What is the contribution of organic agriculture to sustainable development?

A synthesis of twelve years (2007–2019) of the "long-term farming systems comparisons in the tropics (SysCom)"

FiBL SysCom

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Content

SysCom

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About this report

The SysCom Program compares different agricultural production systems (primarily organic and conventional) in three tropical countries (Kenya, India and Bolivia). This report aims to provide a synthesis of the findings of 12 years of research in the three countries in a way that is easily comprehensible by specialists and non-specialist alike. It focuses on productivity, profitability, soil fertility, and other aspects of system performance such as product quality, biodiversity, resource use efficiency and agroecosystem resilience.

The report is divided into eight main sections: The first section, **conclusions**, addresses the findings with regards to the question, "What is the contribution of organic agriculture to sustainable development?". This section is dedicated to the readers who are only interested in a short comprehensive overview of the results. The second section, **introduction**, explains the program's background and objectives. The following sections present the main findings on **productivity, profitability, soil fertility** and **other aspects of system performance**. These sections start with a summary of the key findings, which are then explained in more detail on the concrete research results. They are designed for readers interested in an in-depth understanding of the facts behind inferences as well as the methodology. At the end of each sub-section, references to the relevant scientific publications are provided for further reading. Technical jargon has been kept to a minimum and wherever possible explanations are provided in footnotes. The seventh section includes **policy recommendations** and offers sound advice for policy development. Finally, the **annexes** provide more information about the SysCom program, including the programs' phases, a detailed description of the different sites and the local contexts, as well as SysCom's capacity building and dissemination efforts.

1. Conclusions

What is the contribution of organic agriculture to sustainable development?

The 2030 Agenda for Sustainable Development and the 17 Sustainable Development Goals (SDGs) aim to end poverty and other deprivations. They recognise that this must go together with strategies that improve health and education, reduce inequality, spur economic growth, tackle climate change and preserve natural resources for the future. There is substantial evidence illustrating that the dominant agricultural management practices are not a sustainable option for the future and that they hinder the developed and developing world to reach the SDGs. Organic agriculture is proposed as a sustainable alternative, but its performance under tropical conditions is questioned as long-term studies are scarce. The SysCom program addresses this research gap in three tropical countries (Kenya, India and Bolivia) and has produced valuable insights into system performance. Since 2007, the long-term field trials have studied different crops and cropping systems in diverse agroecologies ranging from semi-arid climate in India to sub-humid highlands of Kenya and humid tropics of Bolivia. Based on these studies, the following conclusions are drawn to illustrate how organic farming can contribute to the achievement of several SDGs by 2030:

The **crop productivity** (yield) of organic systems can match those of conventional systems yet varies depending on the type of crop and management practices. The variation in yields of annual organic crops can primarily be explained by the slow release of nutrients from applied inputs or their lower nutrient content as well as yield losses from pest and disease pressure. For instance, legumes can achieve similar yields in organic and conventional systems because they can assimilate nitrogen from the air. On the other hand, in cereals (e.g. wheat or maize) or crops with high nutrient demand such as cotton, cabbage and potato, yields can be negatively affected when the nutrient availability does not meet the crop demand at crucial growth stages. Application of the correct amount of organic inputs at the right time is necessary to improve organic crop yields. However, pests and diseases can severely reduce yields in organic systems (e.g. in vegetables). This is often the case if organic systems try to mimic conventional methods and only substitute conventional pesticides with bio-pesticides/botanicals. In cacao the pest and disease control approach focused on management practices rather than relying on external inputs, this resulted in comparable incidence levels in organic and conventional systems. Furthermore, in cacao production systems, our results show that the complexity of the system (monoculture vs agroforestry) has a greater influence on the total productivity than the type of farming system (organic vs conventional). Although the monocultures produce higher cocoa yields, agroforestry systems achieve higher total productivity as well as a higher diversity of products (cocoa, plantain, banana, and other fruits/cereals/tuber crops).

The **profitability** of the organic system was found to be mainly influenced by crop productivity. However, by employing a systemic approach and implementing good agricultural practices, organic systems could be managed successfully and profitably. Costs for external (market purchased) inputs are often lower in organic. In contrast, the organic produce can fetch higher market prices, compensating for the economic loss due to lower yields in certain crops. However, labour (e.g. for fertiliser preparation) is a prominent factor contributing to production costs in organic systems (Kenya). Our results show that organic systems can achieve higher returns on production costs (India) and equal returns on labour (Bolivia), making it a suitable option, particularly for capital-poor smallholder farmers.

We also found that organic systems can build up **soil fertility** over the long-term if managed well. Soil organic carbon was increased after a decade of organic inputs through compost, liquid manure, mulch (Kenya), compost, litterfall, and cover crop (Bolivia). We could also show that organic systems build up other nutrients, have a higher biological activity and improve soil physical properties. Nonetheless, certain nutrients (e.g., nitrogen in cotton and wheat in India, or phosphorus in Kenya) are less available in organic systems because they are applied in less plant-available forms. Such missing nutrients at key crop stages lead to lower yields in organic systems.

Our results also show the **additional benefits** that organic systems offer to society as well as to the environment when compared to conventional systems, e.g.: i) reduction of pesticide residues in soils, crop products and run-off water (Kenya), ii) higher concentrations of vital elements in food crops (India), iii) enhanced flora and fauna diversity and abundance (Kenya, India, Bolivia), iv) a reduction of non-renewable energy resources used (Bolivia), and v) increased resilience (Bolivia).

Besides a comprehensive comparison of farming systems across the tropics, our scientific findings as well as the experiences made in and around the SysCom program, highlighted the needs for appropriately incentivising sustainable systems, strengthening market linkages as well as promoting innovative development and capacity building.

2. Introduction

There is substantial evidence that carrying on business as usual with the prevalent agricultural management practices is not a sustainable option, particularly when considering the issues associated with climate change, biodiversity loss and depletion of natural resources. Several alternative production systems, including agroecology and organic farming, are proposed for their environmental and social benefits. Organic farming, as an alternative system to conventional agriculture, precludes the use of synthetic pesticides and fertilisers, relying on crop rotation and intercropping, and emphasising closed nutrient cycles. Organic systems also prioritise the use of locally adapted crop varieties and locally available resources. As such, the organic approach seeks to produce food while improving environmental and human health.

It is, however, legitimate to question whether organic agriculture and other alternative farming practices can contribute to sustainable development as they are often perceived to be based on ideology. Studies conducted under temperate environments (mostly in Europe) have established the benefits of organic farming practices over conventional practices. However, several questions remain open regarding the performance of organic systems under tropical conditions. From the limited number of meta-studies comparing organic and conventional systems across the globe, it is evident that there is a considerable lack of data from tropical environments (Reganold and Wachter 2016[1] ; Seufert and Ramankutty 2017[2]).

The SysCom program has addressed this gap by over a dozen years of successful participatory and production systems research dedicated to the development of sustainable agricultural systems in the tropics. The program is comprised of long-term experiments (LTE) and Participatory On-farm Research (POR). Four LTEs were established in Kenya, India and Bolivia between 2007 and 2008, to systematically evaluate the long-term performance of organic and conventional production systems in different tropical environments. Each project site has a POR component, which aims to develop technological innovations and management practices ensuring that farmers' concerns are taken into account and that they directly benefit from the research. Together the LTEs and POR offer a unique platform in each country to address key questions concerning the sustainability of various production systems and their contribution to development at the local, national as well as international level. See Figure 1 and the annexes for more information on the different SysCom (LTE and POR) projects.

This report provides a comprehensive synthesis of the scientific findings of SysCom presented in a form that is easy to understand for an 'educated non-expert' audience. The findings address the differences between alternative (organic and agroforestry) and conventional production systems in terms of:

- Productivity: yields of main and by-crops in different systems
- Profitability: gross margins and return on (economic and labour) investment
- Soil fertility and quality: nutrient availability, soil organic carbon and other soil physico-chemical properties
- Other: pesticide residues, crop nutrient content, biodiversity, resource use efficiency and agroecosystem resilience

[1] Reganold J, Wachter JM (2016). Organic agriculture in the twenty-first century. Nature Plants 15221.
[2] Seufert V, Ramankutty N (2017). Many shades of gray—The context-dependent performance of organic agriculture. Science Advances. DOI: 10.1126/sciadv.1602638

SysCom

Kenya

Site description

- Sub-Saharan Africa, Kenya, Central Highlands, Chuka and Thika
- Sub-humid, two rainy seasons
- Maize-based systems, 3-year crop rotation with maize, leafy vegetables, beans and potato

Production systems

- Organic vs conventional systems at low and high input level

India

Site description

- South Asia, India, Madhya Pradesh, Nimar valley, Kasrawad
- Semi-arid, monsoon rains June-September
- Cotton-based systems, 2-years crop rotation with cotton, wheat and soybean

Production systems

- Organic and biodynamic vs conventional systems with and without GMO

Bolivia

Site description

- South America, Bolivia, Sara Ana
- Tropical-humid, winter dry (June-August)
- Cacao-based systems, Cacao trees with plantain, coffee and timber trees (depending on system)

Production systems

- Organic vs conventional systems as full sun (monoculture) and agroforestry system

Figure 1: SysCom long-term field trials sites at a glance.

Icons created for the Noun Project by AFY Studio, Amos Kofi Commey, Clockwise, Hamel Khaled, Bernd Lakenbrink, Katerine Melina Quispe Peralta, Brian Saputra, P Thanga Vignesh, Vectors Point, and Yudiyanto.

3. Productivity

Productivity was assessed by comparing the yields in the different systems. Specific attention was paid to the impact of nutrient input as well as pest and disease damage. The results are presented below for annual and perennial crops.

3.1 Annual crops

Annual crops are studied in Kenya (maize, baby-corn, beans, potatoes and leafy vegetables) and India (cotton, wheat and soybean). The yields varied considerably across crops and systems in the project sites (Figure 2). Maize grain, baby corn, common beans and soybean yields were comparable in organic and conventional production systems.

Leguminous crops such as soybean and common beans often perform better or equally in organic systems as they can assimilate nitrogen from the air through symbiotic nitrogen fixation and thus do not depend much on external nitrogen supply. Other important nutrients such as phosphorus and potassium are supplied in abundance through organic manures. On the other hand, some of the non-legume crops (e.g. wheat and cotton) and their modern high-yielding cultivars have high nitrogen demands during certain crucial crop growth stages. Reganold and Wachter

In annual crops, productivity in organic systems is primarily limited by nutrient availability as well as pest and disease damage.

Legumes can achieve similar yields in organic and conventional systems. They receive sufficient nitrogen through symbiotic nitrogen fixation from air, and depend less on organic fertilisers.

Slow nutrient (mainly nitrogen) release from organic manures can limit yields, particularly for crops that need high nutrient inputs at key growth stages.

Promising solutions include adjusting the timing and quality of organic fertilisers as well as incorporating legumes and green manure into cropping systems.

Substitution of conventional pesticides with those allowed in organic production is not sufficient to solve pest and disease problems. A system approach to pest and disease management is necessary.

Crop productivity in Kenya and India

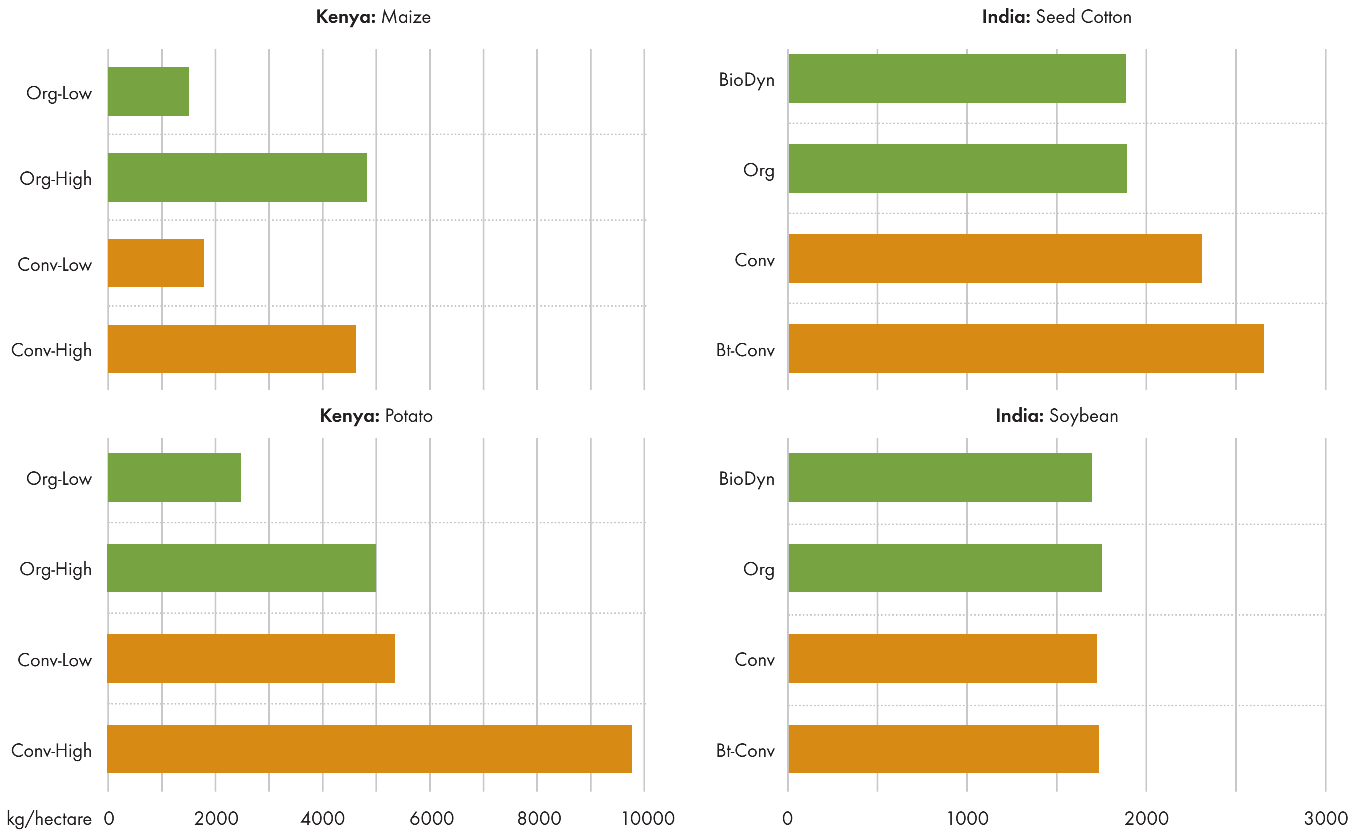

Figure 2: Average yields of maize grain, potato tuber, seed cotton and soybean grain in Kenya and India (2007-2018).

