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Co-designing innovative cropping systems that match biophysical and socio-economic diversity: The DATE approach to Conservation Agriculture in Madagascar, Lao PDR and Cambodia

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Abstract

Rapid changes in agricultural systems call for profound changes in agricultural research and extension practices. The Diagnosis, Design, Assessment, Training and Extension (DATE) approach was developed and applied to co-design Conservation Agriculture-based cropping systems in contrasted situations. DATE is a multi-scale, multi-stakeholder participatory approach that integrates scientific and local knowledge. It emerged in response to questions raised by and issues encountered in the design of innovative systems. A key feature of this approach is the high input of innovative systems which are often although not exclusively based on conservation agricultural practices. Prototyping of innovative cropping systems (ICSs) largely relies on a conceptual model of soil–plant–macrofauna–microorganism system functioning. By comparing the implementation of the DATE approach and conservation agriculture-based cropping systems in Madagascar, Lao PDR, and Cambodia, we show that: (i) the DATE approach is flexible enough to be adapted to local conditions; (ii) market conditions need to be taken into account in designing agricultural development scenarios; and (iii) the learning process during the transition to conservation agriculture requires time. The DATE approach not only enables the co-design of ICSs with farmers, but also incorporates training and extension dimensions. It feeds back practitioners' questions to researchers, and provides a renewed and extended source of innovation to farmers.

Key words: Co-design, innovation, Step-by-step design, learning process, participatory approach, Tropical conditions, Direct seeding mulch-based cropping systems (DMC)

Introduction

Global agricultural systems are currently undergoing rapid changes. The acknowledged responsibility of agriculture for environmental degradation, changes in the demand for food and non-food products, the globalization of trade leading to fluctuations in the prices of farm products and the changing role of agriculture in territories, are major driving forces which require a shift toward new production systems (Meynard et al., 2012). These changes in farming systems will not happen without tension: Tension between economic and environmental objectives, tension between the individual farmers' strategies and territorial governance, and tension between supply chains (Meynard et al., 2012).

Today, conservation agriculture (CA) techniques pave the way for cropping systems which combine sustainability and profitability in contrasted agro-economic contexts. CA is based on three main principles: (i) minimum soil disturbance, (ii) permanent soil cover and (iii) crop rotations/associations (Kassam et al., 2009). Conservation agricultural systems represent a break with conventional practices. Today, farmers throughout the world face a wide range of situations and significant variability in the efficiency of CA systems (Erenstein, 2003; Lestrelin et al., 2012a). Farmers' access to production factors (land, capital, labor, inputs, mechanization, and knowledge) varies greatly not only between countries, but also between regions and even between different types of farms in one country. For these reasons, cropping systems need to be tailored to local conditions, a range of different agricultural systems needs to be co-designed with the farmers at field, farm, and landscape scales, and supporting measures need to be developed to accompany agricultural extension activities.

Before designing conservation agriculture-based cropping systems, we implemented a multi-scale multi-stakeholder participatory approach called DATE, for Diagnosis, Design, Assessment, Training and Extension, in Brazil in the 1990s, on-farm, with and for farmers (Séguy et al., 1998, 2006). Based on the experience we gathered in Brazil, we gradually adapted this approach to contrasted biophysical and socio-economic contexts in Madagascar, Tunisia, Lao PDR, Cambodia and Cameroon. In this paper, using the examples of Madagascar, Lao PDR and Cambodia, we show how these conservation agriculture-based cropping systems were co-designed and adapted to local conditions, and how this innovation process provided researchers with feedback and questions from the field, and farmers with a renewed and extended source of innovation.

Materials and Method

Study sites

We selected two regions in each of the three countries: Madagascar, Lao PDR and Cambodia, to enable a comparative analysis of the performance of the DATE approach in the different contexts. The research sites were characterized on the one hand by their similar small- or medium-scale family-based agriculture and their wet tropical climate and, on the other hand, by their contrasted bio-physical and socio-economic conditions (Tables 1 and 2).

In Madagascar, small-scale family-based agriculture focuses on production for self-consumption, with self-sufficiency as main objective in a context of poor access to markets and to production factors. In contrast, in Lao PDR and Cambodia, family-based agriculture is adapting to mechanization and beginning to access local and regional markets, but in an erratic economic environment involving changing opportunities.

The DATE approach

DATE principles. DATE is a method for co-designing and evaluating cropping systems. The agronomic, technical and economic potential of a wide range of innovative cropping systems (ICSs) were compared with conventional practices over time, in successive loops of experimentation, demonstration and on-farm testing in a network of farmer managed plots (Séguy et al., 1998, 2006; Jullien et al., 2010; Lienhard et al., 2010; Boulakia et al., 2012). DATE builds on the complementarity between different approaches such as Farming Systems Research and Extension (Collinson, 2000), Farmer First (Chambers and Ghildyal, 1985) or 'Unités Expérimentales' (Reboul, 1973). Like other recently developed methods, including Design and Assessment of Innovative Sustainable Cropping Systems (DISCS) (Le Bellec et al., 2012) and Reflexive Interactive Design (RIO) (Koerkamp and Bos, 2008), DATE is a multi-scale, multi-stakeholder participatory approach which integrates scientific and local knowledge. In addition, DATE relies on a large range of innovative systems, often in rupture with conventional practices, and combines *de novo* innovation through expert-based prototyping, keeping the range of possible options wide open, and a step-by-step design process, favoring adaptation and learning (Meynard et al., 2012).

DATE is a holistic approach based on four main components: a diagnosis and three loops of cropping system design (Fig. 1).

The diagnostic stage is conducted by the research team, interviewing and involving multiple stakeholders: individuals and groups of farmers, village authorities, service providers, traders and local policy-makers. The diagnosis is based on the synthesis of available information (as soil maps or production statistics) and opinions combined with farming systems assessment, including visual observation of soil erosion, weed pressure, availability of fodder resources, remaining buffer zones in the landscape, etc. It leads to the identification of the constraints and opportunities, as well as the needs of the actors concerned.

Table 1. Main characteristics of the six study sites (Madagascar, Lao PDR and Cambodia).

Country	Madagascar		Lao PDR		Cambodia	
Study area	Alaotra region Mid-east	Mid-west	Xieng Khouang	Sayaboury	West Battambang + Pailin	Kampong Cham
Area concerned by the cropping systems	Potentially 2 million ha in uplands		80,000 ha	140,000 ha	>400,000 ha rainfed uplands	40,000 ha
Altitude (m a.s.l.)	750–1100 m	600–1200 m	900–1100 m	150–600 m	50–250 m	50–100 m
Climate						
Rainfall (mm yr[1])	800–1400 mm 7 month dry season	600–1500 mm 7 month dry season	1400 mm 6 month dry season	1000–1200 mm Bimodal, 5 dry months	1200–1400 Bimodal, 5 dry months	1200–1800 Bimodal, 5 dry months
Average temperature	20°C (4 month cool season)	20°C (4 month cool season)	20°C (4 months cool season)	25–26°C	27°C	27°C
Soils						
Soil type (FAO)	Ferrasol, Acrisol	Ferrasol	Oxisol	Nitisol, Ferrasol, Vertisol, Mollisol	Oxisol, Vertisol, Mollisol	Oxisol, Vertisol
Soil texture	Clay Silty clay	Clay Silty clay	Clay sandy	Clay sandy Clay silty	Varied	Clay
Soil organic matter (0–10 cm)	<1.5%	1–2%	3–6%	1.7–5%	≤2–3%	2–3%, 3–4%
Soil pH	5.5–6.0	5.5–6	4.0–5.5	4.5–6.5	4.0–8.0	4.5–5.5

The diagnosis involves a multi-scale analysis of the agricultural context (GSDM, 2007):

- At the plot level: technical description of the existing cropping systems, including agronomic and economic performances.
- At the farm level: analysis of existing production systems (including livestock and forest activities and their interactions), and identification of farmers' constraints, opportunities and objectives.
- At the village and regional levels: evaluation of market opportunities and price fluctuations, the availability and cost of agricultural inputs and labor and opportunities for off-farm activities.

