Researchers and farmers during a training/demonstration of the no-till planterin Rattanak Mundol, Battambang, Cambodia
Photo by Stephane Boulakia

CASE STORY 4

Conservation Agriculture for Climate-Resilient Rain-Fed Uplands in the Western Regions of Cambodia

Challenges, Opportunities, and Lessons from a 10-Year R&D Program

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ABSTRACT

The political and territorial reintegration strategy that had been implemented in Cambodia to establish peace and order in the late 1990s caused the degraded evergreen forestlands to be allocated to the demobilized Khmer Rouge families in the western regions of the country. The increasing regional demand for cereals and tubers and the highland saturation in central rice areas have driven massive immigration of smallholder farmers. Almost half a million hectares of those forestlands were thus converted in less than 15 years for annual upland cash crops development. This dramatic expansion of agricultural area, without any plan for sustainability, has exerted tremendous pressures on the natural forest resources and on biodiversity. Its effects rapidly spread on the water and soil resources of Cambodia.

With conventional practices and more frequent flooding and incidents of drought, smallholder farmers could hardly sustain their livelihoods, which are mainly based on annual upland farming. Farmers with investment capacity have shifted to planting tree crops and/or to animal production in order to cope with the hazardous phenomena.

This case story presents the collaborative R&D program between farmers and researchers in Battambang and Kampong Cham provinces in Cambodia. The program aimed to restore soil fertility and build the resilience of smallholder farmers to the effects of climate change while improving crop productivity and profitability of the smallholder farmers.

Using the Diagnosis, Design, Assessment, Training and Extension (DATE) methodology, the project implementers designed, tested, and evaluated crop production systems that are grounded on the principles of conservation agriculture (CA). DATE is a multi-scale, multi-stakeholder participatory approach. It integrates scientific and tacit knowledge, and is composed of four components: agrarian systems diagnosis, field experiment, on-farm assessment, and pre-extension.

A number of CA-based cropping systems have been designed and validated in the program: (1) mono-cropping of maize in association with pigeon pea or mungbean as relay crops, (2) biannual rotation cropping of maize with soybean or cassava, and (3) intensified cropping of maize and cassava. Synergizing this with the benefits of CA, each system has the capacity for climate change adaptation and mitigation, to retain soil fertility, and to increase smallholder farmers' profitability. Based on the results, pigeon pea is the most suitable crop for mollisols used with maize since it can improve the water retention capacity of the soil, reduce soil evaporation, and reduce mineral nitrogen inputs. Moreover, its grain can be sold or used as animal feed to augment farmers' income, a characteristic that smallholders look for in an agricultural production system. Likewise, shifting mungbean to be sown by hand broadcast after harvesting early maize significantly reduces farmers' risks and costs, thereby improving their productivity. Shifting to CA-based cassava production (a key annual crop) using chisel to operate strip tillage on planting rows after the early maize harvest also enables farmers to significantly minimize risks and costs. These risks and costs are estimated to be about USD (United States Dollar) 300–400 per hectare and USD 200 per hectare, respectively.

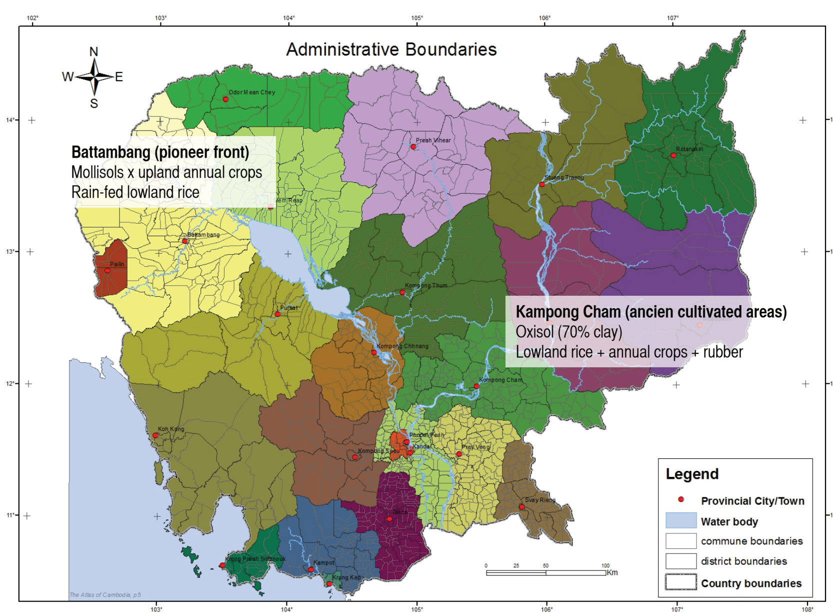
Designing CA-based cropping systems based on the DATE methodology presents clear benefits. DATE is a holistic approach for identifying technical, socioeconomic, and institutional elements for a sustainable and more inclusive intensification of smallholder farmers' agricultural production systems. However, designing such innovative techniques is a combination of context-specific and context-generic features. These issues need to be taken into account should such innovation be replicated in other regions. In addition, this action-research program should be a continuous process; the agro-technical performances of the introduced cropping systems should be continuously validated in multiple locations and for several years. The outcomes of the cropping systems should also be continuously monitored such that their impacts on natural resources (e.g., soil organic carbon, nutrient cycles, xenobiotic dynamic, etc.) can be determined and measured accurately.

INTRODUCTION

The Challenging Context of the Pioneer Front in the Western Uplands of Cambodia

Most of the Cambodian peripheral regions have experienced dramatic changes in their land cover and land use in the past two decades. The pioneer front dynamics of smallholder farmers and the allocation of public state lands to companies through long-term economic concessions have led to forest degradation and deforestations. The peace settlement in the 1990s has been followed by the allocation of degraded evergreen forestlands to demobilized soldiers in the western regions, namely, Battambang and Pailin provinces (Figure 4.1), which are mostly former Khmer Rouge stronghold areas (Diepart and Dupuis 2014). The highland saturation in the central areas of dominant rice-based farming systems and the increasing regional demand for cereals and tubers have driven massive flow of migrant smallholder farmers to these two provinces in the hope that they can possess a secured plot of farmland (Pilgrim, Ngin, and Diepart 2012). More than 400,000 hectares (ha) have been reclaimed between 1996 and 2010 for annual upland cash crops development.

Figure 4.1. Map of the two main regions in Cambodia with ongoing R&D operations on cropping systems for smallholder farmers in upland agro-ecosystems



Note: This map shows Kampong Cham province on ancien agricultural regions (forest reclaiming ended in the 1950s) and Battambang province, which is an area where the pioneer process ended in the early 2000s.

At the national scale, official figures report that rain-fed annual upland crops (with maize, soybean, and cassava as principal key crops) soared from 120,000 ha in 2002 to more than 800,000 ha in 2013. These evolutions are giving birth to a new agriculture sector alongside strong regional demands, which stimulate the development of local agro-industrial processing capacities.