(2016)[3] similarly found soybeans and oilseeds to be the highest yielding organic crops globally, whereas yield gaps of 37% are present in wheat and 33% for vegetables. Correspondingly, the yields from the wheat and cotton LTE were on average 20% lower in organic systems, except for certain years where there was no statistical difference among the systems. The yield gap in wheat was particularly marked in some years (2013 – 2015), which we found out was due to insufficient nitrogen supply from organic manures at key crop growth stages. Such nitrogen deficiencies can sometimes be addressed by intercropping. For example, when maize was intercropped with beans (in Kenya), the yields of the organic and conventional systems were similar. The bean yield depended on the variety used: dry beans (harvested when fully mature) were able to achieve similar yields, whereas green beans (harvested when the pods are still green) yielded 40% lower in organic.

Cole crops and potatoes performed poorly in both high and low-input organic systems (in Kenya). Compared to the conventional systems, potato and brassicas (cabbages, kale) showed 40 – 60% lower yields in organic. This was primarily because the recommended dosage for most biopesticides on the market was not effective in preventing high incidences of pests and diseases. Similarly, the bollworms cause substantial damage to cotton yields in organic production (in India). The SysCom team is developing and testing a system-based approach using 'best-bet practices' for holistic pest management in vegetable, potato and cotton-based production systems.

The low-input systems both under conventional and organic management practised in Kenya were deemed not recommendable, since these systems are not productive enough due to very low nutrient application, poor pest management, as well as inadequate and irregular water supply from rainfall.

Two farm surveys in Nimar valley (India) revealed highly variable yields in all production systems (Figure 3). We also found that yields from organic LTE plots are comparable to or better than the average yields from local organic farms. In contrast, the yields from conventional LTE plots are, on average, much higher than local conventional farms. This indicates that the yield gaps observed between conventional and organic systems in LTE (presented above) are partly due to more effective management of conventional systems under research conditions, which is not always reflected by the realities of the local farmers. Therefore, while deriving inferences from productivity comparisons across systems (e.g., in meta-studies), the farm context of the study should always be kept in mind. The interpretation might differ depending on

[3] *Reganold J, Wachter JM (2016). Organic agriculture in the twenty-first century. Nature Plants 15221.*

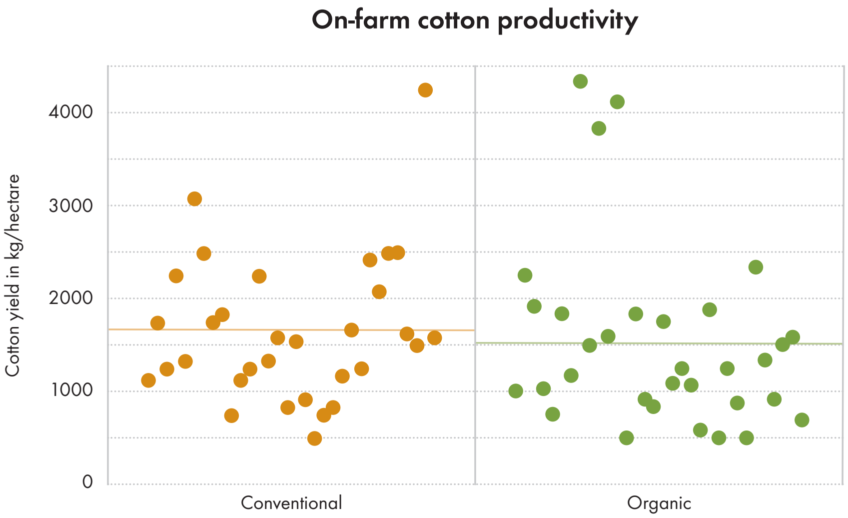

Figure 3: Cotton yield on organic and conventional farms in Nimar valley, India.

whether the study was conducted on-station or under on-farm conditions.

From the comprehensive assessment of these results, it can be concluded that slow nutrient release (especially nitrogen) from organic manures is a limiting factor in organic production. Techniques for improving nitrogen availability under organic management need to be further developed. Adjustments in the timing and quality of organic fertilisers (e.g., compost and manure), as well as novel strategies to incorporate legumes and green manures into cropping systems, are promising options.

The results from Kenya and India also highlight the severity of pest infestation and the urgency to find suitable solutions, particularly in delicate crops such as leafy vegetables, where market-available organic pest control measures have failed to control pests. These results suggest that a mere substitution of conventional pesticides with biological pesticides is not sufficient to solve the pest and disease problems. Therefore, a systematic approach to pest and disease management is necessary.

For more details on these results, please see:

Riar, A., Mandloi, L.S., Sendhil, R., Poswal, R.S., Messmer, M.M., Bhullar, G.S. (2020). Technical Efficiencies and Yield Variability Are Comparable Across Organic and Conventional Farms. Sustainability, 12: 4271.

Riar, A., Mandloi, L. S., Messmer, M., Poswal, R. S., and Bhullar, G. S. (2017). A diagnosis of biophysical and socio-economic factors influencing farmers' choice to adopt organic or conventional farming systems for cotton production. Frontiers in Plant Science – Agroecology and Land Use Systems, 8: 1289.

Adamtey, N., Musyoka, M. W., Zundel, C., Cobo, J. C., Karanja, E., Fiaboe, K. M., et al. (2016). Comparison of conventional and organic farming systems in the sub-humid zones of the Central highlands of Kenya: Productivity and profitability of maize-based cropping systems. Agriculture, Ecosystems and Environment, 235: 61 – 79.

Helfenstein, J., Müller, I., Grüter, R., Bhullar, G.S., Mandloi, L., Papritz, A., Siegrist, M., Schulin, R., and Frossard, E. (2016). Organic Wheat Farming Improves Grain Zinc Concentration. PLOS ONE, 11 (8): e0160729.

Forster, D., Andres, C., Verma, R., Zundel, C., Messmer, M. and Mader, P. (2013). Yield and economic performance of organic and conventional cotton-based farming system – results from a field trial in India. PLOS ONE 8(12): e81039.

3.2 Perennial crops/agroforestry systems

In perennial crops (cocoa and by-crops), the complexity of the cropping system (monoculture vs agroforestry) has more influence on total productivity than the type of management (organic vs conventional).

In monocultures, cocoa yields are higher in conventional compared to organic. This is likely due to suboptimal amount and timing of nutrient delivery from compost, as well as nutrient competition with cover crops in organic systems.

In agroforestry systems, cocoa yields are equal in organically and conventionally managed systems. Yields are lower than in monocultures. This is due to the slower growth of cacoa trees in agroforestry systems and the limited light availability. Regular pruning of shade trees can increase yields in agroforestry systems. The choice of shade tree species as well as timing and extent of the pruning intervention are important factors to consider and should be based on local conditions.

Agroforestry systems have higher total yields of all harvested products (cocoa, plantain, banana, other fruits/cereals/tuber crops) compared to monocultures, resulting in a substantially higher nutritional output of agroforestry systems compared to monocultures.

In agroforestry systems, bananas have particular importance for system yields. With appropriate management, bananas can be kept longer (> 7 years), as farmers of the region are reporting, thus resulting in additional yields.

With the application of good agricultural practices (e.g., frequent harvesting, removing infected cocoa pods and regular pruning of cacao and shade trees) total pest and disease incidence was low in all cacao production systems.

In a farm survey including monocultures and agroforestry systems, certified organic cocoa had higher yields than non-organic cocoa.

Cacao trees from vegetative multiplication (clones grafted on rootstock) performed better with regard to yield than cacao trees from generative multiplication (hybrids produced from seeds).

Cocoa is the main perennial crop in SysCom as well as the main cash crop in the system comparison trial in Bolivia. It is studied in monoculture (full sun) and agroforestry (including banana, plantain, other fruit and tuber, legume and timber trees) systems. As evident from the first six years of data, the complexity of the cropping systems (i.e. monoculture vs agroforestry) has more influence on productivity (total yield of the different crops) than the management system (organic vs conventional) (Figure 4).

Yields from cacao monocultures in the first four productive years were approximately twice as high in conventional monocultures compared to organic monoculture (Figure 5). This is likely due to suboptimal amount and timing of nutrient delivery from compost. Additionally, cover crops may have competed for nutrients in the organic system. The cover crop, however, contributed to weed control and increased soil carbon and nitrogen. Agroforestry systems had lower cocoa yields than both monoculture systems from 2013 onwards. This can be explained by the relative differences in the cacao tree development in different systems. In the seventh year of the plantation, the cacao trees in the monocrop systems had the highest basal area as well as tree crown volume, followed by the agroforestry systems and the successional agroforestry system. This discrepancy could be the result of the competition of cacao trees with the other agroforestry plants for nutrients and reduced light availability (less canopy openness). At the same time, for water, our study on soil humidity has shown that shade trees use water resources from deeper layers than cacao trees.

Several other factors can explain the observed yield differences. Firstly, the canopy openness was highest in monocultures, followed by the successional and the natural fallow, while the agroforestry systems had the lowest canopy openness. The cacao tree has an increased light need at the time of flowering; thus, competition for light reduces cocoa bean yields, in addition, to indirectly affecting yields through slower growth. Secondly, differences in microclimate were found in the systems. While annual mean temperatures were not different, agroforestry systems buffered daily temperature extremes. The soil temperature was lower with increased diversity of plants in agroforestry systems compared to the monoculture systems. In addition, the air humidity was higher in the agroforestry systems while the vapour pressure deficit was lower compared to monocultures.

Importantly, when considering all of the products harvested, agroforestry systems exceeded the food production level of monocultures with a broad diver-

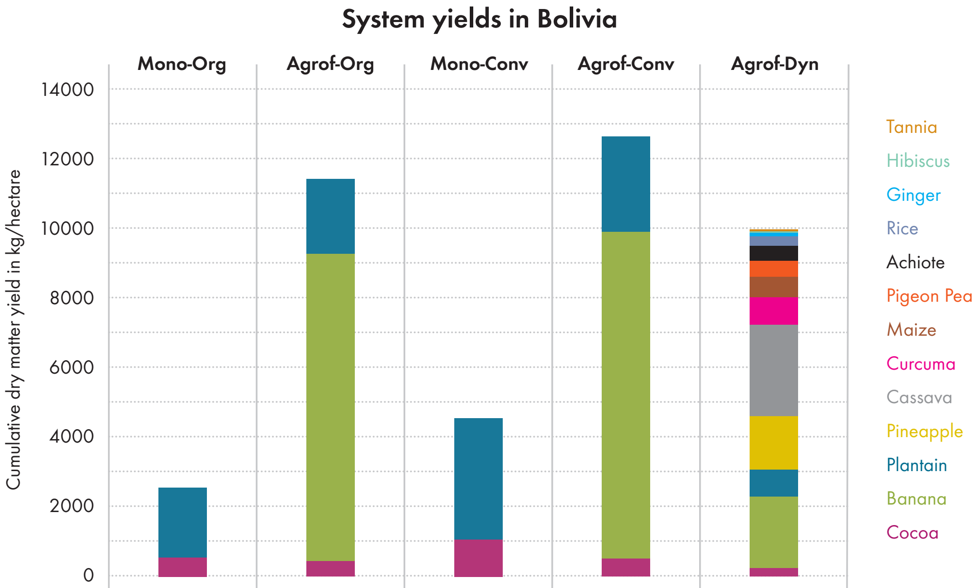

Figure 4: Cumulative yield of all crops harvested during the youth stage of the plantation in Bolivia (2009–2014).

