainable agricultural systems requires changing research methodologies in terms of how scientists and technologists articulate with end-users of technology (Defoer, 2002). Trans-disciplinary research has the advantage of achieving remarkable impacts on society and delivers high-quality research through involving different stakeholders with broader knowledge basis (Enengel et al., 2012). One of the main attributes of trans-disciplinary research is that it generates space for social learning and (hybrid) knowledge production (Raymond et al., 2010). Many studies acknowledge the importance of trans-disciplinary research in effectively addressing societal and environmental problems (e.g., Luyet et al., 2012; Rist et al., 2007; Lwoga et al., 2010). The significant contributions of non-academics in the development of sustainable agricultural practices and technologies have also been reported in many domains, including integrated pest management with Farmer Field Schools (Davis et al., 2012; Van den Berg and Jiggins, 2007), soil conservation and fertility management practices (Dalton et al., 2011; Defoer, 2000), and development of new crop variety through participatory plant breeding (Almekinders, 2011).While there are many projects that document how trans-disciplinary participatory work achieves applied outcomes, there has been relatively little analysis of the social encounter and learning dynamics within such projects (Muro and Jeffrey, 2008) for an exception see (Almekinders, 2011). Scholarly papers often focus on outcomes achieved through participation, but do not provide a full and more disaggregated explanation of social processes and group dynamics behind those outcomes. This chapter aims to address some of the main gaps of the literature on co-production of knowledge in multi-stakeholder processes (Bell et al., 2012; Crane, in press). In particular a joint experiment on quality oil palm seedling production in Bénin is analysed as a social encounter between farmers, nursery holders, extensionists and technologists through which social learning contributes to changes in practices.

Through an earlier diagnostic study (Chapter 2) farmers complained about the low physiological quality of seedlings they buy from officially established nursery holders. In Bénin, the organisation of the oil palm seed system does not allow smallholder farmers to raise hybrid seedlings by themselves. Smallholder farmers are forced to rely on officially established nursery holders to purchase hybrid planting material. The Béninese national oil palm research centre (CRA-PP) trains the official nursery holders and then provides them with hybrid germinated seeds that they raise and further sell to farmers. Rather than following the production technologies they learned during their training, nursery holders adapt the training package to their particular socio-economic conditions. While nursery holders' innovations make their seedling production enterprise more profitable, and have led to a diversification of production practices, not all of their practices ensure high quality of planting material.

The production of high-quality oil palm seedlings for field planting is a job that involves many stakeholders with different roles: farmers are the end consumers of seedlings; nursery holders are local suppliers of hybrid seedlings; extension agents monitor nursery holders' activities; the CRA-PP supplies hybrid germinated seeds to nursery holders and is also in charge of quality control in officially established nurseries. All of these stakeholders, from their various perspectives, have their own particular ideas about what constitutes a good quality seedling.

In order to facilitate interaction and co-production of knowledge among stakeholders for sustainable agricultural practices, we engaged in a joint experiment with stakeholders so that they could share and evaluate their knowledge about seedling production practices. The ultimate aim was to identify seedling production practices that satisfied all stakeholders' interests and needs. The technical results of the experiment have been reported in chapters 4 and 5. In this chapter, we instead analyse the joint experiment as a social process of encounter by multiple stakeholders, wherein they all contribute to the knowledge production process, co-designing, co-implementing and co-analysing the results. Furthermore, particular attention is given to how stakeholders work across their divergent positions and how their knowledge and practices evolve in response to the joint experiment.

The next section presents the theoretical background used to analyse the joint-experiment, followed by the research design, an elaboration of methodologies of data collection and analysis. In the main findings sections, we present and compare stakeholders' perceptions of physiologically sound seedlings, stakeholders' evaluation of tested nursery practices. We also analyse stakeholders' learning processes across the duration of the experiment, paying particular attention to their change in practices. In the Discussion sections, we analyse the connection between research design and its delivery, our reflections on the learning process and major lessons. The chapter ends with highlights of the theoretical and practical challenges of multi-stakeholder joint experimentation processes.

THEORETICAL BACKGROUND

Different ways of organising social learning and knowledge production with stakeholders will affect the outcomes of the process (Jakku and Thorburn, 2010). The quality and nature of the end products of stakeholders' participation is closely connected to the kind of process that led to them (Reed, 2008; Crane, 2009). A pipeline approach to technology production is unlikely to yield the same outcomes as a socially inclusive management regime. The way participants engage in participation significantly affects the outcomes of the process and it is important to use methods and tools that maintain a higher transparency of the process (Bell et al., 2012). Issues that need to be considered for a successful learning process include early integration of all stakeholders, fairness and equity for all stakeholders, their full involvement without barriers and the process facilitation (Jakku and Thorburn, 2010; Luyet et al., 2012). The issue of language when communication takes place among social actors, for example, academics and non-academics is also important (Luks and Siebenhüner, 2007). For example, in such a context scientists need to adapt their language to the audience they are collaborating with.

Besides the design and implementation of social learning process, the way to report on outcomes is important as well. We underscore the failure of researchers to fully account the group dynamics behind reported outcomes of trans-disciplinary works (Bell et al., 2012; Bos et al., 2013). The ability of stakeholders to interact and transcend their personal interests constitutes a key issue that affects outcomes. This chapter analyses these methodological steps, during both process design and implementation, as well as how it leads to outcomes, as defined by changing practices by participants.

The social learning literature shows a wide variety of definitions for the concept but generally admits that its meaning is context-related (Leeuwis and Pyburn, 2002; Muro and Jeffrey, 2008; Rodela et al., 2012). In this study, we understand social learning as different stakeholders interacting to solve a problem, through which they acquire new skills (both technical and social), produce knowledge, and develop relationships (Muro and Jeffrey, 2008). As such, it transcends a mere individual learning (Leeuwis, 2007; Luks and Siebenhüner, 2007). Social learning develops effectively through social spaces which can take different forms. Experimentation is seen as an important means that enables social learning and knowledge production because it generates understanding and facilitates change in difficult socio-technical problems (Bos et al., 2013). The experiment implemented in this study was built upon the inputs from the main stakeholders of the oil palm seedling supply system in Bénin.

Multi-stakeholder platforms are known as processes that bring together the main stakeholders to address an issue and to reach collective outcomes (GIZ, 2011). It is a means to strengthen close cooperation between stakeholders. Multi-stakeholder processes also imply dealing with divergent views of different stakeholders about the same issue (Li et al., 2012). Through multi-stakeholder processes, different players collaborate, learn from each other and share knowledge (Markopoulos, 2012). It has been argued that stakeholders' participation in a problem solution determines their ownership of ensuing outcomes (Ahmad et al., 2012b), which has implications for sustainability (Vallejo and Hauselmann, 2004). In the case presented here, the joint experiment served as a multi-stakeholder platform that aimed to bridge the social gaps between stakeholders in the oil palm seedling supply system in order to improve its material functioning. Such a process will enable an organisation like CRA-PP research centre to adjust their training package for nursery holders through received feedbacks. In this research, we called the stakeholder platform the “learning group”.

RESEARCH DESIGN

Research agenda setting and implementation

The joint experiment described here was part of a collaborative research project involving stakeholders of the oil palm seed system in Bénin (see also Chapter 3). The first step consisted of a diagnostic study that highlights the major constraints hindering the oil palm seed system and that limited smallholders’ access to high-quality seedlings (Chapter 2; Akpo et al., 2012). In line with the underlying approach of the Convergence of Sciences project within which the current research was conducted (for further details see: www.cos-sis.org), we involved the different stakeholders to solve the problem of physiological quality of seedlings that farmers were facing.

Prior to the joint experiment, the first author of this study conducted an introductory field visit to explore seedling production technologies in use in the officially established nurseries as well as stakeholders’ various experiences and perceptions about the quality of seedlings currently produced. Subsequent to that visit, he gathered stakeholders to share findings and discuss possible ways of addressing identified weaknesses in seedling production. Participants reached agreements about the production practices to be tested in the joint experiment. Group members arranged to collectively monitor and evaluate the effects of tested practices on seedling growth. In addition to measuring the biophysical effects of the treatments on oil palm seedlings, the first author observed and recorded stakeholders’ observations, contributions and interactions to analyse the issues shared or perceived in different ways, the way they appreciate effects of different production practices on seedling growth and the overall social dynamics of the joint experiment. We subsequently conducted field observations and interviews to look at changes in stakeholders’ practices further to the joint experiment (Figure 6.1).

Learning group establishment and composition

Provenance of involved stakeholders

Fifteen participants took part in the joint experiment. Their characteristics and provenance are shown in Table 6.1. Most participants were nursery holders and farmers. Each participant was a delegate representing an organisation or peers. All six official nursery holders supplying seedlings to farmers in the region of Sakété were involved in the experiment. The six farmers

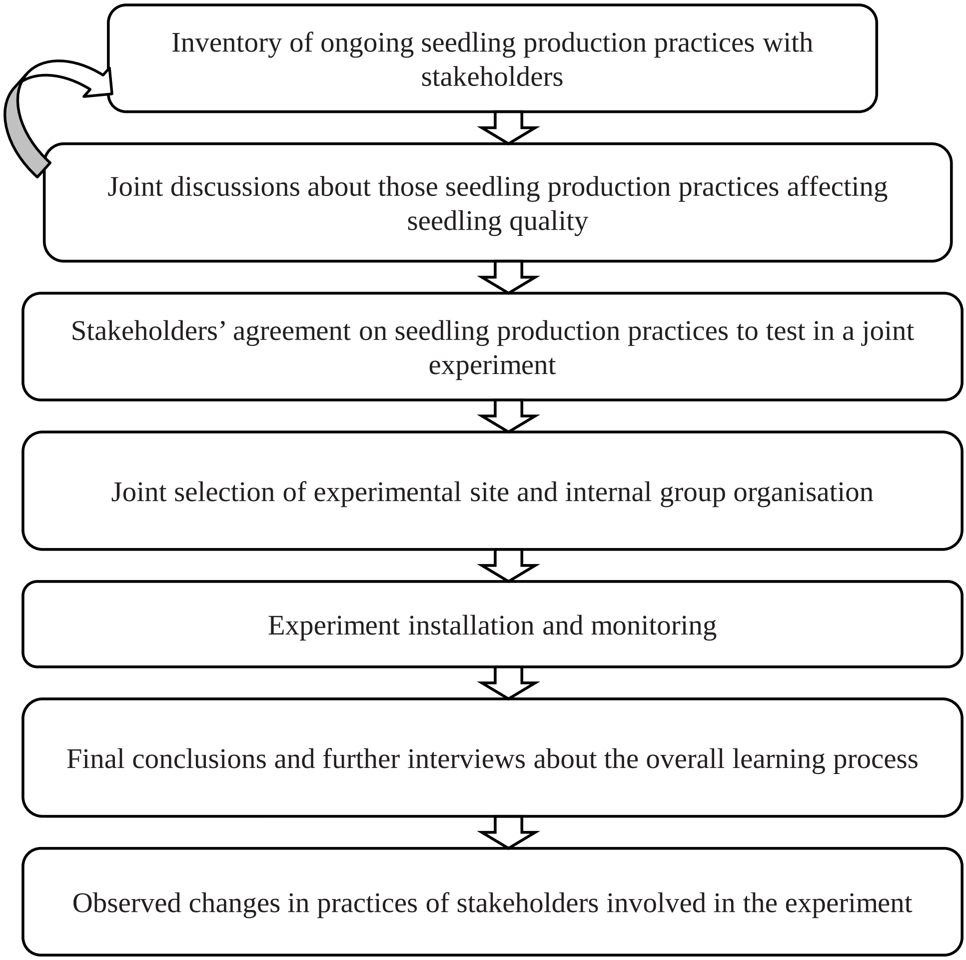


Figure 6.1. Research design.

Table 6.1. Characteristics of learning group

Stakeholders	Provenance	Ethnicity	Gender		Literacy		Total
			Male	Female	Literate	Illiterate	
Nursery holders	Individual nursery holders of Sakété	Nago, Goun	6	0	5	1	6
Representatives of farmers	Farmers’ oil palm organisation in Sakété	Nago	5	1	1	5	6
Extension agents	Local extension service of Sakété	Goun	1	0	1	0	1
CRA-PP researcher	Oil palm research center (CRA-PP)	Nago	1	0	1	0	1
University researcher	Université d’Abomey-Calavi / Wageningen University	Mahi	1	0	1	0	1
Total	-	-	14	1	9	6	15

involved were selected by their peers on a group meeting and included one woman. The representative of research centre (CRA-PP) who took part in the experiment held the position of head of the breeding department of the oil palm research centre. The extension agent was the head of the local extension service of Sakété. The first author of this study is a former employee of the CRA-PP, but was engaged in this process as a PhD researcher.

Roles of involved stakeholders

Participating stakeholders played specific roles in the course of the joint experiment. During the introductory discussions, farmers initially offered to provide a site for the experiment. However, to avoid the risk of seedling robbery before the end of the experiment, and to solve the problem of water availability, the learning group ultimately decided to locate the experiment in one of the nursery holders sites. Farmers further offered to care of the cleaning of the experiment site. The representative of the oil palm research centre offered to get seedlings that were used in the experiment from the CRA-PP. In addition to documentation and analysis of both social and biophysical data, the first author of this study also facilitated the learning process.

Facilitation of the joint experiment

Aware of the importance of the facilitation for the outcomes of the whole process, we made sure that all participants expressed their opinions on the on-going activities. We intervened in such way that the process was democratic and not dominated by any single stakeholder. We encouraged all participants, particularly illiterate farmers, to speak out their mind to let the group know their thinking of the main directions that were given to the on-going activities. We made sure that the minutes of different meetings are produced and its contents shared with all group members for eventual corrections. We kept a particular attention to the language issues and made sure that enough time was spent to share different ideas and gain mutual understanding. Participants were encouraged to use the local language (Nago) instead of French, as it is the language all participants understood. The language choice was also concerned with the way participants understand and express the objects being tested. No scientific concept or term was preferred over vernacular words and expressions.

Joint experiment set-up and monitoring

Selection of the experiment site

When the learning group agreed that one official nursery place would serve for the experiment site, we registered three candidate sites. The group then decided to visit the proposed plots together to choose the one that was more suitable for the experiment. The group graded the visited sites for their characteristics, whether it is a plateau or with a large slope, easily accessible by either foot or bike, ready availability of water. Together, the learning group assessed the three sites and chose the farm “Gbemanwonmede”, which is on a plateau, is easily accessible and has water readily available. Though all candidates were eager to host the experiment, the site selection process was transparent and there were no complaints from the non-selected candidates.