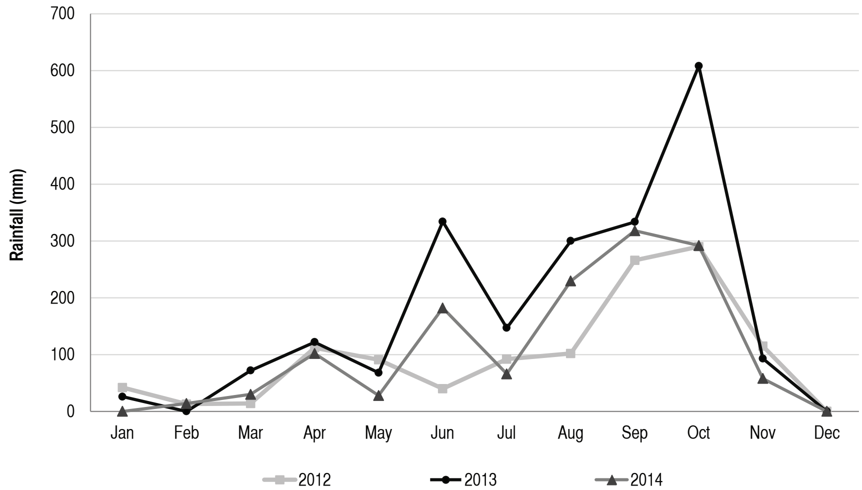
Rapid expansion of agricultural areas exerts tremendous pressures on natural resources. Environmental pressures are exerted on forest resources and biodiversity due to the people's desire to use land for agricultural purposes but without adopting any conservation plan. Soil and water resources are being degraded due to techniques that are based on intensive tillage and herbicide use. In Battambang, maize yields dropped from more than 8 tons per hectare (t/ha) without any fertilizer application after forestlands have been converted to less than 4 t/ha after 10 years of continuous cropping (Boulakia, Kong, and Eberle 2013). Soil fertility decreased due to organic matter mineralization and erosion, which adversely affects the technical performance of agricultural production and limits the possible choices of key annual crops that farmers can produce. Consequently, farmers are gradually forced to apply mineral fertilizers in an attempt to stabilize their yields; they also have to increasingly rely on herbicides to control the weeds (Boulakia et al. 2013).

In addition, cropping systems evolve based on climactic conditions. The changes in Cambodia's climate are influenced by the El Niño and La Niña phenomena, which cause frequent extreme weather events such as drought and flooding. It is projected that changes in climactic conditions would include late onset of seasons, wetter rain season, and longer and drier dry season (IFAD 2013).

These changes have already been observed in Battambang and Kampong Cham (Figure 4.2). In the past, the tropical monsoon climate gives farmers enough time to cultivate two crops per year, with the main season starting in June-July, whereas the secondary season is in February-March. However, the onset of the secondary season has become more uncertain due to the unpredictability of rainfall patterns; more and more farmers have stopped taking risks and have given up planting secondary crops such as mungbean and sesame regardless of the inherent soil fertility. Likewise, such extreme climatic phenomena, such as the flood events in 2013 and drought in 2014 in Cambodia, have affected the production of main crops like maize and cassava.

The combined consequences of depleting soil fertility and the increased incidence of pests and diseases associated with climate change are causing irregular and worsening yield performances of the short-cycle annual crops. Cassava, due to its high adaptive capacity to low soil fertility and to erratic climate conditions (due to its notably longer cycle), then became more economically attractive to farmers. Thus, most farmers had adopted this crop for production, with most regions converting from maize mono-cropping to cassava mono-cropping. Eventually, a threshold was reached in 2014 when almost all of the farmers switched to cassava production. This fast conversion to cassava mono-cropping in the recent Western pioneer front region is similar to what happened in the "old" upland agro-ecosystems of Kampong Cham province (central east region) in the early 2000s.

Figure 4.2. Monthly rainfall (mm) recorded in Battambang and Kampong Cham, 2012–2014



This case story intends to illustrate some insights on the Diagnosis, Design, Assessment, Training and Extension (DATE) methodology that was used in the uplands of Rattanak Mondul district in Battambang province in designing the CA-based cropping systems. These systems helped reverse the soil resource degradation and improve and secure the rain-fed production systems in those regimes with increasing irregular rains. This case shows how DATE allows to (1) monitor and analyze, in real time, the rural and agricultural contexts engaged in rapid changes; (2) build up alternative cropping systems to address the agronomic and economic constraints faced by farmers; and (3) explore the needed measures to support farmers in future development programs. This chapter also proposes some points for consideration to make the approach more efficient.

DESCRIPTION OF THE ADAPTATION

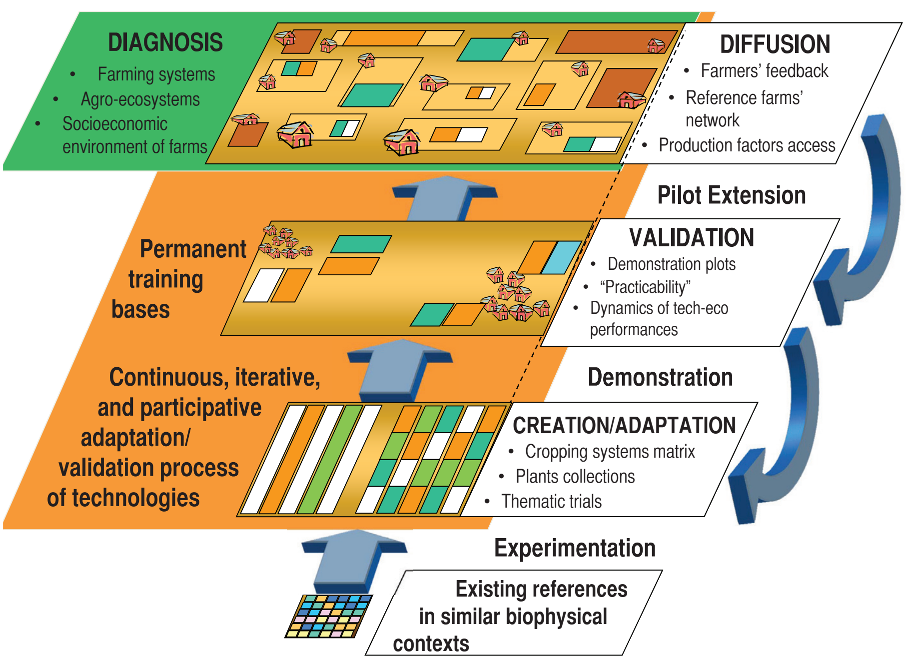
DATE: A Method for Designing CA-Based System "On-Farm, With, and For Farmers"

The DATE methodology involves a multi-stage method that combines expert knowledge source of de Novo proposals with step-by-step and participatory adjustments through practice-and-exchange loops between research experimentation, real-scale demonstration and adaptation sites in farmers' plots, and through a monitored pilot extension network (Husson et al. 2015). DATE is not only for designing innovative systems suitable for farming, it also sets a basis for a permanent training and information-sharing system among stakeholders. The DATE methodology also provides stakeholders with a tool for identifying hierarchized constraints, and for developing test of propositions or orientations that would help address these constraints.

Figure 4.3 shows how the different stages of the DATE approach are articulated in a continuous process (Husson et al. 2015).

