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Modeling attainable yield and yield losses due to pests and diseases to compare performances of coffee farming systems

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1 Introduction

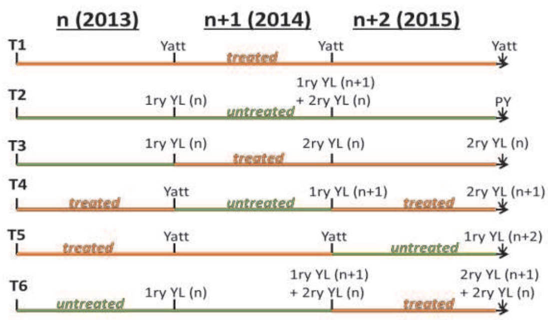
The regulation service of pests and diseases (P&D) can be assessed in terms of avoided crop losses (Avelino *et al.*, 2011). This approach is necessary to compare the performance of agroecosystems with different sets of P&D (injury profiles). For perennial crops, such as coffee, the assessment of yield losses is difficult due to the biennial production cycle, the complexity of agroecosystems where these crops are grown, and the existence of primary losses (in the current year) and secondary losses (losses in the following years due to the physiological damages caused by P&D) (Zadoks & Schein, 1979). Through this work, we contribute to: i) a better understanding of the impact of P&D on primary and secondary coffee yield losses; and ii) build a conceptual model to identify the main factors that determine coffee yield losses.

2 Materials and Methods

Trial: coffee at full sun exposure (5000 plants ha^{-1}) where six treatments with different sequences of fungicide applications are compared, with a duration of three years (Fig 1). In each of four replicates (40 m^2), six coffee plants were marked for measurements: fruiting nodes, fruits per node, dead branches, P&D incidences and severity, and yields.
Studied variables: standardized area under the disease progress curve (sAUDPC) and severity of P&D, dead branches, and yield losses. Depending on the treatment, at the end of each year we can obtain attainable yields (Yatt) and actual yields (Yac), whose differences represent primary or secondary losses (Fig 1). *Yield loss (%) = ((Yatt – Yac)/Yatt)*100*
Statistical analysis: i) sAUDPC, severity, dead branches and yields were compared among treatments trough analyses of variance, with fruit load of the previous year and soil acidity as covariates (they characterize the production conditions of each plot), and LSD (Fisher) with $p<0.05$; ii) correlations (Spearman) between measured and studied variables of 2013 and 2014 to support the relationships presented in the conceptual model.

3 Results – Discussion

Diseases and yield losses. We observed significant effects of the treatments on several diseases in both years (Table 1). In the first year (2013), no difference of yield between treatments was found and therefore no yield loss was calculated. In the second year (2014), significant differences between treatments were observed for sAUDPCof coffee leaf rust and dead branches; and the yield of the treatments conducting to attainable yield (T1&T5) was different to others, making possible to calculate yield losses. The negative impacts of abandon fungicide application from one year to another (T4) can be worse than no fungicide application in two consecutive years (T2&T6), reflected by higher dead branches and similar yields.Both primary and secondary losses were high, showing a severe impact of diseases (Table 1). Although we applied fungicides, there was presence of diseases, which indicates that yield losses could be even higher.
Correlations and conceptual model. Several significant correlations were found between variables from one year to another and within the same year. The fruit load in 2013 influenced negatively the fruit load in 2014; higher yield components (fruits per node, fruiting nodes, fruit load) caused higher sAUDPC and severities of diseases in most cases; dead branches had positive correlations specially with severity of diseases, and dead branches of2013 influenced negatively the yield components in 2014 (Fig. 2). These findings indicate that physiological aspects and impacts of diseases lead to yield losses in a given year and in next years. Based on that, we present a conceptual model, showing how different factors can influence the components of attainable yield, and how this last one can be reduced to actual yield, due to primary and secondary yield losses of coffee (Fig. 3).



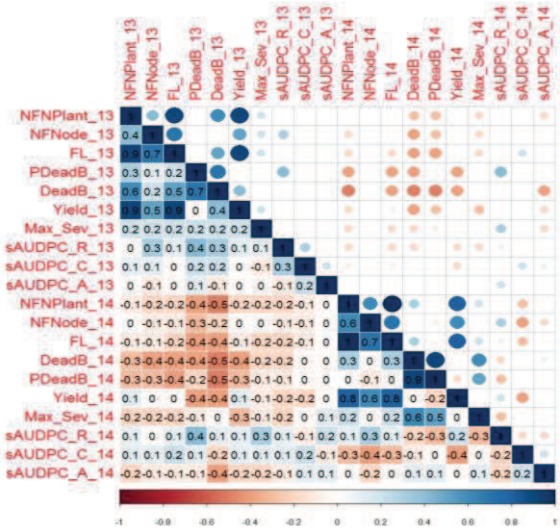
Yatt: attainable yield; YL: yield losses; PY: primitive yield

Fig. 1. Treatments for the assessment of yield losses.