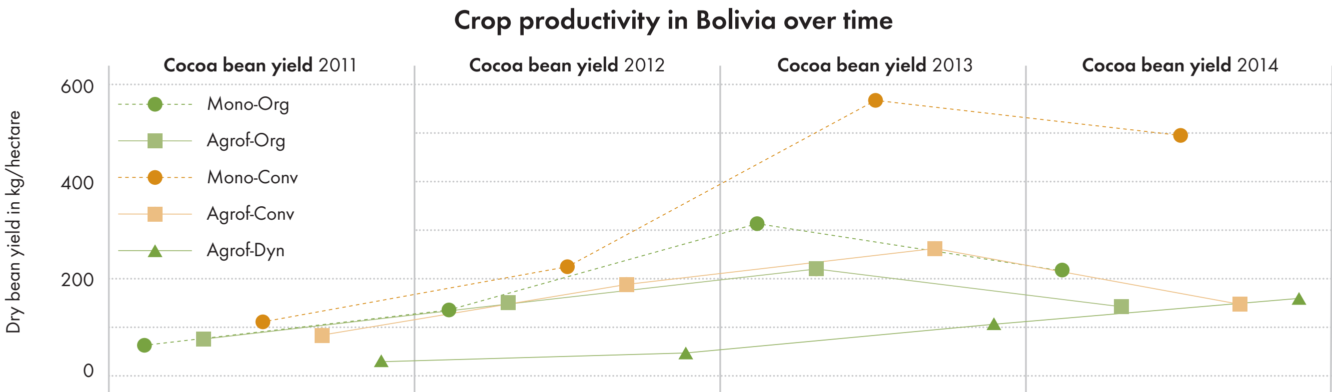

Figure 5: Development of dry bean cocoa yield in the youth stage of the plantation in Bolivia (2011–2014).

sity of by-crops harvested. Although cocoa is the main cash crop, the seasonal availability of diverse and nutritious food products is crucial for the nutrition and food security of farming families and local communities. For example, bananas in agroforestry systems have particularly contributed to the total system yields (Figure 4). With appropriate management, banana plants can be kept longer (> 7 years), compared to local farmers practices, thus resulting in additional yields for a considerable time.

Even though monocultures had higher cocoa yields, the yield obtained in agroforestry systems in full production (2015 onwards) is also higher than the world average cocoa production yields, which is dominated by monocultures. This can be explained by the good management practices applied (cacao and shade tree pruning, periodical removal of infested pods, etc.), in the research fields in contrast to the often poorly managed farmers' fields. By pruning the shade trees as well as cacao, canopy openness can be actively managed, allowing for regulation of light availability, throughfall of rain, evaporation and evapotranspiration. Thereby optimising the timing and extent of light entering the understory and throughfall, when it is most needed can increase cocoa yields in agroforestry systems.

Since yields in agroforestry systems were similar under organic and conventional management, it seems that in agroforestry systems in contrast to monocultures, nutrients were not limiting and mineral fertiliser did not lead to better results than compost. The annual nitrogen input in the seventh year of the plantation, through the pruning residues from cacao and AF trees, amounts to more than 100 kg N/hectare in both monocrop and agroforestry systems. This shows the important function of regular pruning for nutrient cycling.

The good agricultural practices applied in LTE keep pests and disease losses relatively low in all the production systems, which is the reason why no insecticides and fungicides were used.

In a farm survey, the cocoa bean yield was higher in organic (506 kg/hectare/year) compared to non-organic (304 kg/hectare/year), even with a higher percentage of agroforestry systems in the organic farm sample. This is likely because non-organic management in the Alto Beni region of Bolivia is marginal (i.e., without the use of external inputs like mineral fertilisers).

In the system comparison trial, we also evaluate the performance of different cultivars, which in our case are different clones and hybrids[4]. We found that the clones, especially the locally selected ones, had higher yields than the international clones and hybrids. This highlights the relevance of having cultivars adapted to the local conditions.

For more details on these results, please see:

Schneider, M., Andres, C., Trujillo, G., Alcon, F., Amurrio, E., Perez, E., Weibel, F. and Milz, J. (2016). Cocoa and total system yields of organic and conventional agroforestry vs monoculture systems in a long-term field trial in Bolivia. Experimental Agriculture, 53 (3): 351–374.

Armengot, L., Ferrari, L., Milz, J., Velasquez, F., Hohmann, P. and Schneider, M. (2020). Cacao agroforestry systems do not increase pest and disease incidence compared with monocultures under good cultural management practices. Crop Protection, 130: 105047.

Jacobi, J., Schneider, M., Pillco, M., Huber, S., Weidmann, S., Bottazzi, P. and Rist, S. (2015). Farm resilience in organic and nonorganic cocoa farming systems in Alto Beni, Bolivia. Agroecology and Sustainable Food Systems, 39: 798–823.

Schneidewind, U., Niether, W., Armengot, L., Schneider, M., Sauer, D., Heitkamp, F., Gerold, G. (2017). Carbon stocks, litterfall production, and pruning residues in monoculture and agroforestry cacao production systems. Experimental Agriculture, 55(3): 452–470.

Niether, W., Armengot, L., Andres, C., Schneider, M., and Gerold, G. (2018). Tree management affecting shading, throughfall and microclimate in cocoa production systems. Annals of forest science, 75(2): 38.

Niether, W., Schneidewind, U., Armengot, L., Adamtey, N., Schneider, M., Gerold, G. (2017). Spatial-temporal soil moisture dynamics under different cocoa production systems. Catena, 158: 340–349.

[4] Cacao trees are either grown from vegetative multiplication (clones grafted on root stock); or from generative multiplication (hybrids produced from seed).

4. Profitability

In organic arable farming systems, labour is a prominent factor contributing to production costs, whereas in conventional systems, it is mainly determined by the costs for external inputs. High labour costs and low mechanisation lead to increased production costs. In organic systems, lower costs for external (market purchased) inputs and higher market value of organic produce can often compensate the economic loss due to lower yield.

Depending on the crop, returns on production costs and/or returns on labour are higher in organic, making it a suitable option, particularly for capital-poor smallholder farmers.

Cacao agroforestry systems have higher returns on labour compared to full-sun monocultures in the young stage of the plantation. Incomes from harvested by-crops lead to increased returns per labour day invested.

Profitability is a key factor affecting the choice of a production system implemented by the farmer(s). However, context-specific evaluation of production systems is vital as the suitability of any particular production system can be affected by a number of factors such as farm holding size, availability of labour and financial resources of the farmers. The economic analysis here is based on the long-term field trials but also gives due consideration to the context of smallholder farmers in the respective tropical countries. The major results comparing the profitability of different systems are presented below.

4.1 Gross margins

Soybean crops had consistently higher gross margins[5] in organic systems compared to conventional systems due to similar yields and lower costs of production in organic. Similarly, despite higher cocoa yields in monocultures, revenues from banana and plantain sales in agroforestry systems compensated economically for this disparity. Although timber is also an important by-product of agroforestry systems, the future value of the timber trees (which are still young) is not included in this economic assessment.

In other crops, such as maize, cotton, and wheat, gross margins were at the beginning lower in organic systems than in conventional systems, mainly due to the yield gap. However, in maize, this discrepan-

[5] *Gross margin refers to the revenue that the producer retains after the direct costs are subtracted.*

cy evened out in the third year, and organic systems were even more profitable than conventional when the price premium was applied. For example, with a price premium of 25 – 50% for organic products (based on farm gate and Nairobi market), profitability in the high-input organic system was ~30% higher than the high-input conventional system (Figure 6).

On cotton-producing farms in Nimar valley (India), the premium price (10 – 15%) for cotton was not sufficient to compensate losses from other crops in the cropping system. This was also confirmed by the result on gross margin from the long-term experiment (Figure 7). Although these farmers produce all other crops organically, there is no organised market offering premium prices for these crops.

4.2 Return on (economic and labour) investment

The calculation of return on investment[6] revealed that in monetary terms, every unit invested in cotton and wheat in organic systems earned much higher returns than in conventional systems (in India). We found that the main reason for a higher return on investment was the lower cost of production in organic than conventional (Figure 7). These calculations take into account the premium price for organic cotton (after the third

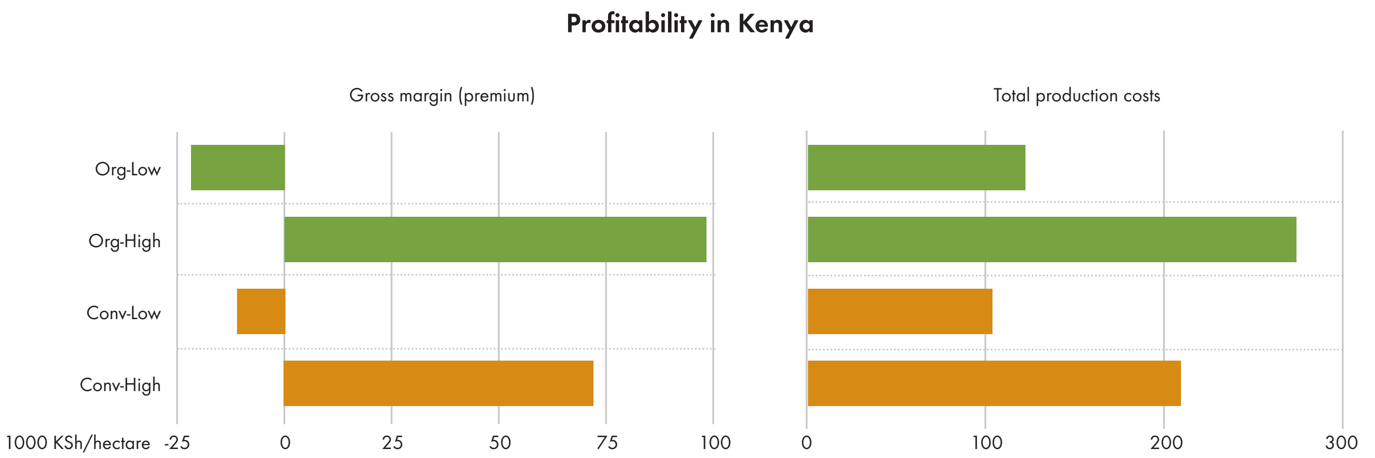

Figure 6: Average gross margins (with premium prices) and total production costs over all crops in Kenya (2007-2018).

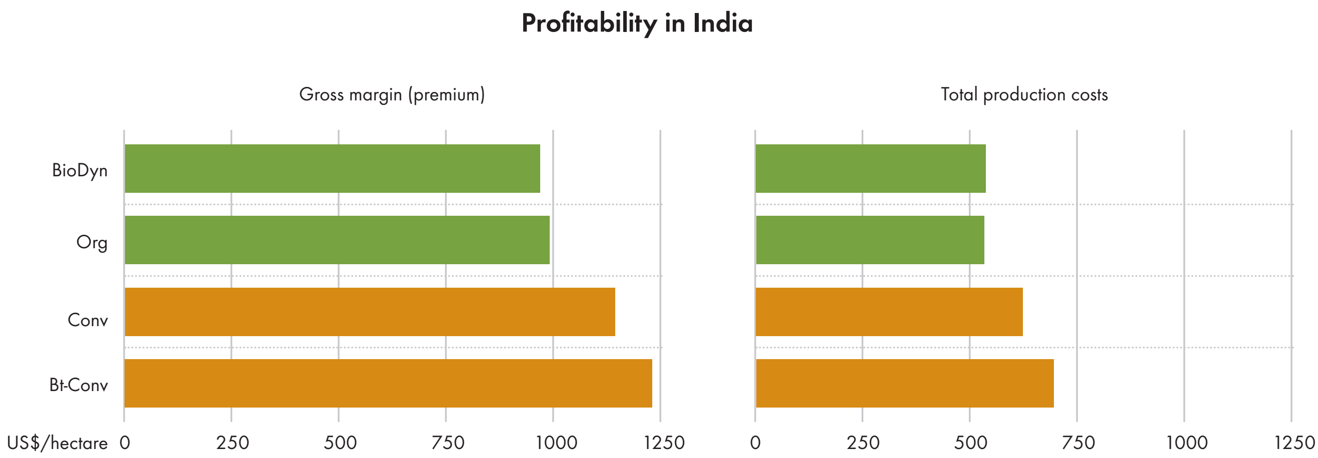

Figure 7: Average gross margins (with premium prices) and total production costs over all crops in India (2007-2018).

[6] *"Return on investment (ROI) measures the gain or loss generated on an investment relative to the amount of money [or labour] invested" https://www.merriam-webster.com/dictionary/ROI It refers to the efficiency of an investment*

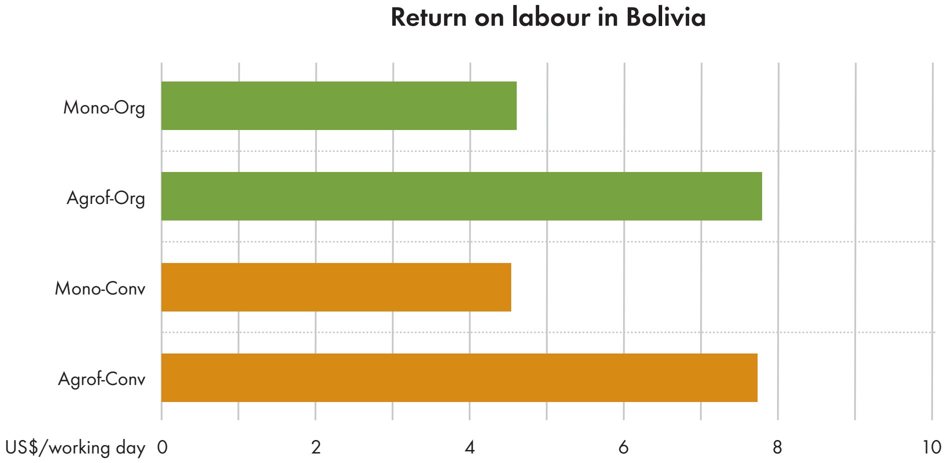

Figure 8: Average return on labour in Bolivia (2010-2014).

year of conversion, as per IFOAM standards) but no premium price for wheat and soybean. If these crops were to fetch a premium price, the return on investment, as well as the gross margins, would be much higher for organic systems. Here, it is noteworthy that some organisations (e.g., bioRe India ltd.) compensate farmers during the conversion period as well, by offering a premium price on the main cash crop (cotton) from the second year onwards.

