Integrated Systems Research for Sustainable Smallholder Agriculture in the Central Mekong

Achievements and challenges of implementing integrated systems research

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Integrated tree, crop and livestock technologies to conserve soil and water, and sustain smallholder farmers' livelihoods in Southeast Asian uplands

Chapter 3

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Summary

After reviewing the main causes and effects of land degradation and erosion in the uplands of mainland Southeast Asia, this chapter presents several case studies of recent land-use changes governed by economic, political and institutional transitions, the expansion of teak and rubber tree plantations in northern Laos and southwest China, respectively, and of monocropping coffee in the Central Highlands of Viet Nam. We explain how these environmental disturbances are altering water and soil resources across different geographic scales, from the agricultural plot to the headwater catchment. Examples of coping strategies combining field trials and participatory approaches are illustrated with several case studies taken from research for development activities conducted in Cambodia, Laos, Viet Nam and the Yunnan Province of China. These activities were part of the CGIAR Research Program on Integrated Systems for the Humid Tropics (Humidtropics) in the Central Mekong Action Area. We propose solutions for sustainable agricultural intensification to diversify income, improve dietary diversity and improve natural resource management. The accomplishment of these objectives requires long-term involvement with ethnic minority communities that have been the particular focus in the target areas. The three-and-a-half-year lifespan of Humidtropics in the Mekong region was a short period. It would require extension to maintain the carefully built and nurtured relationships with local implementation partners and local farming communities, and reach its full promise.

1. Introduction

Over the past two decades, the agricultural sector in the Mekong region (Cambodia, Laos, Viet Nam and the Yunnan Province of China) has experienced profound changes, especially in smallholder farms. Market and population pressure, expanding infrastructure into formerly remote but fragile upland regions, government policies and incentives aimed at modernizing and commercializing the smallholder sector (MPI 2011), have induced a drive towards specialization and commercialization (Baudran 2000, Ducourtieux 2006). Enticed by booming markets for certain commodities and associated foreign direct investments (LIWG 2012), more smallholders have converted part or all of their farms into commercial plantations of rubber, coffee, teak, cashews or cassava (Neef et al 2013, Schönweger et al 2012). While such specialization has the potential to transform subsistence livelihoods into much more lucrative agricultural enterprises, it too often also leads to a weakening of ecological processes typical of more diversified traditional farm systems that integrate trees, annual crops and livestock; the result is land degradation (Cramb et al 2009), compromising ecosystem and livelihood sustainability (Rerkasem et al 2009). The absence of intercropping/crop rotation, animal manure cycling and appropriate plant understoreys to cover and protect soils may lead to increased dependency on inorganic and often potentially toxic inputs to control pests and diseases or maintain soil fertility, while simultaneously exacerbating soil erosion and water runoff problems (Guardiola-Claramonte et al 2010, Ratanawilailak 2013, Valentin et al 2008, Ziegler et al 2009a). Consequently, the future productivity and long-term sustainability of agricultural landscapes in the region may be jeopardised. With specific references to activities conducted as part of the CGIAR Research Program on Integrated Systems for the Humid Tropics (Humidtropics) in the Central Mekong Action Area, this chapter has three objectives:

1. To analyse the magnitude of the problems, specifically to explain how recent land-use changes are modifying erosion rates and runoff processes and the consequences over multiple scales (section 2).
2. To review the methodological approaches and tools applied to analyse the environmental and livelihood footprints and trade-offs in the contexts of i) the northern uplands of Laos where teak tree plantations are gradually replacing cash crops, and ii) rubber tree plantations in southwest China, and iii) on-farm integration, diversification, specialization, intensification and commercialization of integrated tree-crop-livestock smallholder farms in the Central Highlands of Viet Nam (section 3).
3. To provide examples of coping strategies (with enabling factors and constraints) through the case studies introduced in section 3 and with an additional case study focusing on rainwater harvesting for home-based vegetable production in Northwest Viet Nam (section 4).

2. Land use and water-soil interactions across geographic scales

Soil erosion is a major issue for sustainable agriculture in sloping land areas. It can cause severe negative environmental, economic and social impacts both on- and off-site. On-site, soil erosion leads to a loss of topsoil (Valentin et al 2008), the most nutrient and organic matter-rich part of the soil, in some cases even exposing the acid subsoil. Landslides and sediment transfer to down sites (Downing et al 2008, Thothong et al 2011) result in widespread land degradation (Sidle et al 2006) which, in turn, results in a decline in land productivity associated with decreasing soil organic matter levels (Kendawang et al 2005). The off-site effects of erosion on the quality and availability of water can have serious consequences for rural population health and natural ecosystems, and cause accelerated siltation of downstream reservoirs.

Researchers from the International Water Management Institute (IWMI), the French Institut de Recherche pour le Développement (IRD) and their national partners in Laos – the Department of Agricultural Land Management (DALAM) – and Viet Nam – the Soil and Fertilizer Research Institute (SFRI) – have demonstrated that afforestation through teak tree planting or by natural forest regeneration can induce divergent hydrological changes (Lacombe et al 2016). An observatory including long-term field measurements of fine-scale land-use mosaics and of hydrometeorological variables (Valentin et al 2008) has been operating in several headwater catchments in tropical Southeast Asia since 2000 (Photo 3.1). This monitoring network, named 'Multi-Scale Environmental Change' (MSEC, http://msec.obs-mip.fr/) has been funded by the French watershed network SOERE-RBV (réseau des bassins versants), the French Observatory for Sciences of Universe (Observatoire des Sciences de l'Univers), IRD and IWMI. Humidtropics enabled the data collected over the last 14 years to be compiled to produce the analysis reported here. A water balance model, repeatedly calibrated over successive one-year periods and used in simulation mode with the same year of rainfall input, allowed the hydrological effect of land-use change to be isolated from that of rainfall variability in two of these catchments, in Laos (Houay Pano catchment in Luang Prabang Province) and Viet Nam (Dong Cao catchment in Hoa Binh Province). Visual inspection of hydrographs, correlation analyses and trend detection tests allowed causality between land-use changes and changes in seasonal streamflow to be ascertained. In Laos, the combination of shifting cultivation (alternation of rice and fallow) and teak tree plantations gradually expanding and replacing fallow land led to intricate streamflow patterns: pluri-annual streamflow cycles induced by the shifting system on top of a gradual streamflow increase over years caused by the plantations' spread. In Viet Nam, the abandonment of continuously-cropped areas combined with patches of mixed-tree plantations led to the natural regrowth of forest communities followed by a gradual drop in streamflow.

