MAN AND TREE IN TROPICAL AFRICA

three essays on the role of trees in the African environment

by Gunnar Poulsen

IDRC-101e

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three essays on the role of trees in the African environment

Gunnar Poulsen

The views expressed in this publication are those of the author and do not necessarily reflect the views of IDRC.

Foreword

Increasing awareness has recently been shown in the ability of trees not only to produce a variety of products but also to provide and maintain favourable environmental conditions. In this time of environmental awareness and energy consciousness trees will play a more and more important role everywhere, and in particular in the tropics.

The first of the three papers in this book examines, in general, the role of the tree in tropical Africa. Highlighted are the variety of products that can be obtained from the forests, the vital role of trees in nutrient cycling and in soil and water conservation, and their influence on both micro and macroclimate.

The second essay addresses the ever important question of wood-fuel supplies. With increasing petroleum prices, greater demands than ever before are being placed on wood, and with decreasing supplies prices are rising. The pressing urgency of the situation is reflected in this grim statistic: the proportion of their income that some families spend on fuel has risen from 7 to almost 50% in recent years. Wood-fuel shortages have led to a switch to other fuel sources such as manure and crop residues, which has in turn started a vicious circle of decreasing crop yields and environmental degradation. Obviously the provision of fuel must become a priority of governments, and proper management of forest resources is essential if fuel-wood is to be provided for future generations.

The final essay examines the age-old practice of shifting cultivation. Although it was well-suited to the conditions under which it was originally practiced, recent pressures resulting from increasing population have caused an imbalance in the system with associated problems such as increased erosion and leaching. Suggestions advanced here for tailoring new ideas to this traditional practice may well make it possible to modify or improve the system to meet modern realities. Methods involving zero tillage and the use of trees as "nutrient pumps" seem to offer particular promise in this regard.

These papers taken together reflect a fresh approach to the role and importance of trees in Africa. No longer can the forests be thought of as an ever-present resource — they must be properly managed. Although the suggestions here are only tentative, it is our hope that they will stimulate a new approach and lead to better understanding and more efficient utilization of the forest resources of the continent.

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The Role of the Tree in Tropical Africa

Over large areas of the African continent, the trees that grow outside the forest are almost as important as the trees that grow inside the plant communities we call forests.

Before describing the ways in which trees may be useful, in the broadest sense, to man, some definition of what we mean by a 'tree' and by a 'forest' is required. By tree, we include any self-supporting woody plant that, when fully grown, exceeds a height of a couple of metres; really, anything from a straggling desert shrub to the 70-m king of the rain forest. By forest, we mean any area on which trees, either in closed stands or scattered more or less evenly, constitute a conspicuous part of the growing plant community. However we do not consider as a forest a tree plantation or orchard established basically for fruit production.

Trees are useful to man in two distinct ways: as producers of a wide variety of goods, commonly called 'forest produce'; and as custodians of favourable environmental conditions. It would not make sense to try to qualify one of these functions as more important than the other. Both are indisputably essential to the well-beeing, indeed to the survival, of man.

Trees in Africa, as elsewhere, are naturally first of all producers of wood. There are many kinds of wood, however, and their uses are almost innumerable. Wood, in one form or another, enters into practically every sphere of human activity. It is characteristic of almost all African countries, however, that by far the most important utilization of wood is as fuel, principally firewood and charcoal.

Tropical Africa covers approximately 20 million square kilometres. Of this huge area, about half can be described as forest-covered; encompassing everything from the open shrub vegetation at the edge of the desert to the impenetrable rain forest of the Congo basin. Of this total forest area, about 98% is constituted by various types of 'bush,' while dense forests account for less than 2%. The area covered by artificial, and often highly productive, plantations constitutes an infinitesimally small fraction of the total forest area.

In terms of wood, the productivity of the natural African forest is not high. Annual yields vary from a fraction of a cubic metre to about five cubic metres per hectare. In addition to wood produced by 'forests,' a considerable output is obtained from scattered trees on farmland.

Of the total increment of the African tree vegetation, probably less than one fifth, or an estimated 300 million cubic metres, is presently being utilized. Despite this seemingly favourable relationship between

Table 1. The uses of wood from the plantations and natural forests of Africa.

Forest products	Uses	Approximate consumption (%)
Fuel	firewood, charcoal	90
Poles/posts wood-splits	house building, fencing, transmission (electrical), scaffolding	5
Sawn wood (roughly hewn, pit sawn, machine sawn)	construction, form work (concrete), joinery, flooring blocks, furniture, agricultural implements, exports (mainly fine timber)	4
Carvings	Makonde carvings etc., all kinds of tourist curios, drinking vessels for livestock, saddles	extremely small quantities but partly very valuable wood
Panel products	wood-wool cement, veneer, plywood, particle board (chipboard), fibre board (hard and soft board)	0.3
Pulp, paper, and related products	news print, fine paper, (printing and writing paper), industrial paper (packaging etc.), rayon (regenerated fibres used for clothing, tire cords etc.)	0.7

production and consumption, the wood supply situation is far from rosy. The forest resources are in fact dwindling at a frightening pace as a result of the combined onslaught of firewood and timber exploitation, the clearing of land for farming, and last, but not least, annual bush fires. Over large areas of Africa, a severe shortage of firewood and timber is already making life difficult for millions of people.

Table 1 lists the uses of wood coming from the plantations and natural forests in Africa. The percentages of proportional consumption should only be considered as indicative of orders of magnitude. The statistical data that would have made it possible to give precise figures are at present not available.

