CONCEPTS OF AGROFORBSTRY

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ABSTRACT

The existence of large numbers of people In the fragile ecosystems of the developing world, and the fact that these ecosystems occupy the greater proportion of the land of the developing economies suggest that means must be devised which will assist in Increasing the productivity of these ecosystems while at the same time either rehabilitating them or arresting the process of degradation. Agroforestry is a system of land management which seems to be suitable for these ecologically brittle areas, It combines the protective characteristics of forestry with tbe productive attributes of bath forestry end agriculture. It conserves end produces. It is suggested that if the concepts of competition among plants are understood, and appplied in the practice of the system of agroforestry, the system would achieve the objectives that have been stated above. The important considerations are that species must be chosen for their complementarity, and for their ability to utilise in harmony water, nutrients and solar energy, over time.

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Definition of agroforestry

Early in 1977, at the Royal Tropical Institute in Amsterdam in Holland, a group of us was assigned the task of defining agroforestry. The group came up with the following definition:

> "Agroforestry is... a sustainable management system for land that increases overall production, combines agriculture crops, tree crops, and forest plants and/or animals simultaneously or sequentially, and applies management practices that are compatible with the cultural patterns of the local population". (See Bene et.al., 1977).

Later, we at ICRAF amplified the definition slightly to read as follows:

> "Agroforestry has been defined as a sustainable land management system which increases the overall yield of the land, combines the production of crops (including tree crops) and forest plants and/or animals simultaneously or sequentially, on the same unit of land, and applies management practices that are compatible with the cultural practices of the local population" (King and Chandler, 1978).

You will note that by the addition of the phrase "on the same unit of land" we sought to emphasize that zonal arrangements of agricultural crops and forest crops were not considered to be agroforestry, and to imply that the mixtures of the combined agricultural and forest crops should be intimate. However, it is still considered that the definition is inadequate, because, for example, it does not tell us what is meant by a "unit of land", and hence cannot help us to comprehend fully what is the degree of intimacy required to distinguish agroforestry systems from systems in which agriculture and forestry are, to some extent, zoned or occupy adjacent but distinct blocks, or in which there are strips (or lines) of forest trees alternating with strips (or lines) of agricultural crops.

The definitions are inadequate in another respect, in that they do not distinguish the many types of systems which may possibly fall within their ambit. Accordingly, I repeat here an attempt which I have already made (King, 1978) to add to the definitions, to explain more fully the concepts of agroforestry, and to delineate various sub-divisions of the subject.

Agroforestry should be considered to be a generic term which embraces the following specific components:

Agri-silviculture - the conscious and deliberate use of land for the concurrent production of agricultural crops (including tree crops) and forest crops.

Sylvo-pastoral systems - land management systems in which forests are managed for the production of wood as well as for the rearing of domesticated animals.

Agro-sylvo-pastoral systems - in which land is managed for the concurrent production of agricultural and forest crops and for the rearing of domesticated animals. This system is, in effect, a combination of agri-silviculture and the sylvo-pastoral system.

Multi-purpose forest tree production systems - here forest tree species are regenerated and managed for their ability to produce not only wood, but leaves and/or fruit that are suitable for food and/or fodder.

The questions of intimacy of mixture, and of the widths and extent of zones, blocks, strips and rows are still not resolved, however, by these definitions. It is suggested, as a working hypothesis, that agroforestry might be considered to be practised whenever trees and agricultural crops are grown in mixture, provided that the combined widths of the rows of agricultural crops do not exceed the heights, at maturity or at the end of the selected rotation, of the forest tree crops with which they are grown in mixture; provided further that the combined widths of the rows of the forest tree crops do not exceed the height of the tree crop at maturity or at some selected rotation. This suggestion takes into account, to some extent, the possible competitive influence of the tree crop on the growth of the agricultural crop. It assumes that agriculture crops that are grown in strips etc. that are no wider than the final heights of the trees will be positively influenced by the ameliorating effects of the trees on the site.

premises of agroforestry

The premises on which the concept of agroforestry is based are partly biological and partly socio-economic.

a. Biological premises

It is known that, generally, forests have a beneficent effect on the soil. The roots of forest trees take up nutrients from the soil, convert and utilize them for the production of plant material, and then return them to the forest floor in the form of leaves, twigs, branches, fruit, etc. This litter is transformed into humus, and later incorporated into the soil. It is this cycle of uptake, deposition and uptake again which accounts for the presence of forests on soils that are inherently low in nutrients; soils which are often incapable of sustaining annual agricultural crops, the harvesting of which, remove most of the organic matter that has been manufactured by the plant. For, a well managed forest is to a large extent a closed system, and can be maintained that way.