These contrasting hydrological behaviours may appear counter-intuitive but proved to be closely linked to the way the land was managed. In Viet Nam, the natural groundcover including deep litter and soil naturally enriched with humus allowed rainwater to infiltrate the soil, which allowed plants to develop deeper and thicker root systems as well as a denser tree canopy. Rainwater was better absorbed by the soil and then evapotranspirated by the growing trees, resulting in less water leaching into the streams during both the wet and dry seasons, and an overall reduction in erosion. In Laos, farmers moved from a shifting rainfed rice-based system to teak plantations. Teak trees usually develop a thick canopy and deep and dense root systems, which theoretically should reduce streamflow by increasing evapotranspiration. However, the hydrological effects of the teak plantations studied in Laos were very different. The area beneath young teak trees was cultivated with annual crops, inducing a high rate of soil surface crusting; the large leaves of mature teak trees concentrate rainfall into big drops that hit the soil with increased kinetic energy, forming surface crusts. In addition, most farmers intentionally kept the soil bare under mature teak trees by recurrent burning of the understorey[1]. These three actions created a soil crust in the plantations that was four times less porous than fallow land, producing higher runoff and streamflow, and – crucially – intense erosion.

Photo 3.1 The research site in Laos: Houay Pano catchment, part of the 'Multi-Scale Environmental Change' (MSEC) network. A: Stream water level measured within a V-notch weir by a water level recorder equipped with a data logger. B: Teak plantation in the rain. Root exposure illustrates ongoing erosion. C: Small fairy chimneys on steep soil in a teak plantation, revealing intense erosion rates. D: Tipping bucket rain-gauge used to monitor rainfall. Photo credits: IWMI/Guillaume Lacombe

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[1] We assumed that this practice resulted from a mix of beliefs and practical considerations. i) Farmers generally considered that understorey vegetation competed with teak trees in accessing soil water and nutrients. Thus, they believed that burning this understorey vegetation improved teak trees' access to resources even though teak trees were known to explore and exploit deep soil layers much more thoroughly than understorey species. ii) When clearing plots to grow annual crops farmers usually poorly controlled the spread of fire into adjacent teak tree plantations; since adult teak trees are fire-resistant, this represented a convenient and effortless way of suppressing understorey vegetation in teak tree plantations. iii) The absence of understorey vegetation in teak tree plantations also improved access to and circulation within plantations, which was a desirable feature for many farmers for maintenance and exploitation purposes (NTFP harvesting, pruning, thinning, etc).

Soil permeability controlled by surface crusting was the predominant process explaining why two modes of afforestation (natural regeneration versus planting) led to opposite changes in streamflow regime in the two studied countries (Lacombe et al 2016).

One of this research's distinguishing features was its geographic scale. Previous research into this topic looked at 1 m^2 micro plots (Ziegler et al 2004, Podwojewski et al 2008, Valentin et al 2008, Patin et al 2012). By contrast, Lacombe et al (2016) confirmed previous findings at a scale about 1 million times larger (i.e. 1 km^2), which is more appropriate for water resource managers. The authors mapped land-use changes over a 13-year period by conducting detailed field surveys, recording daily water data and using modelling and statistical tools to match water flow differences against land-use changes while isolating the compounding effect of climate variability.

In the reforestation area in Viet Nam, both wet and dry season streamflow dropped by more than 50 percent. In the teak plantations in Laos, streamflow increased by more than 100 percent in both the wet and dry seasons with tremendous implications for natural resource management policy, especially in Laos (Lacombe et al 2016). The Government of Laos has set a goal to increase forest cover to 70 percent by 2020 (MAF 2005). A key driver is the commitment to hydropower development (http://www.poweringprogress.org/) and increasing forest cover will theoretically increase the available water for hydropower in the long term. CGIAR's research demonstrated that these ideas about the relationships between forest cover and hydropower development were not necessarily true. On the Vietnamese side, natural regrowth actually decreased the amount of water released into the catchment. On the Lao side, while streamflows did increase significantly, the high erosion rates associated with teak plantations led to excessively sedimented water unsuitable for hydropower development and detrimental to aquatic ecosystems.

These results were not necessarily typical of afforestation and should be extrapolated with caution. For instance, in Viet Nam, the reduced streamflow observed during the dry season was not necessarily characteristic of all reforested areas (Andréassian 2004, Bruijnzeel 2004, Calder 2007). In other situations, forest growth significantly improved the soil capacity to absorb and store water while the increased evapotranspiration caused by the growing vegetation remained moderate. These two concurrent changes resulted in a net gain in groundwater recharge followed by an increase of streamflow during the dry season, while at the same time total annual flow decreased. As such, it is important to consider the site-specific effects of the vegetation on the soil during both wet and dry seasons when attempting to link water resource management to land use.

Although important for the sustainable management of headwater catchments, the full understanding of hydrological processes altered by land-use changes remains limited in the tropics. While in most cases, afforestation will reduce annual streamflow, the opposite effect may also happen. Put simply, land use has more effect than land cover, sometimes leading to extreme yet opposite hydrological behaviours. Given that commercial tree plantations will continue to expand in the humid tropics, careful consideration is needed before attributing to them positive effects on water and soil conservation.