The return on investment, both in economic and labour terms, makes organic arable systems a more suitable choice for resource-poor smallholder farmers who have limited capital to invest. Whereas small family farms can often meet the higher labour demands of organic practices by utilising the human resources available to them (e.g., for compost preparation or manual weeding), opting for conventional systems requires market-purchased inputs (when accessible) and therefore has the potential to make these capital-poor families more vulnerable to a cycle of debt.

Regarding return on labour, we found that even though agroforestry systems were more labour intensive (mainly due to the management of shade trees and by-crops) the return on labour[7] was almost double in the agroforestry systems compared to monocultures in the youth phase (in Bolivia). This was achieved without having premium prices for organic bananas and plantains. Thus, efforts to develop organic markets for the by-crops such as bananas or plantains can even further increase the profitability of organic agroforestry systems. Unlike the annual crops grown in India and Kenya, labour requirements in Bolivia were similar for organic and conventional. Interestingly, even though yields in conventional monocultures were nearly double those of organic monocultures, the return on labour was similar for conventional and organic, mainly due to the lower input cost and the premium price of organic cocoa beans (Figure 8).

In addition to the economic benefits, the total system benefits realised in agroforestry systems are much higher. For instance, self-consumption of by-crops such as oranges, peach palm, bananas and avocados contributes to the food security and livelihoods of smallholder farming families and could contribute to regular capital flows should a suitable market for these products become available.

For more details on these results, please see:

Adamtey, N., Musyoka, M. W., Zundel, C., Cobo, J. C., Karanja, E., Fiaboe, K. M., et al. (2016). Comparison of conventional and organic farming systems in the sub-humid zones of the Central highlands of Kenya: Productivity and profitability of maize-based cropping systems. Agriculture, Ecosystems and Environment, 235: 61–79.

Forster, D., Andres, C., Verma, R., Zundel, C., Messmer, M. and Mader, P. (2013). Yield and economic performance of organic and conventional cotton-based farming system – results from a field trial in India. PLOS ONE, 8(12): e81039.

Armengot, L., Barbieri, P., Andres, C., Milz, J., and Schneider, M. (2016). Cacao agroforestry systems have higher return on labour compared to full-sun monocultures. Agronomy for sustainable development, 36: 70.

[7] *"Return on labour measures the gain or loss generated per unit labour (typically a work day) invested"*

5. Soil fertility and quality

Organic systems build up soil fertility over the long-term.

After a decade of continuous organic inputs, soils start to build up carbon.

Soils under organic management in annual crops demonstrated higher nutrient stores (e.g., nitrogen, potassium, calcium, magnesium), higher biological activity, and improved chemical properties.

Phosphorus availability in organically managed soils is comparable to that in conventional soils supplied with mineral fertilisers. However, for nitrogen availability, organic soils lag. Nutrient management practices in organic need to be further improved to enhance nutrient availability at key crop stages.

Soil is probably the most important natural resource for farming, particularly for the smallholder farmers in the tropics. In nature, it takes over a thousand years under permanent vegetation for soil to develop just the plough layer (10 – 20 cm). Under current prevalent agricultural management, this vital resource is faced with erosion, fertility depletion and climate variability, posing real threats to sustainable crop production and hence to the food security and livelihoods of smallholder farmers. It is crucial to develop farming practices that contribute to maintaining and improving soil fertility and quality, as well as optimal crop production. The production systems studied in the SysCom LTEs influenced various soil parameters in different ways, as presented below.

5.1 Soil organic carbon

Soil organic carbon (SOC) refers to the organic matter present in the soil. This is a key factor determining soil fertility as it strongly influences different biological and biogeochemical processes in the soil. This, in turn, accounts for soil fertility and quality and is therefore vital for successful crop growth.

After nine years of continuous cultivation with sufficient organic inputs and reduced soil disturbance it was possible (in Kenya) to increase the SOC content (Figure 9). The SOC content was higher in high-input organic systems than in high-input conventional system and low-input production systems.

Similarly, we found that agroforestry systems in Bolivia were much more efficient in adding organic matter (carbon) to the soil (Figure 9). Owing to the higher tree density, the carbon from annual litterfall in the agroforestry systems was higher than in the mono-cropped systems. Furthermore, agroforestry systems are subject to regular pruning, and the carbon input from pruning residues was found to be nearly twice that of the litterfall. When comparing organic with conventional systems, higher soil organic carbon

Soil organic carbon in Kenya and Bolivia

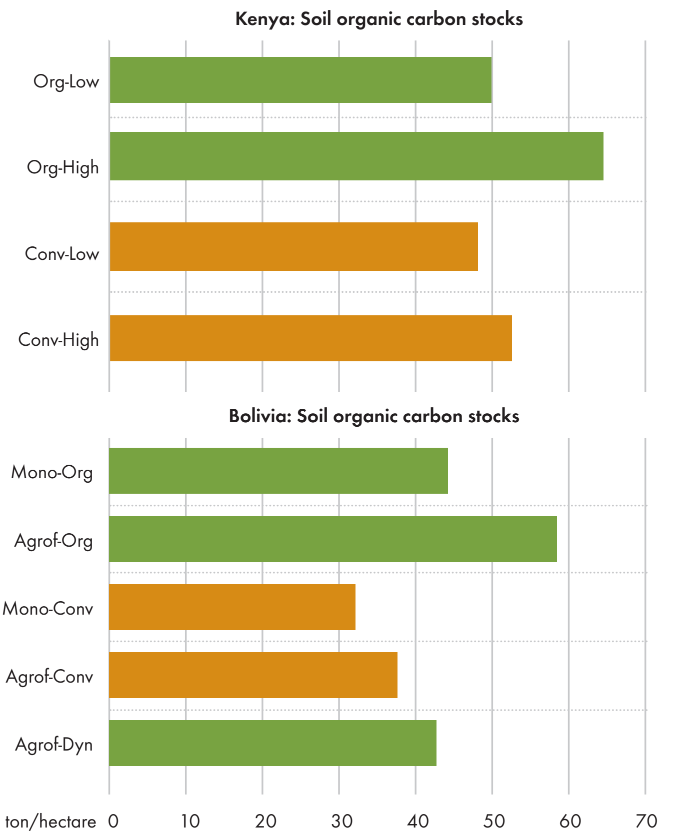

Figure 9: Average soil carbon stocks in Kenya (0–20 cm) and Bolivia (0 – 10 cm) in 2018 and 2016, respectively.

was found in all organic systems, mainly due to compost inputs and cover crops.

After three years of LTE in Bolivia, the agroforestry systems had higher microbial carbon biomass in the soil compared to the monocultures. However, organic and conventional systems showed no differences. The organic matter content was not statistically different between organic monocultures and conventional monocultures, but there was a tendency towards lower values in conventional monocultures.

While the organic matter content in the topsoil (0 – 10 cm) directly under the cacao trees did not differ between the monoculture and the agroforestry systems, there was a tendency toward lower values in conventional monocultures after 6 years.

In an on-farm case study, the humic top-soil layer in the cacao agroforestry system was deeper compared to the cacao monoculture, but no difference in soil organic carbon stocks could be found in the horizon from 0 to 50 cm.

For more details on these results, please see:

von Arb, C., Bünemann, E.K., Schmalz, H., Portmann, M., Adamtey, N., Musyoka, M.W., Frossard, E., Fliessbach, A. (2020). Soil quality and phosphorus status after nine years of organic and conventional farming at two input levels in the Central Highlands of Kenya. Geoderma, 362: 114112.

Alfaro-Flores, A., Morales-Belpaire, I. and Schneider, M. (2015). Microbial biomass and cellulase activity in soils under five different cocoa production systems in Alto Beni, Bolivia. Agroforestry Systems, 89(5): 789-798.

Jacobi, J., Andres, C., Schneider, M., Pillco, M., Calizaya, P. and Rist, S. (2014). Carbon stocks, tree diversity, and the role of organic certification in different cocoa production systems in Alto Beni, Bolivia. Agroforestry Systems, 88(6): 1117-1132.

Schneidewind, U., Niether, W., Armengot, L., Schneider, M., Sauer, D., Heitkamp, F., Gerold, G. (2017). Carbon stocks, litterfall production, and pruning residues in monoculture and agroforestry cacao production systems. Experimental Agriculture, 55(3): 452–470.

Gramlich, A., Tandy, S., Andres, C., Chincheros Paniagua, J., Armengot, L., Schneider, M., and Schulin, R. (2016). Cadmium uptake by cocoa trees in agroforestry and monoculture systems under conventional and organic management. Science of the Total Environment, 580: 677–686.

5.2 Other soil physico-chemical properties

The productivity potential of soil is determined by the physical and chemical properties of the soil and their interactions with each other. The understanding of soil physico-chemical properties helps to design and implement appropriate management practices.

Our study in Kenya showed that after six years of continuous cultivation, the high-input organic management (Org-High) significantly improved soil chemical properties (Figure 10). Soil pH, electrical conductivity, cation exchange capacity, total nitrogen, exchangeable potassium, calcium, magnesium, available boron, as well as soil aggregates were higher in the organic high-input system compared to the other three production systems (Conv-High, Conv-Low and Org-Low). However, soil physical properties (e.g. soil bulk density, porosity, hydraulic conductivity, and available water holding capacity) were similar in all the systems. The relatively short time period (6 years) and the slow pace with which soil physical properties change highlights the need to continue monitoring the trial to determine whether the treatments bring about a fundamental change in soil physical properties and stabilise soil organic carbon. This also emphasises the importance of LTEs in studying the effects of management practices on the functioning of soils. The results show that high-input organic farming effectively protects, restores and builds soil fertility at a faster rate, and can better support sustainable soil fertility management and crop production in sub-Saharan Africa than high or low-input conventional production systems.

In Bolivia, we found that the litterfall and pruning residues from the agroforestry and monoculture systems had similar nitrogen contributions. However, annual nitrogen inputs to the soil from cacao pruning residues and nitrogen-fixing trees were up to 10 times higher than the nitrogen inputs from external fertiliser application. The pH ($CaCl_2$) of the topsoil (0 – 10 cm) directly below the cacao canopy was significantly higher in organic monocultures compared to conventional monocultures after six years of the LTE trial set up in Bolivia. This is a direct effect of the different fertilisation methods used: compost for organic and mineral fertiliser for conventional.

For more details on these results, please see:

Adamtey, N., Bekele, E., Bautze, D., Musyoka, M. W., Karanja, E., Fiaboe, K. M., et al. (In preparation). Organic farming improves soil fertility in the tropics compared to conventional: Evidence from Long-term farming systems comparison trials in Kenya.

Adamtey, N., Musyoka, M. W., Zundel, C., Cobo, J. C., Karanja, E., Fiaboe, K. M., et al. (2016). Comparison of conventional and organic farming systems in the sub-humid zones of the Central highlands of Kenya: Productivity and profitability of maize-based cropping systems. Agriculture, Ecosystems and Environment, 235: 61 – 79.

Gramlich, A., Tandy, S., Andres, C., Chincheros Paniagua, J., Armengot, L., Schneider, M., and Schulin, R. (2016). Cadmium uptake by cocoa trees in agroforestry and monoculture systems under conventional and organic management. Science of the Total Environment, 580: 677 – 686.

Schneidewind, U., Niether, W., Armengot, L., Schneider, M., Sauer, D., Heitkamp, F., Gerold, G. (2017). Carbon stocks, litterfall production, and pruning residues in monoculture and agroforestry cacao production systems. Experimental Agriculture, 55(3): 452 – 470.

