# Agroforestry is more productive than monoculture, and organic agroforestry is competitive with its conventional counterpart

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**Key words**: cocoa, Bolivia, agroforestry, organic agriculture, long-term experiment

## Abstract

*Cocoa (Theobroma cacao L.) is produced in monocultures (MONO) or agroforests (AF). Famers have to decide between two strategies: short-term (rapid incomes by maximizing cocoa yields in MONO) or long-term (diversified, sustainable production and ecosystem services in AF). More long-term data on the ecological, economic and social performance of such systems under different management regimes is needed to make sound recommendations to farmers. Here we describe the only long-term field trial worldwide comparing MONO and AF under conventional (CONV) and organic (ORG) management (full-factorial, randomized complete block design with four replications). First results show significantly faster development of trunk circumferences in MONO compared to AF (+21 %). In MONO, cocoa yields were 47 % lower in the ORG compared to the CONV system. In the AF, however, the ORG – CONV yield gap was smaller (-16 %) and statistically insignificant. The cumulative yields of all harvested products were significantly higher in AF compared to MONO (+161 %). The productivity of cocoa by-crops in AF may contribute to local food security and risk distribution in smallholder contexts.*

## Introduction

Assuming you are a smallholder in the tropics and you want to produce cocoa (*Theobroma cacao* L.), you are confronted with the following question: "Should I go for agroforestry (AF) or for a monoculture (MONO), for conventional (CONV) or organic (ORG)?" Regardless of ORG or not, MONO means maximizing income from cocoa in the first two to three decades after setting up your plantation, which happens to often go together with crop protection using synthetic inputs. In contrast, AF means maintenance of soil fertility, less problems with pests and diseases, and a continuous supply of a range of products over long periods of time of up to a century. Or in other words, higher sustainability in ecological and economic dimensions. Sounds perfect, so where is the problem?

Given that the vast majority of global cocoa production happens in MONO, there must be at least one problem. There are many in fact, and going into detail about all of them would go beyond the scope of this paper. Only so much: there is virtually no long-term data on the performance of MONO and AF under CONV and ORG management. If we are to put the ideological debate around cocoa production on a solid evidence base, and if we want to make sound recommendations to farmers, we have to address this.

## Material and methods

It would be beyond the scope of this paper to explain everything we did in order to enable somebody to repeat our work. For the purpose of this paper, we only provide a general description of the trial. However, a very detailed description of the whole experimental setup and management practices can be found in Schneider *et al*. (2016). The five different cocoa production systems under comparison include two MONO and two AF, one under CONV and one under certified ORG management, as well as a dynamic agroforestry with zero external input under certified organic management (SFAS). The experiment is set up as a full-factorial, randomized complete block design with four replications. The factors tested are: i) crop diversity (MONO vs.

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AF), and ii) management practice (CONV vs. ORG). The combination of the two factors make up the system effect. Figure 1 shows example plots of a MONO CONV and a SAFS four years after planting the cocoa trees.

**Figure 1**: Left panel: young MONO in Bolivia. Right panel: young SAFS after shade tree pruning in Bolivia. Pictures were taken four years after cocoa tree planting. Source: own research.

## Results

*Productivity of cocoa trees (2011 – 2013)*

Mean cocoa dry bean yields in 2013 (5th year after planting) ranged from 587 kg ha$^{-1}$ in MONO CONV to 105 kg ha$^{-1}$ in SAFS (Figure 2, data refer to marketable beans only). MONO CONV showed significantly higher yields than all the other systems (+153 %), followed by MONO ORG which, in turn, achieved significantly higher yields than the two agroforestry systems (+33 %). The two agroforestry systems showed no significant difference between each other, yet they attained significantly higher yields compared to SAFS (+136 %). The percentage of diseased fruits in the total amount of harvested fruits was low, ranging from 0 to 6 %, and did not significantly differ between the systems (data not shown).