A typology of possible users of innovative agricultural systems and the definition of their main objectives, constraints and opportunities are part of this diagnosis. Market imperfections and the lack of clearly defined land tenure are identified as they are often a major constraint to the dissemination of conservation agriculture and consequently need to be taken into account right from the beginning of the design of cropping system (Balarabe et al., 2011). The objectives to be reached to improve local production systems are ranked in order of priority jointly by researchers, technicians and farmers as proposed by Vereijken (1997) and specifications for ICS are then drawn up.

On this basis, a large range of cropping system has been designed and tested at different scales, based on three successive learning loops. For example, on the most favorable agronomic unit in the Alaotra region, 40 cropping systems were tested (first loop) and 24 systems were selected for the second loop (Husson et al., 2013a). The main systems proposed in each study area are summarized in Table 3.

DATE research loops. The first loop is conducted by researchers in experimental plots. Innovative systems based on agro-ecological functions are introduced in a matrix structure. A matrix combines: (i) different crop/cover crop successions, associations and rotations; (ii) different soil management practices, usually conventional plowing versus direct seeding; and (iii) different fertilization levels.

The cropping systems are selected on the basis of expert knowledge (Naudin et al., 2010; Husson et al., 2013a; Naudin et al., 2015) and meta-rules developed by the research team, based on its experience: (i) cropping systems are based on the main staple and cash crops in each region/location; (ii) cropping systems aim at optimizing the main crop production while increasing total biomass production and diversity through cover crops; (iii) cover crops are chosen based on the ecological services they can provide (as contribution of cover crop biomass to carbon (C) sequestration, effect of root systems on soil structure improvement, nitrogen (N) fixation, contribution to nutrient mobilization and recycling, pest control, stimulation of biological activity) and on the practicability of the cropping systems (availability of manpower, machinery, inputs, etc.).

The matrixes are implemented in situations that are representative of the target agro-ecosystem as far as climate, soil characteristics and the water regime are concerned. In these matrixes, the range of options tested is not restricted beforehand. Although most of the systems

Table 2. Main agricultural features of the six study sites (Madagascar, Lao PDR and Cambodia).

Country	**Madagascar**		**Lao PDR**		**Cambodia**	
Study area	**Alaotra region Mid-east**	**Mid-west**	**Xieng Khouang**	**Sayaboury**	**West Battambang + Pailin**	**Kampong Cham**
Type of agriculture	Small-scale family-based agriculture		Small- to medium-scale family-based agriculture		Small- to medium-scale family-based agriculture	
Main crops	Rice, maize, cassava, pulses	Rice, maize, cassava, pulses	Rice, maize, pasture (livestock)	Maize (rapid increase), rice bean, sesame, rice (in lowlands)	Cassava, maize in uplands	Rainfed lowland rice, Rubber and banana (oxisol); Cassava (vertisol)
Main biophysical constraints	Soil degradation (Erosion and low fertility)	Striga, soil degradation (compaction and low fertility)	Acidic soils, low fertility, aluminum toxicity	Soil degradation (erosion and depletion of soil fertility)	Soil degradation (erosion and depletion of soil fertility)	Low soil fertility
Livestock systems	Moderate to high pressure on biomass and conflicts (western shore)	Moderate to high pressure on biomass (bush fires)	Moderate pressure on biomass: extensive grazing on native pastureland	Animal feed (Maize)	Low pressure on biomass	Low-to-moderate pressure on biomass
Integration to market	Subsistence agriculture Limited rice market	Subsistence agriculture	Transition to market-oriented	Market-oriented (Thailand), food processing (rice–bean; Sesame)	Transition to market-oriented (Vietnam) Animal feed and bioethanol	
Access to capital	Very limited (Usury)	Very limited (Usury)	Medium	Medium to good, through traders	Possible through microfinance institutions, but high cost (3–4%/month) not possible for cassava; Usury	
Access to inputs and seeds	Limited and expensive	Very limited and expensive	Medium	Through contractors	Easy and competitive	Easy and competitive
Access to land	Insufficient land security Land shortage	Insufficient land security	Good in the Plain of Jars	Good, but price of land increasing due to rush to grow maize	Mature pioneer front: no more land to reclaim—high price	Limited in smallholders agro-ecosystems (rice plains, upland vertisol)
Access to information	Limited to rural development projects	Very limited, through development projects	Medium	Good	Fragmented (NGO), but poor advice on upland crops management	
Access to labour	Family + hired	Family (lack of available manpower)	Family	Family + hired, with increasing cost	Family + hired with deficit at harvest	Family + hired
Mechanization	Manual agriculture and animal traction		Two-wheel tractors	Four-wheel tractors (contractors)	Two-wheel tractors + contract (plowing)	Two-wheel and four-wheel tractors (contractors)

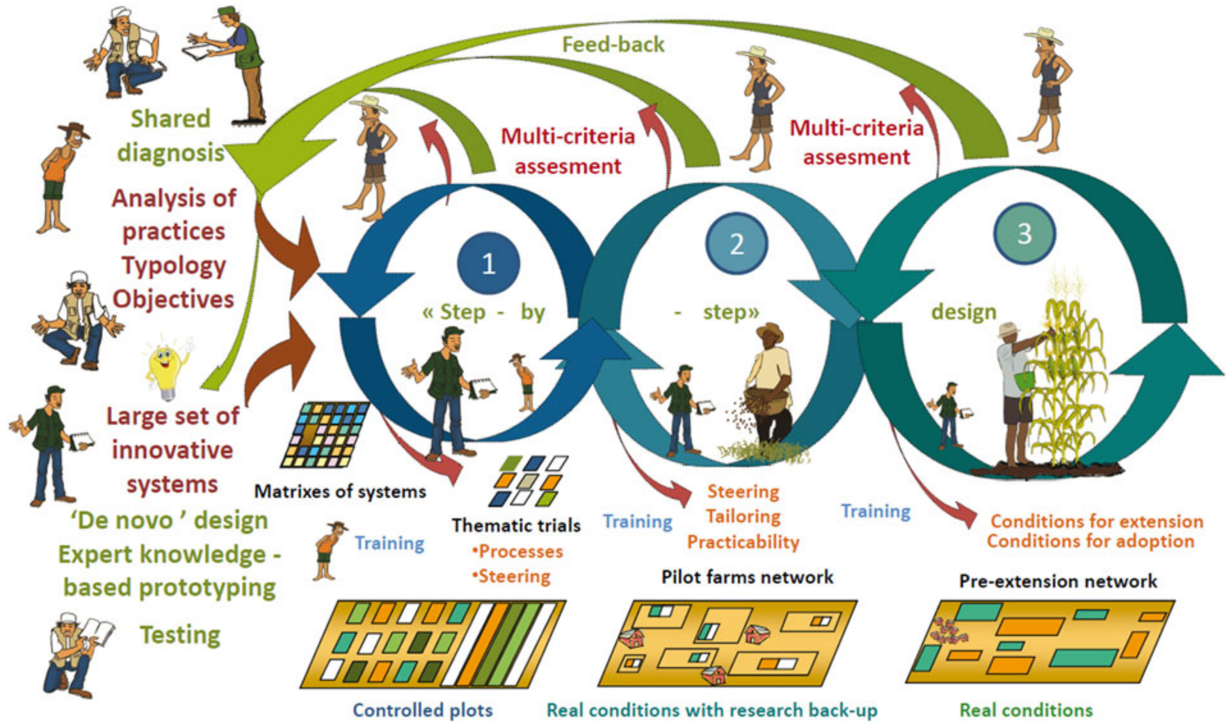

Figure 1. The DATE approach and its three loops of improvement in cropping systems.