Soil chemical properties in Kenya and Bolivia

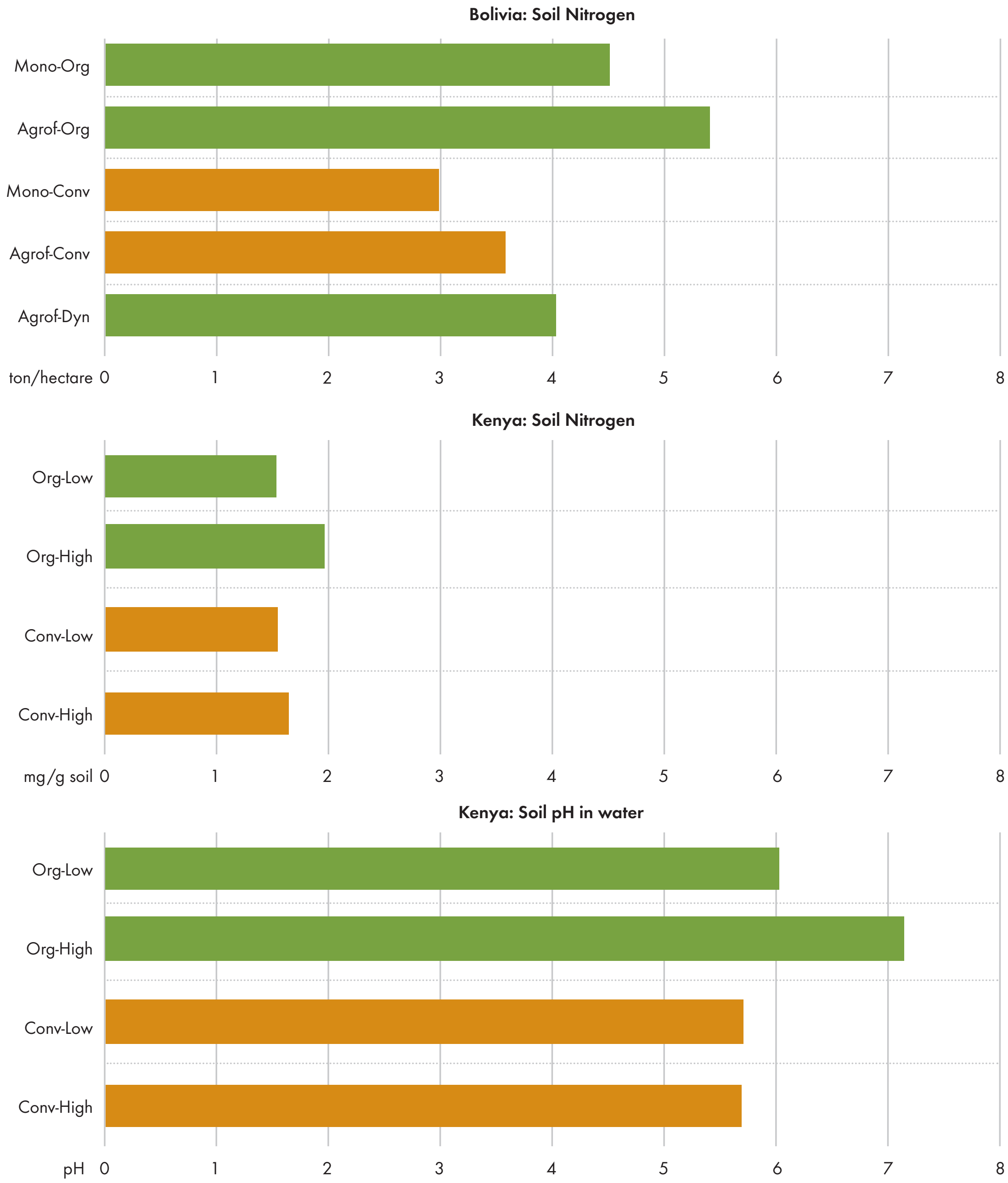

Figure 10: Soil nitrogen and pH in Bolivia (0 – 10 cm) and Kenya (0-20 cm) in 2016 and 2018, respectively.

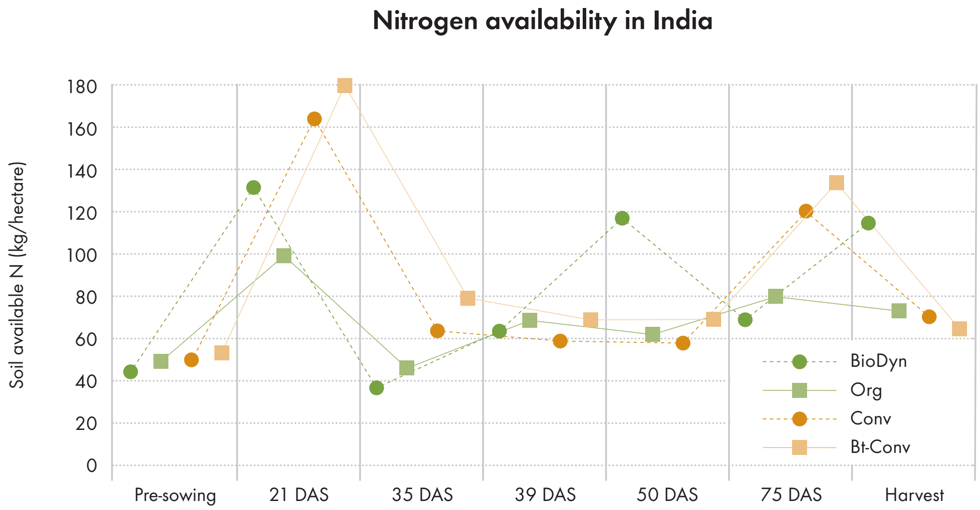

Figure 11: N availability in soils under organic and conventional management in India (2016 and 2017).

5.3 Nutrient availability to crops

Availability of sufficient nutrients such as nitrogen, phosphorus and potassium is crucial for crop productivity, particularly during critical growth stages. However, a number of pedo-climatic, biological and chemical processes mediate whether or not these nutrients are available and can be taken up by crops. In conventional agriculture, the supply of nutrients is ensured through split doses[8] of mineral fertilisers, which quickly release nutrients for plant growth during the period of maximum demand. On the other hand, organic systems largely rely on soil biological processes to release nutrients from inputs of organic origin.

Low availability of soil nitrogen remains a critical limiting factor for increasing crop productivity in organic systems, particularly for crops like wheat and cotton. The lack of sufficient nitrogen availability during key crop growth stages could significantly harm crop yields. In the Indian LTE, nitrogen availability in the organic systems lagged behind the conventional systems (Figure 11). This difference was particularly pronounced when split doses of nitrogenous fertilisers were applied in conventional systems.

It is noteworthy that leguminous crops such as soybean do not suffer from a lack of nitrogen, as they are capable of partially supplementing nitrogen availability through symbiotic fixation of atmospheric nitrogen. The effect is particularly pronounced in the high-yielding varieties of cereal crops, which are bred to maximise productivity.

A seven-year study at one of the sites in Kenya showed that the percentage of the applied nitrogen released into a plant-available form was similar in conventional and organic systems: 38% in potato and 44% in vegetables. In all systems, there was a surplus of nitrogen during the initial growth and harvesting stages of the crop, which indicates that excess nitrogen can be leached into the environment in both high-input organic and conventional systems. Based on the results from Kenya, we have recommended reducing nitrogen application during planting and increasing it during the reproductive stages of all crops. The studies conducted in Kenya also recommended increasing nitrogen application rates in low-input systems and developing a model to guide the application of organic inputs to avoid over or under application of nutrients in organic production systems.

Management practices such as including leguminous by-crops and green manures, can also increase nitrogen availability. At the same time, it is important to breed crops that are adapted to organic and low-input production systems.

Phosphorus is another crucial nutrient for successful plant growth and phosphorus exports from the fields through harvests need to be replenished with adequate external phosphorus sources. Most soils in the tropics, are deficient in phosphorus due to its strong binding to irons, aluminium and calcium ions, depending on the soil pH. In organic agriculture, the challenge of phosphorus availability is even more pronounced, since most of the commercially produced phosphorus fertilisers are not allowed. Organic materials such as bone meal and rock phosphates (RP) are permissible for organic crop production, but they have limited efficiency. RP is a common but ineffective source of phosphorus, especially for soils with high pH and low organic matter.

Several materials of organic origin, with potential to acidulate RP to enhance phosphorus availability, were tested using a farmer participatory technology development approach in India. Many of the tested plant materials were effective in solubilising RP. However, buttermilk turned out to be the material of choice under local conditions for its availability, af-

[8] *Split dose: When the total fertiliser required by the crop is not given at once, rather is divided into several (typically 2-3) fractions applied at crucial crop growth stages*

fordability and ease of application. During the process of technology development, buttermilk-acidulated RP combined with improved composting methods turned out to be an effective solution. From 2010 to 2014, the agronomic effectiveness of this technology to improve crop yields was proven in 61 on-farm trials.

Similarly, a POR study was undertaken in Kenya to mitigate phosphorus deficiency. The study also found that in the given environment, the forms in which phosphate rock is applied can affect crop nutrient uptake, phosphorus recovery and use efficiency. For example, phosphate rock dissolved in lemon juice, when applied together with compost during planting, significantly increased phosphorus and potassium uptake, phosphorus recovery and crop yields. This implies that small-scale farmers can offset the phosphorus deficiency that commonly occurs on their farms (especially in organic farming). The introduction of such lemon technology could also encourage farmers to plant more lemon trees around their farms, which can serve as alternative sources of income as well as improve the environment and ecosystem services (by providing more shade, habitat for pollinators, etc.). However, applying such a system to high-value crops on a large-scale could present challenges in terms of the availability and costs of lemon.

Chemical and biological soil processes further limit the availability of applied phosphorus to crops. Commercial fertilisers used in conventional farming are generally deemed to offer higher levels of available phosphorus. A study conducted in the seventh year of the Indian field trial showed that the phosphorus availability, at five different time points in the soybean-wheat crop sequence, was comparable in soils under organic and conventional management. The study showed that organic soils were more biologically active[9] , particularly at the crop growth stages of reproductive significance. These findings clearly indicate that, with higher biological activity, organic systems are capable of supplying phosphorus for crop growth that is equal to conventional systems, which depend on inputs of mineral phosphorus fertilisers. Six years after the Bolivian LTE was set up, available phosphorus and potassium contents were highest in organic monocultures' topsoil below the cacao trees. Phosphorus was significantly higher than in conventional agroforestry systems, and potassium was significantly higher than in conventional and organic agroforestry systems.

These findings highlight the role of biological processes fuelled by regular inputs of organic matter, in ensuring nutrient supply to crops.

For more details on these results, please see:

Cicek, H., Bhullar, G.S., Mandloi, L.S., Andres, C., Riar, A.S. (2020). Partial Acidulation of Rock Phosphate for Increased Productivity in Organic and Smallholder Farming. Sustainability, 12: 607.

Mwangi, E., Ngamau, C., Wesonga, J. Karanja, E., Musyoka, M., Matheri, F., Fiaboe, K., Bautze, D., Adamtey, N. (2020). Managing Phosphate Rock to Improve Nutrient Uptake, Phosphorus Use Efficiency, and Carrot Yields. Journal of Soil Science and Plant Nutrition, 20(3): 1350-1365.

Gramlich, A., Tandy, S., Andres, C., Chincheros Paniagua, J., Armengot, L., Schneider, M., and Schulin, R. (2016). Cadmium uptake by cocoa trees in agroforestry and monoculture systems under conventional and organic management. Science of the Total Environment, 580: 677–686.

Bhat, N. A., Riar, A., Ramesh, A., Iqbal, S., Sharma, M. P., Sharma, S. K. and Bhullar, G. S. (2017). Soil biological activity contributing to phosphorus availability in Vertisols under long-term organic and conventional agricultural management. Frontiers in Plant Science – Agroecology and Land Use Systems, 8: 1289.

Musyoka, M. W., Adamtey, N., Bünemann, E. K., Muriuki, A. W., Karanja, E. N., Mucheru-Muna, M., Fiaboe, K. K. M. and Cadisch, G. (2019). Nitrogen release and synchrony in organic and conventional farming systems of the Central Highlands of Kenya. Nutr Cycl Agroecosyst, 113: 283.

[9] *E.g., regarding dehydrogenase, b-glucosidase, acid and alkaline phosphatase activities, microbial respiration, substrate induced respiration, and soil microbial biomass carbon*

6. Other aspects of system performance

Organic and agroforestry systems offer several benefits with regards to biodiversity, resource use efficiency, as well as food and nutrition security.

Organic food substantially reduces the risk of pesticide contamination, although there can be traces of drift from neighbouring conventional farms or from previous residues in the soil.

Organically produced wheat grains have higher concentrations of Zinc (Zn) – a vital element for metabolism and enzymatic functioning in the human body – than the grains produced through conventional farming.

Environmental effects caused by the managements practices in different production systems could influence the chemical composition of cocoa beans.

Organic systems lead to enhanced faunal and floral diversity and abundance (e.g., termites, earthworms, microbes). This is caused, among other reasons, by the favourable management practices (mulching, organic manure, crop diversity and reduced toxicity from agrochemicals), which result in favourable living conditions. Increasing the complexity of the systems (agroforestry vs monocultures) results in higher biodiversity and conserves rare and native species.

Nitrogen use efficiency under organic and conventional production systems in LTE Kenya varied with the type of crop.

In cacao, conventional and monoculture systems use more energy from non-renewable resources (e.g., fuel and electricity) compared to organic and agroforestry systems.

Agroforestry systems sequester much more carbon in above-ground biomass compared to monoculture systems. In agroforestry systems regular pruning of trees, many of which are leguminous enhances carbon and nitrogen cycling in the soil-plant system.

Agroforestry systems have higher agroecosystem resilience. Farm-level agroecosystem resilience is higher under successional agroforestry systems compared to simple agroforestry and monoculture systems. Organic farms show more socio-economic and agroecological resilience than conventional farms.

6.1 Pesticide residues

The use of chemical pesticides in conventional farming is a potential threat to human and environmental health due to pesticide residues in soils, water and crops. Results after six years of comparative studies in Kenya showed that (Figure 12):

- Crop products from conventional production had high concentrations of three chemical compounds (Imidacloprid, Acetamiprid and Chlorpyriphos) applied to these crops
- Food crops, biomass, soil and running water from organic fields were free from residues of the applied bio-pesticides.
- Conventional fields were contaminated with chemical pesticides residues and exceeded the acceptable thresholds.
- Traces of chemical pesticides from conventional fields were also found in nearby organic fields, as wind and run-off water led to trace contamination.

Thus, organic farming provides an effective alternative and environmentally sound approach to reducing pesticide contamination in the environment and food products. The above results highlight the need for effective land management in both conventional and organic farming.

6.2 Nutrient and anti-nutrient content of crop produce

Global nutrition security depends not only on the quantity of food produced but also the nutritional quality. Along with other nutrients, Zinc (Zn) has key nutritional value, particularly in countries like India, where a large fraction of the population suffers from Zn malnutrition. Since many soils contain little plant-available Zn, researchers are assessing options to bio-fortify food products through organic amendments in the soil. There is some evidence to suggest this could lead to effective Zn-fortification of cereal grains but data from farmer field conditions, particularly from tropics, is lacking.

