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Advantages, disadvantages and desirable characteristics of shade trees for coffee, cacao and tea

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Abstract. A review is made of the ecological interactions that occur between shade trees and the perennial crops: coffee (Coffea spp. L.), cacao (Theobroma cacao L.) and tea (Camellia sinensis L. Kuntze). These interactions are classified firstly as advantages or disadvantages, and secondly as: effects on crop management; effects on the hydrological cycle; effects on pathogens, insects and climatic conditions; and effects on soils. References are given for the 20 advantageous and 16 disadvantageous consequences of using shade trees, emphasizing publications that provide original data and useful methodologies. Finally a check list of desirable characteristics for perennial crop shade trees is presented.

Resumen. Se hace revisión de las interacciones ecológicas que ocurren entre árboles de sombra y los cultivos perennes: café (Coffea spp. L.), cacao (Theobroma cacao L.) y té (Camellia sinensis L. Kuntze). Estas interacciones fueron clasificadas en primer nivel como ventajas o desventajas, y en segundo nivel como: efectos sobre manejo de los cultivos; efectos sobre el ciclo hidrológico; efectos sobre patógenos, insectos y condiciones climáticas; y afectos sobre los suelos. Se dan referencias para 20 consecuencias ventajosas y 16 consecuencias desventajosas al utilizar árboles de sombra, dando énfasis a publicaciones que proveen datos originales y metodologias útiles. Finalmente se presenta una lista de las características deseables para árboles de sombra para cultivos perennes.

Introduction

The principal biological interactions, that occur between shade trees and underlying crops, have been reviewed by several authors [23, 40, 63, 73, 74]. This report provides check-lists of all the suggested advantages and disadvantages which have been attributed to the shade trees used for coffee (Coffea spp. L.), cacao (Theobroma cacao L.) and tea (Camellia sinensis L. Kuntze) [16, 35, 76, 79, 96]. These check-lists are designed to help the student, researcher or extension agent identify the most important crop-tree interactions, or the most suitable shade tree species, when working with a new (to him) agro-forestry combination and/or new site. The references given in these lists are to publications which contain experimental data, and which describe a methodology used to study a particular interaction. In a few cases, where experimental data is scarce or non-existent, reference is made to previous publications which include the same suggestion (e.g. see below I.IV.7. Beneficial effects on soil organisms [35]).

No references are given when the possible advantage or disadvantage is obvious (e.g. 2.I.4. Mechanization of crop is hampered).

The use of shade trees for tropical perennial crops

The recent tendency of agricultural extension services is to recommend the culture of coffee and cacao without shade trees in order to gain the highest possible yields. These recommendations are based on experimental work, carried out in many countries, which has shown that on the most appropriate sites, intensive management of self-shading monocultures can give 2 and 3 fold yield increases over traditional shaded systems [4, 18, 25, 26, 46, 66, 68, 95, 96]. However, information such as that provided by Akenkorah et al. [1], on the relative long term profitability of the unshaded vs. the shaded crop, is rare.

The inclusion of shade trees is less controversial in the case of small farmers since they are frequently cultivating a sub-optimal site for their crop (see Nair [71], Purseglove [76], Wrigley [96] for descriptions of the optimal conditions for coffee, cacao and tea). Purseglove [76, p. 587] summarizes some of the most important considerations in such a situation when he states "Shade reduces photosynthesis, transpiration, metabolism and growth and therefore, the demand on soil nutrients and so enables a crop to be obtained on soils of lower fertility". Shade is invariably recommended for the establishment of cacao [4, 31] and it should be gradually removed on optimal sites as the cacao becomes self-shading [17, 26, 68]. However, in cases where intensive management, in particular the regular application of fertilizers, can not be guaranteed, some shade trees should be retained for both cacao [95] and coffee [74]. Many reported advantages and disadvantages of shade trees are listed in this report but it appears that the fundamental question, when planning the renovation or establishment of coffee and cacao plantations, is whether the owner has the site, education and resources to maintain these crops without shade. In the case of these export crops there is an additional risk, that the value of the product will temporarily fall to a level where the farmer can no longer afford the necessary inputs and therefore, will temporarily abandon his plantation. Cacao or coffee under shade will survive such a setback far better than monocultures of these crops [44, p. 88].

The higher risk inherent in unshaded cacao cultivation is also illustrated by Cunningham's economic analysis of cacao production in Ghana [24]. "The extra expenditure and work associated with clear-felling and growing unshaded cacao with large amounts of fertilizers would probably be justified only when yields of 3,000 lb. dry cacao/acre (3,360 kg/ha) and over are obtained" (but see also Vernon [90]). It should also be noted that the majority of the shade/fertilizer experiments with cacao have shown that any shade greatly reduces the response to fertilizer

applications [1, 4, 17, 18, 23, 26, 69] and in such conditions they are rarely economically justifiable. Part of the world-wide research effort devoted to these crops, should be reorientated away from the achievement of maximum yields, towards the study of sustained yield systems for farmers of few resources cultivating marginal agricultural land.

