A case study on the effect of bilogical disease control on the rehabilitation of abandoned cocoa (*Theobroma cacao*) farms under two shading regimes and with two application times in Tingo Marái, Perú.

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Introducción

In 1996, the Huánuco Department of Peru, produced 9% of the national cocoa (*Theobroma cacao*) production: 2,026t on 4,290ha. Yields of 472kg/ha were well below the national average of 710kg/ha (Fujimori *et al.*, 1997). Diseases are the most limiting factor of productivity. In the Huallaga Valley, disease incidents of witches' broom (*Crinipellis perniciosa*), frosty pod (*Moniliophthora roreri*) and *Phytophthora* spp. (mostly *P. palmivora*) are 64%, 51% and 24%, respectively. After the arrival of *M. roreri* in 1991, production there fell from 1,236t to 745t in 1992 and 427t in 1993 (Evans *et al.*, 1998). Losses of up to 100% and the lack of economic disease control led to neglect and abandonment of cocoa fields. Webb and Fernández (1997) estimated that 43% of fields are permanently abandoned. Today, Peru is a net importer of cocoa beans (Fujimori *et al.*, 1996). It is striving to reverse this trend by rehabilitation of abandoned fields in a effort to increase production.

Abandonment of farms started a vicious circle as inoculum pressure from surrounding fields counteracts control efforts on managed small-holdings (Krauss, 1998). Years of continuous labour input are required in a perennial crop, such as cocoa, for sustainable production. Technical assistance has to support rehabilitation efforts of abandoned farms. In Peru, approximately 16,000ha of abandoned cocoa have potential for rehabilitation (United Nations, 1991) if disease problems can be solved economically. In order to supplement cultural disease control - the only practicable means available to farmers at present - biological control against the three major cocoa diseases was developed in Tingo María, Peru (Hebbar *et al.*, 1998; Krauss and Hebbar, 1998; Krauss and Soberanis, 1998). The objective of the present study was to determine the value of biocontrol in the rehabilitation of previously abandoned fields. Disease incident and yield were evaluated during the first year of rehabilitation in three fields under different shading regimes and with two different times of control application.

Materials and Methods

Mixed biocontrol inocula against the three major cocoa pathogens, *M. roreri, C. perniciosa* and *P. palmivora,* were designed using *Gliocladium* spp. which had been isolated from cocoa tissue in shaded and non-shaded fields in various climatic zones in the Monzón and Upper Huallaga Valleys, Dept. of Huánuco, Peru (Hebbar *et al.*, 1998). Their effect on disease incident and yield was evaluated in combination with or versus recommended cultural control.

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Three previously abandoned fields under different shading regimes and disease management systems were selected near Tingo María (Table 1). Trees were lightly pruned, weeds were controlled but no fertiliser was applied. In addition to removal of diseased pods according to Soberanis *et al.* (1998) in all treatments, three, monthly sprays of biocontrol agents (5×10^5 conidia ml^{-1}) were administered to flower cushions and pods in part of each plot. Plots were evaluated throughout the production season. Data were analysed by analysis of deviance for binomial or Poisson distributed on GENSTAT 5, release 2.2 as appropriate. The 'rpair-procedure' was employed to determine differences between means.

Table 1. Previously abandoned fields selected for rehabilitation study near Tingo María, Peru.

Site	Crop age (years)	Abandonment (years)	Shade	Onset of disease management
Botanical Garden	34	18	Dense, mixed	Flowering
Tulumayo	ca 40	16	None	Flowering
Jacintillo	ca 35	10-12	None	Pod filling

Results

Differences between the different biocontrol inocula were generally negligible; they were, therefore, pooled for analyses. The incident of *M. roreri*, the main disease problem, was higher in the Botanical Garden than in the unshaded fields (Tables 2&3). Biocontrol reduced its incident from an average of 49% to 25% independent of the shading regime and application time (Table 2). In biocontrol plots, *Phytophthora* was reduced from 4% to 2.3% but this failed to reach significance. Shade and time of application had no influence on *Phytophthora*. Witches' broom was unaffected by biocontrol in all fields. In fruits, witches' broom incident was increased in Tulumayo, and highest in the unshaded plot in Jacintillo where control started late. Shade had no influence on witches' broom in flower cushions. However, in Jacintillo, flower brooms were significantly more (Table 2).

