

Monitoring pest and diseases under different production systems in a long-term trial in Bolivia

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Abstract

Pest and diseases might strongly affect cacao production. Agroforestry systems are thought to have higher pod losses due to diseases compared with monocultures due to for instance higher air humidity and less aeration. The aim of this study is to compare the incidence of pest and diseases in different cacao production systems. The study was performed in 2016 in a long-term trial established in Bolivia between end 2008 and beginning of 2009 (www.systems-comparison.fibl.org). Five different systems were compared, i.e., monoculture and agroforestry systems under organic and conventional management and one successional agroforestry system with organic management.

Frosty pod rot (*Moniliophthora roreri*), one of the most important fungal diseases in the study area, was monitored every two weeks during the harvesting season, from April to October. All the infected pods by frosty pod rot were registered, and were cut to avoid the spread of the spores. The stage of the disease as well as the size of the infested pods were recorded. At harvest, the incidence of other pest and diseases at pod level, was registered. Harvest was done regularly every two weeks.

The results show a very low percentage of pods affected by pests and diseases, about 10% in all the systems. Frosty pod rot was the most important disease, i.e., about 70% of the infested pods were affected by it. Approximately 80% of the pods diseased by frosty pod rot were cut before they entered the sporulation stage and most of them (70%) had a size between 7 and 15 cm.

Witches broom (*Moniliophthora perniciosa*) was the second most important disease, and it was followed by black pod (*Phytophthora*) and pods eaten by birds or mammals. The incidence of the mirid (*Monalonion disimulatum*), which was quite high in the study area some years ago was almost negligible.

The relative total number of pods affected by pests and diseases did not differ between production systems. The same results were found for the pods affected by frosty pod rot, which means that the more humid microclimatic conditions of the agroforestry systems are not promoting its spread and the sporulation of the spores. In the successional agroforestry systems there were more pods eaten by birds or small mammals, which indicates that this system supports the presence of these animals. In conclusion, good management practices (well-pruned cacao and shade trees), and especially a regular and early control of pests and diseases are essential to prevent high pod losses.

Introduction

Cacao production is facing the challenge of controlling pest and diseases. Two of the most devastating ones are witches' broom (*Moniliophthora perniciosa*) and frosty pod rot (*Moniliophthora roreri*), which are reported to cause up to 100% yield loss in susceptible plantations (Krauss & Soberanis, 2001a). Both are basidiomycete and are most severely present in Central and South America, as well as black pod disease which is caused by numerous species of *Phytophthora*, leading to damages in many tropical lowlands all around the globe (Cubillos, 2017; Ploetz, 2007).

Cacao producers have to choose the type of cocoa production system they want to grow, ranging from full-sun monocultures to highly diverse agroforestry systems. Shade tree canopies have a wide role in benefiting local livelihoods and the environment (Armengot et al., 2016). But agroforestry systems might exhibit specific microclimatic conditions, such as high humidity that may benefit pests and diseases (Schroth et al., 2000).

The aim of this study was to identify the relative importance of the incidence of pest and diseases on pod loss, and the most important pest and diseases in different production systems. The study was performed in a long-term trial established in 2009 in Alto Beni, Bolivia, where five different production systems were compared, i.e. monoculture (MONO) and agroforestry (AF) both under organic (ORG) and conventional (CON) management and a successional agroforestry system under organic management (SAFS).

Material and methods

Study site. The experimental trial was located in Sara Ana (390 m a.s.l.), Alto Beni, in the department of La Paz, Bolivia. The climate is tropical humid with dry winters; the average annual precipitation and temperature are approximately 1'540 mm and 26.6 °C, respectively. The soils are Luvisol and Lixisols. The natural vegetation is composed of nearly evergreen humid forests.

