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# STUDIES ON LIGHT AND SHADE EFFECTS OF TREES ON UNDERSTOREY PLANTS

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## ABSTRACT

*This study investigates light transmission dynamics in agroforestry systems, utilizing a comprehensive equation to analyze different scenarios. It examines multi-storey, row-and-alley, and intermediate agroforestry types, addressing concerns about sustainability and canopy management. The analysis emphasizes shade effects on understorey plants, particularly in cocoa agroforestry, and highlights shade tree management considerations for optimal canopy cover. It advocates for informed decision-making in agroforestry design and management, stressing the importance of shade management for enhancing productivity and crop quality. The study concludes by recommending shade as a critical parameter in sustainable food crop production strategies within agroforestry systems.*

**Keywords:** *Agroforestry, Light transmission, Canopy dynamics, Sustainability, Shade management*

## INTRODUCTION

The general equation that defines the proportion (**T**) of light transmitted to the crop is:

$$T=T_f + F_{max}\ e^{-kl}$$

where Tf is the fraction of the available light which misses the trees altogether and would reach the crop even if the trees were totally non-transmitting (i.e., solid and opaque); Fmax is the fraction of the available light which would be intercepted by the trees if they were non-transmitting; L' is tree LAI (m leaf per m total ground surface) divided by $F_{max}$; and K is the light extinction coefficient of the tree canopy.

This equation can be applied to an agroforestry system of any level of complexity. Here it is used in relation to three distinct types of system, the first two being defined in their extreme forms:

1. *Multi-storey systems* in which the trees form a closed canopy through which light penetrates to the crop beneath. Separation between tree and crop is thus primarily in the vertical dimension. The term $T_f$ in equation (1) is zero, $F_{max}$ is 1 and light transmission to the crop will be controlled by vertically-summed tree LAI and the relevant light extinction coefficient K.

2. ***Row-and-alley systems*** in which rows or belts of trees which are so dense that no crop can grow under them are separated by clear alley-ways in which crops can be grown. In this case $T = T_f$, because there is effectively no transmission through the trees. The light energy available to the crop is a function of the pattern of (solid) shadows cast by the belts or rows of trees which, in turn, is dependent on tree height, latitude, row orientation and time of day and season. Scattered, very dense trees casting 'solid' shadows provide a variant of this type.
3. *Intermediate systems* in which transmission to the crop is both of light which bypasses the trees altogether ($\mathbf{T_f}$) and light which passes through the tree canopies ($\mathbf{T_c}$) which is calculated as $F_{max} e^{-kl}$ as in equation (1). Almost all multi-storey systems and row-and-alley systems are likely to be intermediate systems in their early years before the tree canopies grow together (multi-storey systems) or become so dense that crops can only be grown in the alleys (row-and-alley systems).

## MULTI-STOREY SYSTEMS

The key question in such systems is likely to be whether they are indefinitely sustainable as agroforestry systems, i.e. whether light transmission will not ultimately become too low for crop production under the trees. If the system is not indefinitely sustainable the question becomes that of the age at which either the canopy has to be thinned or cropping under it changed to more shade-tolerant crops or abandoned. For calculation of these limits it is essential to measure K for the tree species, the rate of increase in LAI and to know the light requirements of the under-tree crop.

## ROW-AND-ALLEY SYSTEMS

A computer program to calculate cast shadows from non-transmitting hedgerows of varying size, geometry and orientation at different latitudes was used in relation to orchard system design and subsequently modified to deal with transmission through the canopy. Methods were also described in these papers for calculating diffuse light interception in row-and- alley systems. These programmes enable calculation of the light intensity at any point on the 'floor' of a hedgerow orchard or a row- and-alley agroforestry system at regular intervals each day throughout the year, anywhere in the world, given the appropriate input data. This includes tree dimensions and shape, alley-way width, latitude and date (from knowledge of which solar altitude and azimuth throughout the day can be determined).

If the shadows are not effectively solid, information is also needed about canopy density and the light extinction coefficient for the canopy. These latter can be treated simply in terms of leaf area or in more detail separating out effects of branches and fruits as light-intercepting structures. Where there is a close relationship between leaf area and the dimensions of branches etc, which is often the case, then calculations based on leaf area and extinction coefficients determined *in situ* in relation to measured leaf area are likely to be satisfactory.