Identification of tested nursery practices

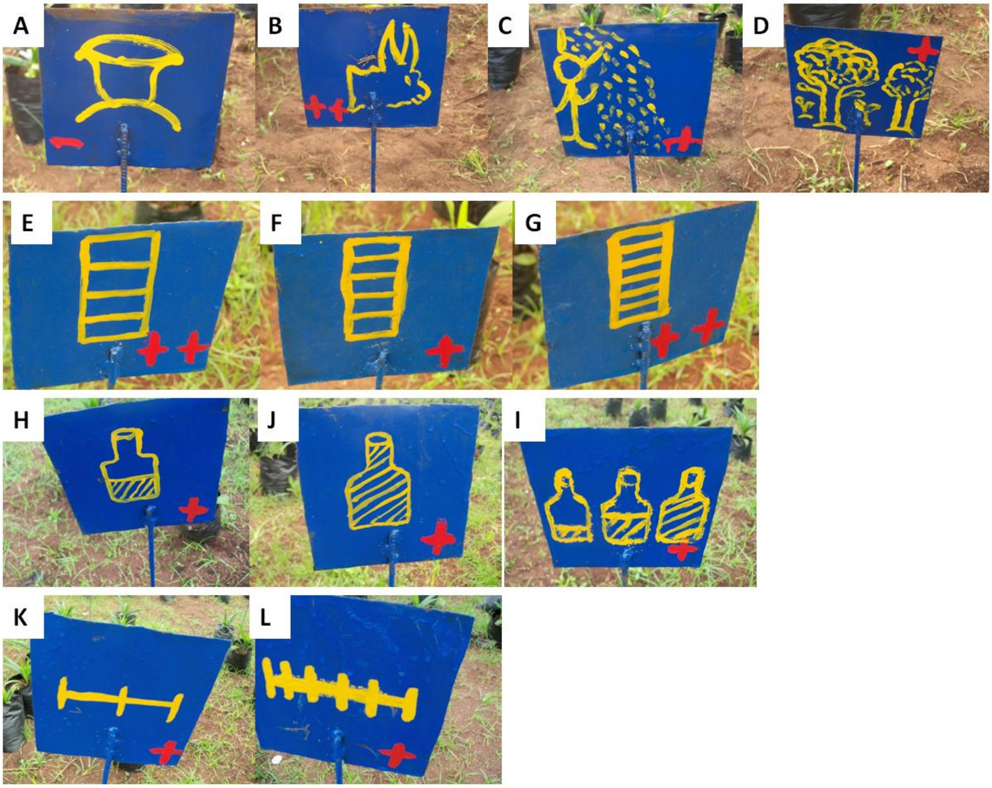
Rather than testing research-recommended seedling production practices, the joint experiment tested actual production practices being used by different official nursery holders, which varied from official CRA-PP recommendations in several ways. Based on our survey of nursery holders’ actual practices, we investigated the effect of six treatments (using participants’ language) on seedling growth: (1) bag sizes, (2) soil substrates, (3) ways of fertiliser supply (4) planting ages, (5) transplanting densities, and (6) watering regimes (Chapters 4 and 5).

Drawings of nursery practices: challenging communication issues

Developing effective communication among participants is an important aspect of trans-disciplinary research (Roux et al., 2010). One out of six nursery holders and five out of six farmers who participated in the experiment were illiterate. At the outset, the learning group had to address the question of how to label the various treatments being tested to improve communication among group members. A farmer suggested that drawings could best represent each nursery practice, an idea that was endorsed by the whole group. Figure 6.2 shows some of the representations that were used.

Co-construction of variables for participatory monitoring of nursery practices

Having identified the treatment variables to test, the next step was to identify variables by which the outcomes would be assessed. Participants listed a variety of different variables through which to measure the effects of each nursery practice. In keeping with their own



Source: Group meeting with stakeholders

Figure 6.2. Examples of nursery practice drawings for the understanding of non-literate group members

Drawings A, B, C and D indicate nursery place arable soil, mixture arable soil and animal manure, household waste and "forest" soil substrates, respectively. Drawings E, F, G represent seedlings transplanted after four, five and six months old, respectively. Drawings H, I, J are half litre, one litre and progressive watering increase from quarter to one litre. Drawings K and L indicate single and double seedling densities, respectively. The symbol -, +, + + indicates that seedlings receive no fertiliser, split dose and full dose fertiliser. As types of bags can be distinguished visually, it was not represented by drawings.

professional perspectives, representatives of extension and CRA-PP initially suggested the use of seven variables to assess treatment performance: seedling height, root-collar diameter, number of leaves, light interception, length of most developed leaf, width of most developed leaf, biomass production. Nursery holders thought height, root-collar diameter and number of leaves are enough to measure treatment effects. Farmers on the other hand suggested that they only look at seedling height, root-collar diameter and the greenness of leaves to assess the physiological quality of seedlings. The discussion among group members concluded that because farmers are the ones who purchase seedlings their criteria are the most important ones. The group members collectively decided to use the farmers' suggested evaluation criteria.

Next, the learning group discussed the way to measure the three variables. Representatives of extension and research centres and the nursery holders suggested that we use scientific instruments to measure height and root-collar diameter, though they added that they don't know how to measure leaf greenness. Farmers pointed out that they do not use any device to measure seedlings before buying; they only appreciate visually. Farmers then suggested the appreciation of treatment on two points scale: good performing and less performing treatments. The facilitator and first author of this study suggested that the group assesses treatment performance through assigning points to treatments on a 5-point (Likert) scale, with the best performing treatment having the highest number of points (Crano and Brewer, 2002). This suggestion was adopted and the learning group assessed each of the three variables on the following scale: 1: very poor performance (not desirable); 2: poor performance (less desirable); 3: acceptable performance (desirable enough); 4: good performance (desirable); 5: best performance (most desirable).

Internal organisation of the learning group

The learning group elected a president who was in charge of the implementation of the learning group activities. A farmer and the CRA-PP researcher both suggested two candidates because nobody volunteered: one among nursery holders and the other among farmers. By consensus, the group finally agreed that the suggested candidate among farmers be the leader of the learning group. The selected president was the one in charge of reminding group members of the periodic meetings. The president was also the spokesman of the learning group in case external visitors came to the experiment site to learn about the on-going experiment. Besides the president of the learning group, a nursery holder was chosen as secretary to take notes on the main points of each meeting. The participants agreed to gather at the experiment site on the last Thursday of each month and held a total seventeen meetings.

Experiment monitoring

At the beginning of each meeting, the secretary reminded the group of main issues debated during previous meeting and main decisions that were made. Other members provided additional comments if important information was missing. Further to the summary, the president distributed group members into sub-groups of two or three people to jointly assess the effects of each treatment on seedlings. Participant distribution in sub-group did not follow any criteria. In each meeting, a plenary presentation and discussion followed assessment activities. Each time, we made feedback on previous meeting to see whether the observed trends per treatment remains unchanged or whether new things emerged. In this way, the group conducted the analysis, evaluation and discussions of the experiment on an iterative basis. The meetings usually lasted approximately two hours.

Methods and tools for data collection and analysis

In order to develop a detailed account of the discussions and group dynamics within the learning group, we used a multi-method approach for data collection. The multi-method approach used included meeting minutes, participant observations and interviews of participants. Altogether, these permitted a multi-faceted analysis of the social dynamics in the joint experiment process.

Meeting minutes

The meeting minutes allowed to keep track of the main issues discussed in each meeting throughout the joint experiment (Schulz et al., 2003). The secretary of the learning group produced for each meeting a documented report for the different activities that were conducted. The discussions revolved around the effect of nursery practices on seedling growth over time, i.e. the better and worse performing nursery practices. The secretary recorded the perceptions of each stakeholder of the different nursery practice being tested. These records facilitated the flow of information among participants in the course of the joint experiment process (Blackstock et al., 2007).

Participant observations

The authors of this study took part in the different activities of the learning group. This allowed minimizing our distance with group members (Johnson et al., 2003) and to get useful information out of the collaborative work. Participant observations were used to collect information related to the way the different stakeholders interacted and communicate among themselves; the terms that participants used to define the different nursery practices and their effects; the way consensus was reached among participants; body languages that expressed their interest in the on-going activities. In the end, participant observation permitted direct evidence of individual experience including the meaning they make of those experience (Elliott, 2005), but also allowed the authors to get further insights into the subject (Iacono et al., 2009) and avoid most of the pitfalls arising in collaborative research (El Ansari, 2005).

Interviews

We used semi-structured and informal interviews to collect participants' perceptions and evaluation of the joint experiment. For example, the farmers, nursery holders and representatives of CRA-PP and extension service were asked to state the way they perceive a physiologically sound seedling. They scored effects of different nursery practices from their views. Participants also provided their views about the way the process was conducted and expressed what they had learned and changed through their participation in the joint experiment.

Data analysis

Through recording the different stakeholders' perceptions of physiologically acceptable seedlings, we synthesized the different views to draw the most important issues that farmers, nursery holders representative of extension and researcher services use to define good quality seedlings. We examined stakeholders' evaluation of the performance of tested nursery practices focusing on the differences of their appreciations. The report of the details of the discussions showed the way stakeholders start from divergent views to reach consensus. To show the observed changes in practices, we compared stakeholder's seedling production practices before and after the experiment. We synthesized and reported farmers' narratives of the improvement of their relationships with other stakeholders. The ranking (Dimelu and Anyaiwe, 2011) permitted us to understand the importance of the variables or issues for different stakeholders and allowed comparison across stakeholders.

RESULTS

Framing of physiologically sound seedlings by different stakeholders

Farmers, nursery holders, the extension agent and the CRA-PP representative did not have the same criteria for what a physiologically sound seedling looks like. Stakeholders defined good quality seedlings based on the type of connections and uses they make of oil palm seedlings. The collective ranking per category of stakeholders of the main indicators of physiologically sound seedlings is presented in Table 6.2. According to farmers who participated in the experiment, a good quality seedling should be disease free and survive pest attacks after planting. It should have a large root-collar diameter, verdant leaves and high enough. It should grow steadily in the first vegetative phase even without additional fertiliser supply.

Nursery holders, on the other hand, mentioned that a physiologically sound seedling should be strong enough and should not wave after a light wind passes. They mentioned that

Table 6.2. Stakeholders' ranking of main indicators that matter to characterise quality oil palm seedlings. The lower the number the more important the indicators.

Variables	Stakeholders		
	Farmers	Nursery holders	Extension agent and researcher
Seedling height	4	2	4
Root-collar diameter	2	5	3
Greenness of leaves	3	3	2
Sanitary state (insect free)	1	4	1
Production costs	-	1	-

the seedling quality depends on the cost of inputs needed for seedling production. Nursery holders underlined the high cost increase of nursery materials that was not followed by an increase in the price of seedlings, which was fixed almost two decades ago by the Government of Bénin. To secure a return on the seedling production enterprise, nursery holders acknowledged using alternative practices that do not always sustain optimal seedling quality, but cut costs. Ultimately, they said that seedling quality is a compromise between production costs and recommended standards.

For the participating extension agent and CRA-PP representative, a physiologically sound seedling has good plant architecture. They highlighted the characteristics of poor seedlings that are not good for field planting: slender, short and leafy, with short leaflets that look close to each other.

Stakeholders' evaluation of tested nursery practices: from divergent views to consensus

Stakeholders' evaluation of the performance of the different nursery practices varied with the use they make of planting material. This section presents stakeholders' evaluation of treatment performance and provides detailed account of the way the discussions went between stakeholders before consensus is reached.

Stakeholders' evaluation of effects of bag size on seedling growth

All participants observed that the best seedling growth (seedling height, root-collar diameter, and greenness of leaves) was registered on seedlings raised in large-sized bags (40 cm × 40 cm) (Table 6.3), though seedlings raised in medium-sized bags (31 cm × 31 cm) showed physiologically acceptable growth for the three variables. Seedlings raised on small-sized bags (25 cm × 30 cm), on the other hand, were of lower quality in comparison to medium and large-sized bags. They looked short, presented narrow root-collar diameter and their leaves looked yellow. Even though the largest-sized bags had the best seedling growth, farmers (who are first consumers of seedlings) expressed that they preferred seedlings raised in medium-sized bags because they are easier and cheaper to transport. Small-sized bags were not favourable enough to seedling growth and it was not preferred by farmers. Nursery holders also prefer medium-sized bags because they lower seedling production costs in comparison to large-sized bags. One nursery holder supported the use of small-sized bags as being good enough for seedling production and further reducing transportation and production costs for both farmers and nursery holders. The majority of participants, however, agreed that the medium-sized bags favour both farmers and nursery holders. This agreement reached by the learning group directly contradicts the CRA-PP recommendation to use large-sized bags for oil palm seedling production.

Stakeholders' evaluation of effects of soil substrates on seedling growth

Participants observed that seedlings transplanted into arable soil mixed with animal manure produced the largest root-collar diameter, greenest leaves and largest seedling height, across the whole seedling vegetative period (Table 6.3). Seedlings grown on household waste substrate came second in performance. Arable soil and "forest" soil, according to participants produced similar and poorer seedling growth. Nursery holders observed, however, that household waste substrate released its nutrients faster than arable soil with animal manure and if after four months additional fertilisers are not supplied, seedlings suffer of lack of nutrients. Farmers, claiming that few nursery holders apply fertiliser on regular basis, suggested that they use arable soil mixed with animal manure because it maintains seedling quality even without additional fertiliser supply. The researcher from CRA-PP outlined the importance of avoiding places where oil palm had been planted before for arable soil collection, as it may lead to the introduction of pests and disease. Nursery holders, however, argued against using true forest substrate, citing increasing land pressure in south Bénin, where forests are increasingly scarce. Finally the learning group suggested that nursery holders preferentially use arable soil mixed with animal waste as it maintains seedling quality even in the absence of additional fertiliser supply. They added that arable soil should be collected carefully away from oil palm stands. The learning group's conclusion is again at odds with the official CRA-PP recommendation to use forest soil for oil palm seedling production.

Stakeholders' evaluation of effects of ways of fertiliser supply on seedling growth

The participants observed that the three fertiliser treatments tested did not produce the same seedling growth (Table 6.3). Seedlings amended with split dose and full dose fertiliser produced physiologically sound quality seedlings. Seedlings raised without fertiliser supply showed the weakest seedling growth: yellow foliage, erected seedling stand, and narrow root-collar diameter. Leaflets on seedlings raised without fertilisers presented more leaf insect holes in comparison to fertilised seedlings. Farmers underlined the importance of fertilising seedlings during nursery phase as they hardly supply fertiliser after field planting. Nursery holders emphasized the labour constraint of supplying fertiliser twice a month in split doses. The participants finally came to the conclusion that fertiliser supply to seedlings in nursery phase maintains green seedling foliage with good plant stand. As split and full dose fertiliser produce similar seedling growth, most participants agreed that fertiliser could be supplied once monthly in full dose instead of twice in split dose. The researcher from CRA-PP, however, highlighted that the supply of full dose fertiliser is counter-productive in periods of abundant rainfalls, when much of the fertiliser will wash out.

Stakeholders' evaluation of effects of transplanting ages on seedling growth

Seedlings transplanted after 4 months of pre-nursery were evaluated as showing the best seedling growth, followed closely by seedlings that spent 5 months in pre-nursery, which showed similar growth for height, root-collar diameter and leaf greenness (Table 6.3). However, when seedlings spend 6 months in pre-nursery before transplanting to full nursery, they grow more slowly in comparison to those of 5 months and 4 months old. The researcher from CRA-PP mentioned that the earlier seedlings are transplanted, the better they grow. Nursery holders argued, however, that the delay of seedling transplanting in the nursery reduces production costs, even though they recognized that a longer delay also reduces seedling vigour. Farmers advocated for earlier seedling transplanting for plantation success. Even though the official research recommendation is to transplant seedlings at 4 months old, participants showed some flexibility and suggested nursery holders to transplant seedlings to full nursery at no later than 5 months old, representing a compromise between physiological and economic factors.