- Stage 1 involves diagnosing (through rapid rural appraisal) the key structural elements of the agrarian context (e.g., biophysical characteristics of the different agro-ecosystems, main agricultural sector and markets, services, land-sharing system, land tenure, etc.) and the farming systems (e.g., crops and livestock systems, size, labor force and organization, off-farm activities opportunity, etc.) that are combined into a partition of farm types. This stage also involves presenting differentiated trajectories of evolution (drivers and anticipation) for the identified farms' types.
- Stage 2 is based on a field experiment that introduces, in comparison with the dominant cropping systems, CA-based alternatives that respond to similar production goals and addresses principal diagnosed agronomic constrains related to soil fertility and weed and pest control.

Figure 4.3. Stages and loops occurring between multi-stakeholders in co-designing cropping systems through DATE approach



- Stage 3 involves applying the "best bet" systems in farmers' fields. This "level" is managed for several consecutive years via research, and is conducted in close coordination with village farmer groups. At this stage, the process allows the farmers and researchers to adjust the cropping systems by working on its technical elements (varieties, tools, weeds control, etc.) and to assess its technical and economic performances in reference to farmers' local practices. This stage also serves as a training ground for farmers and technicians, and demonstrates the farmers' ability to cope with the constraints in their agricultural production under different agro-ecosystems.
- Stage 4 is based on the progressive constitution of a pilot network of farmers who are willing to test innovative technologies in their own respective plots. The activities at this stage can consist, in large part, of the initial proposal that has been introduced and adjusted by research. It can also consist of combinations of activities from traditional practices that have been modified through integrating one or few elements of the developed cropping systems (e.g., planting a new crop variety, no-tillage implementation on the sole crops residues, application of herbicides, etc.). However, this practice of "shopping" among the new technical elements and systems introduced needs to be considered carefully. This reflects the farmers' level of understanding of the introduced innovations and also reveals the kind of problems that farmers want to address and prioritize. At this stage, it may be necessary to provide farmers with incentives although only limited nonmonetary incentive can be provided during the first two years of the collaboration. This support may involve providing farmers with cover crops seeds or access to specific contract services (e.g., direct seeding, spraying, etc.) for a real-based cost charged.

Every several years, the DATE methodology prescribes conducting a plot-level assessment of the cropping systems across contrasted climatic years. The process contributes to the improvement of the design techniques (i.e., crop management modalities and decision rules for rotation) in order to address the marked climate variability.

The process also allows farmers and researchers to observe, at the regional scale (e.g., production basin, river catchment, administrative unit, etc.), the biophysical changes in the farm and the economic changes in farm production. At the community and farm levels, DATE provides stakeholders with the elements to understand how farming systems evolve, the drivers that affect this evolution, and to what extent these evolutions alter natural resources. The process also enables researchers to collect, observe, and record multi-year data that can reveal how climate variability impacts cropping systems' performances, the condition of farm households' livelihoods, and the different types of adaptation measures that farmers use to respond to the climate variability.

This R&D process enables the researchers to interact with farmer groups and village communities, as the researchers directly work with the local farmers at their actual farm settings using comparable production means. Through these continuous exchanges about the practical crop and farm management systems, the researchers and farmer groups are able to conceive technical proposals; they subsequently test, evaluate, and redesign these proposals. Alongside this, program implementers can identify the economic constraints that farmers face in the adoption of the cropping systems. Accordingly, the researchers and farmers are able to discuss and evaluate possible measures that can be applied to alleviate these constraints.

The following are some of the barriers that constrain farmers' access to production inputs:

1. Limited labor and mechanization (i.e., calendar of household labor force, high cost and limited supply of hired labor during peak season, limited availability of specific tools to be able to sow in crop residue and cover crop mulch and boom sprayer as an alternative to knapsack application);
2. Limited access to specific inputs (e.g., high-quality crop seeds);
3. Lack of disposable funds to acquire the needed inputs and services. This is notably constraining, particularly when crop production is subject to income flux, trade-off between funding the households' needs vs. farming input, and when the farm inputs are financed through credit (through commercial banks, micro finance institutions, etc.).

The level of investment spent on and the level of intensification adopted for crop production depend on the farmers' perceived risks and expected benefits. However, nowadays, the risks are increasingly being conditioned by the increasing climate variability and high interannual volatility of farm gate prices.

Accordingly, these difficulties and limitations in understanding the systemic innovations experienced by farmers are progressively addressed through continuous information dissemination and training activities delivered to individual farmers and farmer groups. Such activities include fields visits to researcher- and farmer-managed sites; documentation (through posters, leaflets, video, and so forth); and regular exchanges between farmers and research group about crop implementation and monitoring. DATE explains multi-scale and multi-stakeholders platforms that can also serve to inform policy makers and sensitize farmers in other regions with similar biophysical and/or socioeconomic features.

Status of the CA Cropping System Design and Support Measures for Extension

The agrarian diagnosis (Stage 1 of the DATE methodology) was conducted in 2009 in two communes of Rattanak Mundol, Battambang province. The results revealed that the farming systems in the area were mainly comprised of production of annual cash crops (i.e., maize), raising livestock, and off- and on-farm activities. On average, each farm household has 6 ha of farmland to work on; this farm size is considered to be medium to large scale. The common farm practices in the area were intensive soil tillage and herbicide use. They practice mono-cropping of maize during the main season (July to November), and plant mungbean, sesame, and maize during the preceding secondary season (April to June). Crops are grown only on a small portion of the farmland during the secondary season, often on an elevated area adjacent to the house in order to ensure on-time sowing of the main season crop (i.e., maize).

The second stage was implemented based on the data on red oxisols found in the central upland areas of Chamkar Leu district, Kampong Cham province, which the researchers have been gathering since 2004 using the DATE methodology. In 2009, two experimental plots were set up on mollisols, typical of the regional uplands, to design and evaluate alternative CA-based cropping systems for the mono-cropping of maize, biannual rotation of maize and cassava, and biannual rotation of maize and soybean. In the third stage, which involves applying the best-bet cropping system, the mono-cropping of maize was selected as the best-bet system and was tested on the plots of the volunteer farmers in the target villages. Then, a pilot extension network was developed (Stage 4) through the participation of about 100 interested farmers.

Table 4.1 sketches the progress in the cropping systems implemented through the DATE methodology in the district of Rattanak Mondul (Battambang province) between 2009 and 2014. At least four CA-based cropping systems have been validated on such mollisols:

1. Mono-cropping of maize with pigeon pea: maize + pigeon pea[1]
2. Biannual rotation of maize and cassava: maize + pigeon pea // cassava
3. Biannual rotation of maize and soybean: maize + pigeon pea // soybean + sorghum
4. Intensified cropping of maize and cassava: early maize + finger millet + sunhemp[2] / cassava // cassava

The succeeding subsections discuss in detail how the cropping systems can implemented.