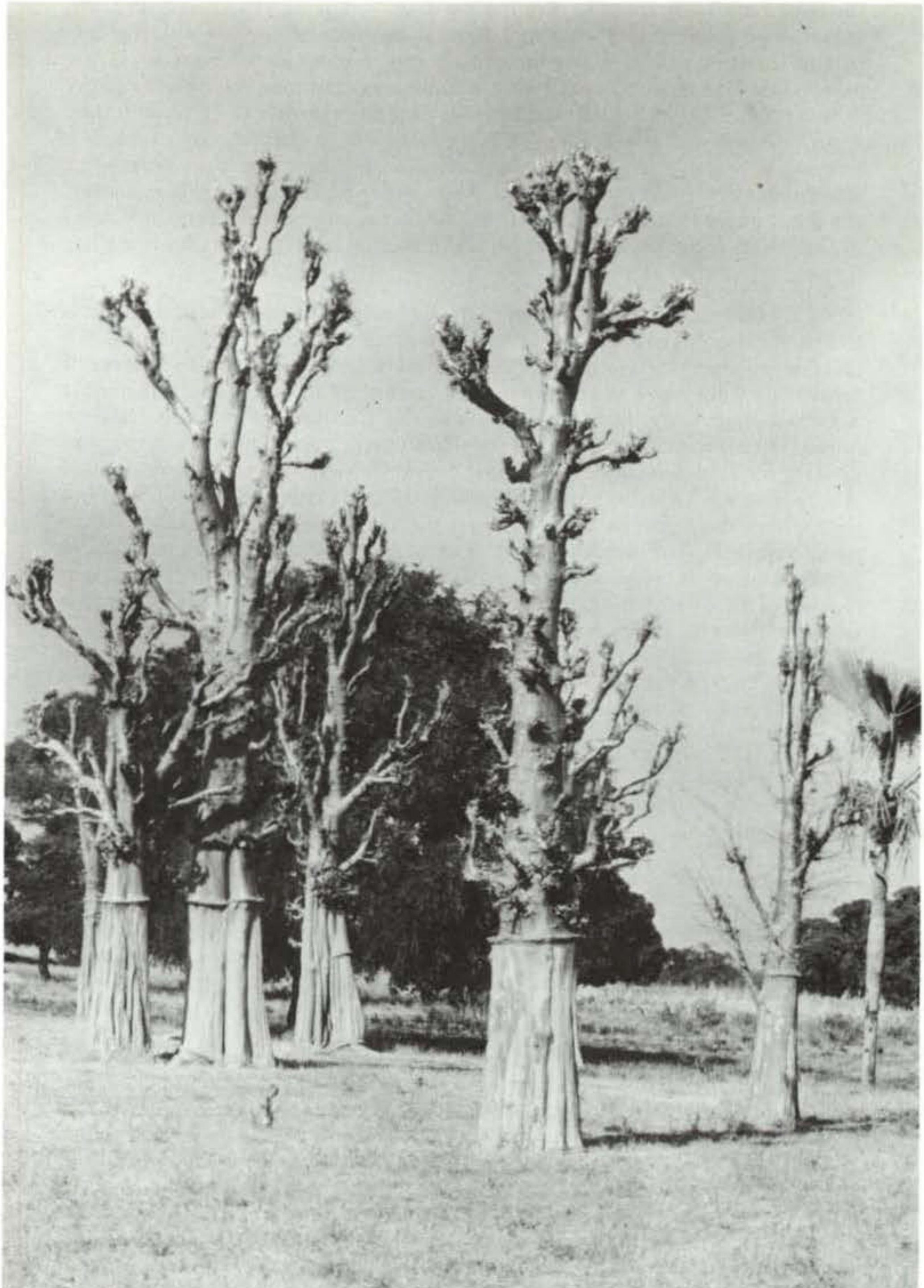
There are, however, many products other than wood produced by African trees. Both the leaves and the fruit of the Baobab are used for human consumption in West Africa. From the bark of the same tree a cord is made that is utilized for stringing beds in the Sudan. From the bark of *Acacia nilotica*, on the other hand, the Masai of East Africa make a stimulating tea-like beverage. In some parts of Somalia, the nut of a desert shrub, *Cordeauxia edulis*, constitutes an important element of the human diet. Elsewhere in Africa, the young seedlings of the *Borassus* palm are cooked and eaten. A refreshing drink is made from the pods of a large savanna tree, *Tamarindus indica*. In Mali this drink is even produced industrially in tins. The fluff, or kapok, of trees of the *Bombax* family is used for upholstery. An infusion of the female flowers of *Hagenia abyssinica* is used as a vermifuge, just to mention one of many medicinal uses of trees. In a few areas arrow poison is still in use on a small scale; a common component is the latex of the desert rose, *Adenium honghel*. Industrially important extractives are obtained from the wood, bark, leaves, and fruits of many species, for example a tanning extractive from wattle, and shea butter from the shea butter nut tree of the West African savannas. Some trees produce valuable exudates, the most important being the gum arabic that is tapped from various acacias in the Sahel zone. Incense gums of the *Boswellia* tree were famous in earlier times.

Of extreme importance, especially in the drier parts of the continent, is the production of cattle feed. Over large parts of Africa, livestock obtain a considerable proportion of their nourishment from the fruits and leaves of trees. Probably more than 100 species are useful in this respect, the most notable being *Acacia albida*. In some areas, the South American tree, *Leucaenea leucocephala*, is being planted for the industrial production of cattle and poultry feed. In this context it should be mentioned that, in some regions of Africa, there is an antagonism between trees and cattle ranching. This is the case where the tsetse fly occurs. Tsetse thrive only within woodland and are often controlled by deforestation. The systematic cropping of wildlife to produce meat in tsetse infected areas is an alternative to deforestation in favour of cattle ranching. While recommended by some scientists, serious doubt must still be expressed about its practicability. On the subject of wildlife, it should be stressed that a well-wooded environment is also a necessity for the survival of many of the species that compose the extremely rich fauna of this continent.

The last nonwood forest product to be mentioned is honey. Many African trees, especially of the Leguminosa order, are excellent nectar producers. For this reason the African forest areas offer an enormous potential for honey production, so far only marginally utilized.

Beside being producers of a variety of useful goods, the African trees play an extremely important role in maintaining a favourable environment. They exercise a useful, often indispensible, role in the cycling of plant nutrients, soil and water conservation, the maintenance of favourable macro- and mircoclimatic conditions, and last but not least, the creation of shelter, shade, and beauty around dwellings.

The importance of trees for the cycling of plant nutrients is often overlooked, to the detriment of the soil fertility on which farming, animal husbandry, and plantation forestry depend. In the tropics, and particularly in the humid tropics, frequently more than 75% of the soluble plant nutrients that are present in a certain area, are held within the biomass of the growing plant community. In this respect, conditions are very different from those prevailing in temperate countries, where most nutrients normally are present within the upper layers of the mineral soil. Under forest conditions in Africa, nutrients released from decaying organic matter do not seep down into the soil as in temperate countries. They are to a very large extent intercepted by a dense web of tree roots just under the surface, a web made almost impenetrable by the additional presence of mycorrhizal



Baobab trees. The leaves have been stripped off for the pot, the bark for making rope.

fungi (the subterranean parts of some mushrooms that live in symbiosis with the roots of certain trees). As a result, the nutrients 'cycle' almost continuously within the biomass, with only a small proportion entering the mineral soil. In this way the vegetation has adapted extremely well, in the course of a long evolution, to the necessities of the environment. Under hot humid conditions, any soluble nutrient element in the soil is in fact exposed to loss by leaching.

In cases where most of the biomass, including the subterranean part, is destroyed by cutting down the forest, usually to provide land for farming, the whole protective system as described above, breaks down. Soluble plant nutrients are released into the mineral soil, which no longer has a 'safety net' of roots and mycorrhiza to intercept these nutrients and prevent them from being leached. A high humus content and a 'crumb' structure of the soil may slow down leaching for a few years, but as the humus decomposes and the soil loses its original favourable structure, the leaching process will accelerate.

The initial release of a large amount of nutrients into the soil will naturally result in great, if transitory, fertility. The farmer will reap excellent crops during the first years after forest clearing. But, as leaching increases, harvests will decline, and eventually the farmer will be forced to abandon a completely exhausted soil — for a long period of bush-fallow or, in the most severe cases, permanently. Some farmers may be able to halt the deterioration of the soil by the application of fertilizer, preferably in combination with some kind of mulching, but many lack the resources to do so.

In some areas of Africa, farmers have adapted extremely well to the imperatives imposed by the pattern of nutrient cycling. By mixing perennial crops, such as coffee, bananas, and sometimes even large trees, with short-cycled crops, such as maize, cassava, and beans, they ensure that the amount of growing biomass does not descend below a critical level. Alternatively, soil fertility may be maintained by the frequent application of mulch. This may be achieved by maintaining a certain proportion of each farm, preferably steep slopes and other erosion-prone areas, under tree cover. Branches lopped off the trees are used to mulch nearby fields.

Acacia albida, a large savanna tree that occurs on sandy soils in some of the drier parts of Africa, deserves special mention in the context of nutrient cycling. In general, the land where it grows is farmed and valued for its high fertility. *Acacia albida* has in fact a remarkable farm-improving influence. Contrary to all normal 'tree behaviour,' it drops all its leaves just at the onset of the rainy season. During the prevailing hot humid weather, the leaves decay rapidly and release nutrients into the soil just when the agricultural crops need them most. In the dry season, on the other hand, the tree is covered by a dense foliage and its cool shade is then much favoured by cattle. Toward the end of the dry season, cattle are even more strongly attracted by the huge amounts of protein-rich pods that drop to the ground under the trees. This continuous presence of cattle under and near the trees assists enormously in the upkeep of soil fertility. Finally the large crowns of *Acacia albida* provide excellent protection against dessicating winds and wind-erosion.

The role of trees in soil and water conservation is no less important, especially in hilly and mountainous country. Better than any other ground cover, forests ensure that the soil layer that is indispensable for water catchment is maintained and not carried away by erosion. At the same time, the soils under the forest develop an open 'crumb' soil structure that permits rainwater to infiltrate quickly and to percolate to deeper soil layers from where it gradually may be released in springs and water courses.