Stakeholders' evaluation of effects of density on seedling growth

Farmers observed that the higher seedling density increased height but decreased root-collar diameter. Nursery holders argued that raising seedlings at double the recommended density did not compromise seedling vigour, but rather saved space and reduced production cost. They also proposed that the double density helped to fight against weeds and thus reduced labour, adding that seedling density could even be increased to further reduce weed

Table 6.3. Stakeholders' joint assessment of tested nursery practices on different variables on a 5-point scale.

Stakeholders' name of nursery practices	Seedling height	Root-collar diameter	Leaf greenness
Bag size			
Small-sized bags	2	1	1
Medium-sized bags	3	3	3
Large-sized bags	5	5	5
Type of soil substrates			
Arable soil	3	3	3
Mixture arable soil and animal manure	5	5	5
Household waste	4	4	3
"Forest" soil	3	3	3
Fertiliser supply			
No fertiliser supply	2	2	2
Split dose fertiliser supply	4	4	4
Full dose fertiliser supply	5	5	5
Seedling transplanting ages			
4 months old seedlings	5	5	5
5 months old seedlings	4	4	4
6 months old seedlings	2	2	3
Seedling density			
Single density	4	5	5
Double density	5	4	5

1: very poor performance (not desirable); 2: poor performance (less desirable); 3: acceptable performance (desirable enough); 4: good performance (desirable); 5: best performance (most desirable).

infestations. The researcher from CRA-PP drew participants' attention to the negative effects of higher density on seedling vigour if the time seedlings spent in the nursery gets longer, for example in case the nursery holder fails to sell all seedlings in a given year. Finally, the participants agreed that raising seedlings at 'double density' is a good option, though it would be risky to further increase seedling density.

Stakeholders' evaluation of effects of watering doses on seedling growth

The participants agreed that the three watering regimes did not show any perceptible difference in growth (Table 6.3). The representative of research centre drew the participants' attention on the seedlings' increasing water demand as they mature. The participants concluded that one litre per seedling three times a week was best in case of lower rainfalls.

Knowledge acquisition, appreciation of the joint experiment and observed changes in practices

All participants reported that they had never taken part in a joint experimentation before. Their appreciation on a 5-point scale of the originality of the learning process (Table 6.4)

Table 6.4. Acquired knowledge and participants' perceptions of the learning, as expressed on a 5-point scale; n is the number of respondents.

Stakeholders (n)	Appreciation of the originality of the initiative on a 5-point scale	Acquired knowledge
Farmers (5)	4.4 [a]	- Technical package of oil palm seedling production - Labour requirement of nursery activities
Nursery holders (5)	4.6 [a]	- New seedling production practices (value of animal waste) - Risk of using soil substrates from oil palm stand to raise seedlings
Extension Agent (1)	4.5	- Seedling behaviour on different nursery practice - Intense workload of nursery activities
CRA-PP researcher (1)	4.5	- Mismatch of research recommendations with field context regarding bag size - Need the update nursery holders' training package

[a]: Average over number of respondents
The originality appreciation scale varied from not new to very original

> Box 6.1
> I did not imagine before that oil palm seedling production involves so many activities mainly at the beginning. Bag filling, their arrangement in the field and water supply in dry period required so many people (a farmer quotation, Sakété, May, 10th, 2011after a group meeting).

showed higher scores (a minimum of 4.4 over 5 points). Nursery holders gave the highest rank on the originality of the learning experiment. All participants thought that their expectations were met because they acquired new knowledge of oil palm seedling production. After the experiment, participating farmers reported that they have a full knowledge of the technical package of seedling production, and better appreciated the difficulties that nurseries holders face (Box 6.1). Nursery holders likewise reported that they had learned new production practices from their peers. Furthermore, the representative of the oil palm research centre came to appreciate how the logic behind current research recommendations is not well-matched with the contextual logics of nursery holders' and farmers' pressures and preferences. Participants also appreciated the free exchange of opinions and insights during the experiment. The democratic environment in which participants took part was valued by all group members. Even though participants rarely came to meetings precisely on time, their participation in scheduled activities was high, ranging from 60 to 93%.

Table 6.5. Observed changes in seedling production practices further to the learning experiment

Production factors	Research recommended practices	Seedling production practices before the experiment running	Seedling production practices after the experiment running
Bag size under use	Large-sized bags	Small- and medium-sized bags	Medium-sized bags
Use of soil substrates	Forest soil (preferably), or household waste	"Forest" soil alone; household waste; arable soil alone; mixture arable soil and animal manure	"Forest" soil alone; household waste; arable soil alone; mixture arable soil and animal manure; mixture "forest soil" and animal manure; mixture household waste and animal manure
Fertiliser supply	Split dose	Full dose, split dose, and 0 dose	Full dose
Transplanting ages	4 months seedling at pre-nursery	Four, five and six months seedlings at pre-nursery	Four and five months seedlings at pre-nursery
Planting density	Single density	Double and single densities	Double and single densities
Watering regimes	Progressive increase of water supply	½ litre to 1 litre per seedling	1 litre per seedling

Observed changes in production practices

Following on the joint experiment, nursery holders who had used production practices that were identified as undermining seedling quality have changed those practices. Specifically, two of the nursery holders who were using small-sized bags have shifted to medium-sized bags. During a field visit after the experiment, we no longer observed small-sized bags in those nurseries. Nursery holders, who participated in the experiment, also used animal manure in combination with soil from *Eucalyptus* plantation and also arable soil. Table 6.5 shows the observed and reported changes in practices so far.

Nursery holders who moved from small to medium-sized bags acknowledged that the move seems to induce additional production costs, but that these are offset through more timely sale of seedlings. These nursery holders reported that farmers delay sometimes seedling purchase when the seedling growth is not optimal.

The CRA-PP participant in the joint experiment is the head of the breeding department of the oil palm research centre. In response to his participation, he instituted new ways of overseeing of official nurseries, increasing the number of field visits from one per year (and even none in some years) to two or three visits. He also reported that he carried additional field visits himself to official nurseries. The CRA-PP has also adjusted the nursery holders' training curriculum to recommend the medium-sized bags instead of the large-sized, representing a systemic change emerging from social learning in the joint experiment. This change has been incorporated into the 2012 training material.

Farmers who took part in the experiment expressed that they have learned about nursery management practices. They reported that the knowledge they acquired on the oil palm nursery improved their appreciation of to what extent which nursery holders used good practices to raise seedlings. Farmers reported that, if they have the choice, they will no longer purchase seedlings that nursery holder fail to raise appropriately. Furthermore, they reported that if nursery holders offer poor-quality seedlings to them, they will not hesitate to bargain for reduced price.

Improvement of social network

Most participants reported that they improved their social network through participation in the joint experiment. Farmers witnessed that this joint experiment has improved their connection with nursery holders, reducing the need for third parties to purchase seedlings. Farmers also reported that the joint experiment has facilitated their contact with the CRA-PP, as they have henceforth got closer to one of the key staff members. The nursery holders also indicated that their experience in the joint experiment has given them easier access to extension agents and services. They reported looking for more input from local extension agents about pesticides and diseases during the nursery phase.

DISCUSSION

Stakeholders' perceptions of quality seedlings and their appreciation of treatment performance as dependent on the use they make of planting material

Even though all stakeholders were gathered around the same planting material, they did not have the same viewpoint of physiologically sound seedlings. While farmers put forward seedling vigour while describing quality seedlings, nursery holders highlighted the involved costs and reported that seedling quality is a compromise with costs. If farmers put seedling vigour first to define quality seedlings, it is certainly due to their position as end users and planters of seedlings. Farmers are the only ones to bear consequences of failure of poor-quality seedlings. If nursery holders integrate the cost dimensions into quality of seedlings, it is because they put first the gain they make from their seedling production enterprise. It appears that stakeholders' perceptions of seedling quality varied with the use they make of planting material.

During the experiment, evaluation of the treatments' effects on seedlings varied substantially according to the stakeholders' social position vis-à-vis oil palm (Crane, 2010). For example, when most participants found small-sized bags not sustaining seedling growth, a nursery holder remarked that it is fine. When the farmers, extension agent and researcher found that seedling delay in pre-nursery inappropriate for seedling growth, nursery holders found it a useful technique to cut production costs. Ultimately, the use stakeholders make of seedlings played an important role in their appreciation of treatment performance. In trans-disciplinary research, where multiple stakeholders are involved (Polk and Knutsson, 2008), it is understandable that sometimes they share different views. During the different exchanges, farmers often find internal agreement among themselves and, later on, shared with the group members. This also applies to nursery holders who sometimes talk to each other to get their colleagues' view that is further shared with group members. This way of sub-group communication per category of stakeholders showed implicitly their different stakes in quality of seedlings. However, through the social learning process, all participants eventually came to appreciate others' positions in relation to seedlings, leading to compromise, consensus and mutual understanding around recommended nursery practices.

Significance of observed changes in practices

It is noteworthy that at the end of the joint experiment, the learning group recommended several practices (regarding bag size, substrate and planting density) that directly contradicted official recommendations from the CRA-PP as well as some nursery holders' practices. Where official recommendations are often based on controlled on-station conditions and narrow biophysical criteria, the learning group's recommendations emerging from this joint experiment represent a balanced appreciation of all stakeholders' interests and evaluation criteria, both biophysical and social. The fact that the CRA-PP has changed its bag size recommendation in its training curriculum in response to this experience is a strong indication that they are now giving stronger consideration to stakeholders' various positions and constraints.

In addition to the CRA-PP's change in recommended bag size, field visits showed that participating nursery holders had incorporated some of the tested nursery management practices in their nurseries. The observed changes in practices by the different participants could be explained by their full involvement in the research from the problem identification to the experiment implementation, monitoring and evaluation. The transparency of the process, the way participants challenged communication-related issues, and ultimately the whole research path have a great deal to play in the observed rapid change in practices (Edwards, 2005; Luks and Siebenhüner, 2007; Luyet et al., 2012). An important question remains as to whether nursery holders will continue with their new practices now into the future, something which would be interesting to assess in follow up study, years later.

Research design on joint experimentation as means to facilitate social learning and knowledge production

The purpose of joint multi-stakeholder collaboration is to enable social learning and co-production of knowledge that is robust for all actors involved. The joint experiment described in this chapter was grounded on nursery holders' existing practices rather than newly introduced or officially recommended practices. Rather than taking a researcher-guided a participatory approach (Schwilch et al., 2012), the study took the path of a joint and free collaboration of stakeholders with a simple purpose of improving seedling production in a way that is both empirically-grounded as well as appropriate to the stakeholders' practical considerations. Through gathering the different parties involved in the oil palm seedling supply system, the process provided space for stakeholders to exchange insights and develop ways to improve the quality of seedling production, contributing to new articulations between stakeholders in the seed system (Offei et al., 2010). Existing knowledge of the various stakeholders has been put together, implemented and monitored jointly with them and new knowledge emerged for participants (Steyaert et al., 2007). Even though nursery holders are working in the same area and had received the same guidelines from the research centre, there was variation in production practices. Individually, nursery holders combined their available resources for seedling production in different ways to make the seedling production enterprise more profitable. Those practices were not known by their peers, who took the opportunity to learn from each other and from farmers, while still receiving useful insights from scientific expertise. In this respect, this study argues that participatory technology production is an effective way to contribute substantially to system innovations (Ramsten and Säljö, 2012) . If stakeholders are to efficiently use the resources at their disposal, their practical knowledge has a large contribution to play (Senthilkumar et al., 2012) and facilitating such processes is highly valuable.

A learning experiment in agriculture is a space where technologies are tested and their fitness in the local conditions is evaluated but also new knowledge and ties are formed. Such process significantly contributed to bridge the gap between the different players through generating knowledge partnership (Berkes, 2009). Before the implementation of the current learning experiment, there were few opportunities for nursery holders in the same community to discuss and exchange their production difficulties and learn from their peers. The implemented learning experiment provided means for them to meet and share concerns and knowledge to improve their practices. From this experience of learning, nursery holders who participated in the experiment reported that they will henceforth continue to exchange about seedling production practices that are both effective and economical.

Reflection on the learning experience and major lessons learned

Working together with people with whom we do not share the same background is challenging, but rewarding (Schwilch et al., 2012). The challenge lies in the fact that participants do not necessarily have a common language to name objects, nor similar experiences. It then requires some time to negotiate among participants to reach joint agreement (Raymond et al., 2010). For example, at the beginning of the experiment, farmers wanted all seedlings be fertilised including those serving as control. It took time to convince participants why, according to good experiment design, not all seedlings should be amended with fertiliser. The challenge also lies in the fact that even though basic language is used to explain issues, it is still hard for others, often non-academics, to understand (Almekinders, 2011). Working with people with different backgrounds is also instrumental because we learn more from others than expected. In the course of the collaboration, we find differences between higher educated people and local community members' ways of thinking. While higher educated people rely more on learned theories, local participants ground their reasoning on available resources, concrete experience, and suggest more straightforward and practical solutions. For example, when more highly educated participants thought we should use seven variables and scientific instruments to assess the effects of tested nursery practices on seedling growth, local participants suggested only using the three variables that orient farmers during seedling purchase and qualitative assessment methods that better represent the realities of their practical.

Even though the explicit objective of involving multiple stakeholders into the learning experiment is to get their contributions to improving the physiological quality of seedlings being sold to farmers, participants have also implicit motivations. Farmers, for example, reported that participation in the joint experiment allows them to produce seedlings by themselves, if they get some additional skills and authorization for opening a nursery. Even though the main purpose of farmer participation is to share their inputs and allow them to see the different activities involved in seedling production, some of the farmers seemed to deviate from the main reason of their involvement in the research.

This social space has generated a platform where different groups of stakeholders interacted to address a problem. For seventeen months, they shared production constraints and approaches to solutions. Some of the outcomes of the process have been already incorporated in the nursery holder training package. This would not have happened if the process did not include the main stakeholders of the seedling supply system, mainly oil palm research centre that trains and installs nursery holders. This is evidence that different ways of organising social learning would lead to different outcomes.

We have shown that a detailed account of group dynamics that support outcomes of trans-disciplinary research is an important step to add value to scholarly published papers and limit criticisms of their outcome validity. We advocate the use of details from stakeholder interactions to be the core focus of such research papers to understand the complexity of reported outcomes.

CONCLUSION AND IMPLICATIONS FOR MULTI-ACTOR PROCESSES

A joint experimentation is a challenging process and key methodological steps are to be considered. Above all, a total integration of the local context into the design is prerequisite. The process requires more skills and management if we are to incorporate people from different backgrounds, from research professionals to illiterate farmers. The process allows social learning and shows the richness of integrating the insights and evaluations from different stakeholders. To succeed in such a process, some skills of facilitation are needed; otherwise, the process may be hijacked by some of the participating stakeholders. For different participants to arrive at a common agreement on main issues, some efforts are needed to reach a common language for mutual understanding. This requires some time for negotiations among stakeholders.

Each stakeholder, based on the use they make of oil palm seedlings, has particular values about what constitutes sound seedlings. Consensus building is sometimes difficult and requires a commitment to work across differences toward a shared objective, which often requires some degree of nuanced facilitation. In the end, for such a process, the successful management of each phase - joint problem definition with stakeholders, co-design of research, co-implementation and co-analysis with all parties involved - is critical. This needs some iterations to revisit issues discussed during former phases of the process for adjustments.