1 Relayed or associated crop

2 Successive crop within the year

Table 4.1. Progression of the CA-based cropping systems design process

Period	Research		Farmer Practices	
	System	Adjustment	System	Adjustment/Reaction
2009	Application of CA-based maize mono-cropping	2 cover crop species for association with maize were proposed/tested	Initial diagnosis: maize (one preceded by mungbean for two successive cycles per year) was assessed to be the dominant farming system	
	Application of CA-based biannual rotation (M // S, M // C)		Limited interest of farmers; they prefer to follow the two-crops-a-year system despite the growing climate uncertainty	
2010–2012	M + PP = "best" annual combination		M + CC combination was tested with the hope of getting secondary grain/income from CC	Farmers were reluctant because of the delayed sowing of PP (i.e., 15 days after M) in M interrow
		Simultaneous sowing of M and PP with reduction in M interrow to 40–60 cm (shade and weed control)	Only few farmers reintroduced soybean; however, they faced marketing constraints (no attractive price when production volume is too limited)	CC makes the weed control method more complex, making it necessary to abandon the use of atrazine, which is massively used by farmers
2012–2014	Introduced rotation based on "dry season" cassava test with sunflower as a relay crop in late sowing (September)	M + PP sown simultaneously (bet on only one "weather slot") to achieve all sowing	Growing demand for NT implementation for the 2nd crop (i.e., main cycle) with soil plowing prior to first cycle	
	Pre-assessment of C performance during the "dry season" at 9 and 18 months growing cycles	M sown at 0.40-meter interrow yielded better results than that sown from 0.80-meter interrow after three years of testing	Some farmers started to broadcast NT sowing of mungbean in residue in early maize harvest	

Table 4.1. (continued)

Period	Research		Farmer Practices	
	System	Adjustment	System	Adjustment/Reaction
2014– to present	Test of rotations: Early M + CC / dry season Cassava (9 months) / M + CC => 2 M and 1 C in two years Early M + CC / dry season Cassava (18 mos) => 1 M + C in two years	Minimum till/strip till prior to C planting; “Flat” vs “erected” cuttings planting initiate contact on minimum till planters	Massive conversion to C in all districts (2013 < 20% surface; 2014, 60%; 2015, > 90% according to declaration of intention), complemented by intensive tillage and ridging	
			Most of the remaining M surface is under CA or under reduced tillage	Few farmers test strip tillage in C

Note: C = cassava, CA = conservation agriculture, CC = cover crop, M = maize, NT = no-till, PP = pigeon pea

Mono-cropping of maize with pigeon pea and biannual rotation of maize and cassava

In this CA-based mono-cropping of maize, pigeon pea is planted in the middle of the maize interrows. Each interrow has a distance of 0.6 meter. The crops are then fertilized using 70-30-30 NPK (Nitrogen-Phosphate-Potassium) formulation. The P and K are all applied as basal, while about two-thirds of N is applied as a soil top dressing. After the maize is harvested in late November, pigeon pea is continually grown during the course of the dry season. The first harvest of pigeon pea is in February, whereas the second harvest is in April. Pigeon pea rapidly grows with the onset of the first rains. The pigeon pea control could be done 3–4 weeks before maize is sown in the next season.

In conventional farming practices for cassava, farmers usually till and ridge the soil. In the CA-based biannual rotation of maize and cassava, however, chisel (equipped with disc-coulters to open the mulch cover before prongs) is used as a strip tillage (prongs at 0.80-meter distance) to loosen and break up the soil on the cassava planting line. The cassava cuttings are then manually planted in a slanted position along the chiseled furrow, using an interval of 0.8 meter in between plants. The crops are fertilized using a formulation of 70-30-60 NPK. Half of K, one-third of N, and all of P are applied 30 days after planting; the remaining K and N are applied 30 days after the first application. Cassava harvest is done manually during the dry season after 8–10 months cycle. The maize-pigeon pea association is implemented in cassava residues during the following cropping season.

Biannual rotation of maize and soybean

In this cropping system, soybean is sown at a 40-centimeter row space using a fertilizer formulation of 24-30-30 NPK. Unlike in the other cropping system, all N, P, and K are applied as basal upon sowing. Sorghum (var. pool preto) is sown at 30 kg/ha using a hand-held broadcast spreader when the leaves of the soybean start to turn yellow and fall in mid-October, which is about 25 days prior to the harvest period. The sorghum grows during the last rains of November and the soil's water reserve and is then harvested in January. The already-harvested sorghum does not completely perish during the dry season, but starts to reshoot when the first rain of the rainy season comes. The maize and pigeon are implemented as mentioned above, about one month after desiccation of the sorghum cover.

Intensified cropping of maize and cassava

The early maize (using a short-cycle maize variety) is sown in mid-May using the same row space and fertilization technique as that used in cultivating normal maize. Two cover crops are used to induce macroporosity and soil structure in preparation for the cultivation of cassava. Finger millet is broadcasted a day before maize is sown at an application rate of 5 kg/ha. Sunhemp is then sown in interrow spaces 15 days after the maize crop has been planted. The early maize is harvested in mid-September, right after the remaining crops and weeds are controlled in preparation for cassava planting. Cassava cuttings can be planted horizontally along the lines that were opened up by chisel. If the soil is too wet, then manual planting using a wooden stick is advised in order to avoid making the soil compact, which happens when a tractor or power tiller is used. The same fertilizer formulation of 70-30-60 NPK is used. However, the first application is delayed until the first rain of the rainy season occurs (usually in April). The cassava could then be harvested in July.

Farmers' Inputs in the DATE Methodology

Table 4.1 also illustrates how the DATE approach remains open to farmers' inputs, particularly in the areas of systems orientations and adjustments. Researchers must take the farmers' inputs as an opportunity to learn about the constraints that farmers face in the adoption of the introduced system, their perceptions of the innovation, and their corresponding adjustments to enable them to continue adopting the introduced innovation process. Such inputs also provide feedbacks that would enable researchers to improve on the following:

- the form of the systems (e.g., number of cycle per year, schedule of succession, variety of catch crop, calendar, crop sowing method, etc.) in order to address production goals and methods (e.g., weeds control, labor allocation and organization, etc.); and
- secondary thematic tunings (e.g., crop variety, level of applied mineral fertilizers, practical management of operations, etc.).

For example, with regard to the timing and row spacing in the pigeon pea-maize cropping system, the local farmers voiced their concerns about the following:

1. Manual sowing of pigeon pea 15 days after maize is sown in the 80-centimeter row space entails high labor cost.
2. Competition might occur between pigeon pea and maize if both crops are sowed at the same time using the planter.
3. The procedures for weed control in the pigeon pea-maize association is more difficult and labor intensive because it is not possible to use some of the active ingredients in herbicides, notably the widely used atrazine.

Thus, the researchers tested different row spaces and time of sowing on the pigeon pea with maize experimental plots. Results showed that the optimal row space and time for sowing pigeon pea is 60 cm and 15 days after sowing maize, respectively. Meanwhile, using a sowing device for planting pigeon pea could save labor cost of up to 8 man-days or USD (United States Dollar) 40 per hectare.

The soil of CA-based plots with mulch has significantly higher water storage capacity (than the normal plots), which is useful for storing the first rains of the rainy season. However, the amount of rainfall during the dry season is very low; thus, planting cassava late in the rainy season after maize could ultimately fail. To cope with this, the researchers and farmers tested in the experimental plot a new system that involves moving the planting schedule of cassava to mid-September.

The results of the experiment were highly appreciated by the farmers. The system was effective as strategies for the following:

1. *Climate change mitigation*. The system reduces GHG emissions as it cancels soil tillage and ridging.
2. *Climate change adaptation*. The system significantly reduces the costs of soil preparation and weed control.
3. *Climate change resiliency*. The new system has zero risk and provides the local farmers with the option of growing cassava in succession with different short-cycle crops options.