The relatively efficient nutrient cycle is only one of the ways in which the forests minimize the leakages of nutrients from the system. Trees are generally deeper-rooting than other types of crops, and are often able to trap and utilise nutrients that have been leached from the upper layers of the soil. In addition, it is often claimed that some tree species have the capacity of "pumping" nutrients from layers that are not normally tapped by other forms of plant-life. This nutrient pumping attribute implies, of course, that the natural nutrient input side of the equation in a forest is greater than that in an agricultural field.

Moreover, the physiognomy of a forest is such that it provides a many-layered defence against precipitation. The crowns in the canopy, and those in the intermediate strata of the forests, progressively reduce the potential impact of rain on the soil below. In addition, the litter and humic layers on the soil surface act as a further cushion. The net effect is that the compacting effects of falling rain on the soil are reduced, there is little or no erosion on the forest floor, and another possible source of leakage of nutrients from the system is at least partially plugged.

There are other attributes.- The most important properties of the earth's surface which influence climate, and which human activity can influence, are

17 The following few paragraphs are based on King, K.F.S. (1976) Forest Resources of the World. Congress Rep.XVI IUFRO World Congress. Oslo

Reflectivity, heat capacity and conductivity, availability of water and dust, aerodynamic roughness, emissivity in the infra-red band, and heat released to the ground (Wilson, 1970).

In all these aspects the forests are important. The reflectivity of the forests is low because of the high radiant absorptive capacity of their green leaves when converting radial energy to chemical energy. Indeed, it is well established that densely built up areas, and deserts as well as grassland, have a higher albedo than forests, and that a unit increase in the earth's albedo will cause a decrease in average surface temperature of 1.8°F (U.S.A. Congress, 1970). Recently, in an interesting experiment two integrations of a global general circulation model, differing only in the prescribed surface albedo in the Sahara, showed that an increase in albedo resulting from a decrease in plant cover causes a decrease in rainfall. Thus, any tendency for plant cover to decrease would be reinforced by a decrease in rainfall, and could initiate or perpetuate a drought (Charney et.al., 1975).

Moreover, because large amounts of latent heat are fixed during the evapo-transpiration process, the capacity of the forests to absorb heat is high. In contrast, forests have a low heat conductivity, because their thick and complex structure prevents rapid cooling or heating, and regulates the heat released to the ground (FAO, 1972).

In addition, forests, by acting as windbreaks, create aerodynamic roughness and assist in arresting dust particules. Their emissivity of the infra-red band is also very high. It is evident, therefore, that the forests play roles which affect all the important factors which influence climate.

This list of the influence of the forests on the micro-climate, and thus of the "forest environment's" capacity for positively influencing the growth of other plant types associated with it, is not exhaustive. It is submitted, however, that it is sufficiently long and wide-ranging to indicate that trees grown in mixture with agricultural crops, or agroforestry systems, might *a priori*, especially in brittle ecosystems, be a productive form of land-use.

There are of course possible constraints: problems of competition for water and nutrients, and problems with respect to competition between the trees and the agricultural crops for solar energy, but these will be discussed in another section of this paper and an attempt will be made to suggest solutions.

B. socio conomic premises

The Socio -conomic factors on which the potential value of agroforestry is are perhaps more straight-forward.

First, forests are being felled in all the developing continents of the world by farmers who require the land to produce food for their very existence. Often, the areas that are so felled are basically unsuited to arable agriculture, either because of the inherent infertility of the soils, or because the sites are prone to accelerated erosion if not under forest cover, or because of a combination of these factors.

The people who clear the forests to produce food are often not unaware of the possibly deleterious effects of their practices upon the ecosystem: in terms of erosion hazards, the possibility of droughts and floods, and the possibility of soil fertility decline. Yet, despite their knowledge of these adverse consequences, they persist in their acts of forest destruction and of destructive land-use. They persist, because to them there are no other courses of action. They are positive that to survive they must destroy and degrade.

Secondly, the consequences of ill-advised land-use are often experienced not only in the areas in which such practices are perpetrated, but also in others that are either adjacent or far-removed from the originally damaged sites. Rivers flood valuable arable land and crops, reservoirs are silted, droughts occur and crops fail; there is famine, there is loss of life, and the total effects on the general economy are burdensome and debilitating.