Involvement of all participants and their active participation at the very beginning is important. This lays the way for the stakeholders' ownership of the outcomes (Ahmad et al., 2012b). Technology uptake by end-users would get easier if the process is more transparent and collaborative from the start to the end, wherein consumers of technologies are also explicit co-producers of it. Social spaces are useful to share knowledge and experiences. Learning takes place each time people exchange and reflect on a common problem that requires timely and appropriate solution. The way the process is designed and conducted has a great effect on the ownership by the participants. In this chapter, we have analysed the joint experiment as a social process of encounter by multiple stakeholders, wherein they all contribute to the knowledge production process, co-designing, co-implementing, co-analysing and co-evaluating the results. Beyond focusing on outcomes, we recommend that initiatives in multi-stakeholder environmental management processes should also document and analyse social processes in order to better understand the mechanisms by which such processes foster socio-technical change, as well as identify potential institutional barriers to such processes.

CHAPTER 7

General discussion

INTRODUCTION

The aim of this thesis was to understand the functioning of the oil palm seed system (OPSS) for quality seedling delivery with emphasis on smallholder farmers. The research generated knowledge of the OPSS that could further serve seed systems (SS) analysis in general but also support policy development in the agricultural sector.

SS are often characterised by many dysfunctions that hinder smallholder farmers from having access to high-quality planting material. Whereas there is a wealth of literature on SS of annual crops, the literature on SS of perennials is scarce, and non-existent for a perennial crop like oil palm. To contribute to closing these gaps in literature, this thesis developed a research approach to analyse SS performance. We used the oil palm crop in Southern Bénin as an example to explore weaknesses of the system and ways to deal with them. But the developed research approach goes beyond the specific case studied in this thesis.

In this synthesis chapter, main research findings are first presented and further discussed. Connections between different chapters are highlighted and the multiple and interrelated issues of quality oil palm seedlings are shown. The methodological approach implemented in this thesis is placed into a broader context of SS analysis. The chapter ends with contributions to policy development, inputs for further studies, some reflection on the CoS-SIS program as framework for PhD thesis research.

At the outset of this Chapter, it is important to recall the main research objectives:

- to identify major constraints in the oil palm seed system using farmers' perspective;
- to assess reliability of genetic quality of seedlings supplied to smallholder farmers;
- to evaluate nursery holders' developed management practices;
- to analyse the social learning process through which nursery management practices were evaluated.

The first objective was set beforehand by the researcher whereas the other three came in during research.

MAIN FINDINGS AND DISCUSSION

Functioning of oil palm seed system from a farmers' perspective and major constraints

Seed systems studies often investigate why farmers do not use high-quality planting material that would improve farming outputs (e.g., Abdulrahman and Ibrahim, 2009; Lunduka et al., 2012; Schroeder et al., 2013). In this thesis, the problem of farmers' access to high-quality planting material was framed in a different way. The assignment was to investigate why smallholder farmers who wish to crop the high-quality hybrid *tenera* palms fail to get the quality seedlings they pay for. To answer this question, the first objective of this thesis was to assess OPSS performance from a farmers' perspective and to identify major constraints. Findings (Chapter 2) showed that the current OPSS is not performing adequately from a farmers' perspective (see Weltzien and Vom Brocke, 2001). Major issues constraining smallholder farmers were poor genetic quality, poor geographic distribution of official nurseries and ensuing presence of non-officially established ones, high price of hybrid seedlings, and poor care of seedlings in nurseries. Farmers in the western and central part of the study area (with few nurseries) were more concerned about genetic quality of seedlings whereas those in the eastern (area well covered with formal nurseries) added the poor care of seedlings leading to poor physiological quality (Chapter 2). Dysfunction of SS for smallholder farming was often reported, although issues differ from one crop to another and from one region or country to another (Loch and Boyce, 2003; McGuire and Sperling, 2013). For tree species seedlings in general, major problems regarding quality and distribution for smallholder farmers were reported (Harrison et al., 2008). For oil palm in Bénin, the current rigid structure of the OPSS does not provide smallholder farmers enough options to avoid poor-quality seedlings. Farmers are in a difficult position because they are not allowed to raise seedlings themselves. Poor distribution of official nurseries worsens farmers' problems of genetic quality. Scholars reported that farmers situated far away from official supply sources experience more problems regarding genetic quality (Kugbei and Bishaw, 2002; Schroeder et al., 2013). In fact, in most developing countries, reaching the majority of smallholder farmers is a major problem for seed delivery (Guei et al., 2011). Smallholder farmers are located in areas difficult to access where additional efforts are needed to reach them. Consequently, they are more vulnerable and have bad experience with the quality of planting material (Anthony and Ferroni, 2012) as showed to be also the case of oil palm in Bénin (Chapters 2 and 3).

Reliability of genetic quality of seedlings supplied to smallholder farmers

While documenting farmers' constraints within and perceptions of OPSS performance (Chapter 2), claims were made and perceptions were expressed about the reliability of genetic quality of seedlings. Looking for empirical evidence supporting or contradicting those recorded claims and perceptions was then indispensable. Chapter 3 thus assessed historical changes in reliability of genetic quality of planting material (second thesis objective). Using the event ecology approach (Walters and Vayda, 2009), we first quantified the genetic quality of oil palms of different age on smallholder farmer plots, and moved on further to find out causal mechanisms. Research findings indicated that proportions of hybrid palms varied with supply source, farmers' geographic position, and year of planting (Chapter 3).

Supply sources of oil palm seedlings for smallholder farmers were reported to significantly affect genetic quality of seedlings (Ngoko et al., 2004). Scholars observed that nursery holders advertised seedling as hybrid that happened to be composed, partly or entirely, of non-hybrid seedlings (Durand-Gasselin and Cochard, 2005). Farmers' location to official supply source was acknowledged as one of main factors that jeopardizes their access to quality seeds for annuals (Kugbei, 2003; Kugbei and Bishaw, 2002; Schroeder et al., 2013). To effectively reach those farmers, tailored SS are advocated. For tree seedlings, Gregorio et al. (2008) indicated that effective supply to smallholder farmers requires decentralised seedling production. For oil palm seedling supply in Bénin, there is a kind of decentralised seedling production since a government initiative in mid-1990s (Adje and Adjadi, 2001). However, recorded quality problems indicated that the current system is not working adequately and, therefore, it requires to be revisited for improvement. In principle, effective decentralised seedling production is expected to cover farmers' demand and then limit flows of poor-quality material supplied to them.

The proportion of non-hybrid palms decreased with year of palm planting. The documentation of causal mechanisms revealed that observed variation in smallholder plots over time was associated with national policy change, local arrangements for seedling supply to smallholder farmers and social criteria. Documented under different concepts (e.g., political ecology (Blaikie, 2008; Yemadje et al., 2012), human-environmental timelines (Reenberg et al., 2013), cultural ecology (Zimmerer, 2004), or event ecology (Vayda and Walters, 1999; Walters and Vayda, 2009), etc.), relations between political, economic and social factors and changes in environmental and agricultural landscapes were acknowledged and reported in literature. Our findings showed relations between social, economic and political events and farmers' received genetic quality of oil palm. They connect with former findings by Carr (2002) and Walters (2003; 2008) about relations between human induced actions and environmental changes.

The political and social environments led to a diversity of practices within the OPSS as reflected by observed proportions of *tenera* in sampled plots (see Figure 3.4, Chapter 3). Plausible scenarios that may have accounted for cases with less than 100% *tenera*, could be inferred as follows:

- volunteer seedlings may have been collected from *tenera* stands and sold as hybrid *tenera*: this is the case for sampled plots where roughly 25% *dura*, 50% *tenera* and 25% *pisifera* were recorded;
- volunteer seedlings may have been collected from *dura* stands and sold as hybrid *tenera*: this corresponds to cases where sampled plots have nearly 100% *dura*;
- volunteer seedlings from *tenera* stands and from hybrid material are mixed and sold as pure hybrid *tenera*: this is the case of sampled plots composed of higher percentage than 50% *tenera* and lower than 25% *dura* or *pisifera*;
- volunteer seedlings from *dura* stands have been mixed with hybrid material and sold as pure hybrid material: this corresponds to cases where sampled plots have higher than 25% *dura*, lower than 50% *tenera* and lower than 25% *pisifera*.

Above mentioned practices are not only empirically grounded, but were also reported during field interviews as behaviour of seedling suppliers.

Social organisation was found to have a positive influence on the genetic quality of material farmers received. Farmers' membership to a local organisation of oil palm producers improved genetic quality of palms on their plots. The positive role of social organisation in seedling acquisition also constitutes a major point reported in SS for annuals. That was the case for rice farmers whose membership to farmer organisation showed positive influence on access to quality rice seeds (Saka et al., 2005). This supports the general argument that social organisations constitute the best means to introduce new improved seeds at community level (Badstue et al., 2007).

Efficacy of nursery holder developed management practices

The second aspect of seedling quality identified in the lead study (Chapter 2) of this thesis was poor care of seedlings in official nurseries. The third objective of this thesis focused on this issue (Chapters 4 and 5). Crop management plays an important role in plant growth and development (Grimble and Wellard, 1997; Tittonell et al., 2008). For tree seedling production, many records underlined the extent to which pot size, growing media, fertiliser supply, planting density, etc., affect seedling growth (Close et al., 2009; Teixeira et al., 2009).

The study of nursery holder developed management practices (Chapters 4 and 5) showed that bag size was the main factor determining oil palm seedling growth. Similar findings have been reported on many other plant species ranging from perennials (e.g., Dumroese et al., 2011) to annuals (e.g., Yang et al., 2010). A larger-sized bag indicates not only more space for plant roots to explore but additional nutrients and water to sustain plant growth. In small pots, plant growth gets limited with time because roots lack space and resources and have their growth restricted (Loh et al., 2003). As root organ activities are restricted, other organs lack resources to expand as expected. In general, pot grown plants are known to be subject to more stress than soil grown ones (Lenzi et al., 2009). This indicates that plants would express more growth limitation in smaller pots than larger ones. Even though large-sized bags produced the best-sized seedlings, medium-sized bags filled with a mixture of arable soil and animal manure without any fertiliser supply was the best balance between quality and production cost (Figure 4.6, Chapter 4).

Taken together, findings of Chapters 4 and 5 suggested that pot size matters (Poorter et al., 2012a). Consequently, appropriate fertiliser addition or substrate selection is not an option to mediate bag size effects. This finding has implications beyond oil palm. In fact, pot size matters not only for plant growth but also for synthesis of bio-chemical compounds. In this context, Vaknin et al. (2009) reported that large-sized pots induced an increase in the concentration of essential oil for a species like *Eucalyptus citriodora* Hook. Such knowledge of pot size on plant growth and its bio-chemical functions indicates that selection of management practices for tree seedling production should be considered carefully. Implicitly, trade-off between production costs and seedling quality needs to be examined by nursery professionals if they are to fit into a particular production season.

Even though pot size matters for physiological quality seedlings, a major point of attention remains market imperfection. In the current seedling supply system in Bénin, selling price is fixed through government policy and additional nursery holders' effort in quality would not lead to price increase. Nursery holders are economic agents who would be keen to invest in quality if it pays off. Bargaining of seedling quality including farmers' willingness to pay more than current set price would be the best motive that would sustain quality. Our findings (Chapter 2) indicate that farmers would not be willing to pay more money for quality seedlings. Farmers have indicated that current selling price of seedlings is already high for them to afford (Chapter 2; Akpo et al., 2012).

Social learning process as means to innovate nursery management

Social learning was recognised as effective means to bring about change in socio-technical systems that require strong efforts to change (Bos et al., 2013). It is a potential means to change norms, values, and ways of doing which govern decision making of social actors (Pahl-Wostl, 2009). Social learning also allows multi-level change through bringing together social actors. Experimentation was reported as a suitable space for implementing social learning to reach sustainable outcomes (Bos and Brown, 2012; Bos et al., 2013). The power of experimentation as a means to facilitate socio-technical and multi-level changes lies, to a large extent, in the fact that it accommodates the concept of learning by doing and doing by learning (Bos et al., 2013). From the Kolb theory of learning, (active) experimentation is one of the key ways human beings process and use information (Manolis et al., 2013).

A joint experiment was run on seedling management practices with nursery holders, farmers, researchers, and extension agents. In addition to generating biophysical findings about nursery practices (detailed in Chapter 4 and 5), the joint experiment was also analysed as a social learning process through which stakeholders arrived at shared understandings through participation and collaboration, findings of which are described in Chapter 6 (fourth thesis objective). Implemented social learning processes permitted participants to learn new production practices from their peers, detect discrepancies between field contexts and research recommendations, and change some of their practices (e.g., nursery holders, research centre) (Chapter 6). Participation was largely used in literature with different levels of stakeholders' involvement (Luyet et al., 2012). However, outcomes of stakeholder participation in research depend on prevailing group dynamics during the process and as such, the process facilitation. The inclusion of key actors contributed to bridge gaps between stakeholders and partly solved some institutional issues through connecting different players of the OPSS in Bénin. The experience was the first one for most participants even though all of them play important roles in the OPSS. The design of this joint experiment induced multi-level change and served then as means to co-innovate the seedling supply system.

In general, sharing experiment findings and related issues with stakeholders allowed participants to discover and understand concerns of other social actors. The understanding of experimentation as effective tool to facilitate multi-level changes justifies its widespread use in different fields involving stakeholders (e.g., water management (Farrelly and Brown, 2011), environmental management (Lankester, 2013), pest management (Yang et al., 2008); soil fertility management and soil conservation (Defoer, 2000; Misiko et al., 2008), etc.).

Multiple and interrelated dimensions of quality oil palm seedlings

Individually, each study of this thesis provides understanding of specific aspects of the oil palm seedling delivery system. Taken together, findings of different studies show the full picture of the current OPSS in Bénin. Findings further indicate that high-quality oil palm seedling delivery involves many dimensions including genetic aspects of plant material, physiological quality of seedlings and the socio-institutional environment, all contributing to the final produce that farmers receive.

First, the genetic aspect of quality seedling production is theoretically under control of the research centre that can only conduct such work due to required skills and resources. Technical failure has not been proven for the research centre in its processes of hybrid planting material production (Chapter 3). However, practices in the OPSS showed that all stakeholders shape, to some extent, the quality of the final produce smallholder farmers receive. This means no single social actor is in control of genetic quality of seedlings smallholder farmers buy for field planting. The fact all social actors introduce different quality materials into the OPSS is a central issue that undermines the reliability of genetic quality of seedlings.

Second, the physiological aspects of quality seedling production, is related to the use of appropriate management practices in nurseries. If genetic quality is met and seedlings are not raised appropriately in the nursery, the final produce is still a poor seedling. The sensitivity of low-quality planting material to biotic and abiotic stresses was reported for other plant species (e.g., Cook and Smart, 1994; Dominguez-Lerena et al., 2006). For oil palm, however, no research has proven consequential effects of poor quality raised seedlings on its productivity. This could be an input to future studies. In contrast to genetic quality that is shaped by all social actors, maintaining physiological quality of seedlings depends mainly on nursery holders who alone decide on management practices.

Third, the socio-institutional environment, in which social actors manipulate seedlings, seems the most important. Genetic and physiological aspects of quality seedling production are technical issues which are shaped by the socio-institutional environment, i.e., policy, current structure of the OPSS, infrastructure facilities, inputs price, imperfection of the seedling market, farmers' values and preferences, nursery holder decision making, social networks and ties. As mentioned above, official or non-official nursery holders or informal intermediaries undermine quality of seedlings that farmers receive. Trustworthiness of people does not seem under control of any social actor.

