

Introduction

Intercropping coffee trees with shade trees is a promising Ecosystem-based Adaptation to increase resilience to coffee berry borer infestations (Vignola et al. 2015).



While shade-grown coffee (SGC) has been shown to be promising at the individual farmer level (Atallah et al. 2018), there has been a lack of investigation done on such adaptation strategies at the landscape level.

The spatial heterogeneity of land cover may generate spatial-dynamic externalities and/or sub-optimal outcomes (Atallah et al. 2017, Fenichel et al. 2014)

Hypotheses

1. Adopting SGC on one farm as an adaptation strategy on one farm is rendered not cost-effective due to the pest externality from the neighboring farm not adopting the SGC system.
2. The existence of free-riding by the sun-grown neighbor (Farmer 2)

Ecological Production Function

Our model has two coffee farmers infestations that creates ecological linkages among the two farms.

Each farm is represented by a two-dimensional grid to represent the spatial construction of a coffee farm. C_1 participates in a shade certification scheme while C_2 grows coffee in an intensive, sun-grown system.

Each cell (i, j) within each grid represents the coffee shrub type, where the yield of each cell can be written mathematically as:

$$y_{cell} = (y + \beta_1 shade + \beta_2 shade^2) * (1 - \phi_{\omega_{i,j,t}}) \quad [1]$$

where $\beta_1 > 0, \beta_2 < 0$

$\phi_{\omega_{i,j,t}}$ is an infestation state reduction factor where, as ϕ increases, revenue from the cell will decrease.

Then, coffee revenue is a function of price, yield, and an infestation reduction ($\hat{y}_{si,j,t}$), mathematically:

$$r_{\omega_{i,j,t}}^{coffee} = p_{i,j,t} * y_{cell} (1 - \hat{y}_{si,j,t}) \quad [2]$$

Pest Dispersal Dynamics

The expected infestation state of cell (i, j) at time $t+1$ is:

$$E(\omega_{i,j,t+1}) = \mathbf{P}' \omega_{i,j,t} \quad [3]$$

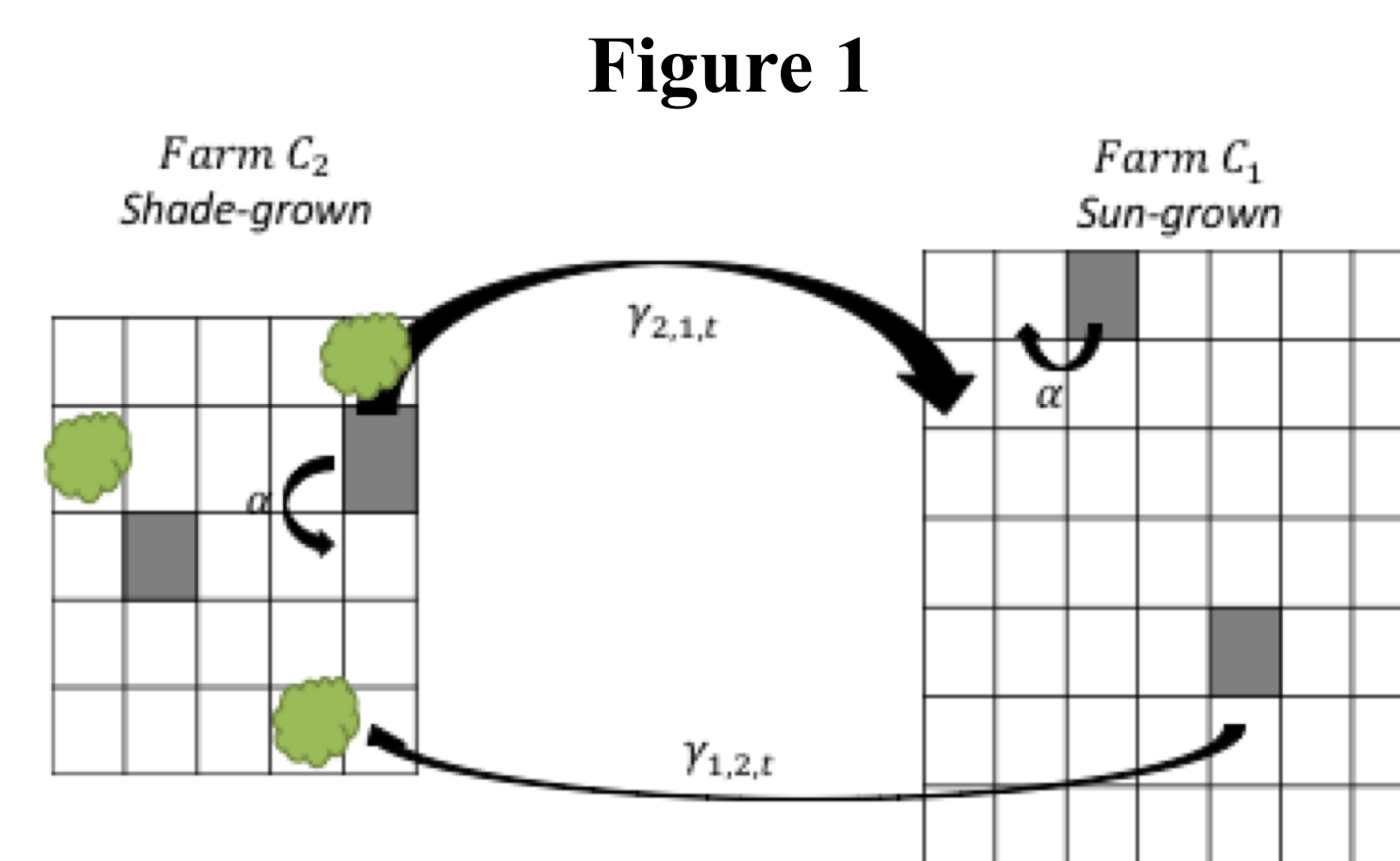
Pest dispersal is described by matrix \mathbf{P} , detailed below:

$$\mathbf{P} = \begin{bmatrix} 1-b & b & 0 & 0 \\ 0 & 1-d & d & 0 \\ 0 & 0 & 1-f & f \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad [4]$$

In [4], b is the transition probability from *Healthy* to *Infested low*, d is the transition probability from *Infested low* to *Infested moderate*, and f is the transition probability from *Infested moderate* to *Infested high*.

$$b = P(\omega_{i,j,t} = I_{low} | \omega_{i,j,t} = H) = 1 - e^{-(N_{i,j,t} * \alpha(net_temp) + (\gamma_{c_1, c_2, j, t}))} \quad [5]$$

Where $N_{i,j,t}$ is the set of infested neighbors of cell (i, j) at time t . Figure 1 depicts the long-distance dispersal rate, $\gamma_{m,k,j,t}$



The probabilities of transitioning from I_{low} to I_{mod} and from I_{mod} to I_{high} are given by d and f below:

$$d = P(\omega_{i,j,t} = I_{mod} | \omega_{i,j,t} = I_{low}) = \begin{cases} 1 - e^{-\frac{1}{w_1^{no\ shade}}} & \text{if } N_{i,j,t} \text{ has no shade trees} \\ 1 - e^{-\frac{1}{w_1^{shade}}} & \text{otherwise} \end{cases} \quad [6]$$

$$f = P(\omega_{i,j,t} = I_{high} | \omega_{i,j,t} = I_{mod}) = \begin{cases} 1 - e^{-\frac{1}{w_2}} & \text{if } N_{i,j,t} \text{ has no shade trees} \\ 0 & \text{otherwise} \end{cases} \quad [7]$$

Objective Function

The economic model consists of each farmer maximizing the ENPV by choosing whether to intercrop their coffee farm with shade trees, or to stay in a sun-grown system and is denoted by the optimal strategy (Ω^*). The objective function can be written as:

$$\max_{\Omega} E[\sum_t \rho^t \sum_{(i,j)}^{C_i} [r(\tau_{i,j}, \omega_{i,j,t}, v_{i,j,t}) - (c_{i,j,t} + v_{i,j,0}(c_{v_{i,j,0}} + c_{v_{i,j,t}}))] \quad [8]$$

Subject to: $E(\omega_{i,j,t+1}) = \mathbf{P}' \omega_{i,j,t}$

Where:

$r(\tau_{i,j}, \omega_{i,j,t}, v_{i,j,t})$ revenue of cell (i, j)
 $c_{i,j,t}$ cost of coffee production
 $v_{i,j,0}(c_{v_{i,j,0}} + c_{v_{i,j,t}})$ additional costs of shade coffee

Results

We describe the case where farmers have different systems. We expect this situation to increase in prevalence in coffee-producing regions if farmers transition to shade-grown systems.

As expected, Figure 2 below shows that shade-grown systems are more resilient to pest infestations