The establishment of the plantation finished at the beginning of 2009. Each production system was replicated four times in a complete randomized block design. The size of the gross plots was 48 m × 48 m, with a net plot of 32 m × 24 m. The cacao tree spacing was 4 m × 4 m (625 trees ha⁻¹), resulting in 48 trees in the net plot. A total of 12 different cacao cultivars were established, 4 local selections out of hybrids from introduced clones (participatory elite tree selection program run by local farmer association), 4 international clones (ICS 1, ICS 6, ICS 95 and TSH 565) and 4 hybrids (ICS 1 × IMC 67, ICS 6 × IMC 67, ICS 95 × IMC 67, TSH 565 × IMC67). Four trees of each cultivar were represented in the net plot. In the agroforestry systems, the main shade trees were *Inga* spp. and *Erythrina* spp., complemented by timber and palm trees. The total density of the shade trees was 304 trees ha⁻¹. In addition, bananas were also planted at a density of 625 trees ha⁻¹. SAFS followed the basic design of the AF, but it included some additional crops such as maize, rice, coffee, pineapple, ginger and palm trees, and higher diversity and density of trees for different use (biomass/ timber/fruits), many of them out of the natural regeneration (Schneider et al. 2016).

The organically managed systems followed the EU regulations. A perennial legume cover crop was sown in the organic full-sun and agroforestry treatment. Compost was used as fertilizer and weeding was done manually and with brushcutters. In the conventional managed systems, mineral fertilizer was applied and weeding was done by means of both herbicides and manual weeding and brushcutters. Due to the low pressure of pests and diseases, control of pest and diseases was done with tree management (pruning) and manually when necessary, no chemical control was applied to any of the production systems.

Data collection. Data were collected only in the net plot to avoid boundary effects. Frosty pod rot (*Moniliophthora roreri*), one of the most important fungal diseases in the study area, was monitored every two weeks. All the infested pods at different stages were registered and cut to avoid the spread of the spores. At each harvest date (every two weeks from March to December 2016), the number of harvested pods and the number of pods affected by any pest and disease were registered, i.e., witches broom (*Moniliophthora perniciosa*), black pod (*Phytophthora* spp.), mirids (*Monolonion dissimulatum*) and other pests and diseases, mainly pods eaten by birds or small mammals.

For data analyses, all the data from the different harvests and monitoring dates were summed up, resulting in one value per tree for each of the parameters evaluated: total number of pods, healthy pods and diseased pods, and number of pods affected for each pest and disease. Data for the different pests and diseases were converted into relative values to enable the comparison of production systems, since the total number of pods produced differed between systems. All analyses were done using mixed-effects linear models in R 0.99.887 (R Core Team, 2015), using the lmer function from the “lme4” package (Bates et al., 2015) and evaluating the significances of effect of the production system using the “lmerTest” package (Kuznetsova et al., 2016). If necessary the data was log- or square-root-transformed.

Results

There were significant differences in the total number of pods produced per tree, i.e., monocultures produced higher number of pods, followed by agroforestry systems and the least pods were produced in SAFS (Fig. 1). There were no differences between the ORG and CONV management in both AF and MONO systems.

The results showed a very low percentage of pods affected by pests and diseases, ranging from 8 %, the lowest percentage in MONO ORG to 11% the highest in the SAFS. There were no significant differences in the percentage of non-healthy pods between production systems.

Frosty pod rot was the most important disease, i.e., about 70% of the infested pods were affected by it (Fig. 2). Approximately 80% of the pods diseased by frosty pod rot were cut before they entered the sporulation, i.e.: 69% of the cut pods were in the stage showing coffee brown fungal mycelium on the surface, 11% of the diseased pods showed deformations and bumps and 2% were cut when oily stain were visible on their surface. Only 18% were cut at the stage of sporulation. Most of the pods (70%) were cut at a size between

7 and 15 cm, 13% were cut before they reached a size of 7 cm and 17% were cut when they were bigger than 15 cm.