Conversely it is known that large-scale deforestation of steep slopes may lead to complete environmental degradation. The soil is carried away from the slopes leaving them bare and useless to man. In the valleys below, a formerly regular water supply becomes spasmodic and unreliable. During heavy rainstorms, flood waters thunder down from the hills burying valley soils under gravel and stones, destroying crops, and silting dam sites.

As insufficient cultivable land is available in many countries, all slopes cannot, normally, be maintained under forest. The steepest slopes and important catchment areas, however, ought never be deforested. On less vulnerable sites good farming practices, possibly combined with the upkeep of some tree rows along contour lines, may provide sufficient protection against environmental deterioration.

Erosion is not caused by water alone but also by wind, particularly in the drier parts of the continent. Wind erosion may carry away the most fertile soil particles from farmland. In other places, on the contrary, it is the sand particles that are blown into cropland from elsewhere that are harmful. Crops may be damaged or even killed by scarification, or buried under a layer of sand.

In all cases the best remedy against wind erosion is the maintenance or planting of trees, either in the form of shelterbelts or more or less evenly distributed tree vegetation. Where there are many trees, there will be no wind erosion.

Trees do not only help reduce the wind velocity close to the ground. More or less dense tree vegetation, or a system of artificially established shelterbelts, exercises a beneficial effect on microclimatic conditions in several other ways. The rapid expansion of desert conditions along the southern fringe of the Sahelian zone has been caused partly by a succession of years with exceptionally low rainfall and partly by man's own destruction of the environment. The combined effect of overgrazing, overexploitation of the already scanty tree vegetation, and in some regions, introduction of mechanical farming in low rainfall areas, has resulted in the denudation of large tracts of land. Within the denuded areas, the microclimatic conditions, coupled with the wind erosion problem, have made conditions for animal husbandry and crop farming unfavourable even in years of above average rainfall. But what may be an even more serious problem is the hot scorching winds that blow from these man-made desert areas into the farmland further south, reducing yields and even destroying crops.

The desertification process is frequently compounded by people, deprived of forest resources, being forced to burn animal manure and crop residues thus depriving the soil of these sources of humus and plant nutrients. This deprivation not only results in poorer crop yields, as would be expected, but plants do not in fact resist drought nearly as well on an infertile soil as on land with a more satisfactory nutrient status. Therefore, in a marginal climate a drop in soil fertility will often lead to more or less complete crop failure.

Although there is no doubt that ground cover, and especially trees, exercises a considerable and favourable influence on the microclimate, hardly any exact information is available about a suspected influence on the macroclimate. Do such phenomena as higher day and lower night temperatures on denuded land, and an increase in the amount of dust in the higher atmosphere over overgrazed and overcultivated land influence the rain-forming processes negatively? We really do not know in a scientific way. We only suspect that this is so. Not knowing for sure, we give the trees the benefit of the doubt and advocate afforestation of dry areas as a means of creating better rainfall conditions. If not, it will at least lead to an improvement of the microclimate and that in itself would be very valuable.

We have considered the importance of trees for the physical environment, the environment on which our supply of food and many other material goods depends. However, man does not live by bread alone. Human fulfillment also depends on a less tangible quality in our environment which we call beauty. Trees with attractive foliage and fragrant flowers around dwellings enrich the lives of those living in them and at the same time protect them against sun, wind, and dust. Greenbelts around towns serve a similar purpose and provide leisure areas where people can escape the hustle and bustle, and fumes and stress, of modern urban life.

Trees may thus provide not only some of man's most basic physical requirements, but some of his mental needs as well. Summing up, we may therefore say that the role of the tree in Africa is to contribute to the maintenance of an environment that is friendly to man and to beast as well.

Wood-Fuel and Nutrition:

the complementarity of tree cover and food supply

A number of top-level experts congregated in 1976 in an East African country to discuss the energy situation. In one of the introductory speeches, the pattern of sources and consumption of energy was outlined: 80% of the national consumption of energy was derived from oil and 20% from hydroelectric power. None of the delegates raised an eyebrow when hearing this unequivocal statement. However, in the same country between 30 and 40 million cubic metres of firewood are being used annually for domestic and industrial purposes. An amount far exceeding, in terms of calorific value, the energy derived from all other sources within the country.

Surprisingly, it is characteristic of many African countries that wood-fuel is looked upon as an ever-present, always available resource in about the same way as, say, atmospheric oxygen. So long as the resource is plentiful, no one gives it more than a fleeting thought. On the other hand, when it starts getting scarce, it requires no effort to convince everyone about its importance for the general well-being. By then, it is too late in most cases to redress the situation without everyone first suffering severe hardship.

Only a few years ago, both expert and general opinion took it for granted that, with economic development, there would follow a more or less complete switch away from wood-fuel as has happened in the industrial countries. The assumption was quite naturally that oil-based fuels would supplant firewood and charcoal, with some additional energy being obtained from hydroelectric sources, wind power, solar heaters, atomic power stations etc. Development has not taken such a course, however. With few exceptions, the consumption of fuel-wood has been climbing relentlessly everywhere on the African continent. It has reached a level of some 300 million cubic metres annually, and most people now recognize that there is little hope of oil and natural gas progressively replacing such a huge amount of firewood. On the contrary, with the expected exhaustion of fossil fuel resources within the next 30-50 years, the world is likely to become more and more dependent on renewable energy sources such as wood. It can be expected, therefore, that instead of declining, the consumption of fuel-wood in Africa will continue to climb far above the present level. But, the needs of the rapidly increasing population will only be satisfied if, and this is an important if that must be qualified, the forestry resources of this continent are managed in a more rational way. Otherwise people in more and more areas are going to suffer from a severe shortage of domestic fuel, as is already the case over large areas of the Sahel.

Especially in countries that have not yet reached the affluent stage, good resource management must be a matter of allocating scarce resources of capital and land in such a way that the most essential human needs are satisfied first. Most people would undoubtedly agree to this statement. However, when it comes to defining priorities, consensus is more elusive. It is a curious reflection on the human psyche that while the production of food is a universally recognized basic need, most governments as well as those they govern, put a low priority on firewood production, if they consider it at all. It should be obvious, however, that it is pointless to produce food without also ensuring that the means for preparing it are available. None of the principal food crops of the topics is palatable unless it has been cooked first. It can in fact be stated as an axiom that, in the African environment fuel supply and nutritional level are interlinked. Surprising as it may seem, lack of fuel can be as much a cause of malnutrition as the lack of grain or root crops. The connection between fuel shortage and level of nutrition can rarely be described as 'linear' however. Rarely will a family go hungry to bed because it does not possess sufficient fuel for cooking the broth. If the family has the raw materials for preparing the meal, it will nearly always find ways and means to do the cooking, but at a price. Where there is a fuel shortage, that price may be higher than the family or community can afford without suffering severe shortages in other areas.

In the towns, the link between fuel shortage and nutrition is the simplest. The average town dweller in the Sahel is not rich: family resources rarely exceed the minimum necessary to keep malnutrition at arm's length. A few years ago, an average family spent, according to some sources, some 7% of its income on fuel. However as the wood cutters had to move farther and farther afield to find sufficient firewood to supply the towns, fuel prices climbed. That the price of kerosene and gas skyrocketed at the same time did not make things any better. There are now places in the Sahel where fuel has become so expensive that some of the poorer families must spend close to half of their budget on fuel. A preemption of this magnitude will obviously reduce a family's purchasing power drastically in all other fields, including that of food. Simultaneous increases in food prices have compounded the difficulty and forced people to eat less well and often too little.

In the countryside, fuel shortages are also leading to malnutrition. But, the causality here is of a much more complex nature, so complex that it is rarely well understood either by its victims or by those making vital decisions on their behalf. With increasing deforestation, the villagers must also collect firewood farther and farther away from their homes. To have to walk 10 km, or even more, everyday under the tropical sun, and to carry back a heavy load is a terrible strain on the women upon whom the transportation of the family fuel supply depends.