tested are based on crops of major economic interest grown by farmers in each agro-ecological region, they nevertheless represent a break with traditional local practices. Other crops are introduced in the first loop as they may become relevant in the future. This broadens the existing range of options and anticipates changes and adaptation of research results in a rapidly changing economic environment. The primary aim of the systems tested is to overcome the main constraints and to achieve the main objectives identified during the diagnostic and evaluation phases. The degree of intensification of the cropping systems is based on increasing use of inputs, labor, investments, equipment, etc. This makes it possible to tailor alternative systems to farm specificities, in relation to the farm typology constructed during the diagnostic phase. The cropping systems tests are conducted in small plots (200 m^2) with no replication in a given matrix. One or two of the reference farmers' practice(s) may be replicated to check for a possible gradient in soil or water conditions. At this stage, evaluation of the performance of the systems is simply based on yield, production costs and practicability. In parallel, thematic trials are conducted with randomized replications for statistical analysis. The themes of these experiments are determined by the systems to be tested. Their aim is to: (1) improve knowledge of the processes, especially ecological processes, that can be mobilized for ecological intensification of the systems and impacts of the cropping systems as for example biomass inputs, C and N changes or soil biological activity (Rabary et al., 2007; Lienhard et al., 2013a, b; Tivet et al., 2010); and (2) increase know-how for the management of the systems, and hence for the incremental improvement/adjustment of the systems that are designed in the first loop, with mainly test of species/varieties, spatiotemporal organization of the plants (sowing date, density, arrangement, etc.) and/or integrated pest control methods. The information obtained in these thematic trials is immediately used to propose improved systems/practices to be tested the next season in the first loop.

The second loop takes place in farmers' fields, at real scale (1000–10,000 m^2), where the most promising systems are tested by farmers in collaboration with researchers. This loop may involve demonstration plots implemented by farmers under the direction of the researchers, or farmers' plots assisted and supervised by researchers. The systems tested in this loop are selected during field visits by farmers and researchers to the research matrixes, to check their performance and their ability to match the means and goals of the farmers. In this second loop of improvement, information is collected on practicability and management principles. For example, the feedback provided by farmers in this second loop was particularly useful to adapt: (i) the sowing method of the cover crop: broadcasting or using planters; and (ii) the sowing period of the cover crop: together with the main crop in association, some weeks after in relay planting or after the harvest in succession. The prerequisites for the integration of ICSs into the farming systems are identified so the cropping systems can be tailored to the specific conditions of the farm. A network of pilot farms is selected to represent the main

Table 3. Main cropping systems designed, promoted and/or adopted by farmers.

	Madagascar		Lao PDR		Cambodia	
Loops, main evaluation criteria and *feedback*	**Alaotra region Mid-east**	**Mid-West**	**Xieng Khouang**	**Sayaboury**	**West Battambang + Pailin**	**Kampong Cham**
First loop Yield, production cost, practicability In selected systems: Biophysical changes: soil organic C & N; bulk density, water infiltration, soil aggregation, soil biological activities *Technical adaptation of the systems at plot level*	1998–2010 Stylosanthes-based cropping systems (rice, maize, cassava) Maize + legume//rice Maize//rice on Pinto cover rice/vegetable; rice /Vetch; rice/ Dolichos; rice/ Crotalaria Maize + brachiaria// Rice Maize + Cajanus//Rice Maize + Crotalaria// Rice Cassava + Brachiaria Pasture (*Brachiaria* sp.) Green bean//soyabean on Cynodon dactylon living cover Soil smoldering practices	1998… Stylosanthes-based cropping systems (rice, maize, cassava) Maize + cowpea// rice Maize + Dolichos//rice Maize + rice-bean//rice Maize and rice in rotation on Pinto cover Maize + finger -millet//rice Maize + finger millet + Cajanus//rice	2003–2009 Improved pastureland (ruzi, stylo) Rice on native pasture + ruzi grass First year of soil improvement: different mix with ruzi, pigeon pea, stylo, finger millet Followed by a 3-year rotation: Rice + stylo//maize + finger millet, or stylo, or ruzi//soybean + oat + buckwheat	2003–2009 Maize monocropping (residues management) 2-year rotation: • Maize//rice–bean • Maize + ruzi// rice–bean Maize + centro Intercropping: maize + rice–bean	2009… 2-year rotation: • Maize + pigeon pea// Soybean + sorghum + sunnhemp • Maize + pigeon pea// Cassava • Early maize + sunnhemp + finger millet/ dry season cassava//maize + pigeon pea • Maize + pigeon pea// rice + stylo	2004… 2 year rotation: • Maize + stylo// soybean + sorghum + sunnhemp • Maize + stylo// Cassava • Early maize + sunnhemp + finger millet/dry season cassava// maize + pigeon pea + stylo Maize + stylo//Rice + stylo
Second loop Practicability: cropping calendar, machinery, cover crop and weed management, labor requirement, production costs, gross and net income, labor profitability, risk *Technical and organizational adaptation of the systems at plot and farm level*	2003–2010 Cassava + Stylosanthes Maize + cowpea + Dolichos Rice + green bean + Vetch	2006… Stylosanthes-based cropping systems (rice, maize) Maize + Cowpea// Rice	2005–2009 Improved pastureland Rice on native pastureland	2004–2009 Maize under no-till Maize/rice–bean	2010… Intercropping maize + stylo, maize + rice–bean, maize + pigeon pea	2005–2012 Cassava + stylo
Third loop	2003…	2005…	2007…	2005…	2010…	2010…

Table 3. (*Cont.*)

Loops, main evaluation criteria and *feedback*	Madagascar		Lao PDR		Cambodia	
	Alaotra region Mid-east	Mid-West	Xieng Khouang	Sayaboury	West Battambang + Pailin	Kampong Cham
Technical and economic performances, adoption rate per system, abandon rate and reasons *Determinant for adoption: access to information, training, knowledge sharing, access to land and machinery, financial requirements and measures to be tested: involvement of service providers, supply chain for cover crop…*	Rice in rotation with maize + cowpea + Dolichos Rice/Vetch	Stylosanthes-based cropping systems (rice, maize, cassava)	Improved pastureland	Maize under no-till Maize/rice–bean Intercropping maize + rice–bean	Chisel cassava, expected rotation with maize Maize under no-till and maize + pigeon pea	Chisel cassava + stylo

ruzi, *B. ruziziensis*; stylo, *S. guianensis*; pigeon pea, *C. cajan*; finger millet, *Eleusine coracana*; sunnhemp, *Crotalaria juncea*; buckwheat, *Fagopyrum esculentum*; rice-bean, *V. umbellata*; centro, *Centrosema pascuorum* cv. cavalcade. Vetch, *Vicia vilosa*. Pinto, *Arachis pintoi*. Dolichos, Lab Lab Purpureus.

farm types identified during the diagnosis phase. In these pilot farms, farmers choose, implement, manage and adapt the best systems. This network is closely monitored by researchers, to provide useful information on economic performances and on the conditions required for the adoption of these systems.

Finally, the third loop takes place through a network of pre-extension, managed by extension agents with back up from the researchers. In this third loop, analysis of farmers' adoption and adaptation of cropping systems provides researchers with precious feedback about how to improve the cropping systems. At this stage, a detailed record is kept of costs, labor requirements and economic performances of a sub-sample of representative farms. Any changes in technical and economic performance are assessed in real conditions and the constraints to adoption are reviewed with the aim of identifying and testing measures to facilitate the dissemination process and to scale dissemination up to regional or national levels (Lestrelin et al., 2012a, b).

The integration of these three loops in a holistic innovation approach feeds the overall learning-by-doing process. At all levels, multi-criteria evaluation feeds the successive loops of technical adjustment and improvement (Fig. 1). This feedback process relies on in-depth continuously updated understanding of the farmers' socio-economic conditions and decision-making process.