This layout of the multiple and interrelated dimensions of quality oil palm seedlings shows that smallholder farmers are not in control of any issue that might lead to failure of the delivery system. Smallholder farmers are only victims, because they are the only ones who bear the consequences of seedling failure. The interrelation of these three aspects of quality seedling delivery suggests that no reliable solution to quality oil palm seedlings can be reached out of socially inclusive processes. This justifies the combination of various methodological approaches used in this thesis to understand the OPSS delivery system.

IMPLICATIONS OF RESEARCH FINDINGS

Implications for seed systems analysis

The analysis of the OPSS was conducted from a farmers' perspective. Starting with a diagnostic study, characteristics of the SS were laid out (Chapter 2). Follow-up in-depth research included historical analysis that traced the way genetic quality evolved in different field contexts in relation to policy, economic and social factors (Chapter 3). Joint experiments assessed which nursery holder developed practices could best sustain seedling quality and replace formal recommendations from the research system (Chapters 4 and 5). The documentation and analysis of these experiments helped to understand the social process of technology production (Chapter 6). These component studies of OPSS performance show how integration of biophysical and social aspects shaping seedling quality provides more substantial understanding of the subject rather than merely biological or social study.

Our research approach suggests the following implications for seed systems (SS) analysis in general. First, in this thesis, we did not limit ourselves to describing dynamics within the OPSS (e.g., Chapter 2). We took further steps that consisted in tackling the described state of the OPSS for more meaningful contributions. SS analysis could move beyond a mere account of dynamics in the systems. Second, our research approach integrates biophysical and social studies. SS analysis could move beyond a research approach that looks at a single aspect of seeds and prioritise approaches that combine both biological and social aspects. Third, beyond the plant material, political, social, and economic environments shape quality of material smallholder farmers receive. Our research approach targeted connections between socio-institutional environments, e.g., past interventions and OPSS performance. SS studies could place emphasis on past interventions to show the full picture of their successes and failures. To map out former experiences, event ecology (Walters and Vayda, 2009), political ecology (Blaikie, 2008), human-environmental timelines (Reenberg et al., 2013), cultural ecology (Zimmerer, 2004), could be helpful research approaches.

Implications for policy

One of main objectives of the Bénin government in the agricultural sector is to improve current performance of the country in palm oil production to close the gap with local needs. To date, smallholder farmers are main contributors to national palm oil production. This research provides an in-depth account of main issues hindering smallholder farmers from improving their oil palm farming productivity. From findings of Chapter 2, poor distribution of official nurseries is a major issue that jeopardizes genetic quality. Supporting farmers would consist of increasing the number of official nurseries in the oil palm growing belt. Scholars argued that all political ecology research bears policy relevance (Walker, 2006). Chapter 3 that drew on historical analysis of OPSS showed successes of former local initiatives that improved farmers' access to genetic quality of palm seedlings. Initiatives intending to facilitate farmers access to quality seedlings could draw on successes and failures of past interventions (e.g., Catholic Church and NGO initiatives). Farmers' social organisation contributed positively to quality access for smallholder farmers (Chapter 3). Records indicated that oil palm farmers in Bénin have been organised from village to the country level (SNV, 2008). Different levels of farmer organisations could be used as means to facilitate smallholders' access to hybrid planting material. For example, each farmers' organisation at the village level could be holder of an official nursery. Farmer-based organisation constitutes the best unit to record yearly needs of farmers for planting material.

For farmers to get healthy seedlings for field planting, management practices need to be improved. Field records showed that often recommended production practices hardly fit into the local production contexts (Chapter 4). In this respect, all aspects of current recommendations of nursery management practices could be revisited to fit better the use context. Social learning processes through participation and collaboration of main players of the OPSS could help in reaching successful outcomes.

In the end, findings of this thesis constitute background knowledge that could serve to improve governmental policy regarding the oil palm sector but also other important commodity sectors in Bénin and other developing countries.

Inputs for further studies

There are important questions that emerged through the course of this study that were beyond the scope and time limit of the project. The OPSS included informal suppliers of planting material. The question remains why they sell non-hybrid material as hybrid. A rush to conclusion could lead to the answer that they are deliberately doing a bad job. From a researcher's perspective, it would be relevant to initiate a study that would identify activities and real motives of suppliers (along the chain) of non-hybrid planting material. A clear understanding of the nature of hybrids may be lacking with most stakeholders. Investigating this could help to gather relevant information that would be useful as to actions to target to improve understanding and practices.

This research did not examine real effects of poor physiological quality seedlings on plant performance at production age in field conditions. It would be relevant to investigate whether poorly-raised oil palm seedlings show more sensitivity to biotic and abiotic agents; and whether it induces poor yield throughout the productive phase (Mexal et al., 2002). Such research findings would provide empirical evidence of how much attention should be given to physiological aspects of seedling quality.

The official nursery control system is still archaic. In consequence, selling of non-hybrid seedlings to farmers is still ongoing because of lack of tools to sample quality at nursery level. A more sophisticated analysis of the manipulation of planting material within the OPSS would require to use molecular tools. Molecular tools that could help to distinguish *tenera*, *dura*, and *pisifera* types are still lacking. Building such molecular tools including phylogenetic aspects would be useful for a quick check of nursery holders' trustworthiness. Up to now, the quality of material being sold could be checked only after production of first bunches at farmer level. Availability of such advanced tools would allow more controls at the very nursery level.

The last issue, though uncertain, that deserves effort from research are possible morphological marker that could identify true hybrid from non-hybrid seedlings. It is obvious that if farmers are able to identify hybrid material from non-hybrid ones, they will avoid being sold wrong material. We have started working on this issue without consistent conclusions that deserved to be reported in this thesis.

Even if the problems of seedling (physiological and genetic) quality were solved, there are also other important challenges for increasing oil palm production in Bénin. These include effective plantation irrigation, and the development of planting material that is tolerant to water stress. The regulation of seedling production must be done in the broader context of oil palm production.

Reflection on the Convergence of Sciences for Strengthening Agricultural Innovation Systems (CoS-SIS) approach

Our research project drew on the general aim and design of the CoS-SIS programme to investigate the oil palm seed system (OPSS) in Bénin. The basic idea of CoS-SIS was that implementing concerted actions with relevant stakeholders would support smallholder farmers through adding value to their activities: better access to markets, inputs, knowledge, credits, improved land tenure arrangements, better organisation, etc. (see http://www.cos-sis.org/ for further details). According to CoS-SIS, solving issues hindering smallholders would require initiatives at system levels above the farm level. The CoS-SIS project design favours interactions between relevant stakeholders who share concerns and collaborate to create improvement.

In our project, for example, we worked on the poor quality of seedlings in the OPSS in Bénin. Farmers are the end-users of seedlings in Bénin, they are not the ones who produce them. They access hybrid seedlings through official nurseries. This means that solving the issue of poor quality for smallholder farmers requires collaboration among relevant stakeholders. We created this collaboration by enhancing interactions between stakeholders of the seed system. The research approach triggered discussion on the poor geographic distribution of the official nurseries, and the poor physiological quality of the seedlings at an above the household or farmer level. Overall, we give credit to the CoS-SIS philosophy that research issues should emerge from the field context and involved relevant stakeholders. It favours multi- and trans-disciplinary approaches to effectively address practice-oriented research problems, it converges different scientific fields and consequently scientists from various backgrounds. It also helps scientists to effectively communicate and use their research results.

The CoS-SIS design, however, was not focused enough in terms of arrays of issues to be covered. Therefore, the CoS-SIS programme spent more time (about two years) than needed to get the research focus shaped (Hounkonnou et al., 2012). The developmental goal at the CoS-SIS programme level seemed over-emphasised. One example in this respect was that at the end of each individual project, impacts on smallholder farmers in terms of livelihood improvement would be measured. Such a goal was ambitious for 30 months of PhD field work, especially for a perennial crop like oil palm, which takes years to bear the first fruits. To our understanding, a PhD work aims mainly to generate knowledge and understanding of the issue being investigated. Generated knowledge will be used later for development purposes. CoS-SIS also downplayed research issues that would require more laboratory work. Because of the donor-driven programme goals, the CoS-SIS PhD researches were consistently shaped at the programme level. This left little room to explore hard core research issues.

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SUMMARY

As basic agricultural input, quality seed is critical for smallholder farmers to improve productivity. Seed is the most precious of resources for smallholder farmers, who struggle to make their livelihoods under challenging conditions. In most developing countries and for most crops, seed quality is a major problem for smallholder farmers. The informal seed sector, characterised by low-quality seed, accounts for more than 80% of smallholder seed supply. The formal seed system, characterised by higher-quality seed than the informal, often falls short to meet smallholder farmer demands. For perennials, where crops spend several years before first harvest of produce and stands are generally maintained for decades, quality of planting material is even more important. For oil palm, which is a strictly allogamous crop, high productivity requires the use of hybrid planting material. Genetic quality of oil palm seedlings accounts for more than 60% of variation in plantation output.

Many dysfunctions are reported to hinder smallholder farmers from having access to high-quality planting material. Whereas the literature on seed systems is well documented for annual crops, it is scarce for perennials, and non-existent for oil palm. To contribute to closing this gap, a research approach was developed in this thesis to analyse performance of seed systems for perennials. The oil palm crop in Southern Bénin served as example to explore weaknesses of the system and ways to deal with them. The main research objective at the start was (1) to identify major constraints in the oil palm seed system using a farmers' perspective; on the basis of identified constraints we further (2) assessed reliability of genetic quality of seedlings supplied to smallholder farmers over past three decades; (3) evaluated nursery holders' developed management practices on seedling growth through joint experimentation with a range of stakeholders; and (4) analysed the social learning process through which nursery management practices were evaluated. To meet these objectives, we conducted social surveys, sampled farmers' oil palm plots, ran field experiments and documented the social learning process for involved stakeholders.

In Chapter 1, we provide background information on oil palm worldwide and the role of quality seeds in agricultural development. We further describe the problem being investigated. We give an overview of the theoretical underpinnings and the overall research design. We also introduce the study area.

Chapter 2 presents the diagnostic study of the oil palm seed system (OPSS). It analyses the OPSS characteristics from a farmers' perspective. It shows, on the one hand, an informal seed sector that involves non-official suppliers of germinated seeds, non-official nursery holders, and farmers; on the other hand, a formal seed system that involves the oil

palm research centre, official nursery holders, State Cooperatives, the extension service, NGOs, oil palm farmers organisations, and farmers. The informal and formal seed systems were interrelated regarding seedling flow, i.e., hybrid seedlings were found in both seed systems. Actors operating in the informal seed sector obtained hybrid seedlings from their peers of the formal system. The four main characteristics of a seed system from farmers' perspective were (1) physiological quality of seedlings, (2) genetic quality and suitability of palm materials to local uses, (3) fine-tuning of supply and demand, and (4) physical and financial accessibility of seedlings. Low physiological quality of seedlings was related to seedling vigour due to poor care in nurseries. Genetic quality and suitability of palm material to local uses related to the presence of non-hybrids within material purchased as allegedly pure hybrid, the impossibility to choose cultivars with redder oil and good oil storage attributes. Poor fine-tuning of supply and demand was shown as a lack of planting material in nurseries at planting time. Physical and financial accessibility of seedlings was found to be compromised by road infrastructures and high purchase price of seedlings. Ensuing major constraints jointly identified with stakeholders were (in order of importance) poor geographic distribution of official nurseries, non-hybrid palms in smallholder plots, high cost of hybrid seedlings, and poor seedling care in nurseries leading to poor physiological quality. The poor care was mentioned in the eastern part of the study area. We also investigated farmers' practices in seedling acquisition that showed trust, nursery proximity, and purchase price as main considerations smallholder farmers put forward as criteria to decide where to buy seedlings.

In Chapter 3, we investigated reliability of genetic quality of seedlings supplied to smallholder farmers as one of studies that emerged from the diagnostic study. We analysed main drivers of genetic quality reliability over the past four decades, using an event ecology approach to document historical events that may have affected the seed system. We sampled smallholder farmer plots to determine the genetic quality of the material they purchased over time. We recorded plausible socio-institutional mechanisms that might have impacted genetic quality of seedlings smallholder farmers planted. We observed that the proportions of hybrid (*tenera*) palms varied with seedling supply source, farmers' geographic position, seedling purchase price and year of planting. Even though higher proportion of *tenera* seedlings were observed for official supply sources, important flows of non-hybrid material came also from these sources. Non-official nurseries have all time supplied a higher proportion of non-hybrid palms to smallholder farmers than official nurseries but generally delivered a mix of hybrids and non-hybrids. Over time, the proportions of *tenera* that individual supply sources delivered differed little compared to differences observed between sources. Farmers' proximity to official supply sources increased the genetic quality of seedlings they purchased. The higher seedling purchase price, the higher was the genetic quality. More recently planted plots contained higher proportions of non-hybrid seedlings than older plots. Socio-institutional mechanisms associated with observed variation in smallholder plantations were national policy changes, local arrangements for seedling supply to smallholder farmers, and farmers' personal characteristics. Local arrangements improved genetic quality in villages located far away from official supply sources. Villages where local seedling supply initiatives withdrew showed severe drops in genetic quality with farmers having lower proportion of *tenera* in fields planted after initiatives were discontinued. Opening of non-official nurseries by formerly official nursery holders explained lower proportions of *tenera* as well. Membership of farmers' organisation correlated positively with proportion of *tenera*. Farmers who belonged to an oil palm farmer organisation showed a higher proportion of *tenera* across villages as members often purchased seedlings together from reliable sources. Farmer's use of informal intermediaries showed negative effects on the genetic quality of purchased seedlings.

Chapter 4 evaluates the effect of on-going nursery management practices on seedling phenotype at planting. The study was conducted in typical nursery holder conditions and as a joint learning experiment. A full 3 × 4 × 3 factorial experiment with 36 treatments was run and carried out in 5 replications in 2011 and 2012. Factors and levels were bag size (small, medium, large), type of soil substrate ("forest" soil, household waste substrate, arable soil, and arable soil with animal manure) and fertiliser supply (no fertilisation, split dose every 15 days, and full dose every 30 days). Allometric variables, i.e., seedling height, number of leaves, length of most developed leaf, root-collar diameter and biomass production were measured 8 (2011) or 6 (2012) months after transplanting. Across the two years, only one third of seedlings raised in small-sized bags with full dose fertiliser supply (all substrates confounded) survived. Except biomass production in 2011, the three way interaction between bag size, substrate, and fertiliser supply was not significant for allometric variables in either year. Bag size proved the main factor determining oil palm seedling phenotype in both experiments. Although large-sized bags produced largest seedlings, medium-sized bags filled with a mixture of arable soil and animal manure without any fertiliser supply sustained seedling growth well and seemed the best balance between physiological quality and production cost. The main reason was that additional labour and transport costs of large-sized bags would make seedlings in large-sized bags unaffordable. Growth variables were highly correlated. Height and root-collar diameter constitute good proxies to estimate seedling biomass differences between treatments in a non-destructive way.

