Agroforestry Systems 34: 27–31, 1996.

The central agroforestry hypothesis: the trees must acquire resources that the crop would not otherwise acquire

M. G. R. CANNELL[1], M. VAN NOORDWIJK[2] and C. K. ONG[3]
[1] *Institute of Terrestrial Ecology, Bush Estate, Penicuik, Midlothian EH26 OQB, UK;* [2] *ICRAF-S.E. Asia, P.O. Box 161, Bogor 16001, Indonesia;* [3] *ICRAF, P.O. Box 30677, Nairobi, Kenya*

Key words: competition, resource capture, agroforestry hypotheses

Abstract. A simple tree-crop interaction equation is re-interpreted in terms of resource capture. Benefits in physical yields from agroforestry are to be expected only when there is complementarity of resource capture by trees and crops. Most of the current biophysical hypotheses formulated for agroforestry research are based on this central tenet, specified for various resources, soil and climatic conditions.

Introduction

The overall objective of agroforestry research is to identify those circumstances (biophysical, socio-economic and policy) in which growing trees will give benefits to farmers. A common approach has been to consider the merits of different agroforestry 'systems', like alley-cropping, parklands, relay-intercropping and home gardens in different climatic regions (Nair, 1989). If the problem is to identify the socio-economic as well as the yield benefits of tree-crop combinations, then it may be important to consider the 'system'. But if the problem is to identify those circumstances in which growing trees and crops together can yield more biomass than growing crops alone, then it is more logical to think in terms of the physical resources of water, light and nutrients that are acquired or 'captured' by the trees and crops, regardless of the 'system' (Monteith et al., 1994). Although Price (1995) indicated a number of specific situations where agroforestry can give greater economic benefits than either a sole-crop or a sole-tree system in the absence of any biophysical yield increase, such situations are the exception rather than the rule and biophysical yield benefits are a good starting point for a more complete economic evaluation.

Recently, Ong (1995) and Ong et al. (1996, see also Sanchez, 1995) put forward the following equation:

$$I = F - C \tag{1}$$

where:

I = the net increase in crop yield attributable to the presence of trees, estimated over the land area occupied by crops plus trees, compared with sole-crop yield,

F = the fertility effect, i.e., the increase in crop yield attributable to favourable effects of the trees on soil fertility and microclimate; in Ong (1995), F is due to tree pruning effects, while the microclimate modification due to the tree canopy is represented by M, which may be positive or negative, and

C = the competitive effect, i.e., the decrease in crop yield attributable to competition with the trees for water, nutrients and light.

Essentially, Equation 1 says that crop yields will increase (i.e., I will be positive) when the beneficial effects of the trees on crop yield (F) are greater than the harmful effects (C). The merits of the equation have recently been the subject of correspondence in this journal (see: Letter to the editor by DCL Kass and the reply from P. A. Sanchez, Agroforestry Systems 33: 101–108, 1996). Here, we attempt to re-formulate the equation in terms of resources captured by the trees and the crop.

Resource-base for tree-crop interactions

Equation 1 can be generalized in terms of resource capture as follows:

$$I' = F' - C' \quad (2)$$

I'	=	F'	–	C'
Increase in crop yield		Increase due to resources of water, light and nutrients acquired by the trees		Decrease due to resources taken by the trees

F' and C' can each be divided into two components, as follows:

$$F' = F_{comp} + F_{noncomp} \quad (3)$$

and

$$C' = C_{comp,\ recycled} + C_{comp,\ nonrecycled} \quad (4)$$

where F_{comp} represents the resources acquired by the trees at the expense of the crop (i.e. competitively), $F_{noncomp}$ represents the resources acquired by the trees that the crop would not otherwise acquire (i.e. non-competitively), $C_{comp,\ recycled}$ represents the resources that the crop is deprived of by the trees, but the nutrients that are acquired can be recycled to benefit the (next) crop, and $C_{comp,\ nonrecycled}$ represents the resources that the crop is deprived of which are used in tree growth and are not recycled.

It could be argued that F_{comp} is approximately equal to $C_{comp,\ recycled}$ that is, that the resources that the trees obtain competitively are the same resources that the crop is deprived of which can be recycled, so that:

$$I' = F_{noncomp} - C_{comp,\ nonrecycled} \quad (5)$$

and thus

$$I' + C_{\text{comp, nonrecycled}} = F_{\text{noncomp}} \tag{6}$$

Equation 6 states that the increase in crop yield brought about by the presence of trees plus the benefit in tree growth, is equal to the quantity of environmental resources that the trees acquire which would not otherwise be acquired by the crop. There is, of course, nothing new in this statement, but this simple analysis shows that the equation of Ong (1995) is no more than a statement about complementarity in resource capture.

If the trees have no direct value but only play a 'support' function, the resources represented by $C_{\text{comp, nonrecycled}}$ do not contribute to the overall benefit function. In that case a tree-crop combination is useful only if I' is positive, i.e. if $F_{\text{noncomp}} > C_{\text{comp, nonrecycled}}$, which means that there is an *absolute* positive effect. If the trees have a direct value as well as a support function, then the total benefit function can be positive if:

$$I' + \alpha * C_{\text{comp, nonrecycled}} = F_{\text{noncomp}} - (1 - \alpha) * C_{\text{comp, nonrecycled}} > 0 \tag{7}$$

or

$$F_{\text{noncomp}} > (1 - \alpha) * C_{\text{comp, nonrecycled}} \tag{8}$$

where α is the fraction of the tree resources reflected in tree products, multiplied by the economic ratio of crop and tree products. Equation 8 shows that the higher the direct value of trees, the smaller the F_{noncomp} term has to be to justify a tree-crop combination. For $\alpha = 1$, when trees and crops give equal 'direct value' per unit resources of water, light and nutrients used, the requirement is simply that $F_{\text{noncomp}} > 0$, or at least some complementarity in resource use (Van Noordwijk, 1996).