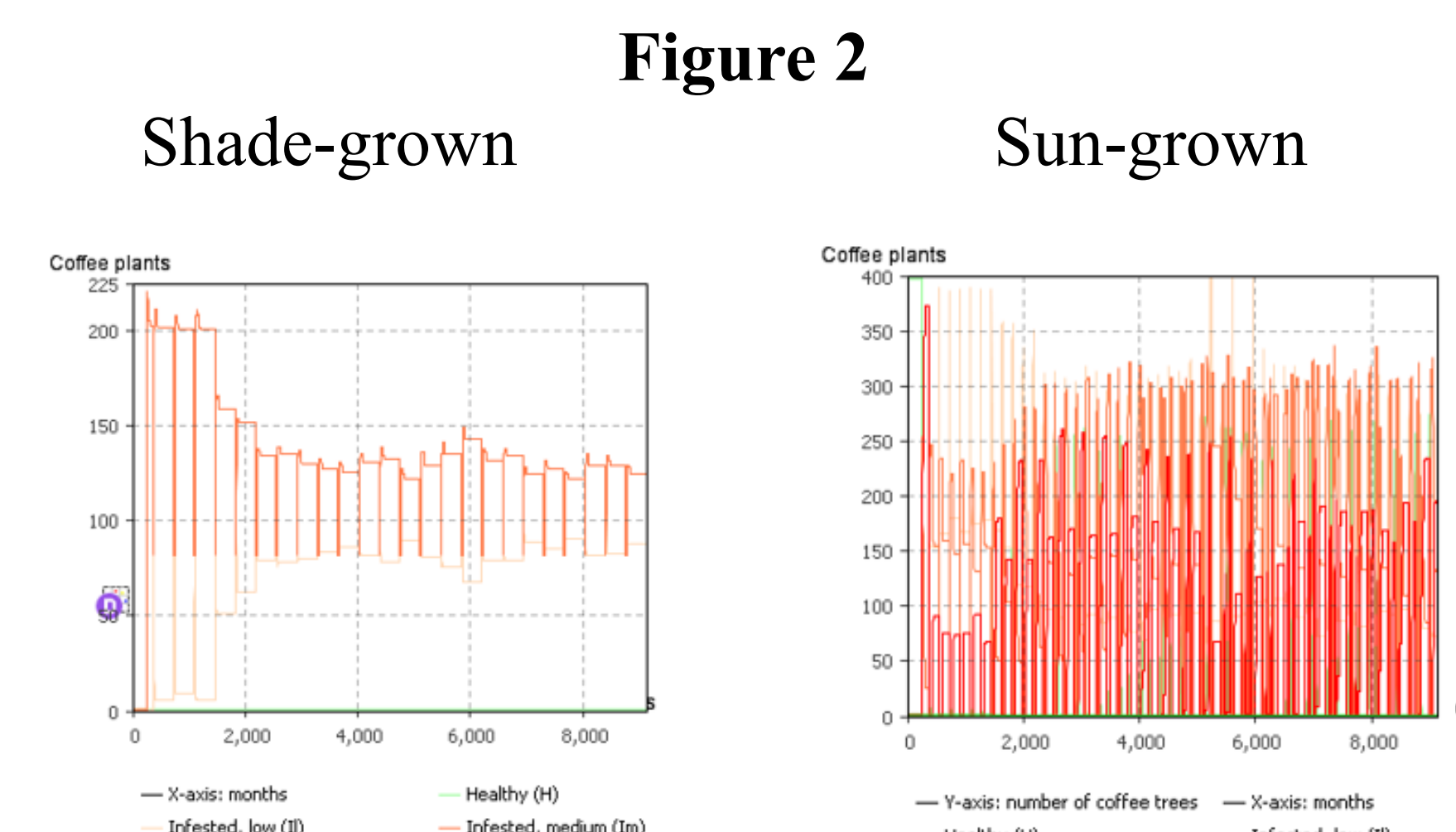


Table 1 shows that this resilience to pests translates into economic resilience whereby NPV losses are reduced from 66 to 13% on the SGC farm (C_2) relative to farm C_1 .

Table 1. NPVs of sun-grown (C_1) and shade-grown (C_2) farms

	NPV (C_1)		NPV (C_2)	
	\$/0.1ha	% loss*	\$/0.1ha	% loss*
no CBB	8,840	n/a	5,567	n/a
SDD	4,577	48%	4,863	12%
SDD & LDD	3,049	66%	4,836	13%

*% loss=(NPV(CBB scenario)-NPV(no CBB))/NPV(no CBB)

Discussion

Typically, externalities are generated by the weaker-link agent, who is not contributing to the pest or disease control, which makes these results surprising at first glance.

It is the adoption of the ecologically sound practice (SGC system) that generates the externality which causes NPVs to decrease from \$4,577 to \$3,049 on the sun-grown farm.

The impact for the ecological connectedness is large on the sun-grown farmer (increase in losses from 48% to 66%). This result is due to the ecological production functions leading to the public bad.

In this paper, self-protection through the adoption of a SGC system increases the infestation risk and damages for the neighboring farmer: shade trees that reduce infestations within the farm also act as a pest repellent, which increases infestations on the neighboring farm.

We expect this result to occur in other agricultural and non-agricultural settings. For instance, adoption of coastal adaptation measures such as concrete infrastructure to protect oneself from waves is likely to increase the risk and damages on the neighbor who has not adopted the adaptation measure, because of the rebounding effect.

Future Work

We will model the land use decision both at the intensive (whether to be in sun vs. shade) and extensive margin (amount of shade to have in a SGC system) for both farms as a function of ecological and economic parameters and as a response to the decision of the neighboring farm, in simultaneous move and sequential move settings.

References

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