Third, the failure to develop the marginal lands often leads to a retardation of the rate of development of the general economy. The social and economic arguments that are frequently adduced in support of theses advocating rural development in general, can be applied with even greater force to the brittle and marginal ecosystems of the tropics. The point is that the developmental and technological options are fewer in marginal than in most other ecosystems.

Accordingly, if inequities that are based on the accidents of geography are not to be perpetuated, if the economies of the developing countries are not to remain skewed in favour of urban areas and of those rural areas that can be farmed in the conventional way, and if the creation of tropical urban slums through the failure of infrastructural development to keep pace with rural migration to the towns is to be avoided, then special efforts should be made to develop a technological package that might be used in marginal ecosystems.

It is one of the arguments of this paper that when the biological influences and services of forests are considered along with the specific socio-economic problems of those who exist in marginal areas, together with the general developmental problems of national economies, this technological package should include agroforestry systems.

Some socio-economic myths regarding the application of agroforestry

The literature is replete with statements which purport to show that if there is no land-hunger and if there is not severe unemployment, agroforestry systems, or more specifically taungya or agri-silvicultural systems, cannot be successfully implemented. Moreover, in a survey which was made a decade ago (King, 1968) most foresters who practised the taungya system gave as their opinion that land-hunger and unemployment were prerequisites.

This is not surprising when it is realised that foresters have in the past concentrated the establishment of forest plantations in their forest reserves: "Forest Departments by the early blanket reservation of unoccupied or poorly occupied high forest land, have created a paradoxical situation. By effectively keeping farmers outside the forest reserves they have in fact acted as land banks of natural high forest, retaining land capital for possible future development outside forestry. Without such reservation, the land now suitable for cultivation might have been long exhausted. On the other hand, this type of reservation has often led to a local shortage of agricultural land, and where the system of shifting cultivation is still practised to a reduction of the fallow period with its attendent evils. In addition, the construction of roads to open up an area of logging also often brings about a population migration to the area, resulting in local land-hunger" (King, 1968).

The point that is being made is that the system of agri-silviculture has been practised,in the past, mainly in the forest reserves, that the farmer had no rights to the land within these reserves, that the land-hunger was in most cases created by the Forest Departments, and that unless a person was destitute (i.e. unemployed and landless) there was no incentive for him to practise agroforestry.

Moreover, the farmers were to some extent exploited by the Forest Departments, in that they were not permitted to farm more than two or three years between the rows of tree crops, the initial espacements were designed so that the forest could establish a closed canopy as quickly as possible, no attempt was made to examine the feasibility of keeping the farmers on the land for longer periods, and in most cases the farmer received no payments for the work which he performed in tending the Forest Department's tree crops. Indeed, the the system was geared to conditions of land-hunger and unemployment which had, in the past, been created by the exploiters.

it is suggested that if the economic returns which accrue to the farmer are siginificant; if the system is designed to optimise the joint productivity of wood and food from the same unit of land; and if the choice of agricultural and forest species, initial espacements, and management practices were such as to permit the farmer to stay on the land for longer periods than he has been hitherto allowed, then the strictures imposed on the system with regard to its socio-economic pre-conditions would no longer apply.

Some Biological Considerations in Agroforestry

Agroforestry is a system of land management in which tree crops are grown together with agricultural crops, one objective being to optimise and sustain the joint yields of the combined crops. We have already examined, albeit sketchily, those characteristics of forest stands which contribute to the reduction in nutrient leakages from the soil, the re-cycling of nutrients, the increase in nutrient levels in the soil, and the amelioration of the micro-climate in the forest area. These, it has been submitted, would positively contribute to the optimisation and sustention of the joint yields of the combined crops, provided that the influence of the tree crops on the agricultural crops and vice versa do not adversely counteract the positive influences of the forest ecosystem. In other words, provided that competition among the different components of the system is not great enough to affect the total productivity of the system in an adverse manner.

Clements et.al. (1929) have described competition as a purely physical process. The authors go on to say that "with few exceptions, such as the crowding of tuberous plants when grown too closely, an actual struggle between competing plants never occurs. Competition arises from the reaction of one plant upon the physical factors about it and the effect of the modified factors upon its competitors. In the exact sense, two plants, no matter how close, do not compete with each other so long as the water content, the nutrient material, the light and the heat are in excess of the needs of both. When the immediate supply of a single necessary factor falls below the combined demands of the plants, competition begins".