Table 1. Effects of treatments on P&D and yield losses.

	Year 2013		Year 2014			
Variable	**T1&T4&T5**	**T2&T3&T6**	**T1&T5**	**T2&T6**	**T3**	**T4**
sAUDPC_R	24 a	34 b	34 a	41 b	40 ab	31a
sAUDPC_C	24 a	29 b	22 a	24 a	24 a	27 a
sAUDPC_A	6 a	5 a	8 a	4 b	6 ab	8 a
Max_Sev	3.1 a	3.2 a	3.5 a	3.4 a	3.2 a	3.6 a
DeadB	37 a	54 b	28 ab	29 ab	13 a	44 b
Yield	2077 a	2267 a	3397 a	1823 b	2125 b	1931 b
Estimated Primary Losses = ((3397-1931)/3397)*100 = 43%						
Estimated Secondary Losses = ((3397-2125)/3397)*100 = 37%						
Estimated Primary and Secondary Losses = ((3397-1823)/3397)*100 = 46%						

See interpretation of Fig. 2. for the meaning of variables and their units



Interpretation. Bellow the diagonal there are the Spearman coefficients; above the diagonal: the darker and bigger the circles, the stronger the correlation (symmetric matrix). Blue color indicates positive correlation; orange color indicates negative correlation. Cells with white color indicate that there is no significant correlation.

NFNPlant: Number of fruiting nodes per plant NFNode: Number of fruits per node

FL: Fruit load (=NFNPlant x NFNode) PDeadB: Percentage of dead branches

DeadB: Number of dead branches

Yield: Coffee yield (grams of coffee cherries per plant) Max_Sev: Maximum of severityof diseases in leaves (scale 0-6)

sAUDPC_R: standardized Area Under the Disease Progress Curve of coffee leaf rust (*Hemileiavastarix*) (% day^{-1})

sAUDPC_C: of cercospora(*Cercosporacoffeicola*) (% day^{-1}) sAUDPC_A: of anthracnoses (*Colletotrichum*spp.)(% day^{-1})

Numbers 13 and 14 represents the variables in 2013 and 2014, respectively

Note: we constructed the accumulated AreasUnder the Disease Progress Curve, but, since there were differences in the total time of incidence measurements between 2013 and 2014, we standardized them per day.

Fig. 2. Matrix of correlations (Spearman) among variables that determine yields.

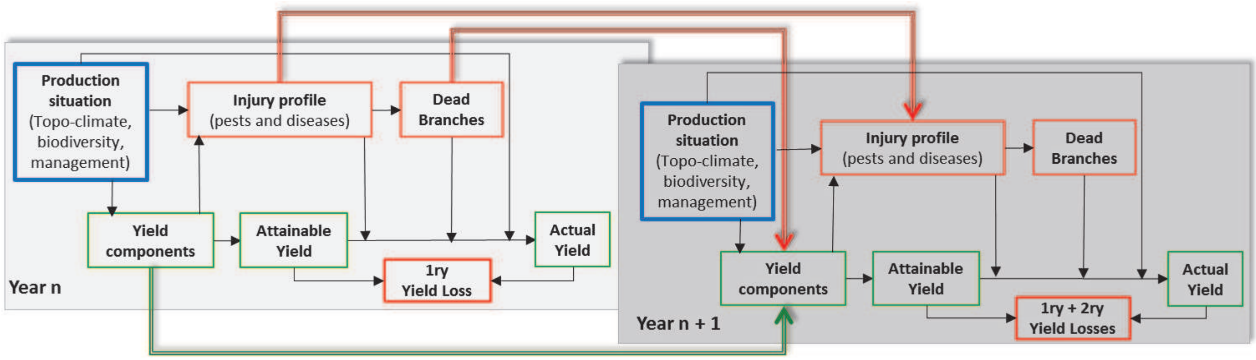


Fig. 3. Conceptual model to assess primary and secondary yield losses of coffee.

4 Conclusions

The negative impacts of diseases in coffee are not limited only to the year where they have developed. The high estimated secondary losses indicate that economic and technical measures to help coffee farmers to face phytosanitary issues (as coffee rust epidemic in 2012-13, Avelino *et al.*, 2015) need to be continued on several years.

The proposed conceptual model shows the main factors that should be taken into account to assess primary and secondary yield losses of coffee. Based on this model, statistical models could be developed (to be finalized in 2015) to estimate attainable yields and yield losses, in order to assess the performance of different coffee farming systems.

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