The increased work load is not, however, the worst calamity resulting from the shortage of fuel-wood although it is the direct cause of what now hits the village community. It becomes tempting, indeed imperative, to find substitutes for firewood. The substitutes available are almost always the same: dried animal manure and crop residues. When people start removing these from their farmland, things are taking an ominous turn. Crop

Camels transporting firewood (it is not always done by women and children).

residues and manure, so long as they lie on the surface, provide protection against wind and water erosion. Later, mixed with the topsoil as a result of the action of microfauna and flora, they help to ensure a favourable soil structure and also act as barriers against leaching. Finally through their decomposition, indispensable nutrients are returned to the root zone of the crops. Inversely, if they are removed to serve as fuel, the soil will suffer degradation, wind or water erosion as well as leaching will increase, and insufficient nutrients will be returned to the soil and crop yields will decline.

The removal of most or all of the trees from farmland affects soil fertility in yet another way. In the tropics, trees serve as very important nutrient pumps. With their deep-penetrating root systems, particularly on coarse-textured soils, they are able to bring nutrients, which have been leached out of reach of the roots of most herbaceous crops, back to the topsoil. Through the roots and stem, the nutrients are pumped up into the living mass of the tree. The return to the soil takes place, at a later stage, in the form of litter fall, and the shedding of leaves, fruits, twigs, and branches. If all the trees are cut, this indispensable cycling of nutrients for the maintenance of fertility is disrupted. Last but not least, rows of trees, or more or less evenly scattered trees, offer protection against wind damage to crops and wind erosion, and help maintain an equitable microclimate.

We have so far considered town and countryside as separate areas with different problems with respect to fuel and nutrition. In actual fact a strong interaction is taking place between the two. Around the towns, deforestation spreads far with all its adverse implications for crop production. In the case of larger towns, a point is often reached where so much must be spent on transportation of firewood that this bulky product is unable to compete with charcoal, a fuel that has a much more favourable relationship between weight and calorific value. This decisive point will be reached when an equal amount of calories can be purchased cheaper in the form of charcoal.

In many African towns, especially those in the drier regions north of the equator, charcoal has been used since time immemorial. However, consumption generally remained at a relatively low level and was confined to houses of the well-to-do, tea houses, restaurants, and small industries. After World War II this modest consumption declined on a per capita basis in many places as people in the middle and higher income brackets switched to more convenient and more status-charged fuels such as gas and kerosene. A few years later came the oil crisis, and its attendant price increases for all oil-based forms of energy, and many middle-class people were forced to abandon their recently acquired modern stoves in favour of more 'primitive' but now significantly cheaper charcoal stoves. As a result, charcoal consumption in some East African towns shot up and may even have quintupled during the years 1973-77. As great as the impact of the oil crisis on charcoal consumption has been, an even more drastic change in consumer habits has taken place in towns where the firewood price has climbed above what one would pay for the same amount of calorific energy in the form of charcoal. Where this has happened, as in several towns in the Sahel, not only middle-class people but the great majority of the population has switched from firewood as the main domestic fuel, causing an enormous rise in consumption.

Charcoal is in many ways a more convenient fuel than firewood. From an ecological point of view, however, any large-scale shift of fuel consumption from firewood toward charcoal may have dire consequences. The trouble is that too much energy is wastefully consumed when firewood is converted to charcoal: it "goes up in smoke." About half of the energy present in the wood will normally be lost during the coaling process, and where traditional coaling methods are applied sometimes this loss is much higher. Consequently, to provide a town with as much energy in the form of charcoal as it formerly received in firewood, more than twice as many trees must be cut.

It is obvious therefore that a shift to charcoal on a large scale will lead to vastly increased deforestation. At the same time the deforestation will affect a much wider zone. Whereas, in most cases, it was prohibitively expensive to bring firewood to a town from farther away than 100 km, it may in fact be feasible to haul charcoal in from as far away as 200-300 km. Deforestation resulting from the domestic fuel consumption of towns is therefore not likely to remain a localized phenomenon but may spread to affect most rural areas. In fact, if we exclude both the driest and most sparsely inhabited regions of the continent and the humid heavily wooded areas of the Congo basin and West Africa, then such a trend can be observed almost everywhere.

Extensive deforestation will, as we have seen, lead to environmental degradation. As a consequence, not only will fuel become harder to obtain and more expensive but agricultural yields will also decline resulting in scarcer and more costly fuel supplies. The decline in yields may be prevented, to some extent, by the application of artificial fertilizer, but few African farmers have the resources to use them on a sufficient scale.

The fates of towns and villages are thus closely linked. Their well-being in the long term is dependent on an interaction of fuel supplies and crop yields that can be influenced by man in one way or another to his benefit or destruction.

What remedial actions will it be possible to take to redress the present deteriorating situation with respect to fuel? It is obviously futile to try to solve the problem by means of prohibitions alone. Do not cut within this area! Do not burn manure . . . etc. No application of the whip will stop people from obtaining kitchen fuel from any source and at any risk, if there is no alternative. Those who make decisions must therefore take steps either to make sure that fuel requirements can be met from old or new sources, without causing environmental degradation, or to ensure that people's dependency on wood-fuel is reduced. There is scope for development in both directions. The ideal solution will, in fact, combine an improvement on the supply side with a decrease in per capita consumption and be achieved without detriment to the way of life of the consumer.

The wood-fuel supply situation can undoubtedly be improved in many ways, some well known, some of a more hypothetical nature requiring research for their confirmation.

Wastage and inefficient utilization of existing forest resources must be stopped. Year after year, violent bush fires sweep across most forest and woodland areas within the subhumid and semi-arid areas of Africa. These fires destroy an appreciable amount of dead wood that otherwise could be collected. More important, they cause a degradation of the forest soil, the species composition, and the stocking of fuel-producing trees. In my opinion, forest productivity may in this way be reduced to less than half of its potential on tens of millions of hectares on both sides of the equator. The remedy? Education of the public, clearing of firelines, and fire surveillance.

Losses of no less importance are caused by the unplanned and unsupervised cutting of firewood in the vicinity of large population centres and, in the case of wood cut for charcoal production, export harbours. The pattern is generally the same: all trees are cut, none are left to ensure regeneration. The area is then invaded by a dense grass vegetation that is subject to annual burning, which eliminates the last hope of new trees replacing those that were cut. In some regions, regeneration may not be prevented by fire but by browsing goats and sheep. As an alternative, sustained productivity might be ensured by the introduction of rotational cropping combined with appropriate silvicultural practices. The present method, or lack of method, followed in many countries is tantamount to the mining of firewood as one might scoop gravel from a pit. No consideration is given to the fact that a forest is a live organism that, if handled with care and knowledge, could continue to produce wood long after all the gravel pits are emptied.

A third type of wastage is the cutting of trees to provide farmland where it is contraindicated environmentally. In such places, wind and water erosion or other environmental calamities will soon destroy the farmland. In this context, it should be mentioned that, fortunately, it is a common practice in many parts of Africa to leave scattered trees over land being cleared for farming, e.g. *Acacia albida* in the Sahel, and cola nut trees and oil palms in the more humid areas of the west coast. Where this practice prevails, a considerable degree of environmental protection is undoubtedly achieved.

Although much can be done to ensure more ample supplies of wood by reducing wastage and managing the existing forest resources more efficiently, there is no doubt that in many places such measures will be insufficient to provide fuel for the rapidly increasing population. This is the case, obviously, where too much forest has already been degraded beyond recovery. It also applies where the inherent productivity of the natural tree vegetation, however well managed, is too low to satisfy the requirements of the local population. In all such cases there is need for reforestation. In the minds of many people, this word evokes a spectre of land being taken away either from peasants already having too little land or from nomads in perpetual search of grazing; in brief, of foresters competing for land with the have-nots and creating social conflict. Admittedly a conflict of interests cannot be avoided where afforestation on some scale must be undertaken. Much can be done nevertheless to minimize friction by intelligent land-use planning and in some cases it is even possible to increase crop and livestock production through afforestation.