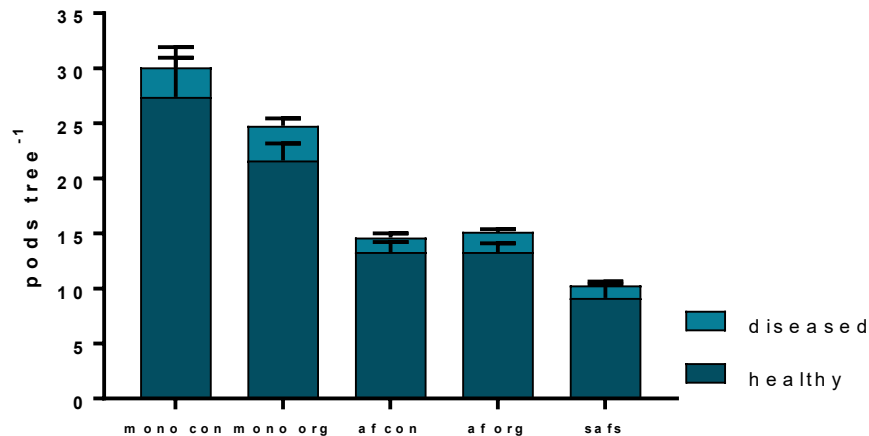


Figure 1. Mean (\pm SE) of the number of healthy and diseased pods per tree for the different production systems: mono con: monoculture conventional, mono org: monoculture organic, af con: agroforestry conventional, af org: agroforestry organic, safs: successional agroforestry system. The sum of the healthy and diseased bars for each system results in the total number of pods produced.

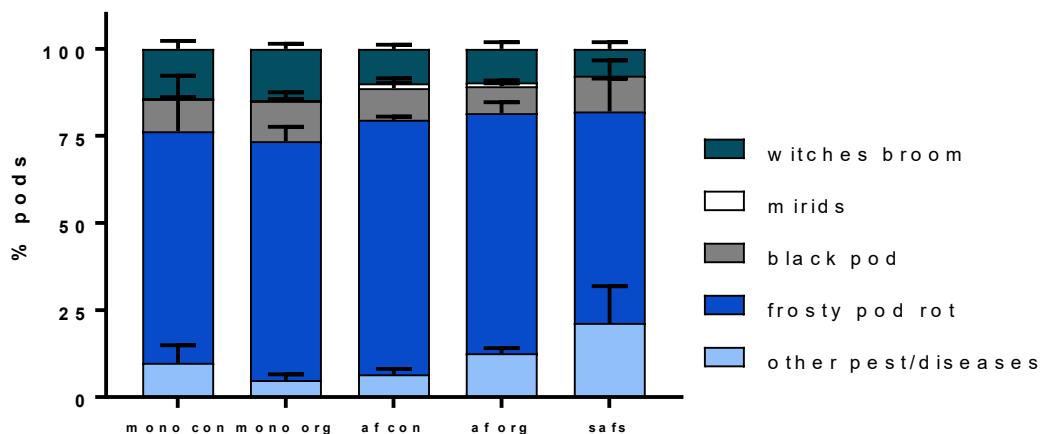


Figure 2. Mean (\pm SE) of the percentage of pods affected by each of the identified pests and diseases for the different production systems: mono con: monoculture conventional, mono org: monoculture organic, af con: agroforestry conventional, af org: agroforestry organic, safs: successional agroforestry system.

Witches broom (*Moniliophthora perniciosa*) was the second most important disease, and it was followed by black pod (*Phytophthora*) and pods eaten by birds or mammals (Fig. 2). The incidence of the mirid (*Monalonia disimulatum*), which was quite high in the study area some years ago was almost negligible.

Although the relative total number of pods affected by pests and diseases did not differ between production systems, when the diseases were analysed separately, we found that witches' broom had a significantly lower incidence in AF than in MONO systems. In SAFS there was a higher incidence of pests (unidentified fruit borer and rodents and birds) than in AF systems, and within the AF systems, the incidence was higher in AF ORG compared to AF CONV. There were no differences between production systems for frosty pod rot and black pod disease.