In this co-construction phase, researchers should be open to farmers' suggestions, and they should also encourage the farmers to participate in the DATE approach. This can be done by discussing with farmers the activities and strategies to be implemented in the DATE approach before the activities are actually implemented; farmers should also be involved in the evaluation process.

For instance, the success of the farmers in coping with the shorter and wetter planting season by using mungbean is quite impressive. Mungbean is a short-cycle crop, drought-tolerant, less costly to produce, and commands high market price. Farmers have stopped growing the crop in the secondary season; they successfully broadcasted it in mid-October on the already-harvested maize plots. Immediately after harvest, mungbean is broadcasted at an application rate of 30 kg/ha, and then the plot is rolled and sprayed on the same day. The mungbean is then harvested in January of the following year.

Should the researchers assess that the farmers' inputs and practices are unsustainable in the long run, they can only comment and raise their concerns; they cannot prohibit the farmers from still practicing them. However, the interactive process does not end at this transition stage. New alternatives must be developed to integrate farmers' inputs and rationale into the new cropping patterns that, in the meantime, respect the necessary conditions for long-term agronomic sustainability. An example of which is the minimum soil disturbance combined with sufficient fresh organic matter (OM) inputs to induce positive soil organic carbon (SOC) balance.

The quality of the farmers' feedback evolves along the design process owing to their interaction with the researchers during the research and design implementation. Farmers' thought process regarding the whole design process matures—from the initial simple interest in the no-till crop practice (to save labor and cash inputs) to being actively engaged in integrating the cropping system into their practices and in adopting the catch crop, association, residue management, and others. Such attitude and behavior signify a progressive understanding and capacity to adopt and adapt to the innovation within the CA framework. The combined application of the three CA principles brings a "warranty" on the agronomic sustainability of farmers' practices and strengthens the economic profitability of the annual rain-fed crops. However, note that the change in farmers' perceptions, their attitude toward accepting a new rationale for fertility management, and the eventual adoption of the innovation could be slow.

One of the challenges encountered in this R&D project of designing sustainable innovative cropping systems is that production structure and patterns in the pioneer front under a changing market evolve very fast. This becomes an issue when the modifications in the farms' environment induce rapid changes in the cropping and production systems, quicker than the minimum required time for evaluating their performances and impacts on natural resources and on the farms production's productivity. This fact strengthens the need to create and maintain plots to assume the role of "technological beacon," where key co-designed cropping systems are compared with one another for several years, alongside past and present farming practices. This method allows researchers to show and quantify the performances of the designed technologies for the following periods: (1) after a transition period where the condition of the soils progressively improved and (2) across several successive years under varying climatic conditions.

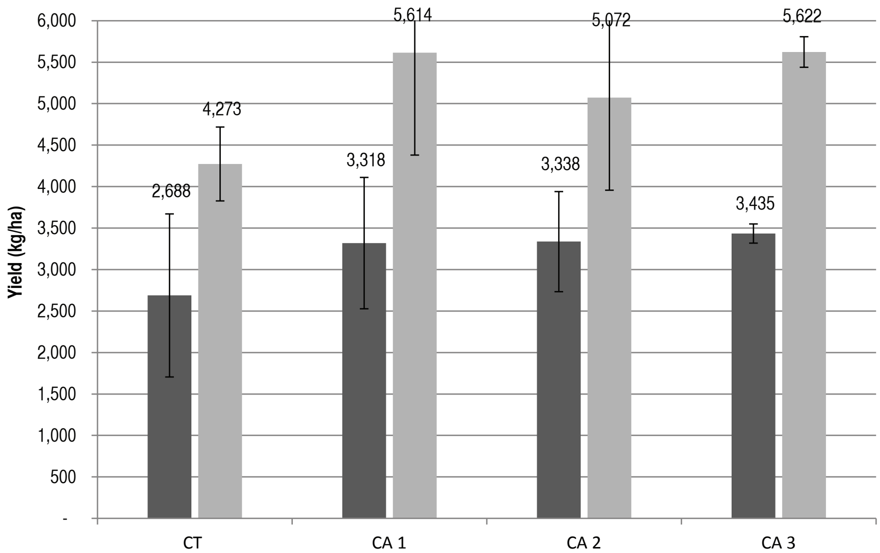
OUTCOMES OF THE ADAPTATION

Adaptation of CA-Based Cropping Systems to Drought and Flood

Figure 4.4 shows the yield comparison, based on the average of three consecutive years (2012–2014), between conventional and CA-based innovative systems at two levels of fertilizers application. The yields were measured on a researcher-managed plot (based on real-scale elementary plot of more than 2,000 m^2), initiated in 2009, which was chosen from the target zone for its severely degraded soil condition. On the other hand, Figure 4.5 presents the gross profit margin (GPM) of the different maize crop management systems.

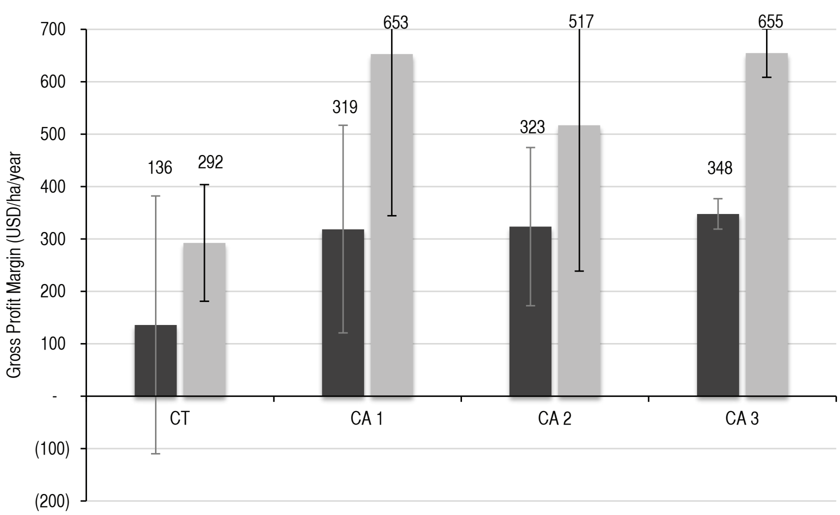
The results confirm the expected improvement in the technical and economical performances of the tested CA cropping systems. Based on the results, crop yields of those under CA increased, on average, by more than 0.5–1.0 t/ha, with GPM of USD 200–350 per hectare. Under a severely depleted soil condition, increasing the application of fertilizers provide marked benefits. These extra fertilizers, when combined with CA system, should be considered as an investment in soil capital recovery rather than as an annual extra charge.