Whereas the light penetrating through a continuous upper-storey canopy is little affected by latitude, solar altitude and azimuth, these factors are very important with respect to $T_f$ in the discontinuous canopy, row-and-alley situation and interact strongly with row orientation. As an illustration, the effects of all combinations of the following were investigated, assuming non- transmitting belts of trees with vertical sides where they abut on the alleys:

1. Ratio of tree height to width of clear alley between adjacent belts of trees:-0.25:1,0.5:1,1:1,2:1;
2. Row orientation:- N-S, E-W, SE-NW;
3. Time of year:- 21 June, 21 September, 21 December;
4. Latitude: - 0 (equator), 30N, 50N.

For latitudes in the southern hemisphere the data for 21 June and 21 December must be reversed: a SW-NE row orientation gives similar results to the SE-NW orientation. Light levels across the alley were first calculated for totally diffuse conditions, assuming a Standard Overcast Sky, and then integrated over the day for clear, sunny conditions using the levels of diffuse and direct light in relation to solar altitude and calculating cast shadows on the assumption that the tree rows or belts were flat-topped and vertical-sided, i.e., of rectangular cross-section. The computer programme assumes that the diurnal pattern of irradiance is symmetrical about true solar gives the variation in light levels across the clear alley-way under diffuse conditions. The term 'clear alley-way' is used to indicate the alley between the (assumed vertical) edges of the tree canopies, not the distance between tree trunks on each side of the alley. As the ratio of tree height to alley-way increases not only does the relative irradiance received on the alley-way decrease but there is much less variation across it.

## EFFECT OF SHADE ON UNDERSTOREY PLANTS

Shaded and agroforestry production systems are characterized by the canopy cover under which cocoa trees grow. During establishment, thinning of the forest canopy and eliminating some trees, helps preserve characteristics of the original forest but also has disadvantages: shade is not uniform, management is more difficult, and farming equipment may be restricted by tree arrangement. Similarly, in fallow land farmers can plant shade trees alongside cocoa.

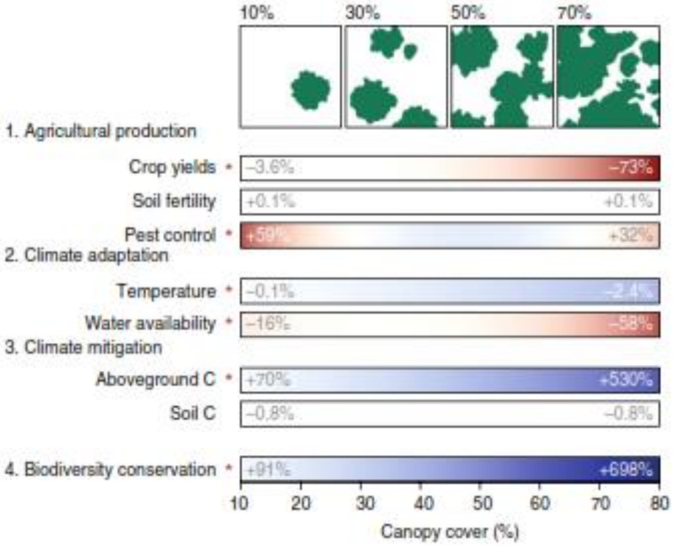
Cocoa agroforestry production systems vary in many aspects: shade tree species and age, canopy cover, canopy height, etc. Multistrata agroforestry systems, for example, have a microclimate defined by trees at different heights. Regarding shade tree species, cocoa-timber agroforestry systems are often recommended to fulfil ecosystem and livelihood objectives. Timber provides shade for cocoa and adds to farmer well-being through the use or sale of timber, or as a type of savings mechanism to be cut and sold when required. Other typical varieties used in agroforestry are fruit trees (banana, orange, peach palm, etc.). Successional agroforestry has been suggested to maximize biodiversity, diversify incomes, enhance soil fertility and provide other valuable ecosystem services. Successional agroforestry emphasizes the inclusion of a large diversity of vertical and horizontal crops associated with the local ecosystem.