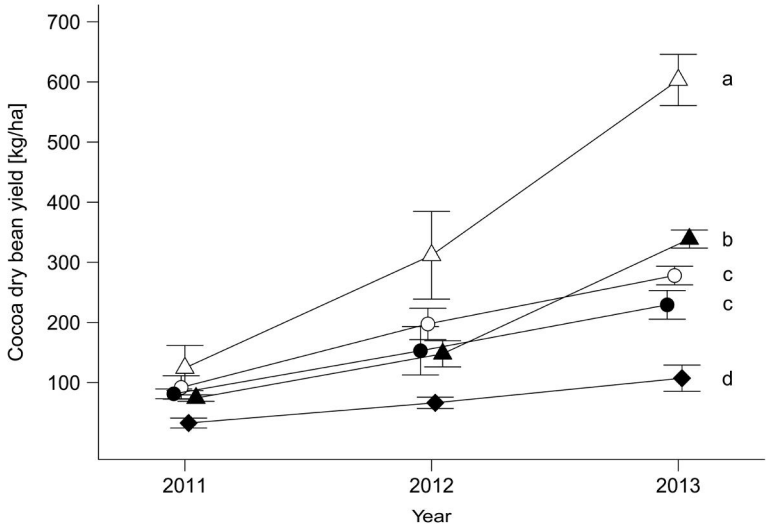


**Figure 2**: Development of cocoa dry bean yields 2011 – 2013 [kg ha$^{-1}$]. Production systems: (Δ) full-sun monoculture under conventional management (MONO CONV), (▲) full-sun monoculture under organic management (MONO ORG), (○) agroforestry system under conventional management (AF CONV), (●) agroforestry system under organic management (AF ORG), (♦) successional agroforestry system under organic management (SAFS, dynamic multi-strata, zero external input system.

Table 1: Cumulative dry matter yields [kg ha$^{-1}$] of marketable products harvested in five different cocoa production systems from 2009 to 2013.

| Factor | Cocoa beans full stock yields[1] (2011 – 2013) | | | | Cocoa beans current stock yields[2] (2011 – 2013) | | | | Plantain bunches (2009 – 2011) | | | | Banana bunches (2012 – 2013) | | | | Diversified grains[3] (2009 – 2013) | | Diversified fruits and tubers[4] (2009 – 2013) | | Total (current stock yields 2009 – 2013) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Post-hoc comparison of Crop diversity and Management practice analysis** | Mean | | | sem | Mean | | | sem | Mean | | | sem | Mean | | | sem | Mean | sem | Mean | sem | Mean | | | sem |
| AF | 598 [b] | | | 48 | 498 [b] | | | 45 | 3'568 [a] | | | 902 | 8'036 [a] | | | 841 | - | - | - | - | 12'101 [a] | | | 1'720 |
| MONO | 1'012 [a] | | | 155 | 756 [a] | | | 110 | 3'874 [a] | | | 921 | 0 [b] | | | 0 | - | - | - | - | 4'630 [b] | | | 1'002 |
| CONV | 1'009 [A] | | | 157 | 767 [A] | | | 109 | 4'469 [A] | | | 930 | 4'478 [A] | | | 1'738 | - | - | - | - | 9'714 [A] | | | 1'914 |
| ORG | 601 [B] | | | 45 | 487 [B] | | | 38 | 2'972 [A] | | | 802 | 3'558 [A] | | | 1'496 | - | - | - | - | 7'017 [A] | | | 1'940 |
| **ANOVA of Crop diversity and Management practice analysis** | | | | | | | | | | | | | | | | | | | | | | | | |
| Source of variation | numDf | denDf | F value | *p* value | numDf | denDf | F value | *p* value | numDf | denDf | F value | *p* value | numDf | denDf | F value | *p* value | - | - | - | - | numDf | denDf | F value | *p* value |
| Crop diversity (D) | 1 | 9 | 26.209 | 0.001 | 1 | 9 | 20.778 | 0.001 | 1 | 9 | 0.151 | 0.706 | 1 | 9 | 91.440 | < 0.001 | - | - | - | - | 1 | 9 | 24.430 | 0.001 |
| Management practice (M) | 1 | 9 | 27.516 | 0.001 | 1 | 9 | 24.376 | 0.001 | 1 | 9 | 3.618 | 0.090 | 1 | 9 | 1.200 | 0.302 | - | - | - | - | 1 | 9 | 2.591 | 0.142 |
| D × M | 1 | 9 | 11.373 | 0.008 | 1 | 9 | 11.347 | 0.008 | 1 | 9 | 0.320 | 0.585 | 1 | 9 | 1.200 | 0.302 | - | - | - | - | 1 | 9 | 0.076 | 0.789 |
| Land preparation | 1 | 2 | 5.467 | 0.144 | 1 | 2 | 4.000 | 0.184 | 1 | 2 | 17.835 | 0.052 | 1 | 2 | 0.610 | 0.517 | - | - | - | - | 1 | 2 | 7.870 | 0.107 |
| **Post-hoc comparison of System analysis** | Mean | | | sem | Mean | | | sem | Mean | | | sem | Mean | | | sem | Mean | sem | Mean | sem | Mean | | | |
| AF CONV | 658 [b] | | | 53 | 542 [b] | | | 53 | 4'093 [a] | | | 1'410 | 8'957 [a] | | | 853 | - | - | - | - | 13'592 [a] | | | 2'183 |
| AF ORG | 538 [b] | | | 74 | 453 [b] | | | 73 | 3'042 [b] | | | 1'275 | 7'115 [a] | | | 1'416 | - | - | - | - | 10'610 [ab] | | | 2'749 |
| MONO CONV | 1'360 [a] | | | 173 | 991 [a] | | | 139 | 4'845 [a] | | | 1'398 | - | | | - | - | - | - | - | 5'837 [c] | | | 1'521 |
| MONO ORG | 665 [b] | | | 35 | 521 [b] | | | 26 | 2'903 [b] | | | 1'172 | - | | | - | - | - | - | - | 3'424 [c] | | | 1'183 |
| SAFS | 239 [c] | | | 30 | 195 [c] | | | 34 | 1'230 [b] | | | 795 | 99 [b] | | | 99 | 1'750 | 104 | 5'118 | 562 | 8'392 [b] | | | 796 |
| **ANOVA of System analysis** | | | | | | | | | | | | | | | | | | | | | | | | |
| Source of variation | numDf | denDf | F value | *p* value | numDf | denDf | F value | *p* value | numDf | denDf | F value | *p* value | numDf | denDf | F value | *p* value | - | - | - | - | numDf | denDf | F value | *p* value |
| System | 4 | 12 | 34.969 | < 0.001 | 4 | 12 | 30.905 | < 0.001 | 4 | 12 | 3.551 | 0.039 | 4 | 12 | 35.115 | < 0.001 | - | - | - | - | 4 | 12 | 8.617 | 0.002 |
| Land preparation | 1 | 2 | 5.079 | 0.153 | 1 | 2 | 3.978 | 0.184 | 1 | 2 | 14.645 | 0.062 | 1 | 2 | 0.713 | 0.487 | - | - | - | - | 1 | 2 | 7.663 | 0.101 |