Figure 4.4. Maize yield under CT and CA systems, 2012–2014



Notes: (1) Left bar = F1 fertilization of 70-30-30 NPK; right bar = F2 fertilization of 116-110-60 NPK. (2) Yields were measured from a three-year CA practice plot with degraded and shallow mollisol; (2) CA = conservation agriculture, CT = conventional tillage; (3) CA1 = mono-cropping of maize, CA2 = biannual rotation of maize and cassava, CA3 = biannual rotation maize and soybean

Figure 4.5. Gross profit margin of maize with F1 and F2 fertilization under CT and CA systems, 2012–2014



Notes: (1) left bar = F1 fertilization of 70-30-30 NPK; right bar = F2 fertilization of116-110-60 (2) CA = conservation agriculture, CT = conventional tillage; (4) CA1 = mono-cropping of maize; CA2 = biannual rotation of maize and cassava; CA3 = biannual rotation maize and soybean

The results confirm the expected improvement in the technical and economical performances of the tested CA cropping systems. Based on the results, crop yields of those systems under CA increased, on average, by more than 0.5–1.0 t/ha with GPM of USD 200–350. Under a severely depleted soil condition, increasing the application of fertilizers provides marked benefits. These extra fertilizers, when combined with CA adoption, should be considered as an investment in soil capital recovery rather than as an annual extra charge.

In addition, the CA-based cropping systems designed under DATE have adapted better to climate change. The physical properties of the soil under CA improved; water storage and drainage capacity of the soil improved owing to the cancellation of the tillage practice. The improved water storage and drainage capacity of the CA plots also helped crop production as they helped to resist waterlogging (due to flooding) and drought. This was experienced in the October 2013 flash flood and in the 2012 and 2014 drought in Battambang. In October 2013, more than 600 mm of rain fell in Battambang, 400 mm of which fell in a span of 10 days, which consequently led to the flash flood. Meanwhile, although the drought in 2012 was drier than that in 2014, the latter dry spell had more severe consequences. The month of June in 2014 offered very good climate conditions for sowing; however, this was followed by 45 consecutive days of less than 100 mm of rainfall, triggering the dry spell. During these incidents, maize productivity under CA was approximately 30 percent higher than that under conventional tillage (CT). Furthermore, pigeon pea with maize can produce an additional 0.5–0.7 t/ha yield without any extra input cost, thereby enabling farmers to employ family labor capacity in low activity period while gaining additional income during the dry season.

Likewise, changing the conventional practice of growing mungbean by soil tillage, manual broadcast, and harrowing during the secondary season to manual broadcast after early maize harvest by mid-October resulted in a higher level of adaptation for better establishment, higher mungbean productivity, and better market price. With this new system, farmers can have a GPM of as much as USD 300-500/ha, as compared to a possible loss of USD 150/ha under conventional mungbean. Thus, the system not only reduces the cost and risks of farmers, it also helps to avoid soil tillage for broadcasting. Farmers prefer this better than the no-till sowing in order to reduce their production cost.

Moreover, shifting the planting schedule of cassava to mid-September (rather than at the onset of the rainy season in April), after the early planting of maize under a CA management, offers a remarkable adaptation against and flexibility to drought, rainfall variability (especially during the secondary season), and market fluctuations. The system significantly reduces the risk of crop establishment failure and the costs of soil preparation and weed control. Crop establishment failure can cost farmers by as much as USD 300–400/ha, whereas savings under CA can be as much as USD 200/ha; farmers can also save by as much as USD 50-100/ha from weed control.

In addition, flat planting without the ridging practiced in conventional management could facilitate the intercropping of short-cycle grain legumes such as cowpea. The system can be adjusted with different possible dates of harvest, according to tubers development and/or price; harvesting cassava in mid-July (after 10 months cycle), allows a succession with maize; harvesting mid-September (after 12 months cycle), a succession with secondary cash crops such as sunflower, sorghum, mungbean, etc. or during the dry season (after about 18 months cycle). Besides adaptation to the length and severity of the dry season following the cassava planting, which conditions the development of the tubers and the possibility of early harvest after 10 months cycle, such flexibility provides farmers with better cash flow, better choices of crops to be produced and marketed, and maximizes farm labor. For instance, the yield from the production of cassava within an 18-month period is more than double than that from a 10-month cycle; this translates to a gain of 10 t/ha from harvesting dried tuber or USD 1,500/ha (price in 2014), without any additional input costs.

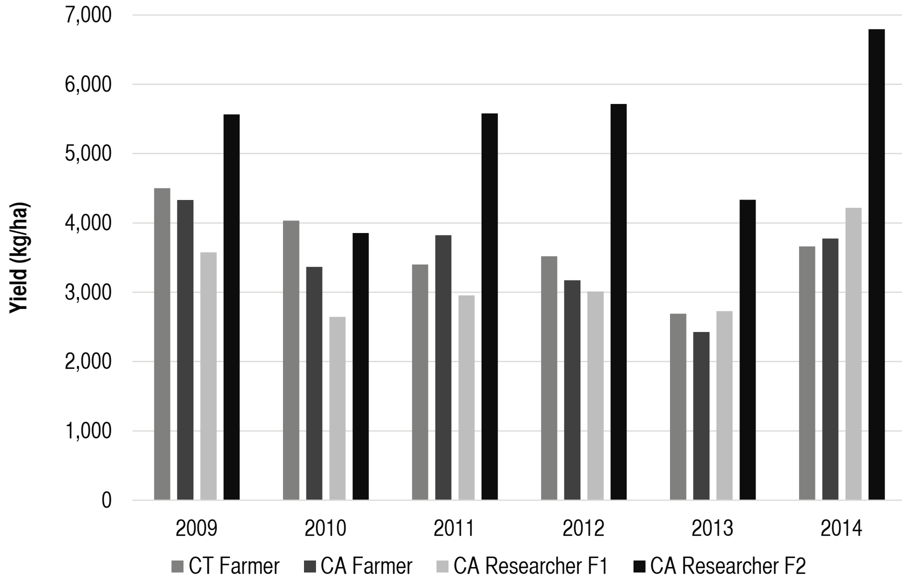
Figure 4.6 compares the maize yields from CT- and CA-based plots. Site 1 (Figure 4.6a) was initiated in 2009 on a plot with degraded soil condition, whereas Site 2, located in the same village, (Figure 4.6b) started in 2010 on less shallow and depleted soil.

In Figure 4.6, *CT farmer* represents the average yield recorded on a network of 30 plots, divided among the four communities located within the 10-kilometer radius of the two experiment sites. Meanwhile, *CA farmer* represents the average yield recorded from the pilot extension network initiated and monitored by the project implementers since 2009. This set of plots had reached a stable volume of about 100 households and 300 ha in 2012, but its composition has evolved due to the high turnover of participating farmers. At this site, five plots have been continuously cropped under the CA system between 2009 and 2014.