3. Understanding the drivers of soil and farming land degradation and water availability

3.1 Land-use management and impacts on water and soil in northern Laos

In 2015, the Humidtropics research team in Laos (IWMI, IRD and DALAM) decided to expand current knowledge on the effects of several land-use types on erosion and runoff to a wider range of farming practices typical of the northern Laos uplands. This work constituted the first exploratory phase of a project that aimed to, together with farmers and local stakeholders, test and develop innovative on-farm land management practices that allowed stream water quality to be improved while sustaining the fertility and productivity of erosion-prone soils in the mountainous environment. The overarching objective was to contribute to improving soil and saving water through collaborative field work between targeted farmers, researchers, government extension agents, community pillars, local knowledge gatekeepers and relevant authorities (Photo 3.2).

A combination of erosion and runoff monitoring in the field, focus group discussions and participatory rural appraisals, field visits and individual in-depth exchanges with farmers and other local knowledge gatekeepers was conducted in the small Houay Dou catchment in Xieng-Ngeung District of Luang Prabang Province, about 20 km south of the Houay Pano catchment. Ten typical land-use types were identified for the monitoring as representing usual farming practices, including annual crops (maize, *Musa spp*; Job's tears, *Coix lacryma-jobi*), tree plantations (banana; vernicia, *Vernicia montana*; rubber, *Hevea bresiliensis*; teak, *Tectona grandis*), with or without understorey, and broom grass (*Thysanolaena latifolia*). For each of the 10 land-use types, three microplots of 1 m^2 each were installed and equipped with a metal frame inserted into the soil at a depth of approximately 10 cm (Photo 3.2). Runoff water was collected in a tapped and buried bucket and the runoff amount was measured after each main rainfall event. Rainfall was recorded by an automatic meteorological station located in the watershed. Hydrometeorological data were collected during the 2015 monsoon season between May and October, and analysed in 2016. Preliminary results (to be published in a peer-reviewed journal article) indicated that farmers did not invest effort in maintaining the two studied annual crops, Job's tears or maize. The reasons appeared to be that a drastic drought in 2015 resulted in a very low crop coverage with significantly reduced crop yields. For these two annual crops, the runoff coefficient was much above the average of the 10 monitored land-use types. In contrast, broom grass was found to be the most efficient crop for erosion control because it efficiently protected the soil with a high interception rate. Broom grass, known in Laos as 'dok khem', is a naturally growing, semi-domesticated non-timber forest product (NTFP) naturally present in upland fallows, degraded forests and degraded land along roads and in villages. It mainly requires labour for harvesting, drying and threshing the inflorescences, which are the plant parts eventually used to make brooms. When cultivated, it is less time consuming than other field crops. Weeds need to be pulled out and then cut back once annually. Yield is estimated to be 1 ton/ha of dried and threshed inflorescences. A family with all members working full-time on broom grass can generate an income up to USD 1200 per year. After harvesting, the broom grass flowers are sun-dried for three to five days. The seeds are removed by manual threshing and the grass stems are bundled for storage until it is time to sell them to traders or for broom making (Khamhoung and Gansberghe 2016).

Although trees usually exhibit a high percentage of canopy cover, teak and vernicia trees were found to be relatively inefficient in protecting soil from runoff and erosion because a rather limited amount of vegetation residues were found to cover the soil. In contrast, because fire was strictly controlled in rubber tree plantations, the percentage of residues on the soil surface was higher than in the teak and vernicia plantations. This coverage protected the soil from the direct impact of raindrops. In management terms, it was paramount to control fire in all types of tree plantations.

Photo 3.2 Land use, erosion and capacity building in the Houay Dou catchment. A: focus group discussion on erosion issues in teak plantations. B: Microplot under fallow. C: Cross-village visit. D: Training with agricultural extension services and district representatives from the Ministry of Agriculture and Forestry. Photo credits: IWMI/Guillaume Lacombe

In partnership with the policy research centre of the National Agriculture and Forestry Research Institute (NAFRI), IWMI conducted surveys among minorities in five villages around Houay Dou Basin to understand the villagers' preferences for cropped species, with a focus on the 10 land-use types monitored during the 2015 wet season. Some differences were observed between the villages, but overall there were good agreements as detailed thereafter (Pers. Comm. Sonali Senaratna Sellamuttu and Anousith Keophoxay). Overall, farmers indicated that they used to grow more upland rice, but because of low yields they switched to several different cash crops. Broom grass, banana and fallow lands were usually the preferred land-use types because broom grass was easy to plant and grew easily with minor inputs. It required minor maintenance due to limited spread of weeds. Field work was simple and could be performed by the household without hired labour. In addition, the market demand was high and relatively stable, although prices exhibited some fluctuations. Broom grass production was stable all through the year. The only major problem was the possible competition for grazing land, which was not a significant concern in this area. Bananas were also a favourite crop. They were easy to grow and local traders usually came on-site to buy. If not sold, villagers were happy to eat the fruit. Fallow lands were appreciated especially by women because this was where they collected NTFP. Job's tears was often preferred, compared to the traditional upland rainfed rice, because it could be planted on previously fallow land with no age requirement (while rainfed rice should be cropped following a fallow plot aged at least five to seven years). In addition, Job's tears could be grown for three consecutive years at the same location. Among all annual crops, maize was a low priority for farmers, who grew this crop to feed livestock only and not for selling. Among the three main tree species planted in the region (vernicia, rubber and teak), teak was the favourite because it was considered a long-term investment that would benefit the farmers' children. Rubber and vernicia were not prioritized currently because of dropping prices on regional markets. Farmers in Houay Dou were considering pulling vernicia trees out to replace with another crop.