Some of the consequences of including shade trees with perennial crops can be either an advantage or a disadvantage depending upon the situation, e.g., the influence upon the water balance of the understory crop. *Whether a particular interaction is detrimental or beneficial will largely depend upon the characteristics of the species and of the particular farming area (climate, soils, etc.).*

Shade trees may be classified [21]: A) As a tool for the management of the environmental conditions in the associated crop plantation, e.g. Erythrina poeppigiana over coffee; B) As a means of diversifying crop production (including timber) from a given area, e.g. Cordia alliodora over coffee; and C) In some cases the shade tree fulfills both management (A) and production (B) functions, e.g. Leucaena leucocephala over coffee.

Based on the interactions suggested in the two lists "Advantages" and "Disadvantages", the shade tree characteristics given in the third checklist are usually considered desirable, though which are deemed most important will depend upon the objective ('1', '2' or '3'). The first question is whether the shade species is indeed adapted to the zone. Finally, the acid test of the suitability of any shade tree is the long term financial yield of the combination *versus* the perennial crop monoculture. The attached lists are only guidelines to the choice of species for testing.

Lists of potential shade tree species have been published for: Brasil [58, 81, 93]; Cameroun [61]; Central and South America [55, 56]; Costa Rica [43, 51]; Gold Coast [42]; India [28]; Ivory Coast [60]; Kenya [64]; Mexico [51]; Sri Lanka [52]; Trinidad [67]; Uganda [89]; Various countries [22, 44, 62, 96]; and Zaire [75].

A. Possible advantages of including shade trees with perennial crops[1]

I. Consequences which facilitate crop management

(1) Prevention of overbearing (and subsequent die-back) results in less variable annual yields which, over a long-term, permits a more efficient utilization of labour and machinery during harvesting and processing [76].
(2) Suppression of weed growth [14, 25, 87, 90].
(3) Product diversification, e.g. fruits, timber. Merchantable trees represent "standing capital" and hence are an insurance against crop failure [84].
(4) Control of crop phenology, e.g. fruit setting and maturation, by manipulating the environmental conditions through the careful

timing of shade tree pruning or the use of an appropriate deciduous tree species [5, 19, 31, 42, 53, 92, 97].

(5) Shade may improve the quality of the crop, e.g. coffee [19, 20, 66].

II. Beneficial influences on the hydrological cycle

(1) Reduction of evapotranspiration of the shaded crop [3, 33, 48, 54, 60, 65, 70, 87].
(2) Removal of excess soil moisture by transpiration of a heavy shade tree cover [31, 63], e.g. in North-East Indian tea gardens [95].
(3) Increased moisture input through horizontal interception of mist or clouds, e.g. *Grevillea robusta* over tea in Tanzania (East African Tea Research Institute cited by Willey, [95]).

III. Protection of the crop from pathogens, insects and adverse climatic conditions

(1) Extension of the productive life of the crop [1, 4].
(2) Reduction of air, soil and crop leaf temperature extremes, and in some cases improvements of the microclimate for the crop, e.g. higher humidity [2, 3, 18, 45, 48, 70, 87, 92].
(3) Reduction of damage caused by hail and heavy rain.
(4) Reduction of some diseases, pests and parasitic plant infestations [1, 2, 72, 83, 88, 89].
(5) Reduction of wind velocities in the crop strata [4, 59, 82].

IV. Improvement of soil fertility and/or soil protection

(1) The growth (and possible die-back) of the shade tree root system can improve soil drainage and aeration, [52], e.g. by breaking up a "hard pan".
(2) The provision of a soil mulch (which helps retain soil moisture during the dry season) and an increase in the soil organic material from natural leaf fall and pruning residues [12, 39, 47, 49, 52, 80].
(3) Reduction of erosion on slopes [85, 92, 94].
(4) Reduction of the decomposition rate of soil organic material (because of reduced soil temperatures).
(5) Recycling of nutrients which are not accessible to the crop [6].
(6) Nitrogen fixation by shade tree root nodules [12, 30, 78].
(7) The management of unshaded perennial crop plantations involves greater use of agricultural chemicals, especially herbicides. These chemicals may have inhibiting effects upon beneficial soil organisms, e.g. organic material decomposers and free living nitrogen fixers [35]. Moreover, the increased soil organic material content, created by the presence of shade trees, can promote the activity of beneficial soil organisms [70].