Biophysical agroforestry hypotheses re-visited

We suggest that the central *biophysical* hypothesis for agroforestry research is that:

> *benefits of growing trees with crops will occur only when the trees are able to acquire resources of water, light and nutrients that the crops would not otherwise acquire*

Thirteen of the 16 biophysical agroforestry hypotheses given by Sanchez (1995) follow from this central hypothesis.

Thus, when *water* is limiting, trees can increase total yield when they increase the fraction of rainfall utilised in plant growth, lessening the fraction that is 'wasted' by soil evaporation, surface runoff and drainage, increasing the fraction that is returned to the atmosphere via stomata (hypotheses 12, 13 and 14).

When *light* is limiting, trees increase total yield when they increase the fraction of annual incident radiation that is intercepted by foliage and used in photosynthesis, which is most likely to occur when the tree and crop canopies develop at different times of year (hypothesis 15).

When *nutrients* are limiting, trees can increase total yield when (i) trees can access nutrients at depth, laterally in non-cropped zones or from chemically occluded forms that are inaccessible to crops, (ii) trees capture nutrients that would otherwise be leached due to incomplete 'synchrony' of supply and demand (providing a 'safety net' so that the system is less 'leaky') and/or when (iii) N_2-fixation by the trees augments N inputs and the fraction of N derived from fixation by the trees exceeds the harvest index (so that more N is added to the tree-crop-soil system) (hypotheses 4, 5 and 6). Hypothesis 11 of Sanchez (1995) states that N_2-fixation can be stimulated by intercropping, and thus elaborates on hypothesis 4. Where trees intercept sediment eroded elsewhere in the field, they probably retain resources in the field which would otherwise be lost (hypothesis 1). Soil erosion control (hypothesis 1) can be based on the presence of surface mulch, increased water infiltration rates due to soil structure improvement and more complete water use (Kiepe, 1995).

When *water, light or nutrients* are acquired by the trees that would otherwise not be acquired by the crop there is likely to be increased biomass production (increased net primary productivity), which may then improve soil fertility by increasing soil organic matter levels, soil physical properties and temporarily reducing soil acidity (hypotheses 2, 3, 7 and 9).

Clearly, increased acquisition of the limiting resource will always be accompanied by increased use of the non-limiting resources: no nitrogen can be assimilated without producing carbon, no carbon can be fixed without intercepting light and no photosynthesis is possible without evaporating water. Thus, the best opportunities for complementarity exist if shortage of one particular resource is clearly limiting plant growth, but other resources are under-utilized and available.

Three hypotheses of Sanchez (1995) are not covered in this analysis. These hypotheses are mostly based on specific effects of trees on the efficiency with which crops utilizes resources captured for growth.

- Hypothesis 8 states that agroforestry can help to reclaim degraded soils, but this formulation is too general, as Sanchez (1995) remarked. It should be specified which resources are limiting and which ones are abundant in a specific 'degraded' soil before it can stated what benefit trees may give.
- Hypothesis 10 states that shade from a tree canopy improves soil biological activity and N mineralization, but it is not clear which aspects of soil biological activity are limiting in a non-agroforestry cropping system in

general. This hypothesis might refer to suppression of specific soil-borne diseases, to the 'synchrony' of N mineralization and crop demand, or to a beneficial lowering of soil temperatures in the tree canopy shade.

- Hypothesis 16 states that competition for water can be reduced by manipulating the spatial arrangement of trees. This may refer to a) the effects of trees on microclimate, by modifying the windspeed and humidity, on water use efficiency of the understorey crop, or b) the distribution of tree roots. Current evidence from ICRAF's Machakos Research Station (rainfall 750 mm per year) indicates that improvement in microclimate is considerably less important than root competition.

References

Kiepe P (1995) Effect of *Cassia siamea* hedgerows barriers on soil physical properties. Geoderma 66: 113–120

Monteith JL, Scott RK and Unsworth MH (1994) Resource Capture by Crops. Nottingham University Press, Sutton Bonnington, UK, 469 pp

Nair PKR (ed) (1989) Agroforestry System in the Tropics. Kluwer, Dordrecht, The Netherlands, 664 pp

Ong CK (1995) The 'dark side' of intercropping: manipulation of soil resources. In: Sinoquet H and Cruz P (eds) Ecophysiology of Tropical Intercropping, 482 pp. Institute National de la Recherche Agronomique, Paris

Ong CK, Black CR and Marshall FM (1996) Principles of resource capture and utilisation of light and water. In: Huxley PA and Ong CK (eds) Tree-Crop Interaction, A Physiological Approach, Chapter 4. CABBI, Wallingford, UK

Price C (1995) Economic evaluation of financial and non-financial costs and benefits in agroforestry development and the value of sustainability. Agrofor Syst 30: 75–86

Sanchez PA (1995) Science in agroforestry. Agrofor Syst 30: 5–55

Van Noordwijk M (1996) A simple model to quantify mulch and shade effects. In: Ong CK and Huxley PA (eds) Tree-Crop Interactions – A Physiological Approach. CABI, Wallingford, UK (in press)