Farmers' adaptation of the direct seeding mulch-based cropping systems (DMC) proposed by researchers into ICSs that only partially respect DMC principles if need be, is an integral part of the innovation process that characterizes the DATE approach. Similarly, exchanges between and the training of all the stakeholders (farmers, extension agents, researchers, policy-makers, service providers and traders) are favored by this multi-scale network and are also an integral part of the process. Modes of interaction between researchers (specialists and agronomists), extension staff and farmers are diverse. They are based on field days, interactions amongst farmer groups, regular exchanges during the cropping season on soil and crop management, and group discussions of the results, during and after the cropping season. This provides information on the perception of the innovations by farmers, their strengths and constraints, as well as needs and possibilities for improvement to be tested the next season. During field days, exchanges are also made on the 'soil health' comparing soil color, aggregation, soil biological activities (macrofauna and fungi) between contrasted cropping systems. Discussions also cover the accessibility and use of machinery and cover/relay crops.

The diversity of systems designed (Table 3) and the capacity to integrate feedback from farmers, on a short-term process, illustrate the flexibility of the DATE approach. A major driver of this approach is the constant need for information from agronomists, extension staff and farmers in order to improve and update in 'real time' the technological, systemic and organizational innovations and to keep them in line with the evolving biophysical, socio-economic and political context.

Capacity building as part of DATE approach. Capacity building of agronomists and extension staff is a key component of DATE (GSDM, 2007; Jullien et al., 2010a; Khamhoung et al., 2010). They are continuously trained, on the choice, setting up, management and fine-tuning of DMC. The learning process is based on five criteria: (i) it is anchored in real situations; (ii) its performance is closely linked to the action; (iii) it takes into account the diversity of knowledge of each participant; (iv) it includes practical, analytical (assessment of changes in soil biological activity or soil aggregation among others) as well as theoretical aspects explaining and justifying new practices; and (v) it is organized in successive modules, each module having a particular significance. Follow-up is organized to assess if training induced changes in practices and behavior, and to know the difficulties encountered in their implementation.
Experimental sites and the reference farms are used as training fields for all stakeholders, learning in various ways such as: (i) researchers and students implementing the research program; (ii) extension staff learning from the matrixes and from exchanges with farmers; (iii) policy makers and local traders during field days; and (iii) farmers learning by doing and accessing information during the many interactions with researchers, extension staff and the farmer group meetings.

DMC systems

A key feature of the DATE approach is its capacity to support the co-design, testing and dissemination of ICSs based on conservation agricultural (CA) practices. More specifically, DMC systems are part of the family of practices known as CA (Kassam et al., 2009). DMC systems aim at ecological intensification, which is defined as the use of biological regulation in agro-ecosystems to achieve a high level of agricultural production while providing ecosystem services (Dore et al., 2011). Mimicking the functioning of a forest ecosystem, they consist in introducing multifunctional cover crops in rotation or in association with the main crop, whenever climatic conditions (rainfall and temperature) make this possible (Séguy et al., 2006). Whenever sufficient space or time is available, these plants are included in the cropping system to increase biomass production and provide ecosystem services (Séguy et al., 2006; Naudin, 2012; Husson et al., 2013a). This leads to better use of available natural resources throughout the year, permanent soil protection, and higher biomass production and the restitution of organic matter (Husson et al., 2006; Séguy et al., 2006; Kassam et al., 2009).

Prototyping of innovative DMC systems uses a conceptual model of soil–plant–macrofauna–microorganism system functioning (Fig. 2). In this model, plants, litter, soil organic matter, soil macrofauna and soil microorganisms are considered as agents, which operate in multiple interactions and trigger ecological processes. Indirectly, these agents fulfill the main ecological functions required for production: improvement of soil structure, plant nutrition and weed and pest control.

DMC systems are based on the assemblage of plants with the functional traits required to activate ecological processes and fulfill the main functions required for production, targeting first the functions that exhibit most constraints in each particular situation. To increase crop production, DMC systems deliberately aim to modify the agro-ecosystem (e.g. soil conditions and biological regulation) by mobilizing living agents. This aim is what differentiates DMC from conventional practices, which rarely try to mobilize natural ecological regulation.

The changes sought in the agro-ecosystem also help optimize the expression of the genetic potential of the species and varieties included in the cropping systems. Thus, optimization of cropping practices is often implemented in synergy with breeding programs (Vales et al., 2009).

In this conceptual model of soil–plant–macrofauna–microorganism system functioning, the quality of the biomass (i.e. the species involved) determines the type of ecological services provided, while the quantity of biomass determines the intensity at which these ecological services will be provided (Séguy et al., 2006; Scopel et al., 2013). Recognition of the importance of biomass production and restitution in ecological processes helps define the recommendation domain of conservation agriculture.

However, managing multiple agents which interact with each other with the aim of modifying the environment requires deep knowledge of ecological processes and a good mastery of management options. Experiments in the implementation of DMC show that there is a clear need for co-learning by all stakeholder groups (i.e. farmers, practitioners, researchers, service providers, traders and policy makers) and acknowledgement of the fact that the adoption, adaptation, dissemination processes require time (Giller et al., 2009; Castella, 2012). This learning process is explicitly addressed in the DATE approach.

Experimenting the DATE approach

In Madagascar, the DATE approach has been used in Alaotra (mid-east region) and west of Vakinankaratra (mid-west region), since 1998. In the first stage, the DMC systems were designed and tested in controlled environments and in demonstration plots in farmers' fields (first and second loops). Large-scale extension (third loop) was organized in the framework of two rural development projects: 'BV Lac Alaotra' which began in the Alaotra region in 2003, and 'BVPI–SEHP' in the mid-west region, which began in 2006. In 2009, DMC was being practiced by 5000 farmers on more

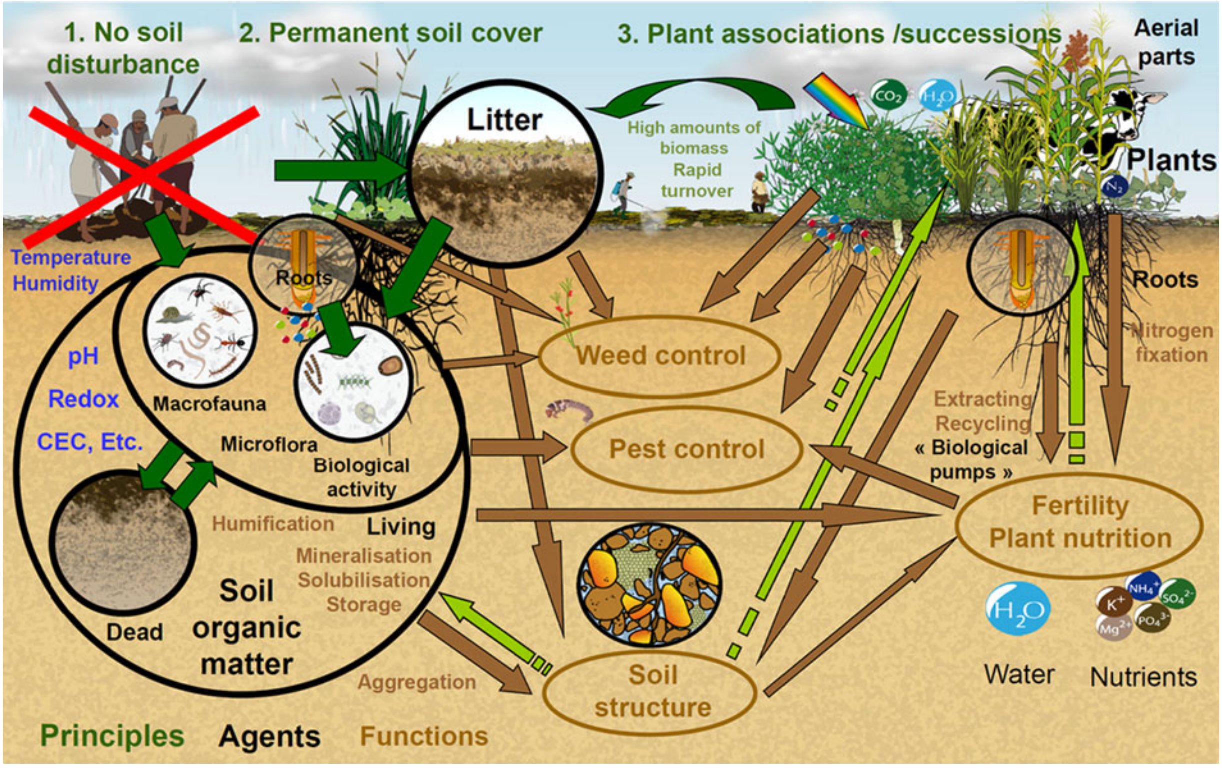

Figure 2. The principles and agents mobilized, and the functions insured by Conservation Agriculture.

than 4000 ha in these two regions (Rakotondramanana et al., 2010).

