

# Light Interception and Resource Capture in Agroforestry Systems for Sustainable Yield

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Agroforestry systems make maximum use of the land. Every part of the land is considered suitable for useful plants. Emphasis is placed on perennial, multiple purpose crops that are planted once and yield benefits over a long period of time. Such benefits include construction materials, food for humans and animals, fuels, fibers, and shade. Trees in agroforestry systems also have important uses such as holding the soil against erosion and improving soil fertility (by fixing nitrogen or bringing minerals from deep in the soil and depositing them by leaf-fall). Furthermore, well-designed systems of agroforestry maximize beneficial interactions of the crop plants while minimizing unfavorable interactions. The most common interaction is competition, which may be for light, water, or soil nutrients. Competition invariably reduces the growth and yield of any crop. Yet competition occurs in monoculture as well, and this need not be more deleterious in agroforestry than monoculture systems. Interactions between components of an agroforestry system are often complementary. In a system with trees and pasture, with foraging animals, the trees provide shade and/or forage while the animals provide manure. Thus, agroforestry systems limit the risks and increase sustainability of both small- and large-scale agriculture. Agroforestry systems may be thought of as principle parts of the farm system itself, which contains many other sub-systems that together define a way of life.

## Summary of Benefits of Agroforestry

- Improved year-round production of food and of useful and salable products.
- Improved year-round use of labor and resources.
- Protection and improvement of soil (especially when legumes are included) and water sources.
- Increased efficiency in use of land.
- Short-term food production offsetting cost of establishment of trees.
- Furnishing of shade for vegetable or other crops that require or tolerate it.
- Medium and long-term production of fruits.
- Long-term production of fuel and timber.
- Increase of total production to eat or to sell

Exploitation of interactions between woody and nonwoody (herbaceous or annual crop) components is the key to the success of all agroforestry (AF) systems. Therefore, a better understanding of the interactions provides a impetus strong for improvement of traditional, as well as evolving, systems

## Radition use in agroforestry systems

In agroforestry, tree and agricultural crops are combined together and they compete with each other for growth resources such as light, water and nutrients. The resource sharing by the components may result in complementary or competitive effects depending upon the nature of the species involved in the system, the manner in which they are grown and depending on the climatic factors, plants and trees may influence its neighboring species, not only adding or removing of some factor, but also by affecting conditions such as temperature, light or wind movement or by altering the balance between beneficial and harmful organism. Opportunities for substantial temporal complementarity exist for storable resources like water and nutrient in a system if major resources demand is at different times. On the other hand for unstorable resources like light spatial complementarity is the only phenomenon available.

The important factor to be considered here is the Maximum light-use efficiency. The biomass yield limit is set by the available amount of light, its efficiency of interception and the efficiency with which intercepted light is converted into biomass. Ecophysiological models calculate quantitative phenotypic traits (e.g. transpiration rate, expansion rate of organs or biomass accumulation) from environmental inputs such as organ temperature, light irradiance or soil water potential.

The capture of radiation and its use in dry matter production depends on the fraction of the incident photosynthetically active radiation (PAR) that is intercepted and the efficiency with which it is used for dry matter production. Intercepted radiation ( $S_i$ ) is often estimated as the difference between the quantity of incident radiation ( $S$ ) and that transmitted through the canopy to the soil ( $S_t$ ). However, this approach has inherent technical and theoretical difficulties since it does not account for the reflection of incident radiation from the canopy surface (typically 5–20% depending on surface characteristics and moisture content), or for radiation intercepted by non-photosynthetic canopy elements. As a result, interception by photosynthetically competent tissues may be greatly overestimated, particularly for canopies which are senescing or contain numerous woody structural elements. Corrections for these errors have often been ignored when estimating  $S_i$  and photosynthetic efficiency.

