Designing pest-suppressive multi-strata perennial crop systems

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Introduction

When farm households and rural communities were developing the multi-strata systems which have given rise to the scientific field of agroforestry, they did not have access to pesticides or sprayers. Pests were present, and may have been a problem, as is illustrated by the collapse of the Sri Lankan coffee sector over 100 years ago caused by rust. We can speculate that traditional agroforestry systems were designed at least in part to reduce pest problems. Now that pesticides are widely available, perennial crop systems are often designed and managed for maximum yield with the expectation that pest problems can be minimized with pesticide use. In modern coffee production, growers often use insecticides, fungicides, herbicides and nematicides in a single season. This approach has produced yield increases, but also pest resistance and secondary pests, increased human and environmental health risks, and costs. Many traditional systems have also been destabilized by introduced pests and land pressure, and are no longer considered economically viable. Multi-strata perennial cropping systems with low pest management costs, low susceptibility to pest losses, and reasonable yields would be an important contribution both economically and ecologically to the rural tropics.

An hypothesis and an analytical tool

Pest management since the discovery of pesticides has undergone a shift from a belief that pest problems had been solved to a realization that agricultural fields are complex and responsive systems which can be studied in terms of food webs just as any natural habitat (Croft & Hull 1983). The complex nature of multi-strata perennial cropping systems in terms of micro-climate, habitat diversity, and trophic relationshipsuggests both an hypothesis and an analytical tool for the task of their design and management for reduced pest susceptibility. We hypothesize that for each combination of soil and climate under which a crop can potentially be grown, a system or systems can be devised in which the potential set of pest problems is at its minimum expression. This can be contrasted to the more common approach in which the system is designed for yield maximization with no attention to pests or redesigned in response to only one pest problem. Such drastic changes often create the conditions for unexpected new pest problems. Shade elimination in response to the introduction of coffee rust (*Hemileia vastatrix*) in Nicaragua produced new and more serious pest problems with cercospora spot (*Cercospora coffeicola*), weeds, and coffee leaf miner (*Leucoptera coffeella*).

To achieve a balanced approach to multi-strata system design and management, we propose food web analysis to examine trophic relations in time and space. Using examples from arábica coffee, first, we analyze climate and soil and the modifying effects of shade. Next we identify autotrophs, herbivores, and secondary consumers, and how they interact during an annual cycle. In the final section we integrate the analysis to identify the optimum range of shade for minimal expression of the coffee pest complex for a low dry zone in Central America.

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Trophic levels

The autotrophs or primary producers in multi-strata perennial crop systems are often described to have ideal climatic conditions, but in practice crops like coffee are grown under diverse conditions. Arabica coffee is grown in tropical regions from 400 to 2000 meters above sea level, with 1000 to 3000 mm annual rainfall distributed in 6-12 months. The average rainfall and temperature at a site influence crop vigor and phenology, such as periods of new shoot and leaf growth, flowering and periods of leaf fall. Most coffee zones in Central America have a dry season of more than three months which establishes a marked period of flower flushes for coffee, while certain zones in Colombia have few dry months with continuous flowering. The duration of rainy and dry seasons also influences pest and predator life cycles such as the growth and seed production of weeds. The incorporation of multi-strata shade alters light quantity (Goldberg and Kigel 1986) and light quality, reduces daily temperature maxima and fluctuations, and increases relative humidity (Barradas and Fanjul 1986), which in turn modifies coffee physiology and food web interactions. Monterrey (1990) found, for example, that in shaded coffee leaf fall and new leaf emergence were delayed several weeks, thereby minimizing leaf miner damage in the dry season.

Each site also has year-to-year rainfall and temperature variability. The average year occurs infrequently. In a 6-year period in the hills of Managua, Nicaragua, annual rainfall varied 3 fold, affecting both coffee phenology and microclimatic conditions in the plantation. The pattern of early rains determines the timing and frequency of coffee flowering. May rains varied 6 fold during this period, and were often followed by either dry periods or excess rain in June, both of which have negative effects on flower set. Occasional frosts damage coffee plantations in high altitude and in southern Brazil. These extremes also affect the fauna that feed on the crop. The design of pest-suppressive multi-strata perennial crops must begin with climatic averages, but also take into account year-to-year weather variability.

In addition to the perennial crop and the shade trees, there are usually many other autotrophs, commonly referred to as weedy vegetation, since it interferes with the growth of the crop of primary commercial interest. The amount of weedy vegetation depends on the available resources for plant growth. Nestel and Altieri (1992) found over twice as many weeds in open sun than in multi-strata coffee in Mexico. The lower weed biomass under shade is often represented by a different species complex, most notably *Commelinaceae*, while in open sun *Poacea* and *Compositae* are common. Nonetheless, problematic shade-tolerant vines like *Syngonium podophyllum* and shrubs may proliferate. Certain tree species have also been shown to have allelopathic effects on understory vegetation (Anaya et al., 1982).

Herbivores feed on autotrophs and complete all or part of their life cycle in the environment of the multi-strata crop system. Herbivores may be specialist feeders which concentrate on only one plant species like coffee or generalists which feed on a diversity of species or have alternate hosts (Table 1). Each species also has a different response to shade effects on light and humidity levels, including some which are affected minimally. There is little documentation of tree species as alternate hosts for coffee pests or with specific microclimatic effects, although a more diverse shade strata with a greater variety of food sources (flowers, fruits, extrafloral nectaries, tender foliage) has been shown to have greater herbivore diversity (Perfecto et al., 1996).