3.2 Rubber plantations in Yunnan

Although rubber was first introduced to Asia from the Amazon rainforest in the late 19th Century, there has been a recent massive expansion of rubber plantations across the Greater Mekong region driven largely by increasing demand for natural latex from China. Huge swaths of formerly multiuse landscapes and natural forests have been replaced by monoculture rubber (Ziegler et al 2009b, Fox et al 2014). Between 2003 and 2010, about 15 000 km^2 of land was converted to rubber plantations in Cambodia, southern China, Thailand and Viet Nam (ANRPC 2010). This massive land conversion had predictable consequences for ecosystem services (Wu et al 2001, Mann 2009, Qiu 2009, Ziegler et al 2009b, De Blécourt et al 2013; Yi et al 2014; Fox et al 2014), including water services, carbon sequestration and biodiversity conservation. About one-quarter of the Xishuangbanna prefecture in Yunnan Province was converted to monoculture rubber, mostly in the species-rich lowlands, including 23 616 ha within protected areas (Chen et al 2016). This land conversion dramatically reduced biodiversity in a prefecture that only covers 0.2 percent of China but used to include 23 percent of the vascular plant species found in the whole country (Liu and Slik 2014, Sreekar et al 2014). Sreekar et al (2016) observed only eight bird species in a monoculture rubber plantation located more than 500 m away from a large forest fragment where 160 bird species were usually found. Moreover, although rubber has been a path-out-of-poverty for many smallholders, there have been severe social consequences with widespread reports of land grabbing and coercion. Reduced access to NTFP and economic dependence on a single commodity has also left many farmers vulnerable to fluctuating rubber prices. Through a bilateral project funded by the German Government (GiZ Green Rubber project), the Humidtropics research team investigated links between land cover change and ecosystem functioning in Xishuangbanna. In this brief case study, we focus on the soil and water.

Several studies have demonstrated that rubber is a relatively deep-rooted plant that can modify local and regional water balances (Guardiola-Claramonte et al 2008, 2010, Tan et al 2011, Liu et al 2011, Carr 2012). Due to their large xylem vessels (Ayutthaya et al 2011), rubber trees consume more water than most native forest species in Southeast Asia. Earlier studies have shown that rubber trees have an extended root system allowing a wide part of the soil to be explored for water uptake. Depending on the season and zoning of soil moisture, the tree is able to shift from shallow to deep soil layers to extract water where water is the most abundant at a certain point in time, indicating significant plasticity in sources of water uptake (Liu et al 2013). As a result, rubber extracts more water throughout the dry season than natural vegetation and extracts water from deeper soil as the dry season progresses (Guardiola-Claramonte et al 2008). This feature enables the tree to thrive through periods of greatest water demand. Studies comparing rubber plantations with natural secondary forests found that soil under rubber had significantly reduced water infiltration capacity (Liu et al 2000).

We investigated the effects of understorey management on soil erosion using surface-flow interception traps. In treatment areas farmers were paid not to spray the understorey with herbicides, which they normally did twice a year, to allow the understorey to regenerate naturally. During the first wet season, six to 10 months after establishment, soil erosion in the current practice (control) areas was six-eightfold higher than in treatment areas, and overland flow was 9-19 percent higher. This experiment was still in its first year and understorey vegetation growth was limited when these measurements were made, hence we expect this effect to increase as the understorey's natural regeneration progresses. Other recently published studies have shown that splash erosion is much higher in monoculture rubber than in rubber agroforestry treatments (Liu et al 2016). Together these results support popular reports of increased wet season flooding and siltation of rivers, and reduced dry season flows following conversion of secondary forests to monoculture rubber plantations. In rubber-dominated watersheds, many formerly perennial streams now regularly run dry during the dry season, often affecting household water supplies. Local communities have also reported deteriorating water quality with increased turbidity and algal growth.

At a larger scale, watershed studies generally confirmed these results although the low density of hydrological stations and complex patterns of land cover change have made it more difficult to interpret patterns. In one 9432 ha watershed in Xishuangbanna, from 1992 to 2010, while rubber cover increased from 9 percent to 44 percent, the natural buffering capacity of the watershed declined by 9 percent, indicating accelerated runoff and deteriorating watershed function.

Following the sharp drop in rubber price in 2012, many farmers replaced rubber with alternatives, especially bananas. However, these options were more available to wealthier farmers, who could afford to write off losses. Farmers in more marginal areas were more inclined to wait out the low rubber prices.

3.3 Monocropping coffee in the Central Highlands of Viet Nam

The Central Highlands of Viet Nam comprise a series of undulating plateaus straddling the border of eastern Cambodia and southern Laos. Elevation generally ranges between 300 m and 900 m. Although fertile basaltic soils exist at the tail end of the Annamite mountain range in the northern and eastern parts of the Central Highlands, soils over much of the rest of the area are commonly acidic, light-textured and of low fertility (Tri 1997, Tran 1998, Thai and Nguyen 2002).

Historically, the agricultural sector was dominated by ethnic minority groups (mainly Ê Đê, Mnong and Tay) practising mixed low input and low output smallholder farming. In these systems, they relied heavily on shifting cultivation to maintain soil fertility. After the end of the 'American' War in the mid-1970s however, the Vietnamese Government encouraged ethnic majority Vietnamese (Kinh) people to migrate from the more densely populated areas of Viet Nam into the sparsely populated Central Highlands (Dang et al 2001, Cramb et al 2004). The Kinh brought more intensified and market-orientated forms of smallholder agriculture. Coffee production in particular was strongly promoted as a livelihood strategy by the national government, becoming the region's agricultural mainstay, especially in the lower lying areas of the southern and southeastern parts of the Central Highlands (i.e. Dak Lak and Dak Nong provinces) (Bui 2003). The coffee boom in the 1980s and 1990s in turn drew more immigrants from other areas of Viet Nam to the Central Highlands, and more smallholder farms became specialized in coffee (Long 2007).

However, this specialization in coffee, while allowing farmers to reap better returns to labour in good times, also made them more vulnerable to market or price shocks. Falling coffee prices in the late 1990s meant that smallholders growing coffee on less fertile land, where coffee yields were lower, had problems breaking even. On the other hand, as Tran and Kajisa (2006) argue, the (over)reliance on inorganic fertilizers in more specialized and commercially orientated monocropping farming across Viet Nam has led to declines in soil organic matter and soil productivity. In such cases, the use of inorganic fertilizers has often replaced traditional practices. These traditional practices typically consisted of i) use of animal manure and plant biomass on-farm for composting and adding to various of crops; ii) use of leguminous rotations to boost nitrogen input into the soils and control pest and disease cycles; and, iii) long fallow periods to allow soils to regain a measure of fertility. As a consequence, the normal ecological processes typical of the more diversified traditional farm systems that integrate trees, annual crops and livestock were weakened, and this resulted in declines in soil fertility. To some extent, Long (2007) corroborated similar perceptions among smallholder farmers in two communes in Ea Kar District in Dak Lak Province in the Central Highlands. Interviewing 42 coffee monocropping smallholders and 49 smallholder farmers practising diversified/mixed integrated farming, she found that while prices fluctuated, soil degradation and poor soil fertility were the two main concerns of the coffee monocropping farmers.