Table 2. Percentage disease incident using cultural and/or biological disease control in three cocoa fields under different shading regime and with two different times of application.

Site	*Moniliophthora roreri*		*Phytophthora palmivora*		*Crinipellis perniciosa*			
					Fruit		Flower cushions	
	CC [1]	BC [1]	CC	BC	CC	BC	CC	BC
Botanical Garden	63	30 [bc]	4.7 [a]	2.7 [a]	3.2 [a]	3.6 [a]	0.5 [a]	0.5 [a]
Tulumayo	48 [a]	22 [c]	4.3 [a]	2.5 [a]	4.9 [ab]	5.4 [ab]	0.5 [a]	0.5 [a]
Jacintillo	38 [ab]	25 [c]	3.2 [a]	1.8 [a]	7.1 [b]	7.8 [b]	3.8 [b]	3.9 [b]

[1] CC = cultural control alone, BC = biological plus cultural control

[a b c] Values for each disease (comparison of six cells) followed by the same letter do not differ at $P = 0.05$

Biocontrol increased the percentage of healthy fruit by an average of 62% in all fields, independent of shading regime and time of application (Table 3). However, only in the shaded plot with early disease management (Botanical Garden) this translated into a net increase in yield. This increase was a substantial 156%. In the unshaded fields of Tulumayo and Jacintillo, absolute yield was not increased by biocontrol (Table 3) although the agent significantly reduced disease independent of shading regime and time of application (Tables 2&3).

Table 3. Relative (%) and absolute yield response in three fields under different shading regimes to biological disease control applied at two different times.

Site	Healthy pods (%)		Number of healthy pods harvested per tree	
	CC	BC	CC	BC
Botanical Garden	36	63	2.5 [a]	6.4
Tulumayo	44 [a]	70 [b]	2.8 [a]	3.4 [a]
Jacintillo	45 [a]	70 [b]	2.9 [a]	2.6 [a]

[a, b] Values followed by the same letter do not differ at $P = 0.05$.

The physiological characteristics, number of active flower cushions per tree (observed over equivalent 6-week periods) and percentage of cherrelle wilt were unaffected by biocontrol. The number of flower cushions did not differ between fields. Cherrelle wilt was lower in Jacintillo than in the other two fields (Table 4).

Table 4. Physiological characteristics of cocoa in three fields under different shading regimes and management systems.

Site	Number of active flower cushions	Cherrelle wilt (%)
Botanical Garden	5.4 [a]	12 [a]
Tulumayo	4.2 [a]	14 [a]
Jacintillo	4.8 [a]	5

[a] Values followed by the same letter do not differ at $P = 0.05$

Discusion

Biocontrol agents are affected by environmental conditions in the field. Inconsistent performance of single-strain biocontrol agents in the field has been attributed to this factor (Leeman *et al.*, 1996). In this study, mixed inocula were designed using organisms from a range of climatic zones and cocoa production systems with the aim to obtain a versatile control agent which will be effective in any field throughout the region. The resulting inocula reduced the predominant disease, *M. roreri*, significantly and consistently even under adverse conditions such as lack of shade and a head-start of the disease.

Although a fundamental challenge was overcome, reduced disease losses translated into net returns only in the shaded field where disease management commenced with the onset of the flowering season. The physiological fruit decay, cherrelle wilt, was unaffected by biocontrol which indicates that increased proportions of healthy fruit (which have to be filled) did not exert any significant stress on the plants. Neither the activity of flower cushions nor cherrelle wilt explained why trees in two fields were unable to respond to improved management within the observation period. The effect of fertilisation merits further study.

This case study gives rise to the following hypothesis which should be tested in a larger trial: "In the rehabilitation of abandoned cocoa fields, only the ones under sustainable management in terms of shade and timing of disease control can realise their production potential even if biocontrol agents which are effective against disease under adverse conditions can be developed."

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