Basically, from a land-use stand point, tree planting can be carried out on two different types of site: inside forest reserves and outside. Large-scale planting for the purpose of supplying large communities or industries with wood-fuel must necessarily be carried out on land set aside for this express purpose. In some places, it may be possible to convert existing and already reserved natural forest to more productive tree plantations without causing any conflict. If such reserves are not available, emphasis must be placed on minimizing friction by selecting land that is unsuitable or unattractive for agriculture and at the same time offers reasonable conditions for fuel-wood production. Fortunately it is commonly not difficult to find such areas. Trees, with their deep penetrating roots, will often grow well on soils that are too infertile to attract farmers. If suitable species and planting techniques are chosen, trees may also be raised on poorly drained swampy land. Steep slopes are in general more suitable for forestry than for anything else. A special case deserves mention here, the greenbelt. In the drier regions of Africa a forested greenbelt of a considerable depth ought to be a must for all self-respecting towns. Rather than leaving the towns surrounded by dust spewing man-made deserts that offer but scanty browse for a few starving goats, all towns ought to be cuddled in the centre of a green forest — with appropriate openings for roads naturally. A fenced forest perimeter, besides stopping most of the dust, can be made to produce an appreciable amount of firewood and poles, and in addition, cows and sheep may be grazed in a controlled way under the trees, feeding not only on the grass but to a large extent also on pods and other tree fruits.

Ranching of livestock and forestry may therefore be combined within an urban greenbelt. Even more scope for associating firewood production with agriculture and cattle breeding, for the benefit of all concerned, presents itself in the countryside. Evenly spaced trees or shelter belts, established at regular intervals, will in most cases improve pasture conditions. Furthermore, if species have been chosen that produce cattle feed, e.g. *Acacia albida, Acacia nilotica, Ailanthus excelsa, Prosopis cineraria,* and *Prosopis chilensis,* the advantage of tree planting will be doubled, or even tripled, as these trees, which are planted essentially to improve conditions for ranching, also will yield an appreciable amount of fuel.

Trees will serve a no less useful function for crop farming. In this case as well, the trees may either be planted evenly over the fields or concentrated within narrow bands. The bands ought to, on erosion exposed slopes, follow the contour. On wind swept plains they should, on the other hand, be established at a right angle to the prevailing wind. Planting of rows of trees along boundaries is an effective and cheap method of demarcation. To obtain the most satisfactory results, the tree species must be selected judiciously according to soil, climate, purpose of planting, and site. Some trees like *Eucalyptus sp., Azadirachta indica, Cassia siamea,* and *Prosopis chilensis* are suitable for strip planting but will suppress the crops if planted in the fields. Others can be evenly distributed within the fields without any adverse effect, indeed quite often with a very beneficial effect. Trees that can be included in this last category are *Acacia albida, Prosopis cineraria, Ailanthus excelsa,* and in the humid tropics, the oil palm, the cola nut tree, and *Leucaena leucocephala* — if appropriately spaced.

The benefits obtained from trees planted, or maintained, on farmland are multiple. They help to sustain a favourable and equitable microclimate, offer protection against wind and water erosion, and ensure that plant nutrients, leached out of reach of the crops, are returned to the surface. In the case of species that produce cattle feed, the trees will furthermore make it possible to fatten more livestock on the land and to obtain more soil-enriching manure in the bargain. Last but not least, the farm trees will yield firewood and possibly poles, thus enabling the farmer to stop burning dung and possibly obtain some cash income from the sale of wood.

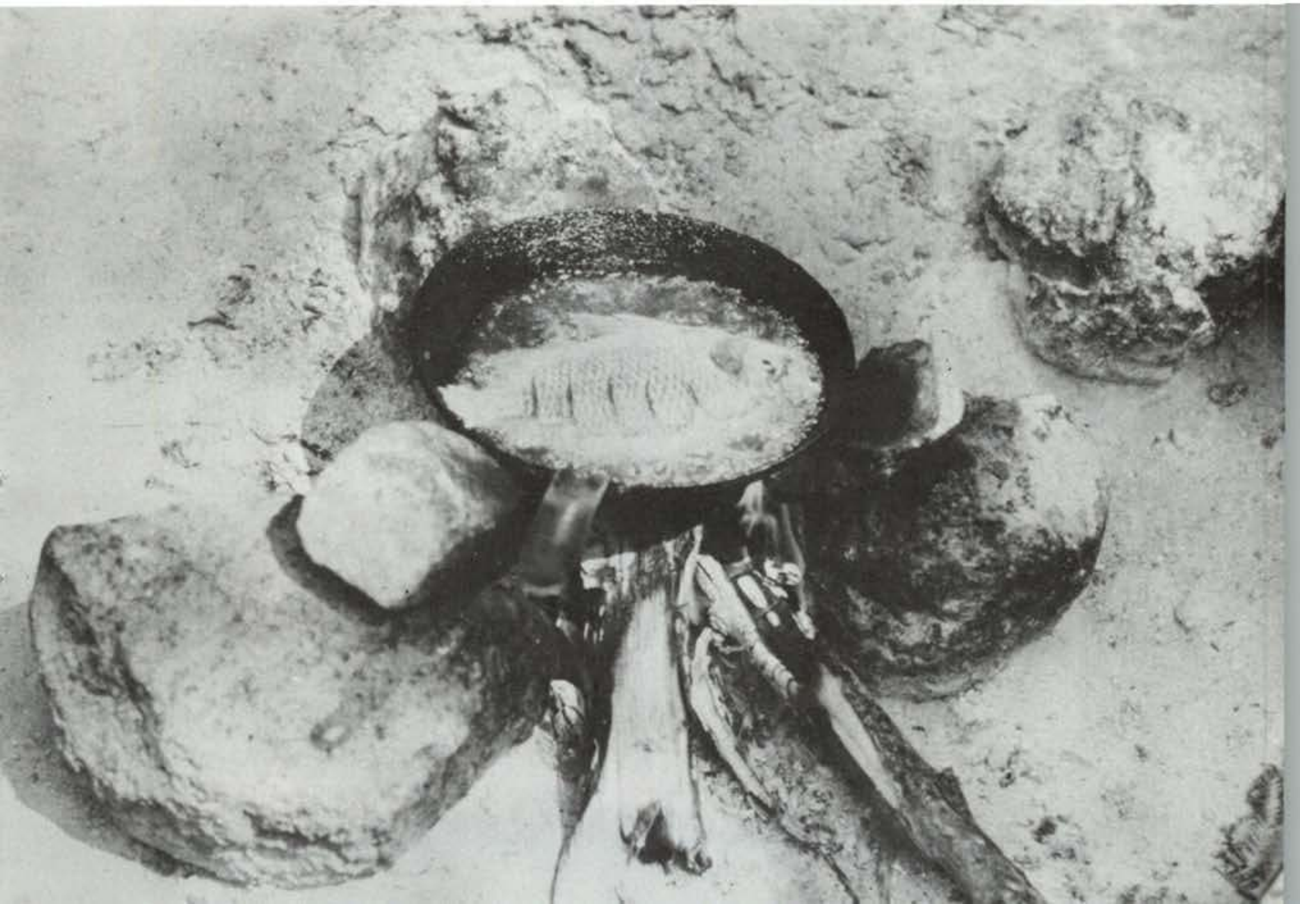
Trees have been virtually eradicated from vast tracts of land in Africa, mostly in an uncontrolled and haphazard way, but in general with the best of intentions - to provide more land for farming. In many areas, and where land clearing has been pushed beyond a critical point, soil fertility and crop yields have dropped. The total output of food crops, milk, and meat, instead of being enhanced has faltered and both towns and rural areas have suffered from the connected consequences of higher food prices and a shortage of fuel. If instead of recklessly removing all trees, some forest vegetation had been left on the farmland, much better conditions for all concerned would undoubtedly have been preserved. Conversely farm yields could in many places be raised if trees were restored to fields and pastures. Over large areas of Africa, it may in fact be profitable to cover as much as 5 - 10% of the existing farmland with trees. The improvement in agricultural yields that could be expected from the beneficial influence of the trees would undoubtedly in many cases exceed the percentage of land occupied by the trees, and in addition the wood produced by the trees would help to overcome the firewood crisis.