In Lao PDR, the DATE approach started in Sayaboury and Xieng Khouang Provinces in 2003 in the framework of the National Agro-Ecology Program (PRONAE), starting with the diagnosis and research matrixes (first loop) and then in demonstration plots (second loop). Large-scale extension (third loop) started in Sayaboury in 2005. A survey of the adoption of DMC covering 1463 households in 20 villages of Xieng Khouang Province (Lestrelin et al., 2012a) revealed significant spatial and temporal variations in the innovation process. The percentage of households applying DMC systems reached an average of 14% in 2008 in villages engaged in the DATE approach with the support of the project, and the highest rate of adoption at the village level was 43%. In addition, the adoption rate of improved pasture, also proposed by the PRONAE project, was 18% in 2008, whereby some villages reached an adoption rate of more than 50%. Another study (Lestrelin et al., 2012b) reported even higher adoption rates in Sayaboury Province, where more support for extension activities was available than in Xieng Khouang Province. In 2008, after 4 years of the third loop, DMC had become a significant component of agricultural landscape, accounting for an average of 40% of the total rainfed area, and up to 100% in some targeted villages.

In Cambodia, the DATE approach started in 2004 with experiments in controlled conditions and demonstration plots (first and second loops). Although this research was not part of a rural development project, a pilot extension network was set up in 2009 (third loop). In Kampong Cham Province, this network includes five villages and 223 households, and DMC systems accounted for 171 ha in 2011 (Boulakia et al., 2012).

Results and Discussion

Defining cropping system specifications

The diagnostic phase conducted at the six DATE sites generated useful information to orientate cropping system design. As a result, the specifications for ICSs varied as a function of each situation.

In Madagascar, chemical inputs are often not available and/or too expensive for farmers whose primary agricultural aim is self-sufficiency and family consumption, especially regarding rice. Consequently, in both study regions, priority was given to the development of rice-based cropping systems able to restore degraded soils and ensure sustainable production with minimum inputs (Michellon et al., 2008). In the mid-west region, it was also necessary to control the weed species *Striga asiatica* which often forced farmers to abandon cereal cultivation (Michellon et al., 2011).

Whatever the study area, soil degradation is characterized by a negative impact of conventional practices on physical, chemical and/or biological properties. Thus, soil erosion, soil compaction, disruption of soil structure, decrease in soil organic C concentration and decrease in biological activity (microbial biomass-C) have been measured (Rabary et al., 2007; Tivet et al., 2010, 2013; Lienhard et al., 2013a, b).

In Xieng Khouang Province (Lao PDR), the tropical acid savannah grasslands of the Plain of Jars offer opportunities for land reclamation. Farmers were interested in expanding their field crops (e.g. rice, maize and soybean) on these marginal soils and in improving pasture for cattle raising (Lienhard et al., 2013c).

In Sayaboury Province (Lao PDR), rapid agricultural expansion to the detriment of forest cover was driven by a maize boom triggered by increased demand from the Thai market. The combination of mechanical tillage by contractors and intensive use of herbicides led to rapid soil erosion, fertility depletion and high production costs, which put the entire agricultural system at risk. The objectives that emerged from the participatory diagnostic phase were therefore to develop sustainable maize-based cropping systems, while increasing profitability by reducing production costs (Lestrelin et al., 2012b).

In Battambang Province (Cambodia), farmers' production goals (producing maize for the Thai market) and organization of labor (mechanized plowing by contractors) resemble those in Sayaboury Province, in a context of reclamation of forest land which began 10–15 years ago. However, despite a high risk of dry spells from April to July, a longer rainy season allows farmers to grow two crops per year, maize planted in June/July preceded by sesame, mungbean or even maize. Here again, the farmers' interest in new cropping systems was in sustaining/restoring production (in the face of climatic risk and soil fertility depletion) and in crop diversification.

In Kampong Cham Province (Cambodia), soil fertility on low plateaus is lower because land reclamation started earlier, 30 years ago. In the context of small-scale agriculture open to Vietnamese markets, cassava monocropping has caused severe soil erosion and fertility depletion. Priority was also given to the development of sustainable cropping systems and crop diversification (Boulakia et al., 2012).

Based on these different objectives, a wide range of cropping systems was developed and adapted to local conditions and specifications.

Co-designing robust cropping systems

The DATE approach, implemented in a network of contrasted situations made it possible to establish meta-rules for the design of DMC cropping systems adapted to local conditions and to create data bases on cover crops/service plants (Séguy and Bouzinac, 2008; Husson et al., 2013a). In each research site, the first loop was implemented in the main agronomic units, defined at the plot level by soil characteristics and water regime (Husson et al., 2013a). In each agronomic unit, cover crops/service plants were selected first for their characteristics, for their ability to grow and produce biomass, to allow management to avoid competition with the main crop, and for their ability to solve the problems identified during the diagnostic phase, especially the most limiting factors for crop production in relation to soil degradation. At the farm level, the choice was made among a range of possible options for cropping systems adapted to the farmer's means and objectives: main crop, level of intensification, labor requirements, the equipment required, the mode of control of the cover crop, integration with livestock systems (Husson et al., 2013a). Constraints at a higher level of organization (village, region) were also taken into account early in the design process. This was the case of cropping systems which enabled preservation of biomass in fire prone environments (e.g. evergreen plants) or prevented damage by straying animal in the village landscape (e.g. toxic or not unpalatable plants such as *Crotalaria* spp.). Another example is the design of systems requiring minimum labor and inputs but which allow a rapid increase in production such as cassava (*Manihot esculenta*) associated with *Stylosanthes guianensis* or *Brachiaria ruziziensis* in the case of unsecured access to land (Husson et al., 2013a).

In the design of the ICSs, these technical considerations are coupled with adaptation at a higher level, such as collective organization and land management rules at the village level.

The implementation of the DATE approach in this network also made it possible to identify robust cropping systems which perform well in a wide range of situations. For instance, cropping systems based on stylosanthes (*S. guianensis*) supply a large number of ecosystem services and are thus efficient in overcoming various constraints such as controlling weeds, including invasive species such as *S. asiatica* (Michellon et al., 2011), reducing the incidence of diseases such as rice blast (*Magnaporthe oryzae*) (Rakotondramanana et al., 2010; Husson et al., 2013b; Lienhard et al., 2013b), ensuring soil protection, and restoring soil fertility through high biomass production and N fixation (Husson et al., 2013a). These stylosanthes-based systems are easy to manage, flexible and work for the major tropical field crops (e.g. rice, maize, sorghum, cassava or pulses), in a wide range of climatic conditions, from humid tropics to semi-arid areas and from the sea level to 1200 m a.s.l. in Madagascar (Husson et al., 2013a). They also perform well in most tropical soils, irrespective of their texture and fertility level.

The practicability, flexibility, plasticity and robustness of these systems and their excellent performance, especially in the restoration of degraded soils, make them extremely attractive to farmers, as witnessed in the BVPI–SEHP Project: in 2009, these systems represented more than 70% of the 1500 ha of upland CA cropping systems cultivated by 1250 families in the mid-west region of

Madagascar, only 4 years after the first demonstration plots were established (Rakotondramanana et al., 2010).