Chapter 5 analyses dynamics of oil palm seedling growth in the experiment reported in chapter 4, to gain insight into expression patterns of effects of bag size, substrate, fertiliser supply, and their interactions on plant growth over time. Monthly observations of seedling height, root-collar diameter and number of leaves from the earlier mentioned experiments were analysed. Overall, in both experiments, bag size explained the largest proportion of experimental error and the explained variance started to increase earlier than for substrate, fertiliser supply, and their two and three way interactions. Explained variance by substrate was second to start increasing. The explained variance by different factors and interaction effects over time revealed that bag size, substrate and fertiliser supply produced fairly small and similar effects on seedling growth during the first two months after seedling transplanting to nursery. Overall, bag size effects increased over time for observed growth variables. In contrast to bag size, the effects of substrate, fertiliser supply, and interactions remained fairly constant across the whole experimental phase, all explaining less than 10% of experimental error when significant. Curve fitting showed different growth models for height, root-collar diameter and number of leaves. While an exponential model gave the best fit for height and root-collar diameter, a linear model gave the best fit for number of leaves. The analysis of growth rates showed that (relative and absolute) growth rates were mainly affected by bag size in both years with larger F-values than substrate, fertiliser supply, and interactions. The three way interaction between bag size, substrate and fertiliser supply was not significant in either year for any of the growth variables. The two way interaction between substrate and fertiliser supply affected growth rates significantly for all variables in both years. Taken together chapters 4 and 5 indicated that bag size matters. Consequently, fertiliser addition or appropriate substrate selection cannot overrule bag size effects which should be considered carefully for tree seedling production in nurseries.

Chapter 6 analyses the joint experiment as a multi-stakeholder process and aims to contribute to the understanding of how the way of organising social learning affects stakeholders' ownership of process outcomes. We documented the process through a multi-method approach including informal and semi-structured interviews, analysis of meeting minutes, participant observations, and field visits. Stakeholders' perceptions of quality seedlings and their appreciation of treatment performance varied with the use they made of planting material. While farmers, as end-users, put forward seedling vigour when describing quality seedlings, nursery holders underlined costs of production and reported that seedling quality is a compromise with costs. Participants, mainly nursery holders, learned new production practices from their peers. The mismatch between research recommendations and users' contexts were revealed. Field observations further to the joint experiment indicated changes in practices of nursery holders, the research centre, and farmers. The level of stakeholders' involvement increased their participation and ownership of the learning process that may thus lead to sustainable practices. The setting of the learning group contributed to bridge gaps between stakeholders through connecting main players of the seedling supply system. Methodological steps taken in this research process showed its efficacy in producing quick and positive feedback mechanisms.

Chapter 7 summarises main research findings and further discusses them. Smallholder farmers did not get the quality of seedlings they pay for. Quality seedling delivery to smallholder farmers had multiple and interrelated dimensions as shown by the different studies. Most of these were not under the direct control of farmers. Although the research station was found to deliver constant good genetic quality seeds, various other actors in the system introduced non-hybrid material thus together shaping the variable genetic quality of seedlings that smallholders purchased. The physiological quality of seedlings was under the control of official nursery holders. The socio-institutional environment shaped the final produce that farmers purchased and seems the most important. Genetic and physiological aspects of quality seedlings are essentially shaped by policy, organisation of the seed system, infrastructure facilities, inputs price, nursery holder decision making, seedling market imperfection, farmers' values and preferences, social networks, and ties. Seed systems analysis should go beyond the plant material and description of on-going dynamics to take appropriate steps to deal with reported issues. Seed systems require approaches that combine biophysical and social studies. Success or failure of former interventions deserve particular attention in seed systems analysis, and this studies shows the options for this in perennial crops. Political ecology is a robust research approach that could be used. Policy could support farmers through increasing the number of official nurseries in main growing areas, and use farmers' organisations as means to reach the majority of smallholder farmers. Further studies could investigate real motives of suppliers of non-hybrid planting material, actual effects of physiological quality seedlings on palm production in field, and development of tools to check on genetic seedling quality at nursery level.

SAMENVATTING

Kwalitatief goed uitgangsmateriaal is een essentiële agrarische hulpbron en van groot belang voor kleine boeren bij het verhogen van hun productiviteit. Zaad kan zelfs beschouwd worden als de meest waardevolle hulpbron voor kleine boeren die zich onder moeilijke omstandigheden een bestaan bevechten. In de meeste ontwikkelingslanden en voor de meeste gewassen is zaadkwaliteit één van de belangrijkste problemen voor kleine boeren. De informele zaadsector, gekarakteriseerd door lage zaadkwaliteit, voorziet in ruim 80% van het zaaizaad van kleine boeren. De formele zaadsector, gekarakteriseerd door een hogere zaadkwaliteit dan de informele sector, schiet veelal tekort bij het voldoen aan de vraag van kleine boeren. Voor meerjarige gewassen, waarbij het enige jaren duurt voor de eerste producten geoogst kunnen worden en opstanden meestal enige decennia meegaan, is kwaliteit van uitgangsmateriaal zelfs nog belangrijker dan voor éénjarige gewassen. Voor oliepalm, een strikte kruisbestuiver, is het gebruik van hybride uitgangsmateriaal vereist om hoge producties te realiseren. Genetische kwaliteit van oliepalmzaailingen verklaart meer dan 60% van de variatie in productie van plantages.

Er is veel geschreven over systeemstoringen die toegang tot kwalitatief hoogwaardig uitgangsmateriaal voor kleine boeren bemoeilijken. Maar waar er een rijke wetenschappelijke literatuur bestaat betreffende zaaizaadsystemen van éénjarigen, is deze slechts mager voor meerjarigen en bestaat er niets over oliepalm. Om bij te dragen aan het vullen van deze leemte is in dit proefschrift een onderzoekaanpak ontwikkeld voor de analyse van het functioneren van het systeem voor uitgangsmateriaal van meerjarigen. Het oliepalmgewas in het zuiden van Benin is hierbij het voorbeeldgewas waarvoor de zwakke kanten van het systeem worden onderzocht alsmede manieren om hiermee om te gaan. Aanvankelijk was het hoofddoel van het onderzoek (1) het identificeren van de belangrijkste beperkingen in het systeem voor uitgangsmateriaal van oliepalm vanuit het perspectief van de kleine boeren; op basis van de geïdentificeerde beperkingen hebben we voorts (2) de betrouwbaarheid beoordeeld van de genetische kwaliteit van zaailingen die over de afgelopen drie decennia aan kleine boeren geleverd zijn; (3) middels gezamenlijke experimenten met een reeks belanghebbenden de groei van zaailingen geëvalueerd bij gebruik van door eigenaren van kwekerijen ontwikkelde opkweek-methodes; en (4) het sociale leerproces geanalyseerd waarmee de opkweek-methodes werden geëvalueerd. Om deze doelen te bereiken hebben we sociaal veldonderzoek uitgevoerd, oliepalmbestanden van boeren bemonsterd, veldexperimenten uitgevoerd en het sociale leerproces van de betrokken belanghebbenden gedocumenteerd.

In Hoofdstuk 1 geven we achtergrondinformatie over oliepalm over de gehele wereld en de rol van zaadkwaliteit voor agrarische ontwikkeling. Voorts beschrijven we het onderzoeksprobleem. We geven een overzicht van de onderliggende theorieën en de globale onderzoekaanpak. We introduceren verder het gebied waar het onderzoek heeft plaatsgevonden.

Hoofdstuk 2 bevat de diagnostische studie van het oliepalmzaaizaadsysteem (OPZS). Dit hoofdstuk analyseert de eigenschappen van het OPSZ vanuit het perspectief van de boeren. Het toont aan de ene kant een informele zaadsector waarbij onofficiële leveranciers van gekiemde zaden, onofficiële kwekerijhouders en boeren betrokken zijn; en aan de andere kant een formele zaadsector waarbij het oliepalmonderzoekcentrum, officiële kwekerijhouders, staatscoöperaties, de voorlichtingsdienst, niet-gouvernementele organisaties, organisaties van oliepalmboeren en de boeren zelf betrokken zijn. De informele en formele zaadsectoren waren verstrengeld voor wat betrof het verkeer in zaailingen, d.w.z., zaailingen van hybriden werden in beide systemen aangetroffen. Actoren uit de informele zaadsector verkregen zaailingen van hybriden van hun collega's uit het formele systeem. Vanuit boerenperspectief zijn de vier belangrijkste eigenschappen van een zaaizaadsysteem: (1) fysiologische kwaliteit van zaailingen, (2) genetische kwaliteit en geschiktheid van uitgangsmateriaal voor lokaal gebruik, (3) afstemming van vraag en aanbod, en (4) bereikbaarheid van zaailingen in fysieke en financiële zin. Lage fysiologische kwaliteit van zaailingen was gerelateerd aan beperkte vitaliteit van zaailingen als gevolg van slechte behandeling in de kwekerijen. Genetische kwaliteit en geschiktheid van palmen voor lokaal gebruik hadden betrekking op het vóórkomen van niet-hybriden in materiaal dat was gekocht als zijnde zuivere hybriden en de onmogelijkheid om rassen te kiezen met meer rode olie en goede oliebewaareigenschappen. De slechte afstemming van vraag en aanbod toonde zich als een tekort aan plantmateriaal in kwekerijen rond het tijdstip van overplanten. Beschikbaarheid in fysieke en financiële zin werd beperkt door de infrastructuur van wegen en de aanschafprijs voor zaailingen. De hieruit volgende belangrijkste beperkingen, zoals samen met de belanghebbenden in volgorde van belang gerangschikt, waren slechte geografische spreiding van de officiële kwekerijen, aanwezigheid van niet-hybride palmen in opstanden van kleine boeren, hoge kosten van hybride zaailingen, en slechte behandeling van zaailingen in kwekerijen leidende tot slechte fysiologische kwaliteit. Deze slechte behandeling werd in het oostelijk deel van het studiegebied gevonden. We onderzochten ook de wijze waarop boeren beslisten over aanschaf van zaailingen waarbij kleine boeren vertrouwen, nabijheid van kwekerijen en aanschafprijs als belangrijkste overwegingen noemden.

In Hoofdstuk 3 onderzochten we de betrouwbaarheid van de genetische kwaliteit van zaailingen die aan kleine boeren werden geleverd aangezien dit in de diagnostische studie als één van de uit te voeren studies naar voren kwam. We analyseerden de belangrijkste sturende factoren voor betrouwbaarheid van genetische kwaliteit over de afgelopen vier decennia, en gebruikten de zogenaamde 'event ecology' benadering om de historische gebeurtenissen te beschrijven die het systeem beïnvloed kunnen hebben. We bemonsterden opstanden van kleine boeren om de genetische kwaliteit van de in de loop der jaren door hen aangeschafte palmen vast te stellen. We legden aannemelijke sociaal-institutionele mechanismen vast die van invloed zouden kunnen zijn geweest op de genetische kwaliteit van zaailingen die door de kleine boeren waren geplant. We namen waar dat het aandeel hybride (*tenera*) palmen varieerde naar gelang de herkomst van de zaailingen, de plek in het studiegebied waar de boeren woonden, de aanschafprijs van de zaailingen en het jaar dat de palmen geplant waren. Hoewel het aandeel hybride palmen groter was als officiële kwekerijen de bron van herkomst waren, waren deze kwekerijen toch ook een belangrijke bron van niet-hybride palmen. Niet-officiële kwekerijen leverden de kleine boeren over de gehele periode een groter aandeel niet-hybride palmen dan officiële kwekerijen maar ook zij leverden meestal een combinatie van hybride en niet-hybride palmen. Over de jaren varieerde het aandeel hybride palmen van eenzelfde herkomst weinig vergeleken met de verschillen tussen de herkomsten. De nabijheid tot een officiële bron deed de genetische kwaliteit van palmen die boeren aanschaften, toenemen. Des te hoger de aanschafprijs van zaailingen des te hoger de genetische kwaliteit. De meer recentelijk aangeplante opstanden hadden een groter deel niet-hybride palmen dan oudere opstanden. Sociaal-institutionele mechanismen die verband vertoonden met de waargenomen variatie in de opstanden van kleine boeren waren veranderingen in het landelijke beleid, lokale regelingen voor levering van zaailingen aan kleine boeren en individuele eigenschappen van boeren. Lokale regelingen verbeterden de genetische kwaliteit in dorpen die ver van officiële bronnen lagen. Dorpen waar lokale initiatieven voor regeling van zaailinglevering stopten lieten een sterke daling zien in genetische kwaliteit waarbij een beperkter deel van de door boeren aangeplante palmen hydriden waren in opstanden die na de afbreuk van het initiatief aangeplant waren. Het starten van niet-officiële kwekerijen door houders die eerder een officiële kwekerij bezaten, verklaarde tevens een deel van de gevallen met lage aandelen hybride palmen. Lidmaatschap van een boerenorganisatie was positief gecorreleerd met het aandeel hybride palmen. Boeren die lid waren van een organisatie voor oliepalm hadden een groter aandeel hybride palmen over alle dorpen aangezien leden veelal gezamenlijk inkochten van betrouwbare bronnen. Gebruik door boeren van niet-officiële tussenpersonen had een negatief effect op de genetische kwaliteit van aangeschafte zaailingen.

Hoofdstuk 4 evalueert het effect van huidige opkweekmethoden op het fenotype van de zaailing bij overplanten. De studie werd onder de omstandigheden normaal voor een kwekerij uitgevoerd als een gezamenlijke leeractiviteit. Een volledige 3 × 4 × 3 factoriële proefopzet met 36 behandelingen werd toegepast en in 5 herhalingen uitgevoerd in 2011 en 2012. Factoren en hun niveaus waren grootte van de plantzakken (klein, middel en groot), het type substraat (bosgrond, huishoudafval, teelaarde, teelaarde met dierlijke mest) en kunstmesttoediening (geen kunstmest, halve dosis elke 15 dagen, volle dosis elke 30 dagen). Allometrische variabelen, d.w.z. zaailinghoogte, aantal bladeren, lengte van het meest ontwikkelde blad, kraagdiameter en drogestofproductie werden 8 (2011) of 6 (2012) maanden na overplanten gemeten. Over de twee jaren overleefden slechts een derde van de zaailingen opgekweekt in de kleine plantzakken (voor alle substraattypen samen). Behalve voor drogestofproductie in 2011, was de drieweginteractie tussen plantzakomvang, substraat en kunstmesttoediening niet significant in beide jaren en voor alle gemeten variabelen. In beide experimenten bleek plantzakomvang de belangrijkste bepalende factor te zijn voor plantfenotype. Hoewel grotere plantzakken grotere zaailingen voortbrachten, was de zaailinggroei ook goed op middelgrote zakken gevuld met teelaarde en dierlijke mest waar geen kunstmest aan werd toegevoegd. Deze combinatie leek ook het beste compromis tussen fysiologische kwaliteit en productiekosten. De belangrijkste redenen hiervoor waren de extra arbeid en transportkosten bij gebruik van grote plantzakken, die zaailingen in grote zakken onbetaalbaar maakten. De groeivariabelen waren onderling sterk gecorreleerd. Hoogte en kraagdiameter waren goede niet-destructieve schatters voor verschillen in zaailing droge stof tussen behandelingen.