From a situation where agronomists, livestock experts, and foresters often only look after their own narrowly defined land-use interest, competing more often than collaborating, it is time that we started to evolve toward a new situation characterized by informed collaboration leading to a high degree of integration of the basic land uses.

The fuel situation may not only be improved by the better management of existing forest resources and the planting of more trees. Another approach to the same problem consists in reducing fuel requirements by the introduction of more efficient heating methods. The methods that are applied in most African households are in actual fact both extremely inefficient and unhealthy. The most commonly used heating method is an open wood fire on the floor. With respect to fuel consumption it is wasteful, because the rate of burning cannot be controlled in more than a rudimentary way, and the open fire fills the room with smoke harmful to lungs and eyes. By replacing the log fire with a simple stove, the same heating effect could be obtained with much less fuel, and the smoke problem would be totally eliminated. Stoves particularly adapted to the requirements of African households have not yet been developed, however. The fuel economy of models still to be designed can therefore only be estimated very approximately. As a conservative estimate it may be possible to halve fuel consumption by replacing the open kitchen fire by stoves having a controlled air intake.

The charcoal stove that is used in many African households may seem a more advanced heating device than the open woodfire. It is certainly more

Fish being cooked over an open fire (it looks delicious but the fuel economy is poor).



convenient and emits less smoke. However, when it comes to consumption of the basic raw material, fuel-wood, the replacement of the open fire by the charcoal stove is in most cases far from beneficial because two or three times more fuel is required to ensure the same amount of heating when using charcoal. However, there is great scope for improving charcoal fuel economy, even more than in the case of firewood heating. The enormous losses that take place when firewood is converted to charcoal in earth kilns can be halved, at least, by the introduction of more efficient kilns, stationary or mobile according to the circumstances. An economy of a similar magnitude may be achieved in the household by replacing the usual iron stove with a more efficient model. The stoves in use in Southeast Asia, made cheaply from clay and old tins, do in fact show a fuel economy that is 30-50% superior to that of their African counterparts. In any case, even after carrying out all possible improvements of coaling techniques and heating devices, charcoal will still remain less economic in use, fuel-wise, than firewood. In one important respect, however, charcoal is vastly superior to firewood. It has a much more favourable calorie to weight ratio or in other words the same amount of energy weighs much less in the form of charcoal than wood, and is therefore cheaper to transport. Consequently, it is possible to produce charcoal, economically, much farther away from the consumer centres. For this reason environmental protection may in some cases be achieved, paradoxically, by switching consumption from firewood to charcoal despite the poor fuel economy of the latter. This is the case where it is possible to bring charcoal from remote but well-watered and highly productive forest areas to consumer centres located in a more arid environment. An alternative fuel supply having been made available in this way, it becomes possible to protect the more vulnerable forest vegetation closer to the town against encroachment.

Firewood and charcoal are not only used for domestic heating but also on a considerable scale for industrial purposes - drying tea, curing tobacco, firing pottery, and making bricks, to mention some of the more important. Where such industries are operating without proper planning of their fuel supply they often cause large-scale deforestation and accompanying environmental degradation. It is therefore strongly recommended that it be made mandatory, wherever enterprises of this type are being given permission to operate, that fuel sources of an adequate size are identified or established.

Daily bread, meat and milk, timber and bricks, warmth in the house, tea and tobacco, dust-free air, and in many areas also water are essentials, the provision of which is closely linked to the upkeep or establishment of a certain tree cover. In the African environment, we can observe not only complementarity of tree cover and food availability but also interaction between fuel supply and nutrition. Human well-being in a much broader sense can also be seen as dependent upon the state of the forests and the no less important trees growing on farms and pasture land. May the trees therefore multiply, prosper, and thrive.

Shifting Cultivation:

soil and vegetation, nutrient pumps, and nutrient cycling

Green hills of Africa. From a distance the hills seem covered by forest but, at numerous points, blue smoke can be seen spiralling toward the sky. As one approaches, the forest opens up. Between the trees appear small patches of open land planted with yam, cassava, and maize. The sharp noise of axes and bush knives can be heard from all directions. Farmers are at work slashing and burning. This picture is still common in many parts of Africa south of the Sahara, and most foresters and agronomists with modern training find it distasteful, although for different reasons. Maybe, however, they should think twice before disdainfully writing off as archaic a cultivation method that has been in use in this continent since time immemorial.

Farmers practicing shifting cultivation, also called slash and burn farming, clear a small piece of land by felling and burning all or most of the forest vegetation. During the first few years they obtain excellent crops on the cleared land, the ashes of the burnt vegetation serving as fertilizer, and in the case of acid soils also helping to raise the pH significantly. Furthermore, the farmers are not plagued by excessive weed competition during the first years after burning. However, after 2-10 years, according to the type of soil and climate, the soil becomes exhausted and the weed problem intractable for the farmer with his simple tools. He then clears another piece of forest, abandoning the first area to bush fallow. The bush fallow is gradually invaded by trees, first by short-lived light-loving pioneer trees, springing up amidst a tangle of creepers, and eventually by true forest trees. Under this forest cover, the fertility of the soil gradually, and seemingly miraculously, is restored. Many years later the same, or another, farmer may clear this area of secondary forest and harvest good crops for a few years before again moving on to a fresh piece of virgin or secondary forest. This farming system has proven well adapted to the environmental conditions of most of tropical Africa so long as there are few people in relation to the amount of cultivable land available. However, with increasing population pressures, the tendency has been to make fallow periods shorter and shorter. It is now exceptional that an area is left under bush fallow for even 10 years before being cleared again, and in some cases the fallow periods have shrunk to half that or even less. In several regions, the fallow system has in fact been abandoned almost completely in favour of "modern" and often mechanized farming practices. Fertility is maintained by the application of artificial fertilizers and weeds are dealt with either mechanically or chemically.

Before discussing how various agricultural systems, involving longer or shorter periods of fallow, may influence such soil properties as capacity to retain moisture and nutrients, level of fertility, soil aeration, and pH, it should be emphasized that shifting cultivation does not necessarily imply the total removal of all forest vegetation from the areas being cleared for farming. On the contrary, in the case of some of the best environmentally adapted traditional farming systems, the maintenance of more or less evenly spaced trees constitutes an essential element. Whatever the original shifting cultivation pattern, where it has been diluted by an excessive shortening, or complete abandonment, of the fallow period, farmers have been faced with hitherto barely known problems and adversities.

Of the various ecological calamities that have befallen farmers who changed to nonfallow cultivation, it is difficult to classify one as more important than the others. According to local circumstances, they have all affected crop yields disastrously, and, as is the case with most misfortunes, they rarely come alone.

Often the first effect is sheet erosion. Caused by water, wind, or both, it starts peeling the soil off the fields. Insidiously it removes layer after layer of the topsoil, gradually exposing the less fertile and almost unstructured subsoil. This removal of the topsoil not only causes a disastrous decline in fertility but also a drop in the soil's capacity to absorb rainwater (except on very sandy soils). With a high proportion of the received rainfall being lost through surface runoff, the land depleted by sheet erosion therefore presents much more arid conditions. In hilly country increased runoff frequently leads to an even worse calamity, gully erosion. Scooping away the soil down to the bedrock, it has in some regions, and in eastern Africa in particular, changed former farmland into barren moonscapes.