It is remarkable that the same cropping patterns can be used in contrasted environments. Although there is no silver bullet (Giller et al., 2009), it is clear that some plants and cropping systems can be adapted to more contrasted conditions and are easier to manage than others. Using such plants to design systems for a wide range of situations can greatly facilitate the dissemination of DMC cropping systems.

Local adaptation to facilitate adoption

The capacity of adaptation of the cropping systems/practices to optimize their practicability and facilitate their adoption, and the reactivity provided by the DATE approach is illustrated by the following examples:

Adaptation of the crop rotations/associations to increase the performance of the cropping system. In the Alaotra region in Madagascar, the association of maize (*Zea mays*) with Dolichos (*Lablab purpureus*) in rotation with upland rice showed good performances and met all the criteria defined during the diagnostic phase: increased fertility with limited inputs, increased and stable rice and maize yield, decreased weed pressure and working time and, as a consequence, increased profitability. Maize associated with cowpea (*Vigna unguiculata*), was also a good candidate for adoption as, despite its lower biomass production, it produces a pulse which can be used for human consumption unlike Dolichos, which not consumed in this region. The pre-extension phase with farmers (third loop in the DATE approach) led to the adaptation of these systems in a 'hybrid' system, associating maize with cowpea and Dolichos in alternate lines (Husson et al., 2013a). This hybrid system presents the advantages of increasing biomass production and N supply by Dolichos and cowpea, thus increasing soil fertility, and production of consumable pulses in addition to cereals, providing supplementary incomes from cowpea.

Adaptation of the cropping practices to improve the performance of the cropping system. In Kampong Cham Province in Cambodia, all CA-based cropping systems without soil tillage led to decreasing cassava yields, below those of the traditional ploughed cassava system, after 4 years of experimentation in controlled plots. The proposed CA systems were not ensuring sufficient soil porosity in these vertisols, which are rich in clay and iron nodules and poorly structured. In 2010, the participants in the DATE approach decided to not strictly respect the CA principles and tried row strip tillage using a chisel plough (Boulakia et al., 2012). In the following years, cassava yields were 20–25% higher in the 'strip tilled' CA plots than in conventional system, demonstrating the capacity of DATE to adapt in 'real time'. This also underlines the fact that CA systems should not be regarded as 'key-in-hand solutions' or as a set of rigid principles, but can be adapted, provided they still efficiently mobilize ecological processes.

Adaptation of the cropping system and/or the cropping practices to improve the practicability and the acceptability of the systems. In Battambang Province (Cambodia): an association involving maize and a legume such as *Vigna umbellata*, in rotation with cassava, performed very well but the farmers were not interested, because of the risk of *V umbellata* climbing the maize stems, making harvesting difficult. Farmers preferred associating maize and pigeon pea (*Cajanus cajan*), an erect legume. In this association, pigeon pea is usually sown in the inter-rows 2 weeks after maize. However, the farmers were unwilling as more time would be required for planting, and as this would increase the climatic risk of poor establishment of the legume, and complicate weeding. The practice was consequently adapted and pigeon pea was planted at the same time and in the same rows as maize with a narrower inter-row spacing. As this was a mechanized system, the pigeon pea seeds were simply mixed with the mineral fertilizer in the fertilizer tank of the seeder (Boulakia et al., 2012).

Adaptation of the cropping systems and/or the cropping practices for better integration at farm level. In Madagascar, because the rainy season is very short, upland crops need to be sown as soon as the rainy season has settled in to avoid the risk of drought either during early growth stages or later during flowering or grain filling. However, at the beginning of the rainy season, farmers usually give precedence to preparing the land and sowing irrigated rice in the safer paddy fields. Due to labor shortages, upland crops are often sown very late and are consequently exposed to drought at the end of their growth cycle. CA makes it possible to prepare the upland fields at the end of the dry season when labor is available, and to sow upland crops in a thick cover in dry conditions or after the first rains, before labor is needed in the paddy fields (Husson et al., 2013a).

Integration of cropping and livestock systems. Dairy farmers in the Alaotra region in Madagascar and those involved in cattle fattening in Lao PDR adopted cropping systems based on stylosanthes. They used part of the stylosanthes biomass, which is an excellent forage, to feed their livestock. In addition, these flexible systems make it easy to shift from crop to forage production and vice-versa. When precedence is given to crop production, grain can be produced every year and the amount of stylosanthes biomass used for forage is reduced. The system can rapidly be changed to pure forage production at no cost, with stylosanthes as a pure stand for one or more years, until the main crop again takes precedence. The crop is then seeded directly in the stylosanthes cover (Husson et al., 2013a). Similar systems have been developed with other service plants in Lao PDR, e.g. with *Brachiaria* spp., to feed cattle, or with a mixture of finger millet and pigeon pea, to feed pigs. These systems should enable the intensification of livestock systems, which is a national priority to alleviate poverty

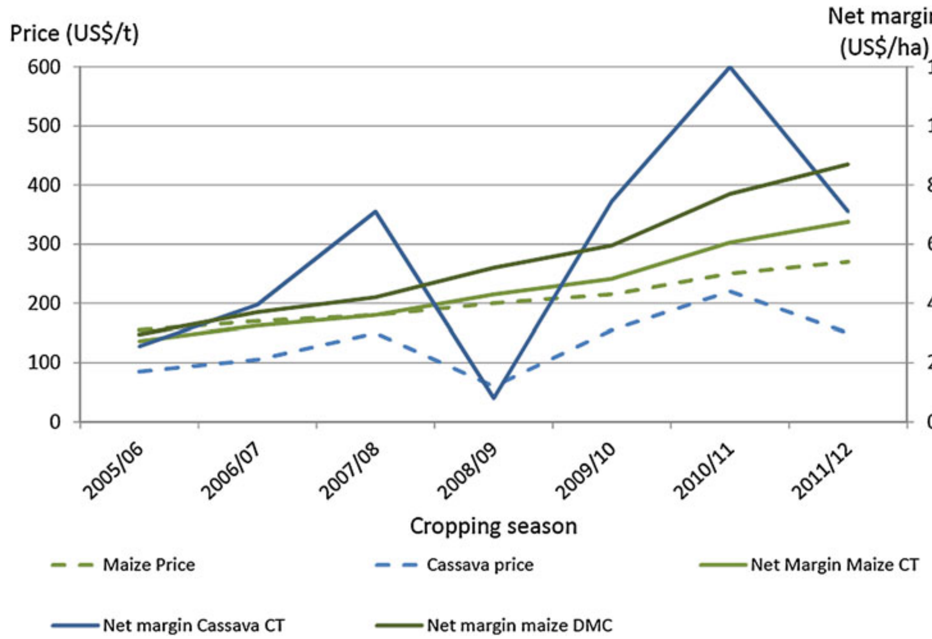

Figure 3. Evolution of cassava and maize price (US$/ton of dry tubers at farm gate) and net margin of cropping systems. CT: Conventional tillage; DMC: Direct seeding, mulch-based cropping systems, with stylosanthes. Basis of calculation: Cassava yield (CT): 7 Mg ha^{-1}; Maize yield (CT): 3.5 Mg ha^{-1}; Maize yield (DMC): 5 Mg ha^{-1} (target in real farmers' conditions). Production cost: Cassava (CT): US$340/ha; Maize (CT): US$270/Ha; Maize (DMC): US$480/ha.

(Lienhard et al., 2010, 2013c; Jullien et al., 2010b). The fodder crop is also considered to be an important stage in restoring soil fertility, such as in Xieng Khouang Province (Lao PDR), where *Brachiaria* was grown as fodder for livestock, at the same time preparing aluminum toxic soils for crop production.