The challenge to sustainably intensify agricultural production in the Central Highlands, therefore, is to develop and diffuse practices and systems that appropriately balance specialization and commercialization as a means of generating increased farm income on the one hand, with appropriate on-farm diversification and natural resource management on the other hand to ensure continued future ecological productivity of smallholder farms.

4. Solutions and interventions to sustainably recover lands while ensuring short-term economic returns

4.1 Improving understorey management of teak tree plantations in Laos

The effects of land-use management on water and soil in the northern Laos uplands (presented in section 3.1) were discussed with the farmers in the study villages and with the Ministry of Agriculture and Forestry (DAFO) district representatives. Two priority actions were identified during the focus group discussions: 1) to raise the awareness of farmers regarding the environmental and agro-ecological consequences of their current practices, such as the frequent teak understorey clearing; and, 2) to identify and implement sustainable solutions for water and soil conservation. Action 1 was achieved through village-level group discussions and learning activities (e.g. cross-learning field visits) with the provision of relevant, farmer-focused, local-language information materials (cf. Photos 3.2). Action 2 required more time and was only partially achieved under Humidtropics. While the identification phase was completed, the implementation phase was only partly initiated.

We found that DAFO usually did not focus on erosion issues but rather advised farmers on how to maximize benefits from teak plantations through seed handling, nursery techniques, transplanting, pruning and thinning. One solution to control erosion, identified during the discussions, consisted of introducing understorey cash crops to the tree plantations. Interspersing teak trees with understorey crops promoted rainwater infiltration into the soil, which reduced soil surface erosion. At the same time, the soil enrichment with organic material improved its water holding capacity, thus enabling plant development during the dry season. Since erosion did not seem to be seen as a major issue for teak tree growers, a realistic incentive to encourage farmers to grow understorey crops was to emphasize the possible additional income they could earn from selling the economically profitable understorey crops and their derived products.

Depending on local soil and climate conditions, several species could be cropped under teak trees with potential economic returns: galangal, ginger (although the market demand was still limited), broom grass (farmers usually preferred this crop because of its high market demand, cf. section 3.1), cardamom (with a potentially high income, although yields are uncertain: cf. Khamhoung and Gansberghe 2016), natural grass (easy to grow, good for erosion control, but no immediate economic benefit although it may have some biodiversity-based ecosystem service benefits like pest control), mountain peanuts (high market demand) and the small fast-growing mimosoid tree *Leucaena leucocephala*, originating from Latin America, for livestock fodder. According to field surveys conducted among DAFO officers, the timing for planting understorey crops was critical as it influenced the plants' successful development. The best time was usually one year after teak trees were planted, except for broom grass which was more invasive. In that case, it was preferable to wait until teak trees were two years old.

Several constraints impeding the introduction of understorey crops were also identified during the discussions and possible solutions were proposed. In Luang Prabang Province, teak trees were usually planted at two-metre intervals. With this relatively high density, the canopy closed only a few years after the trees were planted, which did not allow sufficient light to reach the ground for understorey development. To allow understorey crops to develop, a minimum of three metres between trees was necessary, in addition to pruning and thinning at regular intervals (about three years). These activities were beneficial for both the harmonious and productive growth of teak trees, and also for the development of the understorey crops. Another important constraint to understorey development was fire spreading from adjacent plots cleared to grow annual crops. Some villages have defined rules to avoid fire associated with rice-based shifting cultivation practices from spreading into teak plantations. These rules, which are not legal, are more or less rigorously enforced by village heads. Finally, in some areas around the Houay Pano catchment, erosion under teak plantations was already at an advanced stage. Opportunities for reversal with crop or natural vegetation development were limited because the most fertile topsoil had been washed away already. In this situation, an alternative and mechanistic control of erosion could involve recycling branches from pruning used as natural barriers along contour lines and maintained by the trees.

A few farmers who were already growing broom grass and cardamom under teak trees were identified in the surveyed villages. Trained by DAFO, they started this intercropping only one year ago and were still waiting to see if the technique was profitable. Due to the very limited number of training courses DAFO has been able to provide with limited funding, only a few landholders have adopted such innovative techniques.

4.2 From monoculture rubber to green rubber in China

Many environmental problems commonly associated with rubber and other plantation crops, including teak, Acacia, Eucalyptus and oil palm, derive from managing plantations as monocultures rather than crops per se. For example, rubber has been managed by smallholders in Indonesia, Malaysia and southern Thailand as a component of secondary forest regeneration for more than 100 years and studies of these 'jungle rubber' systems have found that they approximate advanced secondary forests in terms of ecosystem service delivery (Warren-Thomas et al 2015). For example, in Sumatra it was found that jungle rubber supported 50-80 percent of the bird species found in nearby primary forests (Gouyon et al 1993). Meanwhile, carbon sequestration rates were typically as high, or higher, than for natural regeneration. Hence, improved plantation management holds substantial promise for restoring ecosystem functioning across the enormous swaths of land under monoculture management globally.