In a study, we compared 30 organic and 30 conventional farms producing wheat in the Nimar valley in India. We found that the grain Zn concentrations were higher on organic (32 mg/kg) farms than conventional (28 mg/kg) farms. The average grain yield (3400 kg/hectare), as well as the total and extractable Zn concentrations in soil, were comparable across organic and conventional farms. These comparisons suggest that organic systems have higher nutrient efficiency. We also found that the nutrient efficiency of

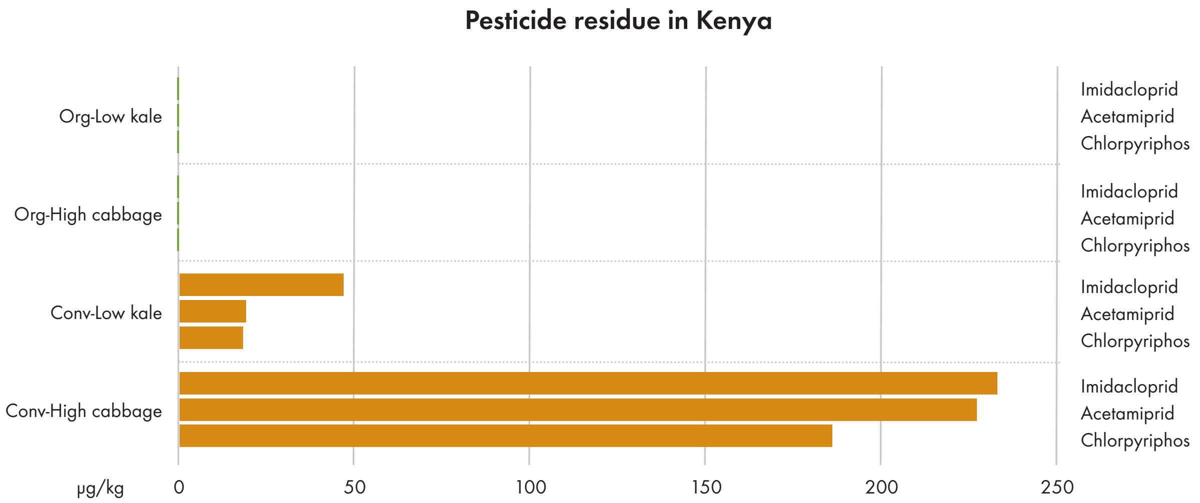

Figure 12: Residues of three chemical compounds in organic and conventional crop products from the 2nd season 2016 in Kenya.

organic wheat was higher for phosphorus, nitrogen and sulphur.

Similarly, in Bolivia, we found that the different production systems influenced the composition of nutritional elements in cocoa beans. The highest concentrations of nitrogen, magnesium, sulphur, sodium, and iron were found in the beans from agroforestry systems under organic farming, while zinc and copper were even more concentrated in beans from the successional agroforestry systems. The chemical composition of cocoa beans was also influenced by the harvesting season (dry or wet) in both agroforestry systems and monocultures, with drier conditions increasing the phenolic content.

In addition to these nutritional elements, which are essential for human health, cacao trees can also absorb cadmium (Cd) and store it in the beans, which poses a threat to human health. We found lower levels of Cd in cacao leaves in agroforestry systems than in monocultures, which is likely due to increased competition for Cd with other plants in agroforestry systems. However, the concentration of Cd in cocoa beans did not differ significantly between production systems. Although these differences between the production systems were not very strong, they contribute to differences in product quality.

For more details on these results, please see:

Helfenstein, J., Müller, I., Grüter, R., Bhullar, G.S., Mandloi, L., Papritz, A., Siegrist, M., Schulin, R. and Frossard, E. (2016). Organic Wheat Farming Improves Grain Zinc Concentration. PLOS ONE, 11 (8): e0160729.

Niether, W., Smit, I., Armengot, L., Schneider, M., Gerold, G., Pawelzik, E. (2017). Environmental Growing Conditions in Five Production Systems Induce Stress Response and Affect Chemical Composition of Cocoa (*Theobroma cacao* L.) Beans" in Journal of Agricultural and Food Chemistry, 65 (47): 10165–10173.

Gramlich, A., Tandy, S., Andres, C., Chincheros Paniagua, J., Armengot, L., Schneider, M., and Schulin, R. (2016). Cadmium uptake by cocoa trees in agroforestry and monoculture systems under conventional and organic management. Science of the Total Environment, 580: 677–686.

Kampermann, I., Bautze, D., Mapili, M., Adamtey, N., Musyoka, M., Karanja, E., Fiaboe, K.K.M., Irungu, J., and Torto, B. (in preparation). Pesticide contamination in organic farming systems: a challenge to sustainable agriculture in Africa.

6.3 On-farm biodiversity

About a quarter of the living species on earth are found in soil (including micro- and macrofauna). This makes it clear that these soil inhabitants, and their functions, cannot be ignored. Unfortunately, soil biodiversity has mostly been overlooked when developing soil management practices, particularly in conventional agriculture. Despite significant progress made in recent years, knowledge gaps remain regarding the function and interactions of different species in numerous biogeochemical process. However, it is widely understood that more biologically active soils are healthier. Termites, earthworms and ants, are some of the major soil macrofaunae. Certain soil-inhabiting organisms, including earthworms, are frequently used as soil health indicators in production systems studies. However, there is a distinct dichotomy within the literature that depicts termites either as 'pests' or as important indicators for environmental sustainability. The extent to which termites can be managed to avoid crop damage, but improve the sustainability of production systems is vital to understand.

Similarly, the aboveground biodiversity of flora and fauna, not only serves as an indicator of sustainability and resilience of a system, but it also contributes to ecosystem services (Figure 13).

The results of our study in Kenya show that the organic high-input production system (Org-High) consistently recorded higher average values for the abundance, incidence, activity and diversity of termites than the other production systems (Conv-High, Conv-Low and Org-Low). However, in all the production systems, termite presence, abundance, etc. were also found to be influenced by several other factors, particularly soil depth, trial site and cropping season.

We hypothesise that the presence and abundance of termites within the different production systems might be influenced by the types of input applied, the soil moisture content and the occurrence of natural enemies. Our findings further demonstrate that the organic high-input system attracts termites, which are an important, and often beneficial, component of soil fauna. In addition, termite-induced damage on maize plants was not necessarily greater in organic plots with high termite numbers.

Earthworms are often called "engineers of soil" and "best friends of the farmers", as they play an important role in soil formation by ingesting decomposed organic matter to then digest in their guts. They also play an essential role in soil fertility and health by converting nutrients into a form that is available to plants.

In the Indian LTE, we assessed the biomass and population density of earthworms after ten years of management under four different production systems. The measurements were taken during the 2017 cotton season. We found that the density and biomass of earthworms were much higher in the soil on organic plots than conventional plots throughout the growing season (Figure 13). Towards the end of the season, when the soil is dried up, the population of earthworms understandably declines in all the systems, and there is no apparent difference between earthworm density or biomass in the compared production systems at this point. However, higher earthworm activity throughout the active growth period of the cotton crop shows that the soil in organic production systems is more biologically active and alive compared to conventional systems. This, in turn, has important implications on the nutrient availability for crops as well as physical and chemical soil properties. For instance, we found that the time required to plough organic fields is less compared to conventional fields.

In the Bolivian LTE, we found that after six years, there was no difference in Mycorrhizal abundance on cacao roots in different production systems; however, it differed with cacao cultivars.

A study on the herbaceous strata in Bolivia found that organic management, and especially organic agroforestry systems, leads to species conservation and less biotic homogenisation (spread of the same species and reduction of rare and native species). Using plant species as a case study, we found that even though species richness did not differ between organic and conventional systems, community composition changed, following the management intensity gradient. In particular, we found that widely distributed species (low conservation value), including some exotic species, were associated with intensive management, i.e. monocultures and conventional systems with high solar exposure levels and/or herbicide (glyphosate) application. More complex agroforestry and organic systems harboured species with a geographical distribution range-restricted to the Neotropics or South America (high conservation value). These results indicate the role of sustainable agricultural management practices in reducing species homogenisation. Similarly, organically certified cacao fields in Alto Beni show higher shade tree diversity compared to non-certified cacao fields.

In another study, we found that the bird species diversity and frequency of bird visits increased with the complexity of vegetation structure and tree diversity (Monoculture < Agroforestry < Fallow) (Figure 13). Bird diversity was more than double in fallow plots than in monocultures. The structural complexity and high tree diversity in agroforestry systems provide the resources to sustain a high diversity of birds.

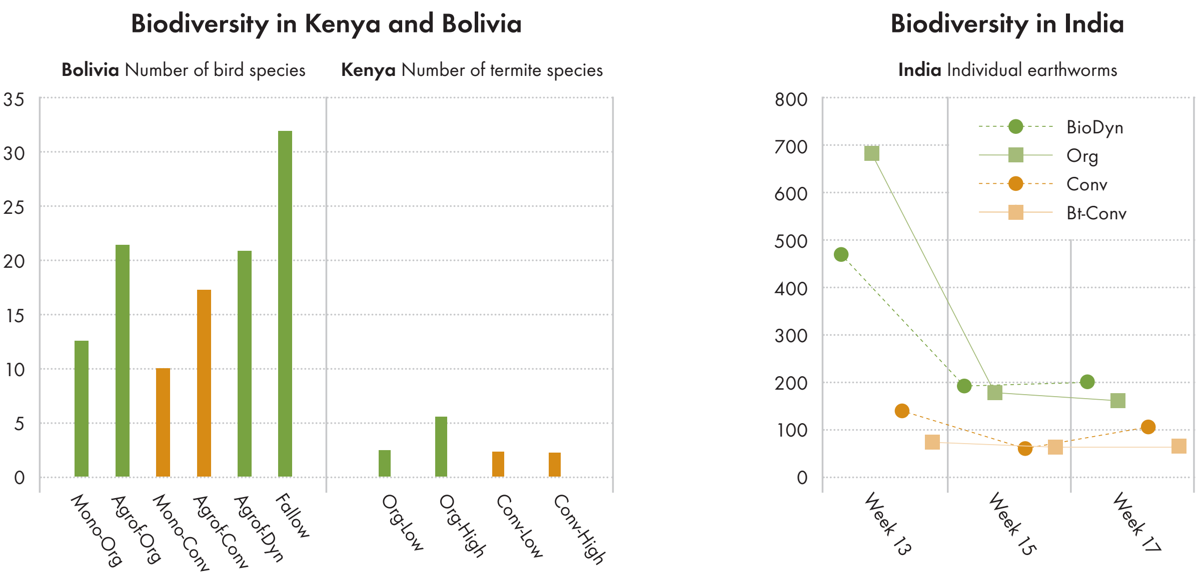

Figure 13: Average abundance of earthworms individuals (India), bird (Bolivia) and termite species (Kenya) across different production systems (years).

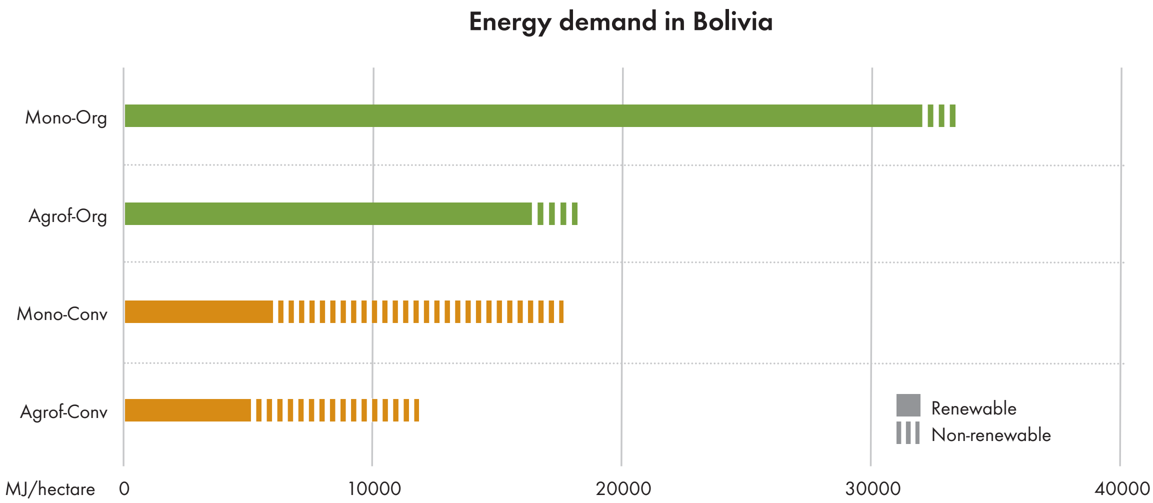

Figure 14: Cumulative renewable and non-renewable energy demand in Bolivia (2010-2014).

For more details on these results, please see:

Anyango, J. J., Bautze, D., Fiaboe, K. K. M., Lagat, Z. O., Muriuki, A. W., Stöckli, J., Onyambu, G. K., Musyoka, M. W., Karanja, E. N., Adamtey, N. (2019). Termite-Induced Injuries to Maize and Baby Corn under Organic and Conventional Farming Systems in the Central Highlands of Kenya. Insects, 10(10): 367.

Ledroit et al. (in preparation) Earthworm population and densities in organically and conventionally managed soils.

Jacobi, J., Andres, C., Schneider, M., Pillco, M., Calizaya, P. and Rist, S. (2014). Carbon stocks, tree diversity, and the role of organic certification in different cocoa production systems in Alto Beni, Bolivia. Agroforestry Systems, 88(6): 1117-1132.