Discussion

The very low pressure of pests and diseases contrast with findings in other South American countries: Panama 80% (Krauss et al., 2006) and 46% to 81% in Brazil (Laker & Ram, 1992). Worldwide about one third of the yield is lost due to pests and diseases (Shapiro & Rosenquist, 2004).

One of the reasons for the low incidence of pests and diseases in the trial could be the large genetic diversity in the plots. As previously shown, a mixture of cultivars offers a number of advantages such as increasing yield stability, greater biodiversity and resilience to abiotic stress, but also restricted disease development (Schöb et al., 2015). For instance, the diversity of cultivars promotes a dilution of susceptible individuals, induction of defences in neighbouring plants of infected individuals and results in an overall greater diversity of resilience (Letourneau et al., 2011).

But probably the main reason for the low incidence was the periodical monitoring and control as well as the good agricultural practices concerning tree pruning. Removal of infected pods was stated as the most successful method for fungal disease management in cacao plantation (Evans, 1981; Fulton, 1989; Krauss & Soberanis, 2001). Placement of infected pods on the ground has been determined as of no epidemiological relevance since the high humidity makes the spores heavier, leading to rapid abrogation of the germination power and the wind is weak at that level, preventing the further dispersal of the spores (Cubillos, 2017). Additionally, saprophytes decompose the cut pods on the ground quickly (Cubillos, 2017). Regular pest and disease management is crucial to detect infected pods and plant tissues before they reach the sporulation stage. Unfortunately, good agricultural practices are not always applied in today's cocoa farms, usually due to labour demand of these activities.

Even though only about 10 % of the pods were lost due to pests and diseases, there were differences in their incidence. Frosty pod rot was the most predominant one. It arrived in the region of Alto Beni in 2010/2011 and caused severe losses in production (Jacobi et al., 2013). Incidences of frosty pod rot have been reported from southern Peru to Honduras, showing the wide climatic range the disease can survive in (Hidalgo et al., 2003).

According to our results, the production system did not influence the incidence of frosty pod rot. Krauss and Soberanis (2001) suggest that both, excessive and lack of shade, are connected to increased incidence of frosty pod rot. However, Schroth et al., (2000) found that moderate shading of 17% to 50% has no effect on their incidence.

In contrast to monilia, the incidence of witches' broom disease was higher in MONO than in AF. According to previous studies, higher humidity resulting from shading may benefit fungal cocoa diseases (Schroth et al., 2000). However, this seems not to be the case for witches' broom, since agroforestry systems have been found to prevent the dissemination of witches' broom disease (Bos et al., 2007).

The third important disease in this study was the black pod disease which similarly to frosty pod rot did not show differences between production systems. The effect of shade on black pod disease is controversial in literature. In some studies shade was found to enhance black pod disease suggesting the pathogen may benefit from higher humidity (Jacobi et al., 2013; Schroth et al., 2000). On the other hand, diversified shading was shown to significantly lower the incidence of black pod disease (Bos et al., 2007). In other studies, shade was found to have no significant effect (Krauss & Soberanis, 2001b).

Alongside fungal diseases, pests were also present in the trial. SAFS showed higher incidence of pests compared to the other production systems, although the share of each pest in the relative value of pods attacked by pest was very low. Higher plant density may offer ideal hiding places and nesting sites and thus increased herbivore pressure but at the same time, supporting animal biodiversity, mainly for birds and rodents.

In conclusion, the more humid microclimatic conditions of the agroforestry systems (Niether, 2017) did not promote pests and diseases in our trial. The good management practices of the cacao plantations (pruning, strict monitoring and control of pest and diseases) are essential to prevent yield losses due to pest and diseases. Moreover, differences in yield between production systems were not caused by pest and disease pressure, since similar percentages of incidence were found in all the production systems. Pod setting, which was higher in MONO was driven by other factors such as light and/or nutrient availability.

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