Increased leaching and erosion are, in many areas, the worst evils that have followed the abandonment of the shifting cultivation system. However, in some places the changes in the microclimatic conditions that have resulted from the clearing of all forest and scrub vegetation over vast areas have also affected crop farming adversely. Where there are many trees around, the crops are protected against extremes of temperature and wind and low levels of atmospheric humidity. Conversely, in open, treeless country, crops are exposed to the full blast of the tropical sun, to dessicating winds and flying sand particles that scarify tender shoots, and in some regions, to squalls that break the stems of maize and sorghum. Last among the ecological reversals that affect the livelihood of our 'modern' nonfallow farmer should be mentioned the decimation of microflora and fauna that takes place where all tree vegetation has been eradicated. A myriad of small organisms, fungi, bacteria, all kinds of insects, nematodes, etc., play an essential role in the upkeep of fertile well-structured soils. Where, for example, in the case of high-rainfall areas, the earthworms are driven away by environment-hostile farming practices, crop farming is adversely affected. The soil becomes compacted and less well aerated and the minerals no longer get as well mixed with the decaying organic matter. These changes have a negative effect not only on root development and root respiration but also on important biological processes such as nitrification.

As already stated, these ecological misfortunes rarely come alone. On the contrary, one may say that they tend to pack like wild dogs and stimulate each other to the great detriment of the poor farmer who often, driven by sheer necessity, has abandoned the well-proven, ecologically sound, practice of shifting cultivation.

Shifting cultivation admittedly has its drawbacks, and it would be wrong to overlook them. During the first years after forest clearing, soil fertility is high, and the well-structured soil, with, at this stage, a high humus content, resists leaching well. Furthermore, the farmer has, at least to begin with, relatively few problems with weeds. This shifting cultivator's 'honeymoon' does not last for very long, however. From the very first year of farming on the newly cleared area, the fertility of the soil begins to decline; to begin with only slowly as the nutrients released from decaying organic matter compensate for most of the mineral elements being carried away in the harvested crops. At this stage, the soil also puts up a relatively effective barrier against leaching. Gradually, however, with the disappearance of the last remaining plant debris from the cleared forest, fewer and fewer elements will be released from decaying organic matter and at the same time the 'leaching barrier' of the soil will become ineffective, resulting in accelerated loss of plant nutrients. From this stage onward, soil fertility starts dropping dramatically. The good thing about the old system was that the deterioration was never allowed to proceed very far before the farmer pulled in the reins and left the land to the rejuvenating bush fallow. Such calamities as wind and water erosion are rare where the system is practiced in its original form.

In only one respect does the farmer practicing shifting cultivation confront a problem that nonfallow farmers encounter in a milder form. It is often extremely difficult for him to protect his crops against birds, monkeys, and pigs, which all find good cover within the bush fallows.

Despite certain drawbacks, shifting cultivation is an ecologically sound system. Its most eye-catching feature is the constant alternation of open-land farming with tree-cover periods. To these alternating periods, or phases, correspond concomitant fluctuations in soil fertility. During the farming phase, fertility declines, only to be raised again to its former level, more or less, during the following tree-cover phase.

A soil restoring agent seems to be at work, and what can this agent be but the trees? How do they bring about this change in an exhausted soil? To answer this question, it is best first to have a closer look at what actually happens to soil fertility during the farming phase. Soil fertility, seen from an agricultural point-of-view, is mainly a function of the available plant nutrients within the root zone of the crops and also to a considerable degree the soil's physical properties. When fertility declines during the farming stage, it results both from a decline in nutrient content within the topsoil and from a deterioration of the favourable soil structure that was established during the bush-fallow period. Decline in nutrient content means that nutrients are disappearing from the soil. But, disappearing to where? Some nutrients are incorporated into the harvested crops, but this 'productive loss' is unavoidable and of such a small magnitude that it can normally be compensated for by the application of manure or mulch, or even, in some cases, by dissolved nutrients in the rainfall. Much more deplorable is the 'unproductive loss' caused by leaching, which increases in intensity during the crop farming period as the soil gradually loses its protective content of organic matter and its equally stabilizing 'crumb' structure. During the final years of the crop-cultivation period, leaching losses greatly exceed the amount of nutrients carried away in the crops. The leached nutrients do not really disappear. They are simply transported deeper into the soil by percolating rainwater. As soon as they have sunk below the reach of most agricultural crops, i.e. approximately below 2 metres, from the farmers point-of-view, they have effectively disappeared. In dry regions, a displacement of nutrients to deeper soil layers through leaching is often all that happens when soils become exhausted. In areas of heavier rainfall many of the dissolved mineral elements will continue their underground journey until they are finally lost in streams and rivers. Here we are mainly concerned with those nutrients that have simply been displaced to deeper soil layers, because these can be brought back to the topsoil by means of appropriate 'pumps.' Trees constitute such 'nutrient pumps.'

Tropical trees often have remarkable root systems. Some are able to send their roots to depths in excess of 30 m, e.g. *Prosopis cineraria.* Others spread their lateral roots 40 or 50 m away from the stem, e.g. *Acacia tortilis.* Many species have root systems that live in symbiosis with various fungi, and thereby achieve greatly enhanced absorptive power. With such roots, the trees are able to intercept and reassemble nutrients thought to be out of the reach of agricultural crops. After reassembly within the biomass of the tree vegetation, in our case the bush fallow, the nutrients are gradually returned to the topsoil in the form of decaying organic matter, first little by little through litter fall and later in the form of ash when the trees are cut and burned.

In addition to this return of leached nutrients, trees also bring up elements that have been released by the weathering of mineral particles. These new elements may compensate for nutrients carried away in the crops. Most African soils are, however, ancient and have been exposed to weathering for so long that they contain few weatherable elements. For this reason, good soil husbandry is much more imperative in Africa than in the temperate regions, where most soils are much younger and to a greater extent able to compensate for lost nutrients through the continuous weathering of mineral particles.

It is, therefore, the periodic reinstallation of nutrient pumps that constitutes the most spectacular feature of shifting cultivation. In a very elegant way it solves the basic problem of the African peasant farmer: how to maintain sufficient soil fertility for economic farming without having to bring inputs from the outside, inputs that often are beyond his financial means.

A striking example of how trees effectively function as nutrient pumps can be observed where crop cultivation is carried out under permanent tree cover as is the case in some of the drier regions of the continent, where *Acacia albida* forms almost pure stands over considerable areas. Farming under even dense stands of *Acacia albida* is possible because this unique tree is covered by foliage only during the dry season and remains leafless during the wet season and therefore does not shade the crops. Under such stands, farming can go on almost nonstop for a remarkably long time without any serious decline in soil fertility.

However, the usefulness of trees for farming is not limited to their function as nutrient pumps. The tree fallow also helps to bring the humus content in the soil back to a high level, thereby establishing a barrier against leaching and also helping to maintain a 'crumby' soil structure. Plenty of organic matter on and in a soil furthermore prevents erosion. A sprinkling of leaves and twigs from scattered trees has in fact a remarkable influence in this respect. Dessicating winds do not penetrate where there are many trees around. Sand does not blow. The importance of the periodic reestablishment of trees for the upkeep of a favourable microflora and fauna has already been mentioned. Quite distinct from these ecological tree roles is the function played by the bush fallow in areas of high rainfall and intrinsically acid soils, such as are often encountered in West Africa. In these areas it is of major importance that the ash obtained from the burning of the tree vegetation raises the pH of the soil above the minimum level required by most agricultural crops.

Although there is little doubt that shifting cultivation is an ecologically sound farming system and that its abandonment is fraught with difficulties, with explosive population growth there is no longer land available in most places to practice it in the old manner. The only constructive solution to this seemingly impossible dilemna appears to be a rationalization of the shifting cultivation system to make it fit modern realities while maintaining its fundamental characteristics. Is such a solution possible?