Shade tree management depends on the chosen system, but 30 to 50% is the CSC-recommended level of canopy cover. Canopy cover should be higher the warmer and drier the climate is. Shade tree species choice should be informed by leaf shedding pattern, deepness of roots to ensure no competition with cocoa tree roots, hosting of natural enemies of pests and diseases (or at least not hosting pests and diseases), and water tolerance, among others.

The relationship between yields and shade is not-monocausal. In many cocoa zones light is not limiting yields, and a parabolic relationship between shade and yield can be found, where in low- to intermediate shade levels yields increase compared to full-sun systems. In the literature, also other relationships can be found, but it is generally agreed that shaded farms are more long-lived and that early positive results of full-sun systems could be reversed when the entire life span of the plantation is considered. Full-sun systems have higher short-term yields, but they are associated with the long-term loss of soil organic matter and nitrogen content, and lower environmental sustainability and food security. Yield is limited in agroforestry by reduction in photosynthesis due to shade and competition for soil resources such as water. However, due to the diverse nature of shade tree species, the degree of soil water competition is hard to quantify.

The yields of cocoa agroforestry systems are sustained over the long-term. Agroforestry systems are more resilient to climate change because farmers can regulate the microclimate of their plots through pruning and planting of shade trees. Shade trees protect cocoa plants from damaging winds and heat stress, among others. A meta-analysis on financial and biodiversity aspects of shaded vs. intensified cocoa and coffee production indicated that shaded production systems are more profitable and cost-efficient. Moreover, agroforestry systems are better at conserving biodiversity than intensified production systems, especially when plant diversity and canopy complexity are considered.

Growing demand and rising prices are likely to make full-sun production more attractive to farmers in the short-term. There is a lack of on-station trials considering different shade cover levels and age-yield profiles and studies working with long-term data on different production systems are rare, and the lack of systematic evidence on agroforestry leads to debates driven by ideology. Further research is required to ensure selected shade trees species do not increase incidence of pests and diseases. The choice of canopy cover is complex, the appropriate cover is dependent on the soil, present and future climate conditions, predominant pests and diseases, as well as farm-level financial decisions. Action plans derived from commitments, such as the Cocoa and Forest Initiative, should consider the CSC as a tool for achieving their environmental, social, and productivity objectives.



## EFFECT OF FIFTY PERCENT SHADE ON GROWTH AND DRY MATTER PRODUCTIVITY

Isolating shade effects from interacting factors such as tree root competition can be very difficult in agroforestry experiments. One alternative is to carry out experiments using artificial shade to investigate effects on crop productivity and soil biological activity.Such an experiment to evaluate the response of taro to shade and mulch without tree root interference, where shade was provided by a canopy of sarlon fifty percent shadecloth and mulch was cut and carried from an adjacent plot, was carried out at Alafua. Results indicated that plant height and leaf area were higher under shade conditions compared to full sunlight. Total plant biomass (dry weight) was also increased by shade, but the percentage of biomass dry weight in the corm was reduced. Corm yields were not affected by shade or mulching in this trial, however, number and weight of plant suckers was increased by both shade and mulch. Corm percentage dry matter, which reflects corm quality, was highest under shade and no mulch conditions and lowest under no shade mulch conditions Although in this experiment there were no advantages from shade in corm yields, there were more suckers, which often form a secondary harvest and a valuable source of planting material. Also shade-grown plants produced corms with better cooking and taste quality for the Samoan market.The fact that total plant biomass was increased by shade indicates greater photosynthetic efficiency under these conditions. However, partitioning of assimilates into corm was not enhanced by shade.

## CONCLUSION

Management of shade levels in agroforestry systems for cropping through timely pruning of trees and density of planting could improve productivity and corm quality while reducing weed competition. Furthermore, information on cultivar responses to growing in different light environments should aid selection of appropriate cultivars for particular farm niches. With increased interest in developing agroforestry systems for sustainable production of food crops, it is suggested that shade is an important parameter to be considered both in breeding programs and agronomy trials.

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