Photo 3.3 Rubber plantations in southern Thailand. A: Young (three years) rubber timber system. B: Mature (10 years) rubber timber system. C: Rubber intercropped with Salak. Photo credits: ICRAF/Rhett D Harrison

Experiments conducted by the World Agroforestry Centre (ICRAF) and partners in Indonesia demonstrated that modern high yielding rubber clones could be intercropped with many other species (Penot et al 1999). In selecting suitable intercrop species, the only critical limitation was that rubber performs poorly when shaded, so intercrop species should be selected to grow under the rubber canopy (Photo 3.3). Typically, smallholder farmers preferred to manage the crop in two phases. In the first three years, the rubber was intercropped with annual crops as this negated the need to control competition and fertilizers benefited both intercrop and rubber. This also provided a short-term return that offset the cost of establishing the rubber trees. In Xishuangbanna, smallholders often contracted migrant farmers to establish rubber plantations; the migrant farmers were unpaid but got a free lease on the land to grow pineapples for two to three years. After about three years the rubber canopy started to close and it was no longer profitable to manage annual crops. The long-term intercrop could either be established with the rubber or after harvesting the annual crop in the third year. Shade crops such as tea, coffee, cacao, salak and Gnetum were often recommended, although some farmers liked to grow fruit trees like mangosteen, mangos and durian because of the ready market even though productivity in the shade was low (~50 percent). Intercrops could also include timber species and species yielding non-timber forest products. In the latter systems, high-value, slow-growing timber species were allowed to grow up under the rubber. Then after the rubber was harvested at 25-30 years the timber was left to grow for another 10-20 years. These systems were potentially very profitable, but farmers in Xishuangbanna appeared very reluctant to make such long-term investments. This may reflect the recent history of displacements and changing land regulations in China. Over time, timber-based systems could become highly diverse and are analogous to advanced secondary forests.

Photo 3.4 Participatory approaches to prioritize agroforestry techniques as part of GiZ Green Rubber Project. Man'e village, Menglun County, Xishuangbanna, China. A: Farmers proposing agroforestry trials. B: Discussion of different options including rubber monoculture and rubber agroforestry. Photo credits: ICRAF/ECA

Through Humidtropics, the research team worked with government officials and farmers in Xishuangbanna to diversify and improve rubber management (Photo 3.4). The principal outcome was an on-farm trial to be established in Man'Dian village near Menglun in 2017. The trial will test the performance of four systems: i) monoculture rubber; ii) rubber intercropped with fruit trees; iii) rubber intercropped with timber and non-timber forest products; and, iv) natural regeneration enriched with species from iii). The species were selected together with the farmers who are also providing their land and labour. This trial is now being extended to northern Thailand, northwest Laos and Sumatra.

4.3 Integrated crop-tree-livestock farming in the Central Highlands of Viet Nam

Aimed specifically at addressing suitable entry points for building on the potential of sustainable intensification and diversification of agriculture in the Central Highlands of Viet Nam (cf. section 2.3), the International Centre for Tropical Agriculture (CIAT), together with Tay Nguyen University (TNU) and the Western Highlands Agriculture and Forestry Science Institute (WASI), convened a multistakeholder platform in Buon Ma Thuot, Dak Lak, Central Highlands of Viet Nam, in September 2014. The platform comprised representatives from the local Department of Agriculture and Rural Development (DARD), the National Agricultural Research Systems (NARS), non-governmental organisations, local authorities, a coffee consultancy firm, three CGIAR centres, TNU and WASI. Discussing research avenues to appropriately balance specialization and commercialization with on-farm diversification, the platform reached consensus that there was an urgent need to facilitate the development and diffusion of smallholder farming systems that integrated livestock and crop activities in a manner that allowed both the risk of crop failure and the needs of labour on- and off-farm to be better spread. At the same time, they had to ensure environmental resources were not exhausted and that dependency on external inputs was not exacerbated at the cost of short-term production boosts. In particular, the platform highlighted the need for research on improved soil conservation and more effective nutrient cycling.

Small funds by Humidtropics to support multistakeholder platform research projects afforded the platform the opportunity to take action and address the expressed needs through a specifically designed project. Due to its research expertise on integrated crop-tree-livestock smallholder farming systems, WASI was designated to lead the project. The platform further selected two pilot sites for project interventions: Ea Tyh Commune of Ea Kar District in Dak Lak Province, and Dak Dro Commune of Krong No District in Dak Nong Province (Photo 3.5A). These two study communes differed to some extent in population densities and predominant crops and farm types (Table 3.1). Both have predominantly poor soils (mostly sandy and Gley soil). This allowed for testing interventions that accentuated soil fertility maintenance or improvement.

Table 3.1 Characteristics of two targeted communes

Commune	Population densities*	Average farm size	Percentages of HH engaged in different productions					
			Perennial tree crops			Annual crops		
			Coffee	Pepper	Cashew	Rice	Cassava	Sugarcane
Ea Tyh	>220 person/km^2	2.1 ha	40	15	15	45	35	24
Dak Dro	<150 person/km^2	1.4 ha	80	20	30	50	15	1

Note: Values rounded to the nearest 5 are based on a survey of randomly-selected households (HH) undertaken in each commune in early 2016 (See Chapter 2; Ea Tyh: 153 households in 6 villages; Dak Dro: 157 households in 5 villages).

* Annual Reports of the People's Committees of each commune (2014).

Within each commune, two target villages were selected in consultation with local authorities and based on criteria including relatively high numbers of ethnic minority smallholders and the possibility of finding specialized coffee monocropping farms close to integrated and more diversified farms. Meetings were held in each village to introduce the project aims, and a suite of participatory rural appraisal approaches were applied to gain a better understanding of the village setting and the farmers' major aspirations, priorities and main challenges (Photo 3.5B). Subsequently, in participation with the whole village, five smallholder farms in each village were selected as pilot sites for participatory research and visible demonstrations or village learning activities. Special attention was paid to ensure the selected farms represented a broad spectrum of diversification and integration, potential challenges and opportunities, and ethnicity and gender. Both Kinh and Ê Đê or Mnong smallholder farms were explicitly included, as well as female- and male-led households among the pilot farms. The final farm selection included about 50 percent female-headed households in all villages, and about 75 percent and 16 percent ethnic minority farmers in the villages of Ea Tyh and Dak Dro Commune respectively.