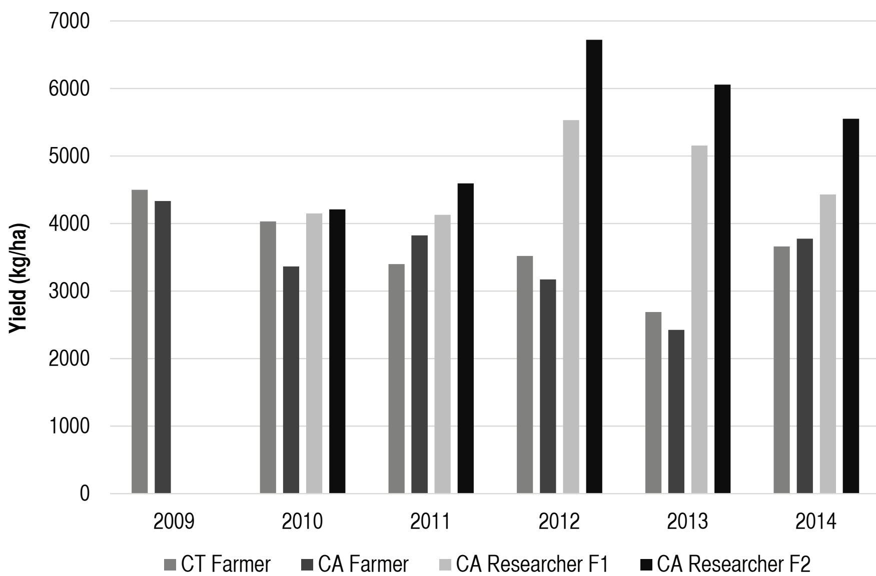
Most of the farmers adopted CA in one of their plots—usually in the worst area of the farmland—for one or two years before they decide whether or not to abandon the system. Some of the cited reasons for abandoning CA are as follows:

1. Farmers experienced technical difficulties in applying the introduced practices; notably the weed control in the first two years after the suppression of the tillage and banning of Atrazine (a highly polluting herbicide used in CT-based management).
2. Some abandoned CA farming because there is a no market for pigeon pea, even if its production requires minimal extra labor.
3. Some reasoned that they wanted to return to the two-crop cycle in annual succession.
4. Some cited economic reasons such as they cannot afford the cost of fertilizers required in CA management and the reduced profit margins during the initial years of CA farming.
5. Other reasons were not related to CA experience such as deciding to shift to perennial crop, change in land tenure, and shifting livelihood activities to off-farm activities.

Figure 4.6. Yield gap of maize between CT and CA under farmer- and researcher-managed plots, 2009–2014



a. Site 1 = maize crop planted on plots with degraded soil



b. Site 2 = maize crop planted on plots with less shallow and depleted soil

Notes: (1) CA farmer used F1 level of fertilizer application until 2012; thereafter, fertilizer application was the same as that in CT; (2) Figure 4.6a compares the two farms' plots sets with the yield of CA1 in the first researcher-managed site (degraded and shallow mollisols soil); Figure 4.6b compares the two farms' plots with the yield of CA1 in the second researcher-managed site (representative mollisols soil type with average fertility conditions).

This rapid turnover, after testing CA one or two years with limited fertilizer application and cover crop biomass inputs, prevents most farmers from getting clear benefits from CA, which start to emerge only after two or three years of continuous practice. Meanwhile, for those farmers who managed to continue CA farming, their level of understanding of the rationale behind keeping crop residues on field to prevent soil erosion and to improve soil fertility have increased significantly. Crop residues that used to be burned after harvest are now being conserved or incorporated into the soil by plowing (if they could not guarantee their access to the no-till sowing service).

However, one key and urgent constraint that needs to be addressed is the availability and affordability of CA-required equipment like no-till planters and chisel. Currently, farmers are totally relying on the sowing service provided by the program. As the program proponents cannot assure the farmers that such equipment will be provided whenever they need them, farmers prefer to plow the plot in preparation for sowing either through the no-till planter or through conventional ones. At this point, they have not yet observed any clear difference between CA and CT, and thus prefer to not rely on the limited program logistic when it is time to sow. Similar bias linked to material access was observed in cassava production under CA due to a limited service offer for strip tillage with chisel equipped with mulch-cutting disc (disc coulters).

Another factor that could greatly encourage the farmers to adopt the CA practice is to develop a market for pigeon pea grain using a threshold price of USD 400/t. Having a market for this produce can effectively make the farmers interested in CA, and consequently help them to experience the benefits of CA practice.

Meanwhile, the monitoring and analysis of the cited technical difficulties experienced by farmers are at the heart of the DATE methodology, which feeds on the process of the cropping systems design and adaptation. The feedback mechanism serves as beacons with regard to the possibility and conditions of appropriations by the various types of farmers. It orients researchers and farmers on how to create the accompanying measures to support dynamic extension and to enlarge the socioeconomic domain of diffusion, notably toward smaller farms that are too constrained to invest time and resources in CA adoption without supports. These flanking measures to ease the adoption process should rest on the farmers' access to economic production factors as the following:

1. *Money or other financial tools* to address the usual household cash flow deficit and the investment requirements (e.g., for soil fertility restoration, specific CA-equipment) during the onset of the crop planting season;
2. Minimum *land tenure security*, which is a key precondition for farmers to convert from CT- to CA-based crop management;
3. Farm decision regarding *labor allocation*, which is directly influenced by farm structure. This can be improved if support (technical or financial) could be provided to producers so that they can enhance their farm organization and coordination as well as access to mechanization (e.g., individual or collective equipment, contractors' offer, etc.).

The R&D process could also be improved through developing ways to help farmers to access specific technical elements that would help make the implementation of the designed cropping systems easier. Initial inputs could be through improving farmers' access to cover and fodder crops seeds and access to specific farming tools such as roller-crimper, planter and seeder, boom sprayer, among others.

R&D Methodology and Linkage with Agricultural Development

Characteristics of the CA cropping systems and precautions in the design process

This section highlights the essential features of the CA-based cropping management systems and some precautions that researchers and farmers need to consider when designing such systems. In the design and implementation process, researchers and farmers need to primarily consider two major ontological characteristics of CA cropping systems:

- CA-based systems should be viewed as a "technical object" that belongs to the "method" type, which means that they aren't characterized by their proper structure and functioning scheme, such as tools and machines for instance, but by the shape and functions they confer to a "medium" of application (i.e., the plots and its soils).
- The major and essential factor in "medium shaping" is done indirectly through the complex biological processes triggered during the implementation of the CA cropping systems. These biological processes are nurtured through the combined application of the three CA principles.

The design process focuses both on the operational sequence of crop production and on the transformation of the agro-system into a cultivated ecosystem. Farmers can give a short-term assessment of the newly developed cropping methods in terms of their capacity to produce yield (i.e., grain yield and biomass inputs) and feasibility as a crop production method. However, at this level, farmers and researchers may assess this crop production system as ineffective due to factors such as mismanaged operations (e.g., sowing, weeds control). As such, lack of skills in implementing CA-based practices and the perceived difficulty in trying new practices can lead farmers to abandon a good system prematurely.

However, such rapid assessment still does not consider the medium- to long-term evolution of the fertility parameters and changes in the bio-aggressors regulations. During the design phase, those evolutions can hardly be forecasted; the effects can only be observed, analyzed, and evaluated after a certain period of time—a kind of "relaxation" time of the agro-ecosystem in its "oscillations" toward a new "equilibrium." By transforming the crops' environment, these evolutions modify the effect of the technical operations which, in turn, needs to be adapted along this transition phase. Thus, the technical design process of the CA-based cropping systems (i.e., type, sequence, pattern, and modality of operations) needs to be carried out in consonance with the evolution of the biophysical elements of the field (i.e., biological diversity and function, structure, composition).