Donald (1963) has expressed the same principle in another way: "Competition occurs when each of two or more organisms seeks the measure it wants of any particular factor or thing and when the immediate supply of the factor or thing is below the combined demand of the organisms".

Both Clements (1929) and Donald (1963) have stressed that competition for space is exceptional, and that what are really important are water, nutrients, light, oxygen and carbon dioxide. In the reproductive phase, the agents of pollination and dispersal are of course important. Temperature and humidity which also affect growth are not commodities in finite supply and therefore are not the subject **of competition.**

Water nutrients and light are the factors most commonly in short supply, and it is these **that will be borne in mind in the** discussion which follows. However, **it is perhaps apposite at this stage, before referring** specifically **to** the **agroforestry requirements, to emphasize the following:**

1) **"Most of the factors for which there is competition** are **found as** a **pool of material from which competitors** draw **their** supplies. If **the pool is of limited volume, or if it** is subject to intermittent **depletion by the** competing plants, then the successful competitor is the plant which draws most rapidly from the pool or which can continue to withdraw from the pool when it is at low ebb or when its contents can no longer be tapped by other plants. If all the plants in the community are nearly equal in competitive ability. . . . they will tend to share equally in its supply until it is exhausted, and then, simultaneously, to suffer the effect of depletion of the pool". The foregoing applies chiefly to water.

ii) **With** respect to nutrients, "the capacity to draw from the pool is in varying degree an expression of the differing ability of plants to **make** use of the nutrient **in different** chemical and physical forms".

iii) The concept of **a** "pool" is not applicable, is not valid, when competition for light is considered. "There is no store of light energy in the immediate environs of the plant... Light is available as a passing stream which must be intercepted by the leaves if it is not to be permanently lost to the plant. A dense canopy will intercept **all** light, but the young crop characteristically covers only a small proportion of the soil surface and most of the energy is absorbed or reflected by the soil" (Donald, 1963).

General conclusion may be drawn from this, simplified analysis of the important factors and processes in plant competion, with respect to agroforestry. As far as possible, the forest and agricultural species that are utilized in the system should be compatible and should complement each other in growth patterns over most stages of their lives. More specifically, with respect to water they should be unequal in competitive ability; with respect to nutrient, they should vary in ability to utilise the nutrients in different forms; and, with respect to light, those species should be selected which display growth patterns, rates of growth, phenology, and architecture which permit maximum interception by both the agricultural and forest crops at any one time, but which also minimises competition between the two groups of crops at all stages of their growth.

Elsewhere (King, 1979), I have indicated the characteristics of the tree species that should be grown in agroforestry systems:

a. they should be amenable to early wide espacement;
b. they should possess self-pruning properties;
c. if not self-pruning, they should be able to tolerate relatively high incidences of pruning, i.e. their photosynthetic efficiency should not significantly decrease with heavy pruning;
d. they should have a low crown diameter to bole diameter ratio i.e. the width of their crowns should be small relative to bole diameter;
e. they should be light-branching in habit;
f. they should be tolerant of side-shade, if indeed not of full over **head** shade in the early stages of growth;
g. their phyllotaxis should permit the penetration of light to the ground;
h. their phenology, particularly with respect to leaf flushing and leaf-fall, should be advantageous to the growth of the annual crop in conjunction with which they are being raised;
1. their rate of litter fall and litter decomposition should have positive effects upon the soil;
j. their "above ground" changes over time in structure and morphology should be such that they retain or improve those characteristics which reduce competition for solar energy, nutrients and water;
k. their root systems and root growth characteristics should ideally result in the exploration of soil layers that are different to those being tapped by the agricultural species; and
1. they should be efficient nutrient pumps.

This list of characteristics of the ideal tree species for use in agri-sllvicultural systems is not exhaustive, but it indicates the principles which should be followed in the selection of such species. In addition, cognisance must be taken of the known responses of the tree species to various management practices (such as pruning, thinning, and coppicing, for example) and to individual tree and stand manipulation. The same procedure should be followed with respect to the agricultural crop component of the system.

Put in another way, the plant architecture and morphology, the phenology of woody perennials, and the root distribution, root growth and root activity of the trees, must be examined. Moreover, assessments must be made of those factors which affect net carbon fixation with respect to such factors as species differences, differing source/sink situations for annuals and perennials, and leaf and plant ageing.