Hoofdstuk 5 analyseert de groeidynamiek van oliepalmzaailingen in het experiment dat in Hoofdstuk 4 gerapporteerd werd, om verder inzicht te verkrijgen in de temporele veranderingen in de omvang van de effecten van plantzakomvang, substraat, kunstmesttoediening en hun interacties op de plantengroei. Maandelijkse waarnemingen aan zaailinghoogte, kraagdiameter en aantal bladeren uit het eerder beschreven experiment werden geanalyseerd. Over de beide experimenten samen verklaarde plantzakomvang het grootste gedeelte van de experimentele variantie en de verklaarde variantie nam eerder toe in de tijd dan voor substraat, kunstmesttoediening en hun twee~ en drieweginteracties. De door substraat verklaarde variantie nam als tweede toe in de tijd. De in de loop van de tijd door de verschillende factoren en hun interacties verklaarde variantie liet zien dat plantzakgrootte, substraat en kunstmesttoediening beperkte en vergelijkbare effecten hadden op zaailinggroei tijdens de eerste twee maanden na overplanten. Over het geheel genomen namen de effecten van plantzakgrootte toe in de tijd voor alle waargenomen variabelen. In tegenstelling tot plantzakgrootte bleven de effecten van substraat, kunstmesttoediening en hun interacties beperkt gedurende het gehele verloop van het experiment waarbij geen ooit meer dan 10% van de experimentele variantie verklaarde indien significant. Vergelijking van groeicurves liet zien dat planthoogte, kraagdiameter en bladaantal verschilden in groeimodel. Terwijl hoogte en kraagdiameter het best overeenkwamen met exponentiële groei volgde bladaantal een lineaire groei. De analyse van groeisnelheden liet zien dat (relatieve en absolute) groeisnelheden voornamelijk afhingen van plantzakgrootte, in beide jaren, met grotere F-waarden dan voor substraat, kunstmesttoediening en interacties. De drieweginteractie tussen plantzakgrootte, substraat en kunstmesttoediening was in geen van beide jaren voor geen van de variabelen significant. De tweeweginteractie tussen substraat en kunstmesttoediening beïnvloedde alle drie de variabelen in beide jaren. Hoofstukken 4 en 5 samen overziend doet plantzakomvang er toe. Dit wil zeggen dat toevoegen van kunstmest of keuze van een goed substraat het effect van plantzakomvang niet teniet kan doen hetgeen zorgvuldig overwogen moet worden bij het opkweken van zaailingen van bomen in kwekerijen.

Hoofdstuk 6 analyseert het gezamenlijke experiment als een proces van meerdere belanghebbenden en heeft tot doel om bij te dragen aan het begrip hoe de wijze van organisatie van sociale leeractiviteiten effect heeft op eigendom van procesuitkomsten van belanghebbenden. We documenteerden het proces middels een combinatie van methoden, onder andere formele en half-gestructureerde vraaggesprekken, analyse van verslagen van bijeenkomsten, deelnemerwaarnemingen en veldbezoeken. De beoordeling van zaailingkwaliteit door belanghebbenden en hun waardering van behandelingen hingen af van het gebruik dat ze maakten van het geproduceerde plantmateriaal. Waar boeren, als eindgebruikers, zaailingvitaliteit naar voren schoven bij de beschrijving van zaailingkwaliteit, onderstreepten kwekerijhouders de productiekosten en gaven aan dat zaailingkwaliteit een compromis was met kosten. Deelnemers, voornamelijk kwekerijhouders, leerden nieuwe productiemethoden van hun collega’s. De discrepantie tussen aanbevelingen vanuit onderzoek en de gebruikerspraktijk werden blootgelegd. Veldwaarnemingen na afloop van het gezamenlijke experiment gaven aan dat kwekerijhouders, het onderzoekcentrum en boeren hun handelen aanpasten. De mate van betrokkenheid van belanghebbenden vergrootte hun betrokkenheid bij en het gevoel van eigendom voor het leerproces en dit zou kunnen leiden tot duurzaamheid van uitkomsten. De opzet van de leergroep droeg bij tot het slaan van een brug tussen de belanghebbenden doordat de belangrijkste spelers in het systeem voor de zaailingvoorziening met elkaar werden samengebracht. De methodologische stappen uit dit onderzoeksproces bleken effectief bij het produceren van snelle en positieve terugkoppelingsmechanismen.

Hoofdstuk 7 vat de belangrijkste onderzoeksuitkomsten samen en bespreekt deze nader. Kleine boeren verkregen niet de zaailingkwaliteit waar ze voor betaalden. De levering van kwaliteitszaailingen aan kleine boeren had vele onderling verweven dimensies zoals door de verschillende studies werd getoond. De meeste stonden buiten directe controle door de boeren. Hoewel het onderzoeksstation zaailingen van constante goede genetische kwaliteit bleek af te leveren, introduceerden verschillende andere actoren in het systeem niet-hybride zaailingen en daarmee werd gezamenlijk een variërende genetische kwaliteit geschapen in het materiaal dat kleine boeren zich aanschaften. De fysiologische kwaliteit van de zaailingen werd bepaald door officiële kwekerijhouders. De sociaal-institutionele omgeving bepaalde het uiteindelijke product dat boeren kochten en lijkt het belangrijkst. Genetische en fysiologische aspecten van kwaliteitszaailingen worden in essentie gevormd door beleid, organisatie van het zaaizaadsysteem, infrastructurele voorzieningen, prijzen van basisproducten, beslissingen van kwekerijhouders, imperfecties in de zaailingmarkt, waarden en voorkeuren van boeren en sociale netwerken en verbintenissen. Analyse van zaaizaadsystemen moet verder gaan dan het uitgangsmateriaal en de beschrijving van de aanwezige dynamiek en de benodigde stappen te nemen om de gerapporteerde zaken aan te pakken. Zaaizaadsystemen vereisen een aanpak die biofysische en sociale studies combineert. Succes of falen van eerdere ingrepen zouden daarbij extra aandacht moeten krijgen bij de analyse van zaaizaadsystemen, en deze studie laat de mogelijkheden hiertoe zien voor meerjarige gewassen. Politieke ecologie is een robuuste aanpak van onderzoek die hierbij gebruikt kan worden. Beleid zou boeren kunnen ondersteunen door het aantal officiële kwekerijen toe te laten nemen in de belangrijkste oliepalm productie gebieden en door boeren organisaties te gebruiken als een middel om de meeste kleine boeren te bereiken. Vervolgstudies zouden de motieven van de leveranciers van niet-hybride plant materiaal moeten onderzoeken, evenals de uiteindelijke effecten van fysiologische kwaliteit van zaailingen op olieproductie in de plantages en methodieken moeten ontwikkelen om de genetische kwaliteit van zaailingen in kwekerijen mogelijk te maken.

RESUME

Intrant agricole de base, la semence de qualité est cruciale pour que les petits producteurs puissent améliorer leur productivité. La semence est la ressource la plus précieuse pour les petits producteurs qui se battent pour leur bien-être dans un environnement aussi difficile. Dans la plupart des pays en voie de développement et pour la plupart des cultures, la qualité de la semence est une préoccupation majeure pour les petits producteurs agricoles. Le secteur semencier informel, caractérisé par une mauvaise qualité de semence, fournit environ 80 % des semences utilisées par les petits producteurs. En effet, le système semencier formel, caractérisé par une bonne qualité de semence, ne parvient souvent pas à satisfaire la demande des petits producteurs. Pour les plantes pérennes, qui passent plusieurs années avant d'entrer en production, et dont les exploitations sont généralement gardées pendant plusieurs décennies, la qualité du matériel de plantation est d'ailleurs plus importante. Pour le palmier à huile, une culture strictement allogame, une bonne productivité requiert l'utilisation de matériel hybride. La qualité génétique des plants du palmier à huile explique plus de 60% de la variation des produits de plantation.

Il existe plusieurs dysfonctionnements qui empêchent les petits producteurs agricoles d'avoir accès au matériel de plantation de bonne qualité. Alors que la littérature est bien documentée pour le système semencier des cultures annuelles, elle est rare pour les plantes pérennes et non existante pour le palmier à huile. Afin de contribuer à combler ce gap, cette thèse a développé une approche d'analyse de performance des systèmes semenciers. Le palmier à huile au Sud-Benin a été utilisé come exemple pour explorer les faiblesses du système et les moyens d'y faire face. L'objectif initial visé à travers cette recherche est : (1) d'identifier les contraintes majeures du système semencier du palmier à huile suivant la perspective des producteurs ; sur la base des contraintes identifiées, nous avons ensuite (2) évaluer la fiabilité de la qualité génétique des plants fournis aux producteurs durant les trois dernières décennies ; (3) évaluer les effets des pratiques de conduite des pépinières sur le développement des plantules à travers une expérimentation conjointe avec les acteurs clés et (4) analyser le processus d'apprentissage conjoint par lequel les pratiques de conduite des pépinières ont été évaluées.

Pour atteindre ces objectifs, nous avons conduit des enquêtes sociales, échantillonné des champs de palmier à huile, mené des expérimentations en milieu réel et documenté le processus d'apprentissage social des acteurs clés impliqués. Les résultats de la présente recherche ont été structurés autour de 7 chapitres.

Dans le chapitre 1, nous avons fourni des informations essentielles sur le palmier à huile au niveau mondial, le rôle de la qualité de semence dans le développent agricole. Nous avons ensuite décrit le problème de recherche. Nous avons donné un aperçu du cadre théorique et de la conception globale de l'étude. Le milieu d'étude a été aussi brièvement introduit.

Le chapitre 2 présente l'étude diagnostique du système semencier du palmier à huile au Bénin. Les caractéristiques du système semencier ont été analysées suivant la perspective des producteurs. Le chapitre 2 montre, d'une part, un secteur semencier informel qui implique les fournisseurs informels de graines germées, les pépiniéristes informels et les producteurs ; d'autre part, un système semencier formel qui implique le centre de recherche sur le palmier à huile, les pépiniéristes formels, les coopératives d'aménagement rural, les services de vulgarisation, les organisations non-gouvernementales, les organisations des producteurs, et les producteurs. Les systèmes semenciers informel et formel sont liés du point de vue des flux de semence, c'est-à-dire, les plants hybrides se retrouvent dans les deux systèmes semenciers. Les acteurs du secteur semencier informel obtiennent de plants hybrides de leurs pairs du système formel. Les quatre principales caractéristiques d'un système semencier suivant la perspective des producteurs sont (1) la qualité physiologique des plants, (2) la qualité génétique et la convenance des palmiers aux usages locaux, (3) l'ajustement de l'offre à la demande, et (4) l'accessibilité physique et financière des plants. La mauvaise qualité physiologique des semences est liée à la vigueur des plants due aux pratiques de pépinière peu adaptées. La qualité génétique et la convenance des palmiers aux usages locaux sont liées à la présence de palmiers non-hybrides au sein du matériel acheté et supposé être composé d'hybrides, l'impossibilité de choisir des cultivars qui donnent une huile beaucoup plus rouge avec de meilleurs attributs de conservation. Le mauvais ajustement de l'offre à la demande est lié au manque de plants pendant la campagne agricole. L'accessibilité physique et financière des plants est liée aux infrastructures routières et le cout élevé des plants. Les contraintes majeures qui en découlent et ayant été identifiées conjointement avec les acteurs clés sont (par ordre de priorité) la mauvaise distribution géographique des pépinières agréées, la présence de palmiers non-hybrides dans les champs des petits producteurs, le cout élevé du matérielhybride, et le mauvais entretien des plants au sein des pépinières donnant des palmiers de mauvaise qualité physiologique. La mauvaise qualité physiologique a été mentionnée dans la partie est du milieu d'étude. Nous avons également investiguer les pratiques des producteurs dans l'acquisition des plants. La confiance, la proximité des

pépinières, et le prix d'achats étaient les principales considérations qui motivent la décision des petits producteurs dans le choix de l'endroit d'achat des plants.

Dans le chapitre 3, nous avons investigué la fiabilité de la qualité génétique des plants livrés aux producteurs comme l'une des études ayant émergé de l'étude diagnostique. Nous avons analysé les principaux facteurs déterminants de la qualité génétique sur les trois dernières décennies en utilisant l'approche "*Event ecology*" pour documenter les événements historiques qui auraient pu affecter le système semencier. Nous avons échantillonné les champs des petits producteurs pour déterminer la qualité génétique du matériel qu'ils ont eu à acheter au cours du temps. Nous avons enregistré les mécanismes socio-institutionnels plausibles qui auraient impacté la qualité génétique des plants que les petits producteurs ont plantés. Nous avons observé que les proportions de palmiers hybrides (*tenera*) varient avec la source d'approvisionnement, la position géographique des producteurs, le prix d'achat des plants, et l'année de plantation. Bien que des proportions élevées de *tenera* aient été observées au niveau des sources d'approvisionnement officielles, d'importants flux de matériels non-hybrides venant de ces sources ont été observées. Les sources informelles ont tout le temps fourni aux producteurs des proportions plus élevées de matériel non-hybrides comparativement aux sources formelles. Comparativement aux différences observées entre sources d'approvisionnement, la proportion de *tenera* a peu varié au cours du temps pour la même source. La proximité des sources officielles d'approvisionnement augmente la qualité génétique du matériel que les producteurs achètent. Plus le prix d'achat des plants est élevé, plus élevée est la qualité génétique. Les champs de palmiers récemment plantés ont montré des proportions élevées de palmiers non-hybrides comparativement aux champs les plus anciens. Les mécanismes socio-institutionnels associés à la variation observée au niveau des plantations des petits producteurs sont le changement de politiques gouvernementales, les arrangements au niveau local pour approvisionner en plants les petits planteurs, et les caractéristiques individuelles des producteurs. Les arrangements locaux ont amélioré la qualité génétique du matériel au niveau des producteurs éloignés des sources formelles d'approvisionnement. Les villages où les initiatives d'approvisionnement en plants se sont estompées ont montré une chute importante de la qualité génétique et les producteurs ont enregistré de faibles proportions de *tenera* le temps d'après. L'ouverture de pépinières informelles par d'anciens pépiniéristes agréés explique aussi la faible qualité génétique. L'appartenance à l'organisation des planteurs de palmier à huile a corrélé positivement avec les proportions de *tenera*. Dans les villages d'étude, les producteurs membres des organisations de producteurs de palmier à huile ont des proportions de *tenera* plus élevées car achetant leurs plants ensemble avec d'autres membres auprès des sources fiables. L'utilisation d'intermédiaires informels par les producteurs affecte négativement la qualité génétique des plants achetés.

Le chapitre 4 a évalué l'efficacité des pratiques de conduite des pépinières sur le phénotype des plants à l'âge de plantation. L'étude a été conduite en milieu réel sur le site d'un pépiniériste agréé, et sous forme d'expérimentation en apprentissage conjoint. Un essai factoriel complet 3 × 4 × 3 avec 36 traitements, a été conduit en 5 répétitions en 2011 et en 2012. Les facteurs et leurs niveaux sont la taille du pot (petit, moyen, grand), type de substrat (substrat de "forêt", gadoue de ville, terre arable, mélange terre arable et fumier), apport d'engrais (non apport, dose fractionnée : apport de 5 g d'engrais tous les 15 jours, dose complète : apport de 10g d'engrais tous les 30 jours). Les variables allométriques (hauteur, nombre de feuilles, longueur de la feuille la plus développée, le diamètre au collet et la production de biomasse) ont été mesurées 8 mois (2011) et 6 mois (2012) après transplantation. Pour chaque essai, seulement un tiers des plants transplantés dans de petits pots et fumés avec de l'engrais à dose complète (tous substrats confondus) ont survécu. A la différence de la production de biomasse en 2011, l'interaction 3 voies entre taille de pot, substrat et apport d'engrais n'était pas significative sur les variables allométriques pour chaque année expérimentale. La taille du pot s'est révélée le principal facteur déterminant le phénotype des plants pour chaque expérimentation. Bien que les grands pots aient produit les meilleurs plants, les pots moyens remplis avec du mélange terre arable et fumier sans apport d'engrais, ont maintenu une bonne croissance des plants et semblent être le meilleur compromis entre qualité physiologique et coût de production. La principale raison est la main d'œuvre additionnelle et le coût de transport des grands pots qui sont plus élevés. Les variables de croissance sont hautement corrélées. La hauteur et le diamètre au collet sont de bons indicateurs qui peuvent être utilisés pour quantifier la biomasse par méthode non-destructive.