Gramlich, A., Tandy, S., Andres, C., Chincheros Paniagua, J., Armengot, L., Schneider, M., and Schulin, R. (2016). Cadmium uptake by cocoa trees in agroforestry and monoculture systems under conventional and organic management. Science of the Total Environment, 580: 677–686.

Marconi, L., and Armengot, L. (2020). Complex agroforestry systems against biotic homogenization: the case of plants in the herbaceous stratum of cocoa production systems. Agriculture, Ecosystems and Environment, 287: 106664.

Naoki, K., Gómez, M. I., Schneider, M. (2017). Selección de diferentes sistemas de producción de cacao (*Theobroma cacao*, Malvaceae) por aves en Alto Beni, Bolivia – una prueba de cafetería en el campo. Ecología en Bolivia, 52 (2): 100–115.

6.4 Resource use efficiency

In a study conducted in SysCom Kenya, we found that nitrogen use efficiency under organic and conventional production systems varied according to the type of crop. For maize and vegetables, conventional and organic production systems had similar effects on nutrient use efficiency (recovery and utilisation), while for potato, conventional systems improved nitrogen use efficiency compared to organic systems. This underscores the need to improve management practices to enhance nitrogen uptake and utilisation (especially at the initial growth stage) in organic potato production.

In Bolivia, we compared the cumulative energy demand (CED) of different production systems. We found that the conventionally managed systems have higher CED from non-renewable resources (e.g., fuel and electricity). Under organic management, less than 10% of the cumulative energy demand was from non-renewable sources, while it reached 75% in the conventional systems (Figure 14). Despite the higher yield per hectare of cocoa grown under conventional systems and monocultures, organic management has a lower non-renewable energy demand per kilogram of cocoa produced. If the by-crops are taken into account, the agroforestry systems were more energy-efficient than monocultures (higher return on the energy invested), especially when organically managed. These results are highly relevant when aiming to reduce the energy dependence of agricultural systems.

For more details on these results, please see:

Pérez-Neira, D., Schneider, M., Armengot, L. (2020). Crop-diversification and organic management increase the energy efficiency of cacao plantation. Agricultural systems 177: 102711.

6.5 Carbon Sequestration

Agroforestry systems could play a significant role in mitigating climate change by sequestering atmospheric carbon. In an assessment carried out in SysCom Bolivia, the total aboveground carbon stocks in the agroforestry systems were more than threefold those in the monoculture systems, although the biomass of cacao trees was greater in the monoculture systems compared to the agroforestry system (Figure 15). In an on-farm case study in Alto Beni, Bolivia, the total carbon stock was also significantly higher in cacao agroforestry systems compared to cacao monocultures.

For more details on these results, please see:

Schneidewind, U., Niether, W., Armengot, L., Schneider, M., Sauer, D., Gerold, G., Heitkamp, F. (2019). Carbon stocks, litterfall production, and pruning residues in monoculture and agroforestry cacao production systems. Experimental Agriculture, 55(3): 452–470.

Jacobi, J., Andres, C., Schneider, M., Pillco, M., Calizaya, P., and Rist, S. (2014). Carbon stocks, tree diversity, and the role of organic certification in different cocoa production systems in Alto Beni, Bolivia. Agroforestry Systems, 88(6): 1117-1132.

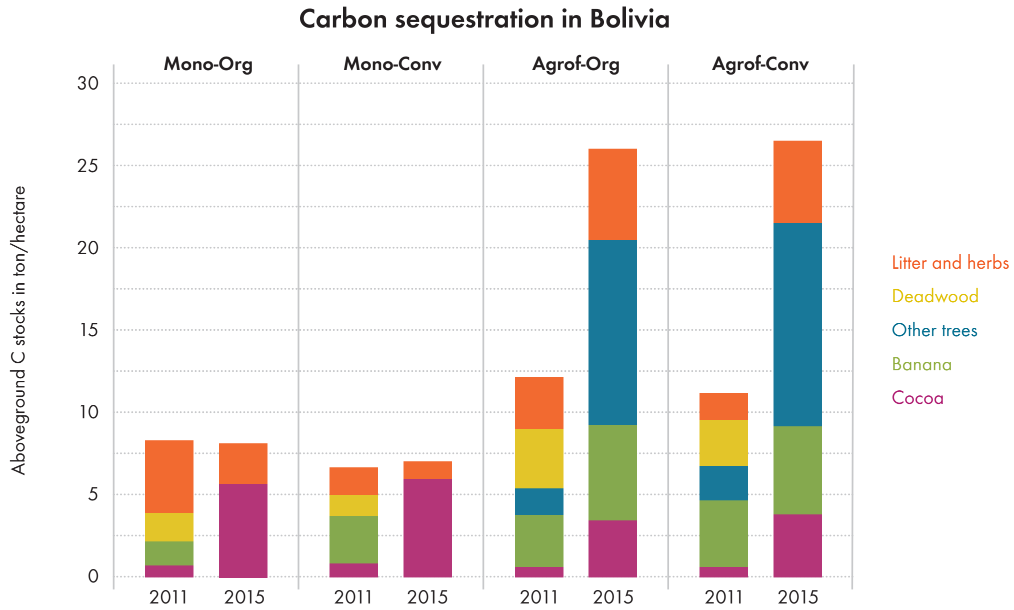

Figure 15: Aboveground carbon stocks from trees, litter, herbs and deadwood in Bolivia (2011 and 2015).

6.6 Agroecosystem resilience

An agricultural production system is considered resilient when it can sustain the adverse effects of biotic and abiotic stresses. Enhancing system resilience is an inherent feature of sustainable farming practices.

In East Africa, the incidence of plant-parasitic nematodes (PPN) and other soil pathogens is high, which consequently affects crop productivity on smallholder farms. A study was conducted in Kenya to assess the resilience and effectiveness of different production systems in managing PPN. Two field trials using maize and beans one on a farmer's field and one on-station, compare organic, conventional and farmer practice. After three years of continuous cultivation, twelve genera of PPN were recovered from trial soil and/or root samples. The abundance of PPN was significantly reduced in the organic system compared to the conventional. Organic farming practices were effective in keeping the abundance of PPN genera below the control for a longer period (4 months) compared to conventional farming and farmer practice (2 months). The findings demonstrated the resilience of organic production systems against PPN at the farm level.

In Bolivia, an analysis of agroecosystem resilience was conducted, which considered eight criteria defined in collaboration with farmers. We found that farm-level agroecosystem resilience is higher under successional agroforestry systems compared to simple agroforestry and monoculture systems. Agroecosystem resilience decreases according to system complexity (Agroforestry > Monoculture). Organic farms showed more socio-economic and agroecological resilience than conventional farms. Organic farms had a higher tree and crop diversity, as well as higher yields and incomes; organic farmers had more social connectedness and participated in more courses on cacao cultivation. Resilience was further enhanced by local farmers' organisations, which provided organic certification and supported diversified agroforestry with seedlings and extension services, going beyond basic organic certification requirements.

We also found that the shade trees in agroforestry systems protect the understory cacao trees from climate extremes. Shade tree pruning manages microclimatic conditions in favour of cacao production while maintaining tree diversity.

For more details on these results, please see:

Atandi, J. G., Haukeland, S., Kariuki, G. M., Coyne, D. L., Karanja, E. N., Musyoka, M. W., Fiaboe, K. K. M., Bautze, D., Adamtey, N. (2017). Organic farming provides improved management of plant parasitic nematodes in maize and bean cropping systems. Agriculture, Ecosystems & Environment, 247: 265–272.

Jacobi, J., Schneider, M., Bottazzi, P., Pillco, M., Calizaya, P., et al. (2015). Agroecosystem resilience and farmers' perceptions of climate change impacts on cocoa farms in Alto Beni, Bolivia. Renewable Agriculture and Food Systems, 30(2): 170.

Niether, W., Armengot, L., Andres, C., Schneider, M., and Gerold, G. (2018). Tree management affecting shading, throughfall and microclimate in cocoa production systems. Annals of forest science, 75(2): 38.

Niether, W., Schneidewind, U., Armengot, L., Adamtey, N., Schneider, M., Gerold, G. (2017). Spatial-temporal soil moisture dynamics under different cocoa production systems. Catena, 158: 340–349.


Identification of beneficial uses of biomass for organic vegetable production: Participatory technology development trials in Kenya

7. Policy recommendations

Policy and market instruments are essential to creating an environment that allows organic agriculture to reach its full potential in contributing to the SDGs. Based on the lessons learnt from the farming systems research conducted in Kenya, India and Bolivia, pursuant to the goals of sustainable development, the following recommendations are relevant to agricultural policies at the national and regional level, as well as to the actors in specific commodities (i.e. cotton, cocoa) and sectors, organic value chains, and standards:

System-oriented pricing

For many organic farmers, premium prices are only available for certain cash crops destined for export markets (such as cocoa and cotton) and not for other crops in the rotation. A conducive policy environment providing production system-oriented pricing and/or compensation schemes will support profitable organic production systems that enhance livelihoods.

Market linkages for diversified production

Organic farming and agroforestry systems offer a wider range of products than conventional farming based on monocultures. Organic farmers, therefore, need to be able to sell the different products they produce as 'organic'. Reducing farmers' dependency on particular (mostly export-oriented cash) crops will improve their livelihoods and support diversified farming systems. This requires a stimulating business environment that fosters market innovations and primes local markets for a diversified range of organic produce.

Capacity building and extension services

Farm performance varies widely across different agricultural management practices and production systems, suggesting a lack in implementation of best practices. Capacity building on good management practices improves yields and reduces losses due to pests and diseases, thereby increasing farmers' income. Policies should recognise the importance of know-how for the successful management of sustainable farms and prioritise capacity building for farmers. Organising farmers into cooperatives and (self-help) groups has the potential for building capacities e.g. through peer-to-peer learning as well as development and dissemination of innovative solutions.

Technical innovations and medium-scale mechanisation

Challenging labour requirements and declining labour availability force smallholders to either scale down their activities or opt for simpler farming systems, threatening food security and livelihoods. Technical innovations and medium-scale mechanisation adapted to the local conditions, reduce the need for manual labour, and are thus key to empower small scale organic farmers. Such innovations can help farmers to sustain and increase their activities, lower their production costs and improve their livelihoods and food security.

Research gap

Critical gaps in research on the management of organic farms are a) soil fertility management, b) pests and diseases, and c) water management/drought. Holistic systems design, building on diversified, interlinked and thus complex production patterns, can address these challenges by considering a) optimising nutrient management, carbon storage and tillage practices, b) implementing a systems approach for pest and disease management, and c) setting up suitable water conservation systems. Research and technology development must acknowledge that resilience increases with the complexity of a system and strengthens farming to face the threats imposed by climate change.

Provision of public goods

Organic farming sustains public goods by providing ecosystem services such as supporting carbon sequestration, conserving biodiversity and improving nutrient cycling. Awareness among consumers and decision-makers for these benefits of organic farming enables an environment in which organic farming can grow and contribute to truly sustainable food systems, providing healthy food for a growing population without damaging human and environmental health.

Syscom Kenya

8. Annexes

8.1 About the SysCom program set-up

The activities of SysCom program are coordinated under three projects, each pertaining to a partner country: SysCom Kenya, SysCom India and SysCom Bolivia. In each country, the team carries out long-term experiments (LTE) and participatory on-farm research (POR).

Phases of the SysCom Program

For effective monitoring, financing and progress evaluation, the program runs in phases of four years each. The first phase of SysCom (2007 – 2010) focused on setting up the experiments and making/strengthening the institutional arrangements to run the long-term trials successfully as well as to develop crop management plans and research protocols. Substantial effort was invested in setting up the necessary functional infrastructure at the remote project sites and recruiting as well as training the local research staff. The second phase of the program (2011 – 2014) saw an expansion of research activities. Several student projects in collaboration with other institutions were initiated, focussing on specific issues in each country. The component of 'Participatory Technology Development' (PTD) was also strengthened during this phase. In the third phase of the program (2015 – 2018), the participatory component was broadened and scientifically strengthened to take the form of 'Participatory On-farm Research' (POR). In 2019, the program entered its fourth phase, which prioritises developing the institutional capacities at the local level, as well as the LTEs and POR. Starting in the third phase, there was a significant push to analyse and disseminate the data collected at the project sites by increasing staff capacities at FiBL. This has proven fruitful in increasing the rate of publications, which will continue in the coming years.

Capacity building & dissemination

In addition to the research findings, the program has made significant contributions towards capacity building by training project staff, several interns, 16 BSc, 17 MSc and 7 PhD students. The LTE sites in each of the partner countries have established itself as an important focal point for sustainable agriculture, inspiring hundreds of visitors (including farmers, extension workers, students and researchers) each year. In terms of disseminating the research, 41 peer-reviewed articles have been published in scientific journals, as well as more than 130 conference contributions and 23 leaflets to be used by farmers and extension workers. More than 50 international and national media releases/ radio broadcast programs have been produced.

8.2 Description of project sites

The SysCom project set up in each project country is described in more detail below.

SysCom Kenya

The SysCom project in Kenya is comprised of two long-term field trials located at Chuka and Thika, as well as participatory on-farm research trials as described below. The trials are implemented by the International Centre of Insect Physiology and Ecology (icipe) and the Kenyan Agriculture and Livestock Research Organisation (KALRO). Furthermore, a national scientific advisory board (NSAB) consisting of different local stakeholder (icipe, KALRO, Kenyatta University, Kenyan Institute of Organic Farming, Kenyan Organic Agriculture Network) was formed to support the trial planning, implementation and dissemination of results. The project areas are situated in the sub-humid Central Highlands of Tharaka Nithi County (Chuka) and Murang'a County (Thika). Both sites are located at about 1,500 m above sea level and have an annual mean temperature of 20°C and two rainy seasons per year. At Chuka, the mean annual rainfall varies between 1,500 mm and 2,400 mm, and the soil is Humic Nitisol. At Thika the mean annual rainfall ranges from 900 mm to 1,100 mm and the soil is Rhodic Nitisol. Also, POR trials were established in Kangari, which is located in the premise of Murang'a County.