[1]Cocoa dry bean yields after fermentation and drying (water content: 8 %), full stock yield = current stock yield standardized with number of trees > three years; sem: standard error of the mean; [2]current stock yield = actual surface yield; [3]diversified grains included maize, rice, pigeon pea and achiote (for details see Schneider *et al*. (2016)); [4]diversified fruits and tubers included cassava, hibiscus, pineapple, tannia, ginger and turmeric (for details see Schneider *et al*. (2016)); MONO CONV: Monoculture under conventional management, MONO ORG: Monoculture under organic management, AF CONV: Agroforestry system under conventional management, AF ORG: Agroforestry system under organic management, SAFS: Successional agroforestry system under organic management (dynamic multi-strata, zero external input system); different superscript letters indicate significant difference between mean values (multilevel modelling approach according to Gelman *et al*. (2012), $P(\text{Diff}>0) < 0.05$ *p* value and degrees of freedom (numDf: nominator Df, denDf: denominator Df) of fixed effects in linear mixed effect models, random factors in the model: Block (n=4).

*Total system yields (2009 – 2013) and ecological benefits*

In the AFs, substantial amounts of banana were harvested in 2012 and 2013 (8'036 kg $ha^{-1}$). In SAFS, considerable amounts of diversified fruits and tubers were harvested between 2009 and 2013 (5'118 kg $ha^{-1}$, Table 1). SAFS was the only system in which these crops were cultivated. The MONOs achieved both the highest cocoa dry bean yields, and MONO CONV additionally exhibited the highest plantain yields (4'845 kg $ha^{-1}$, harvested from 2009 to 2011) compared to all the other systems (+72 %). Despite this, the cumulative yields of all marketable products in MONO CONV and MONO ORG could not reach the level of the three agroforestry systems (Table 1).

Total system yields ranged from 13'618 kg dry matter $ha^{-1}$ in AF CONV to 3'464 kg dry matter $ha^{-1}$ in MONO ORG (Table 1). The AF CONV showed significantly higher values than SAFS and the MONOs (+131 %), followed by AF ORG and SAFS which were significantly higher than the MONOs (+105 %) but did not differ significantly from each other. The MONOs ranged lowest (-57 % compared to the other three systems) and were not significantly different from each other.

## Discussion

Did we succeed in providing long-term data on the performance of MONO and AF under CONV and ORG management? Partly. One would not typically call results from the establishment phase of a cocoa plantation "long-term". So we have a way to go. But the fact that we dispose of this unique long-term trial described in this paper makes us optimistic that we will be able to do so in the future. The results we showed in this paper underline the reported potential of AF to contribute to local food security and risk distribution in smallholder contexts, and call for the elaboration of sound management recommendations in ORG cocoa production. Given the projected price increases for cocoa on the global market in the coming decades, the economic evaluation of our findings (addressed in a separate publication) is of utmost importance. Future research on trade-offs in ecological, economic and social dimensions may eventually allow for a holistic assessment of the different cocoa production systems.

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