Le chapitre 5 a analysé la dynamique de croissance des plants de palmier à huile au niveau de l'expérimentation rapportée au chapitre 4 pour comprendre le mode d'expression des effets de la taille du pot, du substrat, de l'apport d'engrais et leurs interactions avec la croissance végétale au cours du temps. Les observations mensuelles de hauteur, de diamètre au collet et du nombre de feuille de l'expérimentation précédemment mentionnée ont été analysées. En général, pour chaque expérimentation, la taille du pot explique la majeure partie de l'erreur expérimentale, et la variance expliquée à commencer par augmenter plus tôt comparativement au substrat, l'apport d'engrais, leurs interactions à deux et trois voies. La

variance expliquée par le facteur substrat vient en seconde position. La variance expliquée par différents facteurs et interactions au cours du temps a révélé que la taille du pot, le substrat et l'apport d'engrais ont produit des effets assez modestes et similaires sur la croissance des plants au cours des deux premiers mois après transplantation en pépinière. De façon générale, l'effet de la taille du pot augmente avec le temps pour les différentes variables de croissance observées. Contrairement à la taille du pot, les effets du substrat, de l'apport d'engrais et des interactions sont demeurés assez constants durant toute la période expérimentale, expliquant moins de 10% de l'erreur expérimentale lorsqu'ils sont significatifs. L'utilisation des courbes de croissance a révélé différents modèles de croissance pour la hauteur, le diamètre au collet, et le nombre de feuilles. Alors que le modèle de croissance exponentielle était plus conforme pour la hauteur et le diamètre au collet, le nombre de feuille suivait un modèle de croissance linéaire. L'analyse de la vitesse de croissance a montré que les vitesses de croissance absolue et relative étaient principalement affectées par la taille du pot pour chaque année, avec de plus grandes valeurs de F comparativement au substrat, l'apport d'engrais, et les interactions. L'interaction trois voies entre taille du pot, substrat et apport d'engrais n'a pas produit d'effets significatifs pour chaque année expérimentale sur les variables de croissance. Pris ensemble, les chapitres 4 et 5 indiquent que la taille du pot importe pour la croissance du plant. En conséquence, l'ajout d'engrais ou la sélection appropriée de substrat ne permet pas de juguler l'effet de la taille du pot qui doit être considéré avec beaucoup d'attention pour la production en pépinière des plants d'arbre.

Le chapitre 6 a analysé l'essai conjoint comme un processus multi-acteur avec pour but de contribuer à comprendre comment la façon d'organiser l'apprentissage social affecte l'appropriation des résultats par les acteurs clés. Nous avons documenté le processus en utilisant une approche multi-méthode incluant des entretiens informels et semi-structurés, l'analyse des rapports de meetings, l'observation participante et la visite de terrain. La perception des acteurs de la qualité physiologique des plants ainsi que leur appréciation des traitements mis en œuvre varient suivant l'utilisation qu'ils font du matériel de plantation. Alors que les producteurs, utilisateurs finaux, mettent en avant la vigueur des plants en décrivant le plant de qualité, les pépiniéristes mettent l'accent sur les coûts de production et ont rapporté que la qualité du plant est fortement liée avec les coûts. Les participants, en particulier les pépiniéristes ont appris de nouvelles pratiques de production de leurs pairs. La discordance entre les recommandations de la recherche et les exigences du contexte d'utilisation a été révélée. La visite de terrain à la suite de l'essai conjoint a montré des changements de pratiques au niveau des pépiniéristes, du centre de recherche et des producteurs. Le niveau d'implication des acteurs clés a augmenté leur niveau de participation et leur appropriation du processus d'apprentissage ; ce qui pourrait induire des pratiques durables. La mise en place du groupe d'apprentissage à contribuer à rapprocher les acteurs clés en facilitant leur contact. Les initiatives méthodologiques prises dans ce processus de recherche ont montré leur efficacité à produire des changements rapides et positifs.

Le chapitre 7 résume les résultats majeurs de recherche qui sont ensuite discutés. Les petits producteurs du palmier à huile n'obtiennent pas la qualité de matériel pour laquelle ils ont payé. La livraison de semence de qualité au producteur a des dimensions multiples qui sont interconnectées telles que montré par différentes études. La plupart de celles-ci ne sont pas sous le contrôle direct du producteur. Bien que le Centre de Recherche de Pobè continue de livrer des semences de qualité, les différents acteurs du système semencier introduisent de matériels non-hybrides et chacun en ce qui le concerne influence la qualité génétique du matériel que le producteur achète. La qualité physiologique des plants est sous le contrôle des pépiniéristes agréés. L'environnement socio-institutionnel influence la qualité du produit final que les producteurs achètent et semble être le facteur le plus important. Les aspects génétiques et physiologiques de la semence de qualité sont sous l'influence de l'environnement politique, de l'organisation du système semencier, des facilités infrastructurelles, du prix des intrants, du système de décision des pépiniéristes, de l'imperfection du marché des plants, des valeurs et préférences des producteurs, des réseaux sociaux et des liens divers. L'analyse des systèmes semenciers doit aller au-delà de la simple description de la dynamique au sein du système et prendre des initiatives appropriées pour aborder les préoccupations soulevées. L'analyse des systèmes semenciers requiert des approches de recherche qui combinent des études biophysiques et sociales. Les succès ou échecs des interventions passées méritent une attention particulière dans l'analyse des systèmes semenciers. "Political ecology" est une approche de recherche assez robuste qui pourrait être utilisée. Les politiques de développement du secteur palmier pourraient supporter les producteurs en augmentant le nombre des pépinières agréées dans la ceinture de production du palmier à huile, et utiliser les organisations des producteurs pour atteindre la majorité des petits producteurs. Des études futures pourraient investiguer les motivations réelles des vendeurs de plants non-hybrides, les effets réelles de la qualité physiologique du matériel de plantation sur la performance de production des palmiers au champ et le développement des outils de contrôle de la qualité génétique des plants au niveau pépinière.

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PE&RC PhD Training Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (6 ECTS)

- Dynamics in smallholder oil palm sector

Post-graduate courses (7.5 ECTS)

- CoS SIS course; CoS SIS programme (2009)
- The art 0f crop modelling; PE&RC (2013)
- Introduction to R for statistical analysis; PE&RC (2013)

Laboratory training and working visits (1.6 ECTS)

- Variation in oil palm; Cirad (2010)

Invited review of (unpublished) journal manuscript (2 ECTS)

- Bulletin de la recherche agricole du Benin: evaluation des effets de doses de compost et la couverture du sol sur le rendement et la rentabilité de l'ananas (Ananas comosus) au Sud-Bénin (2012)
- Bulletin de la recherche agricole du Benin: evolution et contraintes de la production et de la commercialisation de l'oignon au Nord-est du Bénin (2012)
- African Journal of Agricultural Research: Integrating the Formal and Informal Wheat Seed Supply Systems to Improve Farmers' Access to Modern Cultivars in East Gottam Zone of the Amhara Region, Ethiopia (2013)

Deficiency, refresh, brush-up courses (3 ECTS)

- Advanced crop physiology (2009)
- Innovation management and cross disciplinary design (2009)
- The methods, techniques and data analysis of field research (2009)
- Basic statistics (2013)

Competence strengthening / skills courses (4.5 ECTS)

- Competencies for integrated agricultural research; WGS (2009)
- PhD Competence assessment; WGS (2010)
- Scientific publishing; WGS (2013)
- Techniques for writing and presenting a scientific paper; WGS (2013)
- Data management; WGS (2013)
- Career assessment; WGS (2013)

PE&RC annual meetings, seminars and the PE&RC weekend (1.5 ECTS)

- PE&RC Day (2009)
- PE&RC Weekend (2010)
- WASS Day (2013)

Discussion groups / local seminars / other scientific meetings (7.5 ECTS)

- CoS-SIS Seminar; Wageningen, the Netherlands (2009)
- CoS-SIS Seminar; Bamako, Mali (2010)
- CoS-SIS Seminar; Accra, Ghana (2011)
- CoS-SIS Seminar; oral presentation; Cotonou, Benin (2012)
- CSA Seminars (2010, 2013)
-

International symposia, workshops and conferences (9 ECTS)

- CoS-SIS Convergence of Sciences Workshop; oral presentation: A participatory diagnostic study of the oil palm seed system in Benin; Cotonou, Benin (2010)

- “3eme Colloque de l’UAC des Sciences, Cultures et Technologies”; oral presentation: analysis of production constraints of oil palm; Abomey-Calavi (2011)
- CoS-SIS Convergence of Sciences Workshop; oral presentarion: addressing technical and socio-institutional issues to improve the oil palm seed system in Bénin; Bamako (2011)
- Oils and Fats International Congress (OFIC); poster presentation: supply of hybrid oil palm seedlings to smallholder farmers in Bénin: current stat and institutional support needed to sustain genetic quality of seedlings; Kuala Lumpur Convention Centre (2012)
- CoS-SIS Convergence of Sciences Workshop; oral presentation: drivers of a reliable oil palm seed system; Cotonou, Cape Coast (2012)

Supervision of 1 MSc student (3 ECTS)

- Analysis of production constraints of oil palm: case of physiological quality and sanitary state of seedling in Sakété district

ABOUT THE AUTHOR

Essegbemon AKPO was born in Ouessè, Republic of Bénin, on October 13, 1977. In 1998, he completed his senior high school education. He joined the "Faculté des Sciences Agronomiques" of "Université d'Abomey-Calavi" where he studied agriculture, with a major in Crop Science. He obtained his Engineer degree in Agronomy in 2003 and his thesis was about characterisation of allelopathic effects of *Justicia anselliana*, a depressive cowpea weed in Ouémé valley, Bénin. From 2004 to 2005, he worked as research assistant under the Convergence of Science for better Management of Crops and Soils (CoS) project. He was involved in design and implementation of field experiments, data collection and household surveys. During his research assistantship, he was awarded a scholarship by the CoS project and did his "Diplome d'Etudes Approfondies" (DEA) (equivalent of MSc degree) in plant genetic resources and crop protection. For his DEA thesis, he investigated the biological control of cotton bollworms in Northern Bénin. In 2006, he taught a general agronomy course at "Université Catholique de l'Afrique de l'Ouest". From 2007 to 2009, he was hired as Junior Researcher by the Bénin National Agricultural Research Service where he served in the oil palm breeding programme "Centre de Recherche Agricole - Plantes Pérennes". In this position, he was mainly involved in oil palm seed germination and design of experiments to improve seed germination rate. He was also involved partly in breeding activities. Since March 2009, he joined Wageningen University for his PhD where he carried out an interdisciplinary research within the Convergence of Science for Strengthening Agricultural Innovation Systems program, funded by the Dutch government. His PhD work is about analysis of the performance of the oil palm seed system in Bénin. He carried out diagnostic surveys and conducted field experiments on the physiological quality of oil palm seedlings. Through these experiments, he analysed growth dynamics of oil palm seedlings during their nursery phase. His PhD research is entitled: *Analysing seed system performance: the case of oil palm in Bénin*. His PhD was conducted within the Centre for Crop Systems Analysis group and Knowledge, Technology and Innovation Group of Wageningen University. He did his PhD jointly with "Université d'Abomey-Calavi".

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WHAT IS CoS-SIS?

Definition and Purpose

Convergence of Sciences-Strengthening Innovation Systems is an action research programme in Benin, Ghana and Mali. It carries out scoping and diagnostic studies, agrarian system analyses and participatory field experiments with innovation platforms at the local, district and national levels. Its purpose is to identify pathways for creating opportunity for smallholder farmers in West Africa. Focusing on the enabling conditions at levels higher than the field and farm, the Programme supports sustainable intensification of smallholder farming for food security.

Partners and Funding

CoS-SIS is a partnership among the *Université d'Abomey-Calavi* at Cotonou, Benin; the *University of Ghana* at Legon, Ghana, and the *Instut Polytechnique Rural de Formation et Recherche Appliquée*, at Katibougou, Mali; and *Wageningen University*, and the *Royal Tropical Institute* in the Netherlands. It is funded to a total of € 4.5 million for six years (end 2008-mid 2014) by Dutch International Cooperation.

History and future

CoS-SIS is the second phase of CoS. CoS1 (2001-2006) focused on participatory technology development (PTD) in Benin and Ghana. It showed that smallholders can capture only limited benefits from even the best-adapted and appropriate technologies because of their constrained opportunities. Hence CoS1 researchers started to experiment with institutional change (in addition to their agronomic work). Their early results inspired CoS-SIS in that they convincingly demonstrated that institutional change is both important and feasible. CoS-SIS is currently supporting CORAF in implementing its IAR4D strategy with its West African partners.

Personnel

CoS-SIS employs eight post-doc Research Associates (RAs), recruited part-time from national research organisations and universities, and nine African Ph.D. researchers. Some of the RAs are graduates of the COS1 programme. The RAs facilitate Concerted action and Innovation Groups (CIGs) (multi-stakeholder platforms composed of key actors in an agricultural domain) at the district and national levels to experiment with institutional change. The Ph.D. researchers work at community level with groups of local people to analyse constraints and experimentally develop livelihood opportunities. The doctoral research feeds into the deliberations of the CIGs. The work is overseen by National, Regional and International Programme Coordinators, who together form the Programme Management Committee (PMC). Responsibility for each country programme rests with a Programme Management Team (PMT) composed of senior representatives of universities, ministries, R&D organisations, the private sector, NGOs and FBOs. The PMTs and coordinators are proving to be high-level networkers and important advocates of the institutional change initiated by the CIGs and PhDs.

Domains reflect national priorities

- *Benin*: cotton, oil palm (inter-cropping oil palm and annual crops, and the oil palm seed system) and integrated water management (agro-pastoral dams in the North, and rice production in valley bottoms in the South);
- *Ghana*: palm oil and cocoa (work in the domain of small ruminants ended when the RA was promoted to another location by his home organisation);
- *Mali*: integrated water management, integration of crop and livestock production (both in the Office de Niger), and shea butter (*karité*).

Key activities

- Identifying key constraints that specific categories of smallholder farmers and processors experience when trying to improve their livelihoods and incomes through productive or value adding activities.
- Identifying and researching the institutional reasons for the constraints at the local and higher system levels.
- Identifying key actors, networks and mechanisms that maintain the constraints, as well as entry points for action to by-pass, or transform the institutional context to overcome them.
- Assembling multi-stakeholder platforms of key actors who can be expected to engage in institutional change in their respective domains.
- Enabling platform actors to experiment with institutional arrangements.
- Institutionalising achievements in university curricula, the programmes of research institutes, government policies, the structure of agricultural industries, and arrangements among enterprises and services and in value chains.
- Researching the processes of change and the work of the CIGs by means of real-time monitoring and a form of modified causal process tracing, based on two declared theories

of change (intervention theory focused on internal and external activities and relationships of the CIGs; and power theory, focused on networks that have power to change or maintain institutional contexts linked to each domain).

- Ensuring that the outcomes of the action research are published and disseminated through international scientific media, and shared with local, national, and regional government agencies and political decision makers.