A premature evaluation is risky due to factors such as improper management and insufficient biophysical transformation of the environment and concretization of biological functionalities. In this transition phase, the technical operations should be adjusted in relation to the environment and should engage in a continuous process of experimentation and innovation through adjusting the operations in accordance with the evolving conditions of the field. The whole process is complex; some procedures can get temporarily lost in deadlock, but it ultimately leads to simpler crop management methods owing to the increasing number and efficiency of the integrated ecological services. Designing CA-based cropping systems is a reflexive process, in which the techniques should be adjusted in accordance with and should be adapted to the biotic evolutions of the crops' environment.

The deliverables in this R&D process must be twofold:

1. the designed cropping systems at the plot level within built agro-ecosystems and
2. the transitional technical stage(s) to be used as a simplified procedure for converting CT farming practices to CA-based crop management.

The first output involves a technical description of the crop and cover crop management systems of the different annual successions of the rotation. These recommendations are completed by introducing options and decision-making rules for adjusting the operations in accordance with the physical and/or economic conditions (e.g., climate, crop cover development, market price, etc.). Meanwhile, the second output involves specific technical guidelines to manage the conversion of cropping systems from CT- to CA-based. This second output is rarely done, which contributes to the confusion between the collaborative and complex innovation process of the cropping systems and the initial stage of the extension and development operation.

The research and design process must be continuous and should entail constant monitoring, evaluation, and adjustments in order to

1. improve the technique in accordance with the conditions of the field;
2. make the cropping systems resilient to climate change through the development of decision-making patterns that would address climatic and economic blips, and
3. integrate into the thematic adjustments of the systems the acquired knowledge on the mobilized biological processes.

Specificities of CA cropping systems and precaution in the knowledge-sharing process

When practitioners (farmers, technicians, and agronomists) shift from CT- to CA-based cropping system, their mindsets have to undergo a tremendous adjustment as to how they perceive their farm work—a shift from the direct and immediate construction of an artificial crop substratum, which is associated with a comforting (but largely illusory) perception of control, to an indirect and progressive elaboration of a field ecosystem through biological processes that are induced. Although this is favored, it remains partly controlled and largely unknown.

This change is even more difficult to operate for "pioneer" farmers who have been involved in the participatory design process because they face the risk of committing mistakes and goes through the complex stages of mastering the technical steps. This apparent progression via trial and error, but framed by agronomical laws mobilized with CA principles, reinforces the perception of risk and complexity attached to any novelty. The feeling stems from the strength of any well-established and shared habits and the initial lack (in the farm environment) of technical elements needed to implement the co-invented technique.

Addressing the first type of resistance that farmers experience against the CA-based cropping system (i.e., technical difficulties in applying the introduced CA-based practices) requires changing stakeholders' perception with regard to traditional practices—from the community to administrative and policy makers' levels. Landcare, as developed and implemented in Australia and the Philippines, is an efficient approach to diffuse and infuse innovation (e.g., natural vegetative strip in Mindanao, Philippines) across farmers groups. In the meantime, it reverses vision on natural resources protection and norms for farming practices among stakeholders arranged in networks (Landcare Foundation 2009).

Alongside this, developing a favorable technical environment within farming communities could significantly encourage farmers to continue with the implementation of the introduced cropping system. In this case story, the initiatives undertaken toward this goal includes providing farmers with access to specific inputs and tools such as

- seeds of cover crops, which have to be accessible and affordable both in terms of quantity and quality; and
- specialized CA planters through the local development of a small-scale power tiller draught units (Figure 4.7a) for individual investment, and medium-scale tractor draught units (Figure 4.7b) to support the development of contractor services.

Figure 4.7. Collaborative design between the pilot farmers' network and Machine Auto Part Co., Ltd. on different appropriate scale planters

a

b

Other inputs that could be provided are inoculum for soybean, bio-pesticides, and other machinery like roller or boom sprayers. For each of these elements, the co-design phase is about refining the specification (e.g., shape, size, active ingredient, dose, etc.) of the cropping system and the socioeconomic arrangements for the supply of inputs. This duality of the "what" and "how" in the supply chain of the technical requirements should also be extended to include the classical economic production factors. In a process of co-innovation, issues such as access to money, land, and labor in relation to the variable interests, opportunities, and capacities of farms would contribute to the determination of the precise limitations of an "extension domain," and would define social pathways and institutional support for the inclusion of the poorer households. These considerations tend to set the construction of a technical innovation against the one of its technical and economic "medium." In other words, if the innovation process involves needing to adjust the cropping method to adapt to farm structures and contexts, the improvements in productivity and ecosystemic services attached to CA-based innovations should allow for raising concurrent questions regarding the farms' context organization.

These series of remarks highlight the complex elaboration of the CA-based technical pattern. The cropping system design process has to progress in relation to the triggered biological transformations of the agro-ecosystems at the field and landscape levels; it also has to evolve through and under an evolutionary perception and appropriation of the new practices of farmers.

CONCLUSIONS

This research and development program conducted in the pioneer front of the western regions of Cambodia illustrates the capacity of CA to restore soil conditions and dramatically improve crop productivity. It proves that CA opens ways to set the technical basis of sustainable intensification of smallholder farmers' production systems. It can thus help to enhance and secure agro-industrial sectors that are linked to the annual crop production in the basin. However, in order for new proposals for agro-technical validation process to progress, relay research work is still needed that would enable researchers and farmers to continuously validate, based on multi-year and multi-location assessments, the performance of the systems and their impacts on natural resources (e.g., positive balance of SOC, nutrient cycles, xenobiotic dynamic, etc.).

The DATE approach has proven to be effective in inducing a dynamic participatory design process of cropping systems. It appears well-embedded, and it suits the complex evolutions of the recent pioneer front. In this context, the farms' environment is notably marked by rapid changes in its biophysical and socioeconomic conditions.

With sound choices of agro-ecological zones for implementation, this holistic approach addresses real situations representing important challenges. The complexity of the biological and cognitive changes sought for calls for an "in vivo" process conducted "on farm, with, and for farmers" established for several years. The designed techniques are composed of combinations of context-specific and context-generic features. Through the latter, channels are created to initiate the application of designed proposal from one context to another one. This can be exemplified in the case of the CA-based cassava cropping systems that had been developed in the central upland regions between 2007 and 2012 (Boulakia et al. 2013). When cassava appeared to be the next key annual crop in 2013 in the western regions, designing pre-developed systems using the DATE platform was quickly achieved.

This capitalization in co-designed systems then allows for a fast reaction to the brutal changes occurring in the farm environment; it is a way to build up "antibodies" to strengthen the resistance and resilience capacity of smallholder farmers in face of external chocks.

The presented R&D methodology in this chapter offers clear benefits and provides a holistic approach for identifying technical, socioeconomic, and institutional elements for a sustainable and more inclusive intensification of the production systems of smallholder farmers. Integrating this action-research process into agriculture and rural development programs is therefore recommended in order to induce and support the shift in farmers' production patterns that would address the increasing climate variability and include the poorest farm households.

In this regard, such R&D platform could be considered as a public investment in natural resources restoration and conservation. Such perception could help proponents to develop new and shared financing mechanisms in support of conservation agriculture. This will be made easier if the presented R&D process and the expansion of this program can be clearly articulated to be proposed for adoption under public-private partnership programs in Cambodia.

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