Adaptation of cropping systems to market opportunities. In Cambodia, at the beginning of the experimentation in 2005, a rotation of maize and cassava, both associated with *S. guianensis* was recommended because of its agronomic and economic performance. At that time, the economic performances of the two crops was similar, and the overall system was efficient and sustainable. However, while there was only a moderate increase in the sales price of maize, the price of cassava peaked at over US $100 per ton in 2008 (Fig. 3) making the cultivation of cassava much more profitable than maize. Above this threshold, small-scale farmers rapidly abandoned rotation of cassava with maize, and opted for an association of cassava and stylosanthes, which they grew every year. Nevertheless, in fluctuating market conditions, the system allowed farmers to shift back to maize cultivation after a drop in cassava price, which happened in 2008/09. This example illustrates the variability of the rationale for DMC adoption by different categories of farmers and the ability of the flexible DMC cropping systems to adapt to changing market conditions.

Variability in farmers' feedback and cropping systems adaptation. The examples above illustrate the variability in farmers' answers to local constraints and how their feedback was used for rapid adaptation of the innovative systems. Technical performances at plot level were optimized locally, with the available means, and ICSs were incorporated into the farming systems, optimizing the most constraining factors: inputs and land where cropping intensity is high in Madagascar, labor and machinery in Lao PDR, market opportunities in Cambodia, biomass use where livestock is competing with crops, etc. Thus, according to farming systems, the same cropping system can be adapted in various ways. For example, the systems based on *S. guianensis* were adapted differently in Madagascar and Cambodia. In the mid-west of Madagascar, they aimed at optimizing rice production with limited inputs. Rice was produced in rotation with maize and manual control of the stylosanthes cover. In Cambodia, the same initial system shifted to cassava associated to stylosanthes as main production to take advantage of market opportunities. The control of the cover crop was done mechanically and chemically due to labor constraints.

Sustainability assessment

The biophysical sustainability was assessed through specific surveys, monitoring simple indicators of soil health as C and N content, or biological activity (macrofauna, microbial biomass). This was done through specific surveys conducted for the main cropping systems developed in each region (Tivet et al., 2010; Lienhard et al., 2013a). In addition, the biophysical sustainability of the diverse cropping systems was assumed because of the increase and/or stabilization in yield under DMC systems during all the study period, when yield decrease was observed in conventional systems.

When implemented over long periods of time, the DATE research sites can become observatories or the evolutions of farming system and also be essential tools to document the impact of cropping practices on soil characteristics. This is regarded as necessary in soil science (ANR, 2014).

Socio-economic determinants of the dissemination of DMC systems

DMC systems proved to be efficient in increasing and sustaining production, as observed in Madagascar (Rakotondramanana et al., 2010), Cambodia (Chabierski et al., 2012) or Lao PDR (Lienhard et al., 2010; Tran Quoc et al., 2010). However, marketing opportunities, market imperfections and the relative price of the different commodities can have a dramatic impact on the dissemination of DMC systems, as illustrated by the three following examples.

1. In Madagascar, the yield of upland rice increased progressively under DMC and, in farmers' conditions, reached 4 t ha^{-1} after 4 years at a recommended level of fertilization of 65N-15P-20 K in stylosanthes-based cropping systems. However, faced with the increasing price of fertilizers, the absence of a structured market, and because their main aim was rice self-sufficiency, farmers in Madagascar preferred to apply low doses of fertilizer. In 2009, the rice yield obtained with such low inputs was only 2 t ha^{-1} on average in the mid-west region (Rakotondramanana et al., 2010). Nevertheless, this yield is often higher than the usual yield in rainfed lowland conditions in the area (1 t ha^{-1}). In this context, the performance of rice-based DMC systems made them very attractive.
2. The situation was not the same in Cambodia, although rice production in DMC systems was also good: in large-scale experimental plots, yields averaged 4 t ha^{-1}, with medium fertilization (70 N-13P-25 K). The gross margin was US$425/ha at a mean price of US$230/t of paddy and reached US$675/ha with aromatic rice selling at US$320/t. However, upland rice cannot compete with maize yields of 6.5 t ha^{-1} (90N-13P-25 K) and sold at US$250/t, representing a gross margin of US$1100/ha in the market oriented agriculture in Cambodia.

   Upland rice cannot compete with cassava, even in a context of constantly fluctuating prices. In 2010/11, cassava sold for US$220/t, providing a gross margin of US$2200/ha. Even after a drop in cassava prices in 2011/12, it still provided a gross margin of US $1100/ha, equivalent to the margin obtained with maize and 2.5 times higher than the margin obtained with upland rice. Consequently, under current market conditions commercial production of upland rice, even with CA practices, cannot be recommended in Cambodia.
3. In Lao PDR, a major constraint to the dissemination of DMC systems was the lack of equipment, especially for direct seeding. It was thus necessary to import the equipment, and to encourage exchanges between farmers and local traders to enable access to inputs and services with the aim of transferring more farm operations to the service providers, which already carries out most cropping operations and supplies hybrid maize seed on a contractual basis (Jullien et al., 2010a).

Local traders and service providers

Local traders are involved mainly at two levels with respect to farmer groups and communities: (i) selling agricultural inputs, providing loans, buying products; and (ii) providing services for land preparation and threshing, among others. These stakeholders are the first link between the farmers and the agricultural industry. Lestrelin et al. (2012b) emphasized that the involvement of the local traders, providing specialized services in CA and facilitating market opportunities for secondary crops, appears to be a fundamental prerequisite for facilitating the dissemination of CA systems. In Lao PDR and Cambodia, service providers are engaged in no-till planting, renting to farmers the planters that were introduced by the projects. In addition, connection was made with the medium-scale manufacturer to duplicate the no-till planters initially introduced from Brazil. Traders, service providers as other stakeholders participated in field days and machinery exhibitions with the objectives to strengthen the connection between them and the farmers and also to use the machinery as an intermediary object to facilitate the interaction between stakeholders.

Training and policy-making

Through continuous capitalization of knowledge acquired at the grassroots level, the DATE approach contributes to draw lessons and feed evidence-based policy design (up-scaling). It creates an enabling institutional environment, favorable to CA-based innovations adoption.

Several surveys conducted in each country revealed important aspects that should be taken into account at the policy making and planning level. Lestrelin et al. (2012a, b) emphasized in the southern part of Sayaboury and in Xieng Khouang Provinces that: (i) access to information and technical knowledge, (ii) environmental sensitization and (iii) introduction of CA in the broader agricultural industry with the involvement of the service providers and market for secondary crops appear to be fundamental prerequisites for facilitating the dissemination of CA systems.

Consequently, the Council of Ministers of Lao PDR requested the Ministry of Agriculture and Forestry

(MAF) to facilitate the promotion of these techniques, and called for this approach to be included in university and school courses. The MAF of Lao PDR launched a degree program to promote the dissemination of this approach targeting an environmental sensitization.

In Cambodia, the Ministry of Agriculture, Forestry and Fishery established in early 2015 the Conservation Agriculture Service Center which takes stock of the previous activities implemented in three provinces.

In Madagascar, the Groupement Semis Direct de Madagascar (GSDM) was established in 2002 to bring together several stakeholders involved in Agroecology and Conservation Agriculture. These included NGOs, research organizations, agricultural training centers and private companies involved in extension. A strategy was elaborated to support extension of these systems (GSDM, 2007), with a special focus on long-term (6–12 months) training for field extension agents from various stakeholders and on sensitization of policy makers and local administrators. The GSDM sets up a course for training on Conservation Agriculture in vocational schools, targeting extension staff and trainers. This course has been approved by the authorities and is now officially registered in the curriculum of vocational training in Madagascar.

The DATE approach also contributes to projects' 'exit strategies' through scenario exploration involving project beneficiaries, other projects and local agencies. This was the case in Lao PDR, where a fund was created in Sayaboury Province for the long-term financing of CA adoption: The Conservation Agriculture Development Fund (CADF) was created in 2008 and validated by the Governor of the province. It was primarily funded by a 10 LAK kg^{-1} (10 USD/ton) 'tax' on the maize sold and exported out of the province, collected by the department of commerce of eight districts. Although the collected funds were low when compared with what could be expected considering the total production of maize, they amount to US$790,000 between 2010 and 2014. This fund still finances demonstration sites, support to public sector and administration, support to traders' associations and farmers' associations and seminars on agricultural production, 5 years after the end of the project.