In addition, the influence of genotype and environment on dry matter distribution in herbaceous and woody plants; the effects of management on plant growth, dry matter distribution and plant development; and the factors affecting the plant's nutrient needs and the distribution of nutrients within plants should be examined.

Although there is very little information regarding competition in agroforestry systems per se, it must not be imagined that no knowledge exists which is applicable to competition in agroforestry systems, with respect to conventional agriculture and conventional forestry. This is not the place to review the prodigious volume of literature that is extant, but Iwaki's (1959) work on interspecific competition in plant communities, Hall's (1974 and 1974a) and de Wit's (1960 and 1963) work on the nature of interference between plants of different species, the analysis of Trenbath and Angus (1975) on the relationship of leaf inclination and crop production, Grime's (1966) investigations on shade avoidance and tolerance, and the studies of Puckridge and Donald (1967) on competition among plants sown at a wide range of densitites, give but a small proportion of the knowledge that is already available and that can be used with advantage in the practice of agroforestry, in the formulation of research policies and in the design of research projects in agroforestry. More important in the context of this paper, they indicate the concepts which may be applied to agroforestry systems.

lt is also possible to construct predictive, models which would suggest the probable responses of plants in various mixtures and combinations in agroforestry systems (Trenbath, 1974 and 1978)

REFERENCES "

Bene, J., Beall, H., and Cote, A. (1977) - Trees, Food and People, IDRC Ottawa.

Charney J., Stone, P., and Quirk, W. (1975) -Drought in the Sahara. Science, Vol. 48

Clements, F.E., Weaver, J.E. and Hanson, H. (1929) - Carnegie Inst.Wash. Publ. 398

Donald, C M . (1963) - Competition among crop and pasture plants. Adv.Agron. 15.

F.A.O. (1972) - Environmental Aspects of Natural Resources Management: Forestry. U.N. Conf. on the Human Environment, Stockholm.

Grime, J.P. (1966) - Shade avoidance and shade tolerance in flowering plants. In R.Bainbridge, A.C. Evans and 0. Rackham (Eds). Light as an Ecological Factor. Blackwell's. Oxford

Hall, R.C. (1974) - Analysis of the nature of interference between plants of different species. I Concepts and extension of the De Wit analysis to examine plants. Aust. J.Agr.Res. 25.

Hall, R.C. (1974a) - Analysis of the nature of interference between plants of different species. II Nutrient relations in a Nandi Setaria and greenleaf Desmodium association with particular reference to potassium. Aust.J.Agr.Res. 25.

Iwaki, H. (1959) - Ecological studies on interspecific competition in a plant community.I. Jap.Journ.Bot. 17(1)

King, K.F.S. (1968) - Agri-Silviculture. University of Ibadan, Ibadan

King, K.F.S. (1976) - Forest Resources of the World. Congr. Rep. XVI IUFRO World Congress. Oslo

King, K.F.S. (1978) - Agroforestry. In Pm.c. 50th Symposium on Trop.Agr. Bul. 303, Dept. of Trop.Agr. Res., R.T.I. Amsterdam.

King, K.F.S. (1979) - Some principles of Agroforestry. Pap.Pres.Mat. Seminar on Agroforestry, India - Imphal.

King, K.F.S. and Chandler, M.T. (1978) - The Wasted Lands. ICRAF, Nairobi

Puckridge, -D.W. and Donald C M . (1967) - Competition among wheat plants sown at a wide range of densitities. Aust.J.Agric.Res. 18.

Trenbath, B.R. (1974) - Application of a Growth Model to Problems of The Productivity and Stability of Mixed Stands. Proc.l2th Int. Grassland Congr. Moswow

Trenbath, B.R. (1978) - Models and the interpretation of mixture experiments. In Plant Relations in Pastures,J.R. Wilson (Ed.). CSIRO, Melbourne.

Trenbath, B.R. and Angus, J.F. (1975) - Leaf Inclination and Crop Production, Field Crop A
Wilson, C.L. (Ed.) (1970) - Man's Impact on the Global Environment M. I. T. Boston

de Wit, C.T. (1960) - On competition. Verst. Landbouwkd. Onderz. 66(8)

de Wit, C.T. (1965) - Competition between herbage plants. Nath. J. Agric. Sci. 13.

U.S.A. Congress (1970) - The First Annual Report of the Council
on Environmental Quality. Washington, D.C.