Photo 3.5 Coffee dominance in the Central Highlands of Viet Nam. A: Typical smallholder coffee farm landscape in Dak Dro Commune, Krong No District, Dak Nong Province, Central Highlands. B: A group of ethnic minority Ê Đê smallholder farmers undertaking an exercise to rank different farm activities in terms of importance to household income, labour, subsistence, future sustainability of the farm, etc. The exercise here was led by a commune extension worker sitting at the table (second from right). Photo credits: WASI/CTM Long

WASI project staff then started regularly contacting the local district and commune DARD extension offices in the target areas, and together with specially designated government extension agents from these DARD offices, visiting the target villages and pilot farmers. Experience from previous projects led by CIAT, TNU and WASI in the same Central Highlands areas highlighted that project staff needed to take sufficient time on the ground in study sites to build relationships with farmers, field advisors and other local actors, as local extension can be the difference between success and failure (CIAT-IFAD 2016). This is crucial, especially with ethnic minority smallholders, not just to understand the priorities, aspirations and challenges of smallholders and the extension agent closest to the farmers, but also to effectively work with them on a mutual trust basis. In discussions during the regular visits over the first few weeks with the pilot farms and the larger community, several potential technologies for further investigation were elucidated. These included planting small parcels of land (approximately 1-2000 m^2) on the farm with forages or intercropping forages within coffee gardens, and fattening or finishing cattle for market using these forages in a cut-and-carry system. Planting highly productive, nutritious forages on-farm may allow smallholders to increase livestock productivity without relying on increasingly scarce natural resources (Peters et al 2001). Importantly, if forages were planted close to the homestead and animals kept close by, this had the potential to decrease the labour required to collect feed, or tether or herd animals far away from the farm (Stür et al 2006, Dimang et al 2009, Ba et al 2013). By cut-and-carrying the forages to stalled animals, this in turn allowed manure to be collected in the stalls. Other technologies highlighted for further study and development by both the platform and smallholders in the target villages during community meetings included intercropping fruit trees such as durian and avocados within the coffee trees, as well as technologies focused on improving coffee yields such as grafting new plant material to older trees.

WASI staff sampled and analysed soils from various plots on all 20 pilot farms for pH, organic matter, total and available potassium, total and available phosphorus, calcium and magnesium to create a baseline on soil fertility. Subsequently, trials involving the various proposed potential technologies were initiated on the pilot farms in the second half of 2015. Initially, experienced WASI researchers trained local commune and district extension staff on the relevant technologies in a series of training-of-trainer events. The WASI staff, supported by the freshly-trained extension agents, subsequently trained trial farmers and their neighbours over several days on each technology, using the trial farms as training venues and thereby initiating the on-farm trials. WASI and district DARD extension agents continued to follow up and monitor the trials, while convening and facilitating several village learning activities, field days and farmer cross-visits where the other farmers in the village or from neighbouring villages and communes were invited to examine and assess the proposed technologies. Additional training on issues such as composting or local pig husbandry and manure management was provided at regular intervals and included both local extension agents and more than 200 farmers from the study communes. While disseminating knowledge on these methodologies, these regular training events also provided a forum for regular interaction and relationship building between farmers, extension agents and WASI project implementers. The biophysical and economic outcomes of the trials were to be evaluated at the end of 2016.

4.4 Harvesting rainwater to improve home-based vegetable production in Northwest Viet Nam

In the Greater Mekong region uplands, rainfall is often the only water resource available for agriculture. River streams in headwater catchments are ephemeral and often too far away from farming lands, while groundwater is often too deep and saline with high extraction costs. In the absence of water for irrigation, the monsoon climate in Southeast Asia forces farmers to limit cultivation to the rainy season, mainly between June and October. To sustain vegetable production year-round and improve the nutritional value of food for smallholder farmers, rainwater harvesting and storage is seen as a way to secure water resources outside of the rainy season and during drought spells.

The World Vegetable Center (WorldVeg), IWMI and the Fruit and Vegetable Research Institute (FAVRI) have explored possible options to store rainwater for dry season vegetable production using rooftop rainwater harvesting, ponds and demonstration sites for further development at a scale larger than villages. The aims were to improve water access for vegetable gardening in the Northwest Viet Nam uplands. If managed well, home gardens can produce enough vegetables and the micronutrients (vitamins and minerals) contained therein, to nourish a family all year-round (Chadha and Oluoch 2007, Chadha et al 2011). However, the productivity of most household gardens was low because of poor soil quality, limited water availability, low quality seed, crop pests and diseases, poor crop management and the destruction of crops by livestock (World Vegetable Center 2016). The location and size of the household garden was largely determined by access to water during the dry season. Household wastewater could be reused in the garden if it did not contain sewage water or excessive amounts of detergents. Mulching could make water use more efficient by reducing soil evaporation.

Thong village in Mai Son District, Son La Province, was isolated from the commune centre by a 3.7 km rough road that complicated market access during the wet season and water access all year-round (Photo 3.6). It was inhabited by Hmong ethnic people who cultivated a mono-maize crop on sloping lands. They had limited experience cultivating vegetables. Since 2014, Humidtropics has supported several families to set up field trials of vegetable gardens with the support of WorldVeg and FAVRI. Villagers wanted to extend vegetable production during the dry season but were constrained by lack of water. WorldVeg, IWMI and FAVRI implemented a rainwater harvesting system using rooftop rainwater stored in a tank. In a rainwater harvesting system, the water tank's storage capacity was the most expensive element, directly influencing water availability and construction costs. IWMI developed a water balance model to evaluate the optimal storage volume to maximize the storage capacity (i.e. minimize the risk of water shortage) while minimizing investment costs. A simple spreadsheet daily water balance model was developed in MS Excel to simulate the daily volume variations of the water stored in a tank collecting rooftop rainwater. The model used daily time series of rainfall, referenced evapotranspiration and associated crop water demand to compute the tank water inflow (originating from the roof), and outflow (for crop irrigation). A failure function evaluated the frequency of water-stressed days (i.e. when the amount of water stored in the tank was lower than the crop water demand) over each multi-year simulation period accounting for interannual climate variability. This model included several parameters that determined the size and type of the roof, size of the vegetable garden, cultivated crop species and associated water demand. The model simulations indicated that a storage capacity of about 20 m^3 was sufficient to secure vegetable production all through the dry season with a garden of about 50 m^2 and a roof (to collect rainfall) of about 100 m^2.