B. Possible disadvantages of including shade trees with perennial crops

I. Consequences which hinder crop management

(1) Natural fall of branches and trees, or the harvest of mature trees, will damage the understory crop [9, 11].
(2) Sudden defoliation of the shade trees, by insects or disease, could cause severe shock to a shade adapted crop and consequent die back (hence a mixed shade is preferable to one species).
(3) Additional manual labour is necessary for combinations where the trees are regularly pruned [29].
(4) Mechanization of the underlying crop is hampered.
(5) Establishment of erosion control structures (e.g. terracing) is hampered once the trees are established.
(6) New crop varieties are invariably bred for monocultural conditions and may not be suitable under shade [10, 20, 29, 45, 66].
(7) Heavy shading can reduce the quality of a crop, e.g. tea [50, 65].

II. Detrimental influences on the hydrological cycle

(1) Shade tree root competition for moisture during the dry season and oxygen during the wet season [3, 34, 36, 47, 57, 90].

III. Promotion of adverse influences such as pathogens, insects and detrimental environmental conditions

(1) Reduced air movement and increased humidity may favour fungal diseases [18, 19, 27, 83].
(2) Insect attack may be greater when the crop is shaded [83, 92].
(3) Allelopathic effects [7, 77], e.g. the combination of Nogal (Juglans spp.) with coffee is potentially hazardous.
(4) Shade trees can act as alternative hosts for pests and diseases [17, 60, 83].
(5) In addition to reducing the quantity of available light, and hence yields on fertile soils [15, 17, 19, 91, 92], shade trees reduce the quality of transmitted radiation since there is a preferential absorbtion of photosynthetically useful radiation [8, 70].

IV. Reduction in soil fertility (with respect to the associated crop) and increased erosion

(1) Shade tree root competition for nutrients [32, 37].
(2) Stemflow, and the drip of rain drops which coalesce on shade leaves, can adversely redistribute rainfall thus increasing erosion, crop damage, and reducing moisture absorbtion by the soil [13, 41, 62, 86, 94].
(3) Harvesting of fruit and/or wood from the shade tree constitutes an additional drain of nutrients from the site [32, 38].

Desirable characteristics for perennial crop shade trees[2]

(1) Compatibility with the crop, which means minimal competition for water, nutrients and growing space, e.g. does not produce suckers; the crown branches above the crop; deep rooting; minimum overlapping of understory and overstory species root zones.
(2) Strong rooting systems (not susceptible to wind throw). Shade trees are more exposed to adverse climatic conditions than are trees in a forest or a plantation and should be capable of adaptation to open-grown conditions.
(3) Rooting ability of stakes to permit rapid shade establishment by vegetative propagation.
(4) Ability to extract soil nutrients which are not trapped by the crop[3].
(5) Ability to fix nitrogen.
(6) A light crown that provides a regular mottled shade pattern rather than uniform shadow of photosynthetically poor quality light.
(7) In the case of objective "2" (timber producing species). A small diameter light crown to: a) reduce the wind resistance of the foliage and hence the risk of wind throw, b) permit relatively high shade tree densities without reducing light levels below critical values for the crop; and c) minimize crop damage when individual trees (continuous timber yield system) are harvested.
(8) Non-brittle branches and stem.
(9) Thornless stem and branches to facilitate management.
(10) Rapid apical growth (Obj. "2").
(11) Self-pruning and the ability to form a straight unforked stem in open-grown conditions (Obj. "2").
(12) Tolerance of repeated heavy pruning or pollarding (Obj. "1").
(13) High biomass productivity of material that is recycled, through leaf-fall and/or pruning. Readily decomposed leaves and woody material.
(14) If deciduous, rapid flushing of new leaves to regenerate the shade cover.
(15) Absence of major disease or insect susceptibility which could lead to sudden defoliation.
(16) Small leaves to minimize rain drop coalescence and subsequent drip damage.
(17) No allelopathic properties.
(18) Smooth bark that does not harbour epiphytes.
(19) Valuable wood, fruit or other product, e.g. rubber from Hevea spp.
(20) Not an alternative host for insects and pathogens which are major enemies of the crop.
(21) Shade tree species should not have the capacity to become a weed e.g. Ricinus communis and Leucaena leucocephala (certain areas).

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Notes

1. Principle sources: Budowski [16], Purseglove [76], Willey [95], Wrigley [96].
2. See also Haarer [44], MacMillan [62], Martinez and Enriquez [63] and Thomas [89].
3. This is a contentious point since many authors describe trees as nutrient pumps bringing up elements from soil levels below the crop roots. However, Budowski gives as an advantageous characteristic "superficial long horizontal roots" since few nutrients then escape the combined crop-tree root system [16]. In fact, with the exception of sandy soils there is little evidence in the humid tropics to show that crop and tree root systems occupy different levels. In areas of high rainfall most feeding roots of all plants are near the soil surface.

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