Secondary consumers complete their life cycles by feeding on the energy and nutrients of herbivores. Without these naturally occurring organisms, pest levels would escalate. Understanding whether they are specialist or generalists, and what conditions favor their presence and increase, is essential to the design of pest-suppressive multi-strata systems (Table 2). Many beneficial species are favored by the buffered shade environment, although little is known about the effects of specific tree species on secondary consumers. The presence of a diverse shade strata is favorable to generalist predators like spiders and ants (Perfecto et al., 1996).

The final dimension of the food web is the detritus feeders. In shaded coffee the detritivores feed on 5,000-20,000 kg/ha/year of leaf and branch organic matter (Beer 1988) which enriches the soil substrate with energy and nutrient sources. The organic matter rich soil represents a less favorable environment for plant-parasitic organisms like *Fusarium/Roselinia* and nematodes which interact to cause the slow wilt syndrome which is increasingly common in sun-grown coffee in Central America (CATIE 1996).

Table 1. Factors affecting generalist and specialist herbivores in multi-strata coffee

	varietal response	**alternate hosts**	**light response**	**humidity response**	**life form**
Hemileia vastatrix	yes	None	none	++	fungus
Cercospora coffeicola	yes	None	+++	none	fungus
***Colletotrichum* spp.**	yes	Erratic	erratic	erratic	fungus
Mycena citricolor	yes	Yes	none	+++	fungus
Meloidogyne incognita	yes	Yes	none	++	nematode
Hypothenemus hampeii	not verified	None	none	none	insect
Leucoptera coffeella	not verified	???	none	---	insect

Table 2. Selected secondary consumers in coffee

	coffee pest consumed	**other feed sources**	**life form**	**light response**	**humidity response**
Beauveria bassiana	berry borer	other insects	fungus	--	++
Cephalonomia stephanoderis	berry borer	None	insect	none	+
Verticillium lecanii	rust	Insects	fungus	none	+++
spore-consuming *Diptera*	rust	other rust spores	insect	not known	not known
nematotrophs	nematodes	Diverse	nematode	none	++

Tools for design and management of pests

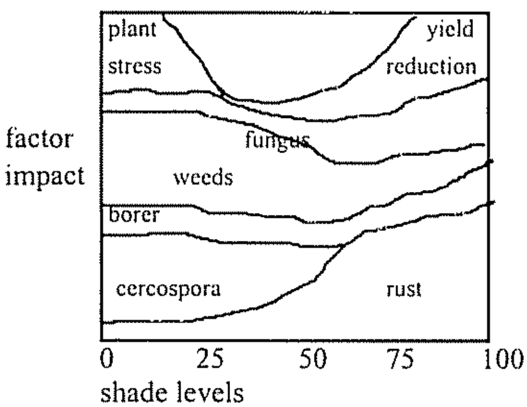
The initial food web characterization must then be specified further: phases of the annual cycle, location in the coffee system at each moment, and identification of factors which favor increase or decrease. These become the possible pressure points for designing and managing a pest-suppressive multi-strata system. Several approaches can be identified: 1) strengthen crop tolerance or capacity to recover; 2) create unfavorable conditions for pests; or 3) create conditions more favorable for natural biological control mechanisms. Multi-strata management exemplifies each approach. As a last resort, pests can also be controlled by direct suppression, either through augmentation of existing biological organisms or the use of pesticides which should be done with minimum disturbance of natural control mechanisms. These mechanisms can be illustrated for weeds, leaf diseases and berry borer in coffee.

Weed growth and seed production follows rainfall distribution. Vigorous coffee bushes well distributed without gaps reduce many weeds. Multi-strata shade further reduces light levels and also provides natural leaf litter and prunings to diminish weed growth. Leaf prunings, slashing, and herbicides can be directed selectively to reduce the growth and seed production of rank-growing, *aggressive weeds, while leaving relatively undisturbed ground cover weeds characterized by their low growth habit and shallow roots for soil conservation (Staver 1998).

The microclimate created by multi-strata shade management affects the annual development of the disease complex. New disease-free leaves emerge into residual inoculant from the previous year and are infected depending on the coffee variety and the physiological state of the leaf, the general weather conditions, and microclimatic light and humidity. The design and management of multi-strata shade should achieve moderate light levels without elevating microclimatic humidity at the coffee leaf surface during critical high moisture periods. Tolerable shade percentages are lower in cloudier, cooler, more humid zones and periods and higher in drier, hotter, sunnier zones and periods. Regular, systematic disease monitoring provides criteria for adjusting shade structure and percentages and for the application of fertilizers and fungicides. Other practices like pruning diseased materials can also be used to reduce disease inoculant.

Microclimate, particularly humidity, plays a major role in the development of secondary consumers, primarily fungi which feed on insects or diseases. Although coffee berry borer appears to perform equally well in open sun and managed shade, naturally occurring *Beauveria bassiana* multiplies and spreads more quickly with greater humidity and fungus applications should coincide with peaks in rainfall (Guharay & Monterrey, 1997).

Conditions for minimum expression of pest complex



An additive approach to define the conditions for the minimal pest problems is illustrated in the graph to the left. For a low dry coffee zone, shade should be managed between 35-60%. Similar graphs could be developed for the major annual phenological periods to identify shade pruning alternatives (Munschler 1997). For a wetter zone some of the curves would shift to the left, while others would be unaffected.

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