Based on these results, a rainwater harvesting system was set up in the village. Two main water storage options were considered to collect rainwater from the roof of a shed nearby the WorldVeg experimental site: i) a cement tank partially buried in the soil with a total storage capacity of 10-15 m^3, and ii) four inox tanks each with a 5 m^3 storage capacity. The second option was selected for its greater flexibility (tanks can be moved as necessary) and because it was easier to install using materials readily available in the region (Photo 3.6). The roof, already equipped with gutters, had a total area of 169 m^2 and the vegetable garden was 42 m^2, making the total storage capacity of 20 m^3 appropriate for this system. The total system cost was reasonable compared with the concrete tank. Moreover, it could last for at least 10 years. The rainwater harvesting system was set up on October 2015. The field trial included two treatments, one with irrigation (Photo 3.6C) and one without. Vegetables were selected and cultivated during the dry and the wet seasons from October 2015 to June 2016. Twenty-one and 17 vegetable crops were selected to grow in the irrigated and strictly rainfed garden respectively, based on the climate pattern and their water requirements.

Yield corresponding to each species was found to be greatly improved with the use of the rainwater harvesting system. Without irrigation, crops with limited root penetration (e.g. leafy vegetables) or high water content (e.g. cucumber) were the most affected by water shortages. Solanaceous and root vegetables, and legumes with a smaller leaf area were less affected. This study demonstrated that water is one of the most important biophysical factors that affect crop growth and yield. Maintaining gardens during the dry season was possible when using drought-tolerant crops such as legumes, solanaceous and root vegetables. In addition, these vegetables provided diversified nutrients for villagers who often suffer from malnutrition.

Photo 3.6 Harvesting rain to produce vegetables in Northwest Viet Nam. A: typical Hmong house in Thong village. B: the four tank units installed by WorldVeg/IWMI/FAVRI to store rainwater from the roof of a shed. C: vegetable garden irrigated with a rainwater harvesting system. D: traditional gutter made from bamboo sticks in Thong village. Photo credits: IWMI/Guillaume Lacombe

5. Conclusion

The Mekong region (Cambodia, Laos, Viet Nam and the Yunnan Province of China) has experienced profound transformations over the past decades: the 'modernization' of agriculture, in particular, is occurring at an unprecedented pace. Traditional, highly diversified, low external input/low output subsistence and semi-subsistence smallholder farming systems are being replaced by more specialized, commercially orientated farms and plantations of teak, rubber or coffee. In these new sloping land systems where trees are commonly monocropped, the soil between trees is often left bare and exposed to erosion from rain and overland flow. Additionally, farmers practising more specialized forms of agriculture often rely increasingly on inorganic fertilizers and agrochemicals to sustain soil productivity rather than the traditional practices of long fallow periods to allow the soil to regenerate its fertility. While the larger income generated from these plantations may benefit the household in the short run, if not done properly such monocropping systems have the potential to gradually erode the land's fertility, leading farmers to use ever-increasing amounts of inputs to sustain yields and ultimately even jeopardising the land's future productivity. It also makes farmers much more vulnerable to price fluctuations for the single commodities they are producing.

However, it does not have to be one extreme of unsustainable production for short-term income gains pitted against another extreme of poorly remunerative but environmentally sustainable subsistence or semi-subsistence farming that perpetuates poverty. To ensure productive agriculture and food production for future generations, the challenge is really centred on how to best harmonise income generation from commercially-oriented, specialized tree and monocropping systems with the benefits of more diversified farming systems that allow soil and water to be better conserved. Such an integrated approach also enables the production of multiple other ecosystem services including carbon sequestration and biodiversity conservation.

To achieve this, Humidtropics brought researchers from a variety of disciplines together with local farmers and government extension workers, as well as other important stakeholders of agricultural development processes in northern Laos, southern Yunnan and the Northwest and Central Highlands of Viet Nam. Indeed, in this context, the very core of the Humidtropics effort lay in marrying holistic scientific ideas on improving on-farm soil and water conservation with bottom-up participatory approaches to ensure that the local stakeholders' priorities, concerns, perspective and analyses were addressed and placed in the centre.

Humidtropics initially facilitated and funded the establishment of local and thematically orientated multistakeholder platforms to kickstart the process and bring together a range of broader systems thinking to complex problems. Specially developed on-farm and on-station trials, a variety of hands-on training sessions for local extension agents and farmers, various village learning activities and inspirational cross-visits and on-farm demonstrations followed. These allowed new methodologies to be tested and displayed, while at the same time ensuring that the local farmers remained owners and co-drivers of any innovation. Additionally, it also allowed the local DARD or DAFO extension agents, crucial to the future link between research and farm practice and perhaps also for future up- and out-scaling, to have sufficient buy-in to the processes. Importantly, such on-farm trials also enabled increased interaction between researchers, project staff, local extension and farmers.

When working with ethnic minorities and disadvantaged households making up a considerable part of the sociocultural fabric of the study areas, it was of paramount importance that scientists, project staff and extension agents spent sufficient time in the study areas. This allowed them to create dynamic exchanges and to build and foster relationships and mutual trust with the local actors. This in turn could greatly assist the development and diffusion of suitable soil and water conserving technologies and systems, both in and beyond study sites. But this also takes time, often many years. Humidtropics is set to close, even while now showing some initially promising results in developing suitable intercropping, or water harvesting activities, or on-farm diversification that can enhance whole-farm income generation and nutrition cycling from animal manure. Many activities and trials are still ongoing. Some of the first cycles of comprehensive biophysical and sociocultural evaluations are planned for later in 2016 or in 2017. Therefore, as both a postscript to the Humidtropics soil and water conservation efforts in the Central Mekong Action Area and as a recommendation for future initiatives, we propose that funding, even small amounts, over much longer timelines be explored; funding that allows partnerships with co-implementers or relationships with ethnic minority communities that, in our case, have just started to develop, to mature and be deepened so that future research for development becomes more effective.

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