Transitioning from conventional to DMC systems

The DATE approach also provides adequate support for farmers in the successive stages of transition from conventional agriculture to DMC systems:

Transition in an ecological perspective. The shift from conventional to DMC systems and the activation of ecological processes requires time. The longer the transition, the more difficult it becomes to ensure dissemination of the system. It is thus indispensable to propose DMC systems able to rapidly activate ecological processes and shorten the transition period. The duration of the transition period, and more generally the efficiency of DMC systems, rely to a great extent on the amount of biomass that is produced and returned to the soil system (Séguy et al., 2006, 2001; Husson et al., 2013a). The most efficient systems are thus those which are able to rapidly produce a large quantity of biomass. A corollary of this is that the transition to DMC systems is easier and faster on reasonably rich soils than on degraded soils, where starting production of biomass is difficult and requires external inputs for the rapid restoration of soil fertility (Husson et al., 2013a). Furthermore, below a soil fertility threshold, soil restoration becomes extremely difficult, and cannot be achieved without considerable external organic inputs. In a context of small-scale family-based agriculture, the cost and the long period of time needed to restore such degraded soils may be prohibitive without external support.

On the other hand, when only one agronomic factor is responsible for preventing potential yield being achieved, production can be rapidly increased. Specific cropping systems can be designed to maximize biomass production of a service plant able to efficiently overcome this constraint, and thus shorten the transition period. A good example is the rapid increase in cassava yield on compacted soils, which can be doubled from the first year on when cultivated in association with *B. ruziziensis, Brachiaria brizantha* or *Brachiaria humidicola*, as observed in the Alaotra region in Madagascar (Charpentier et al., 2006).

Transition in a technical perspective. One of the advantages of the DATE approach is that the proposed cropping systems are flexible and this approach allows/encourages their further development and adaptation through a learning process. The sustainability of these systems is mainly based on their ability to rapidly adapt to changing environments. As a consequence, the cropping systems proposed in the first learning loop are not optimized, and require certain adaptations. The example of cassava associated with stylosanthes in Cambodia (Boulakia et al., 2012) illustrates this adaptation process that necessarily takes the local context into account. Strip tillage was needed in a cassava/stylosanthes association on black vertisol, but not on red oxisol, perhaps because the transition phase is longer on black vertisols, or because the system with stylosanthes was not sufficient to restore degraded soil structure on this particular type of soil.

Transition in a learning/knowledge perspective. Farmers who shift to DMC systems need to gain experience and acquire know-how to be able to master the new cropping systems and practices. This learning process takes time and requires a major investment in training and support. To facilitate the process, the transition to full DMC systems can be made step by step as in Sayaboury Province (Lao PDR): although the association maize and *V. umbellata* was rapidly identified as an efficient DMC system, a decision was made to first demonstrate the potential of simple crop rotations. Alternating maize, for high biomass production, with *V. umbellata*, for N fixation, was proposed. Direct seeding was introduced, and the benefit of leaving crop residues on the surface of the soil was demonstrated. Once farmers got used to these practices and were convinced of their advantages, associations of maize with legumes such as *V. umbellata* were progressively introduced in the second loop, which had the advantage of producing two commercial crops in the same cropping season (Jullien et al., 2010a). More complex cropping systems were introduced in a stepwise process to increase the agronomic performance and sustainability of the overall farming systems, for example biennial rotation of maize associated with *B. ruziziensis* and soybean with a succession of *Eleusine coracana* and *Crotalaria* sp., or the biennial rotation of maize associated with *Cajanaus cajan* and *S. guianensis*, and rice associated with *S. guianensis* (Jullien et al., 2010a). This increase in the complexity of the cropping systems and the concomitant increase in production were introduced progressively as the opportunities arose to facilitate the learning process promoted in the DATE approach.

Conclusions

The DATE approach is based on three principles which are central to several research endeavours: participatory learning approach, iterative reflexive loops, and multi-criteria evaluation (Reau and Dore, 2008). It also addresses the three main components of an innovation process in agricultural production systems (agronomic processes, farm management and advisory services), which is rarely done in a single research framework (Le Gal et al., 2011).

The participatory elaboration of specifications for improved cropping systems is a major guideline in the design of ICSs adapted to local conditions.

The DATE approach was originally influenced by concerns related to co-designing, adapting and disseminating DMC systems. In return, this approach improved and facilitated the process of innovation beyond DMC and CA systems up to the levels of farming system and regional agriculture. Still, the DATE approach relies on the introduction of a large set of innovative alternatives, as proposed by DMC systems or more generally by CA cropping systems (Husson et al., 2013a). Without inputs of innovation, the DATE approach, like any innovation process, is unlikely to succeed. Demonstration plots located at the heart of farm communities enable the demonstration of technicians' and agronomists' skills, a prerequisite for the building of mutual trust and relationships based on confidence (Boulakia et al., 2012). In return, this approach both facilitates and improves the process of innovative research and combines innovation with prospection. DATE is particularly suited for CA systems, which largely rely on local adaptation. The original combination of '*de novo*' and 'step-by step' design allows both the introduction of innovations in rupture with conventional systems as well as their necessary adaptation to local means and constraints.

Local implementation of the DATE approach in contrasted bio-physical and socio-economic conditions allowed us to identify the main interactive drivers of DMC performance: adoption, adaptation, and dissemination. In particular, it revealed the important role of fresh organic matter in the functioning of soil systems, in relation to climate (Séguy et al., 2006, 2001; Husson et al., 2013a).

Besides agronomic and economic performance, the practicability of these cropping systems and their integration in agricultural systems is of major importance and largely determines their extension potential at a large scale. The DATE approach provides information on the determinants of adoption and the necessary conditions for the dissemination of ICSs (Lestrelin et al., 2012b). All this information improves our understanding of the best conditions to apply CA systems and what is needed for their efficient development and wide diffusion (Scopel et al., 2013).

However, the activation of biological processes, collective learning and capacity building, farmers taking ownership of the systems which are in evolution and institutional changes all take time. As a consequence, DATE should be implemented over long periods of time. Furthermore, biophysical sustainability is not sufficient and assessing sustainability in a global way requires studies over longer periods of time than those usually possible in the framework of research and rural development projects.

The DATE approach would also benefit from increased integration of territorial dimension in extension activities. In addition, engaging whole villages in the innovation process might lead to higher and faster adoption of innovations.

Another important feature of DATE is the replication of a wide range of DMC cropping systems in a network of contrasted experimental situations, enabling the identification of plant species which may be suitable to activate specific ecological processes and thus fulfill specific ecosystem services. For instance, in Madagascar, Brazil and Cambodia, rice blast was dramatically reduced when rice was grown on a mulch of stylosanthes or after maize associated with finger millet and pigeon pea. Such observations are fundamental as they provide research tracks for (i) understanding crop nutrition x disease interactions; (ii) the design of cropping systems and (iii) practical solutions to major problems. They open new avenues for agronomic management of major bioagressors.

They also raise research questions regarding the ecological processes modified by these cropping systems, which are still regarded as urgent (Scopel et al., 2013).

Thus, these platforms for cropping system design are fed by scientific knowledge in interaction with local stakeholders and confronted to the reality of agro-ecology in the field, farm organization and market structure. In return, they provide scientists with research questions, especially regarding fundamental ecological processes such as the role of C inputs and microbial activity in the functioning of these systems (Sá et al., 2015; Tivet et al., 2013; Lienhard et al., 2013b) or the importance of redox potential in soil/plant microorganism system functioning (Husson, 2013). DMC systems are also new research objects, as they aim to activate ecological processes and do not function like conventional systems which are often based on chemical inputs.

Last but not least, DATE encourages the emergence of learning platforms which facilitate exchanges between different stakeholders and are very useful for the integration of local, scientific and expert knowledge for the benefit of all.

Posthumous tribute

This article is dedicated to the memory of our colleague and friend, Dr. Johnny Boyer, who left us far too early in May 2015.

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