LTE

The LTE sites compare conventional and organic production systems that use both high and low levels of inputs, which are representative of commercial growers and subsistence farming, respectively. Each treatment has been replicated four times in Chuka and five times in Thika. Each plot measures 8 m × 8 m, with an inner plot size of 6 m × 6 m for data collection. Cereals, vegetables, legumes and potato are included in a 6-season 3-year crop rotation.

POR

Participatory on-farm research (POR) started in 2009 and is currently being applied to examine management options for optimising the use of rock phosphate. The POR activities have been later extended to Thika and Chuka. At Thika, farmers are currently addressing soil fertility issues, comparing organic, conventional fertilisers and the combined application. At Chuka, farmers are comparing traditional, conventional and organic methods for dealing with soil-borne nematode disease.

SysCom India

In India, SysCom has a focus on cotton-based cropping systems. Cotton is a major cash crop predominantly cultivated by smallholder farmers across the tropics. Since ancient times, India is an important exporter of cotton and is also the leading producer of organic cotton, accounting for over half of the global organic cotton production. Besides the socio-economic importance of cotton in India and other tropical countries, the environmental impacts of cotton production make it crop to study. Cotton production accounts for 16% of global insecticide use – more than any other single crop, and exerts a global average water footprint of 10,000 litres/kg cotton. These concerns strengthen the case for organic production of cotton, while many challenges in the production practices remain to be addressed.

SysCom India is conducted in collaboration with the bioRe Association in India. The project setting has unique advantages because of close collaboration with the organic cotton-based agricultural value chain of bioRe India Ltd. and Remei AG in Switzerland.

The project area is located in the Nimar Valley (Madhya Pradesh) at about 250 m above sea level. The climate is semi-arid, with an average annual precipitation of 800 mm in a single peak monsoon season, usually lasting from mid-June to September. The mean annual temperature is about 30°C. The soils are mainly fertile Vertisols (LTE) and marginal Inceptisols and Entisols.

LTE

The LTE is located on the research farm of bioRe. The systems comparison in India is implemented in a cash-crop based production system with cotton, soybean and wheat in a two-year crop rotation. The following treatments are being compared: (a) organic, (b) biodynamic, (c) conventional, and (d) conventional farming with genetically modified Bt cotton. These choices reflected the prevailing concerns and opinions of farmers, farmers' organisations and politicians. Organic and bio-dynamic farming is being carried out according to IFOAM/Demeter standards and adjusted to local conditions. The conventional treatments follow the recommendations of the Indian Council of Agricultural Research (ICAR). Gross trial plots are 16 m × 16 m, with an inner net plot size of 12 m × 12 m. The treatments are replicated four times.

The farming landscape of the Nimar valley is typically comprised of resource-poor farmers with small (<2 hectare) to medium (2 – 4 hectare) landholdings. Therefore, besides productivity, the economic viability of production systems is an important concern for the farmers. As many farmers in the area often lack capital for investment and have a low-risk bearing ability, they are interested in less capital intensive farming practices. Cotton has traditionally been an important crop in this region, which is grown in rotation with a range of other crops including cereals, pulses, vegetables etc.

Since the beginning of the trial, a 'Farmer Advisory Committee' comprising of nine organic and nine conventional farmers was established to ensure that SysCom field trial corresponds to the on-ground realities of local farmers. The committee meets annually with the research team, typically in spring, i.e. before the sowing of cotton. The issues related to crop man-

Syscom India

agement, crop varieties and any changes in the farming practices are discussed. In the case of important decisions/changes related to the management of LTE, the suggestions of farmers are subsequently discussed with the international 'Scientific Advisory Board' before they are implemented.

POR

The participatory on-farm research component is very well established in India. Field trials are conducted both on-station and on farmers' fields, with full involvement of farmers. The technologies developed using a POR approach include, improved composting enriched with buttermilk acidulated Rock-Phosphate, best bet pest management practices and standardisation of botanicals preparation. Improvement of resource (water and nutrients) use efficiency and pest management remain vital issues to be addressed. The main productivity limiting nutrient continues to be nitrogen (N). Composted manure applications do not sufficiently meet the crop requirements for N, in intensive production systems, where cotton and wheat are particularly affected by N deficiency. Therefore, POR activities have prioritised the enhancement of N supply. Considering the limited opportunities to supply N through external inputs, the emphasis is on leguminous crops planted in mixes with other crops for grain or as green manures. Activities have a broader focus, encompassing the development of pest management for organic cotton, enhancing nutrient (nitrogen) availability to different crops in the cotton-based production system and assessing the socio-economic impact of developed innovations.

SysCom Bolivia

The project is located in Alto Beni (La Paz Department), in the river valley of Alto Beni. The valley bottom is at 350 to 490 m above sea level and enclosed by the Andean mountain chains. The climate is tropical-humid, winter dry; the average annual precipitation is about 1,540 mm and the average monthly temperature ranges from 22°C to 27°C. The soil of the trial site is classified as Luvisol and Lixisols.

In Alto Beni, farmers traditionally practice a slash and burn system. The average farm surface of the settlers is 13 hectare, of which half is still under secondary forest or fallow. The main annual crops are upland rice, maize and cassava, mainly for subsistence. The main perennial cash crops are citrus fruits, bananas and plantains for the market in La Paz, and cocoa (*Theobroma cacao*) for the national and export market. About 3,000 farmers produce cocoa, and more than 1,400 cocoa farmers are associated with El Ceibo, an umbrella organisation of producer cooperatives which processes and trades cocoa. Much of the cocoa (60% of producers) in Alto Beni is produced organically at low to no input levels.

The main partners of the project are Ecotop, the Insititute of Ecology, and Piaf-El Ceibo. Ecotop is a foundation that offers training, consultancy and extension work for sustainable agricultural development in tropical and subtropical regions with a focus on agroforestry systems. The Institute of Ecology, of the University San Andres, is a national competence centre for biodiversity and carries out research and academic capacity building. Piaf-El Ceibo is a foundation which does training, capacity building and extension, provides plant and input material for cocoa growers of El Ceibo, and carries out applied research activities in agroforestry and forestry.

Syscom Bolivia

LTE

FiBL planned to investigate perennial crops of the tropical humid lowlands in Bolivia. El Ceibo offered 40 hectare of land from its property called Sara Ana over twenty years. Cocoa was selected as the main crop in the LTE. The choice was based on the importance of cocoa for the region. In 2007 and 2008, initial activities such as field homogeneity assessment, field preparation, staff recruitment, the definition of trial concept and methods for data collection, and infrastructure setup were carried out. In 2008, a baseline of biodiversity at the research site Sara Ana and trial soil fertility was also realised. At the end of 2008, the long term experiment with cacao was established. Gross trial plots are 48 m × 48 m (2,304 m^2), while net plots are 24 m × 24 m (576 m^2). The experiment is arranged in a randomised complete block design with four replications.
In the experiment, the following production systems (treatments) were defined: i) monoculture, full sun with conventional management (Mono Conv), ii) monoculture, full sun with organic management (Mono Org), iii) diversified, shaded agroforestry sys-

tem with conventional management (Agrof Conv), iv) diversified, shaded, agroforestry system with organic management (Agrof Org), v) diversified, shaded successional agroforestry system with organic management (Agrof-Dyn), and vi) fallow land (no crops) as reference for biodiversity and soil fertility studies. The treatments increase in complexity and biodiversity: from full sun to agroforestry to successional agroforestry. The organic treatments comply with the European regulation for organic production. Conventional treatments are based on best practices developed by Latin-American research institutions and the Sustainable Tree Crops Program (STCP) of the International Institute of Tropical Agriculture (IITA), adapted to the Bolivian context.

For all production systems, the cacao tree spacing is 4 m × 4 m resulting in 625 trees/hectare, and the cacao tree pruning and tree architecture is the same. Nutrient supply in organic systems is done with compost, legume cover crop (perennial soybean) and trees (leaves and branches). In the conventional system, synthetic fertilisers are used. The monoculture full sun systems get double the amount of nutrients (N, P, K) of the agroforestry systems, as full sun cacao has a higher rate of photosynthesis and with that a higher yield potential. In the establishment phase of the plantation, the weeding was done manually and with the suppressive effects of cover crop. In the conventional systems, weeding is done with herbicides, alternated with mechanical and manual weeding. In conventional (Agrof Conv) and organic agroforestry (Agrof Org), the principal shade trees are Inga and Erythrina, both legume trees which are frequently used in the region and across Latin America. This shade layer is complemented by timber, palm and fruit trees, with a total starting tree density of 303/hectare. The same trees were planted in the Agrof-Dyn plots as in the agroforestry systems; additional tree species were used for natural regeneration. In Agrof-Dyn other crops were also planted like rice, maize, pigeon pea, pineapple, ginger and cassava. The fallow plots were managed comparable to the other production systems until the end of 2008. From that moment onwards no management was done, besides to cut back the border trees starting to overshade neighbouring plots. From 2009 onwards, data have been collected regularly and according to the plan and various studies, such as soil and biodiversity surveys, were carried out.

POR

In 2009, the topics for the participatory on-farm research were identified at farmers' meetings, and first activities began concerning the cacao variety test aiming at the identification of well-adapted varieties for organic management. Besides the variety evaluation, practices of good cocoa producers are studied and yields assessed. These results also support our management decisions of the LTE. Losses due to the cocoa mirids and, newly arrived, frosty pod rot disease are of significant concerns. Pest control strategies and practices are explored. The Bolivian National Cocoa identified as a specific genetic cluster of Cacao forastero is getting interest from the market side, which raises the question; In which systems and with what type of tree management could farmers increase the production? These questions are addressed with demonstrations plots in Sara Ana. In addition, we are transforming our research station into a training centre, where we elaborate training material, conduct training for local and international farmers on agroforestry and organise visits and exchange between farmers, student, scientist and technicians.

8.3 Peer-reviewed project publications

Kenya

Adamtey, N., Musyoka, M.W., Zundel, C., Cobo, J.C., Karanja, E., Fiaboe, K.M., et al. (2016). Comparison of conventional and organic farming systems in the sub-humid zones of the Central highlands of Kenya: Productivity and profitability of maize-based cropping systems. Agriculture, Ecosystems and Environment, 235: 61–79.

Anyango, J. J., Bautze, D., Fiaboe, K. K. M., Lagat, Z. O., Muriuki, A. W., Stöckli, J., Onyambu, G. K., Musoyoka, M. W., Karanja, E. N., Adamtey, N. (2019). Termite-Induced Injuries to Maize and Baby Corn under Organic and Conventional Farming Systems in the Central Highlands of Kenya. Insects, 10(10): 367.

Anyango, J.J., Bautze, D., Fiaboe, K.K.M., Lagat, Z. O., Muriuki, A. W., Stöckli, S., Riedel, J., Onyambu, G. K., Musoyoka, M. W., Karanja, E. N., Adamtey, N. (2020). The impact of conventional and organic farming on soil biodiversity conservation: a case study on termites in the long-term farming systems comparison trials in Kenya. BMC Ecol 20(1): 1-14.

Atandi, J. G., Haukeland, S., Kariuki, G. M., Coyne, D. L., Karanja, E. N., Musyoka, M. W., Fiaboe, K. K. M., Bautze, D. and Adamtey, N. (2017). Organic farming – an alternative to management of plant parasitic nematodes in different cropping systems. Agriculture, Ecosystems and Environment, 247: 265–272.

Karanja, E. N., Fliessbach, A., Adamtey, N., Kambura, A. K., Musyoka M., Fiaboe, K. K. M., Mwirichia, R. (2020). Fungal diversity within organic and conventional farming systems in Central Highlands of Kenya. African Journal of Microbiology Research, 14(6): 242–258.

Musyoka, M. W., Adamtey, N., Muriuki, A. W. and Cadisch, G. (2017). Effect of organic and conventional farming systems on nitrogen use efficiency of potato, maize and vegetables in the Central highlands of Kenya. European J of Agronomy, 86: 24–36.

Musyoka, M. W., Adamtey, N., Bünemann, E. K., Muriuki, A. W., Karanja, E. N., Mucheru-Muna, M., Fiaboe, K. K. M. and Cadisch, G. (2019). Nitrogen release and synchrony in organic and conventional farming systems of the Central Highlands of Kenya. Nutrient Cycling in Agroecosystems, 113 (3): 283—305.

Mwangi, E. N., Ngamau, C. N., Wesonga, J. M., Karanja, E. N., Musyoka, M. W., Matheri, F., Fiaboe, K. K. M., Bautze, D., Adamtey, N. (2020). Managing Phosphate Rock to Improve Nutrient Uptake, Phosphorus Use Efficiency and Carrot Yields in Kenya. Journal of Soil Science and Plant Nutrition, 20(3): 1350-1365..

von Arb, C., Bünemann, E.K., Schmalz, H., Portmann, M., Adamtey, N., Musyoka, M.W., Frossard, E., Fliessbach, A. (2020). Soil quality and phosphorus status after nine years of organic and conventional farming at two input levels in the Central Highlands of Kenya. Geoderma, 362: 114112.

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