The quantity of radiation intercepted depends on the amount received by the canopy, its size and duration and fractional interception ( $f$ ). The seasonal time course of  $f$ , defined here as  $S_i/S$ , varies greatly depending on canopy architecture and the phenology of the vegetation involved; thus,  $f$  increases more rapidly in cereals such as sorghum (*Sorghum bicolor*) than in legumes such as groundnut (*Arachis hypogaea*), reflecting their differing rates of leaf initiation and expansion. The variation in  $f$  between crops is generally smaller than that in green leaf area index, partly because the extinction coefficient for radiation ( $k$ ) is often larger in species whose canopy expands slowly; maximum  $f$  values may therefore differ little between crops grown under non-limiting conditions. Mean  $f$  values calculated over the duration of the crop ( $f_N$ ) are generally lower in short-duration cereals (ca. 0.5) and legumes (ca. 0.15) than in perennial species (ca. 0.9), largely because of the differing duration of ground cover

The conditions and methodologies used in radiation studies in monocropping and annual crops are clearly not met in intercrops or agroforestry systems because of the extensive horizontal and vertical variation in canopy structure introduced by the intimate mixture of species with differing planting dates and arrangement, heights and maturity dates. Canopy architecture is also constantly changing in mixed cropping systems because of the differing growth rates and canopy durations of the component species. For example, compact legumes growing adjacent to taller cereals initially experience greater competition than in the equivalent monocrop because of the faster growth of the cereal, but subsequently experience less competition for much of the reproductive phase due to the earlier harvest of the cereal component. The methodological problems involved in characterising the spatial and temporal variation in radiation interception are much greater in mixed communities than in monocultures, and the partitioning of radiation interception (and also water uptake) between the components of such systems has provided a major challenge. When growth is not limited by water or nutrient supplies, the quantity of biomass produced by monocrops is limited primarily by the quantity of radiation captured.

Transmitted radiation under trees shows variability in space and time that may have implications for the understorey. Light measurements are made in a young agroforestry system to assess the radiation distribution below the tree canopy. Measurements show that the variability of the

transmitted radiation is mostly due to the size of the tree shadow and to the irradiance distribution in the shaded area. The light measurements are used to test the predictive capacity of a three-dimensional radiative transfer model based on the turbid medium analogy. The model correctly simulates the fraction of sunlit area and the irradiance distribution in the shaded area. However, it underestimates low radiation values and fails in describing the fine spatial pattern of transmitted radiation because of the stochastic nature of the radiation field. To obtain a mean error less than 15% of the incident radiation, the distribution of transmitted radiation has to be described by elementary soil surface areas over 0.08 m<sup>2</sup>. By manipulating time and number of hedgerow prunings and pruning height, it was possible to reduce competition for light and water and to decrease water stress in the crop, thereby increasing crop yield. The use of the acquired resources was therefore assumed to depend on the conversion coefficient of the species involved and environmental influences such as drought. A major advantage of expressing productivity in these terms is to emphasise the apparent conservativeness of  $e$  under many conditions. This approach has subsequently been widely adopted in studies of resource partitioning in intercropping and agroforestry.

### **Shade Tolerance**

Currently, there is no acceptable definition of shade tolerance but it may best be defined, agronomically, as the relative growth performance of plants in shade compared to that in full sunlight as influenced by regular defoliation. It embodies the attributes of both dry matter (DM) productivity and persistence. Morphological acclimatisation of forages to light attenuation is an adaptive strategy to compensate, at least partially, for the lower photosynthetic rate per unit leaf area. In addition, chemical changes may also occur under low light to enhance photosynthetic efficiency. For both grasses and legumes, species differences were greater under moderate to high light transmission than under low light. The low yield potential of all species in low light remains a major constraint to forage productivity in plantations which close their canopies with age. However, in plantations with open canopies such as coconut, species with medium shade tolerance can be exploited to obtain higher yields.

### **Challenges Ahead**

Progress in tropical agroforestry is more advanced, and perhaps more urgent at present, than in temperate agroforestry. However, many challenges still lie ahead in tropical agricultural research. So far, most studies have considered only two species growing simultaneously in intercropping or agroforestry systems, but the question remains of how to deal with the multi-species ecosystems which typify the vast majority of tropical agriculture. It is not an exaggeration to say that scientists and development experts are somewhat frustrated about the results and progress of agroforestry research. Scientists are unhappy that the science of agroforestry has not progressed to the extent desired and are, perhaps, also concerned that progress during the immediate future will be no brighter. Another major challenge facing tropical biologists is how to look beyond the plot and farm in order to deal with the 'interactions' between the mosaic of land uses at the landscape, regional and global scale. For example, agroforestry practices such as boundary planting and the use of widely scattered trees may create extensive interactions both above-ground in terms of microclimatic modifications and below-ground in terms of resource capture since tree roots may extend 20–60m from the trunks. Hence more progress may be made by defining relevant concepts and establishing general principles, than by collecting yet more empirical information.