Within the last few years, research to explore this possibility has been carried out in various institutions, notably at the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria. The investigations have almost entirely been concerned with shifting cultivation in humid and subhumid regions, while little has been done to investigate the problem in the drier regions of the continent. Possibly the most significant advance toward finding a solution to the problem has been achieved in the experimental development of farming systems that combine zero tillage with the application of branch mulch.

Research at Ibadan and elsewhere has shown that leaching is accelerated by soil cultivation, such as ploughing and harrowing, and conversely that it can be kept at a minimum by practices that do not upset the natural soil structure, i.e. zero tillage farming. During the first 2 or 3 years, better crops may be obtained from ploughed fields than from untilled land, but, if no inputs are brought in from the outside in the form of fertilizers, soil fertility will decline faster on cultivated fields and after a few years the untilled fields will produce higher yields and maintain this superiority for as long as economic farming can be maintained. Naturally, this will not be forever; the removal of nutrients through crop production and leaching, even at a reduced rate, will gradually exhaust even the untilled field. To compensate for this relatively slow decline in fertility, an input, other than chemical fertilizer, has been devised that is available to most

Branch mulch applied under cassava.

small-scale farmers, branch mulch. Lopped-off young shoots and leaves of trees are distributed on the ground in the same way as one would apply manure. The benefits from this application of branch mulch are manifold. Nutrients from the decaying mulch are released into the soil, almost complete protection against erosion is provided, microflora and fauna are favoured, helping to develop a porous soil structure, and finally the loss of plant nutrients by leaching is reduced because the organic matter content of the soil is raised. Some worry has been voiced that the use of branch mulch favours pest organisms. This fear is justified, but it seems that a biological balance between harmful and beneficial organisms normally becomes established when this type of mulch has been used for some time and in this way the population of pest organisms is kept at an acceptable level. Branch mulch does therefore serve as an ideal type of fertilizer because it is easy to obtain and offers additional advantages in the bargain. But where do the nutrients, which are obtained so cheaply, come from? Obviously, they must be drawn from the soil that is supporting the lopped trees. But, they cannot be pumped from this source forever. That is a crucial point about which more shall be said later.

Zero tillage does not mean that the weeds are left undisturbed to compete with agricultural crops. At IITA, they are suppressed by means of herbicides, and research is being carried out to develop methods that may put chemical weed control within the reach of ordinary farmers. Elsewhere, superficial scraping off of the weeds with a hoe has been tested in combination with zero tillage. The practices of some small-scale farmers of the Rajasthan in India may provide another valuable insight to the solution of the problem of how to rationalize shifting cultivation. These farmers do not in general practice shifting cultivation. Nevertheless, some of them seem to be able to maintain a certain level of fertility in their land almost continuously. How do these farmers compensate for nutrients lost through leaching? By using trees as nutrient pumps. They would probably not say so as they are not concerned with the mechanism of their farming system but only with its results. What they are doing resembles the farming practiced under *Acacia albida* in Africa. They are not so fortunate as to have a tree that is leafless during the crop season; nevertheless, they choose to grow their crops under or among trees. Partly because experience has shown them that soil fertility is maintained best in this way — and partly, and probably most decisively in their minds, because they have learned to choose and maintain tree species that benefit them in more than one way while having no adverse effects on their crops. The most remarkable of these trees are *Prosopis cineraria* and *Ailanthus excelsa*. The latter requires a rainfall of not less than 600 mm and is normally planted in rows along farm boundaries and to separate fields. The more drought-hardy *Prosopis cineraria* is favoured wherever natural regeneration produces a sapling in the fields. This species only throws a light shade, and because it has a vigorous taproot system and does not develop any strong lateral roots it hardly competes with the crops. In fact, agricultural crops can be seen growing healthily right up to its stem. Farmers will maintain as many as 40 *Prosopis cineraria* per hectare. Both trees produce excellent fodder for milk sheep and goats, and they are regularly lopped for this purpose. The mineral nutrients that have been pumped from deep soil layers by the trees are thus not returned directly to the soil as in the case of shifting cultivation. Instead, they make a detour through livestock before returning to the fields in the form of the manure that the Rajasthan farmers regularly apply to their fields. Really, this is an ideal way of solving the recycling problem.

Human knowledge in all spheres has been built up pyramid-wise over the centuries with the oldest and most fundamental insights constituting the broad base on top of which layer upon layer of new knowledge has been accumulated, the layers gradually becoming narrower and of a more specific character as we approach the top. Occasionally it has been necessary to rebuild some weak structures and discard some cracking stones even while raising the level of the top.

From the vantage point of the little shifting cultivation pyramid we have been endeavouring to construct here, and with our new insights into the mechanisms of nutrient cycling constituting some of the top stones, we should now be able to see a way, indeed a road, toward land-use systems in the field of crop cultivation, that are well adapted to present-day conditions in tropical Africa. Certainly, these systems should be better adapted than systems imported uncritically from temperate countries.

Before starting to build a road it is normal to stake it out roughly. The following tentative solutions to the shifting cultivation problem are proposed as beacons along the new road alignment toward productive and environmentally sound farming. It is fully realized that a considerable amount of research will be required to verify certain points and find practical solutions to others, and that the final road alignment will by-pass some of our beacons.

Basically, it is possible to imagine two distinct ways in which the advantages of shifting cultivation may be preserved within farming systems that are better adapted to present-day circumstances. The simplest consists in modernizing the old system while conserving its main features. The second approach would on the other hand discard the 'shifting' part of the system and only maintain the most fundamental of all its characteristics: the use of trees as nutrient pumps. Hereafter, these two possibilities will be considered separately.

For present-day farmers the old system has two main weaknesses. First, too much land, and often more than is available, is required to feed a family. In fact, a four to ten times larger area must be kept under bush fallow than the area effectively used for crop cultivation. Second, the large area maintained under bush fallow remains unproductive for too long a period to satisfy the aspirations of modern-minded people. Apart from improving the soil, the all important feature of the system, the bush fallow, lasting 10-30 years, rarely produces anything more than firewood and a few sticks for the farmer's own consumption. Although this production is of great importance, present-day farmers expect something more. Both of these weaknesses are linked to the unorganized nature of the bush fallow. The fallow must last for so long because, when left to nature, it takes several years for forest vegetation to reoccupy the abandoned land, and until trees and shrubs are back, the nutrient pumping cannot start. Leaving it to nature to decide the composition of the bush vegetation results in the second weakness, too low a productivity of forest products of marketable value. An exception to this pattern is found in areas where the fallows, without any human intervention, are invaded by almost pure stands of *Acacia senegal*, the gum arabic tree. This was the case over large areas of the Sudan until cultivators began to overstretch the farming periods.

A considerable improvement of the old system could therefore almost certainly be achieved by the replacement of natural bush fallow with a planted tree fallow. Research is needed to select suitable trees for a variety of environmental conditions and for different production goals. In order to qualify, the trees must combine several important characteristics: they must grow to economic maturity within a relatively short rotation; they must be good nutrient pumps, able to rejuvenate soils in the best possible way, including raising the nitrogen content; and finally, they must be easily raised by the ordinary farmer, preferably by direct sowing or by using nursery stock he can produce himself. If valuable products can be expected from the trees, the use of more expensive stock produced in central nurseries may be economically possible. The forest fallow would not be started, as in the case of the bush fallow, after the discontinuation of farming. On the contrary, it would be possible, in order to economize on time and reduce the work spent on weeding, to plant the trees with the last one or two agricultural crops, so that the trees are already well established when the area is finally left to fallow.

Farmers will only be willing to make the extra effort of planting trees, rather than leaving the revegetation to nature, if they can expect some return from their work in the form of better soil rejuvenation and yields of, and income from, useful forest products. The products that they might be able to produce on fallow land vary, but they could include fruits, gums, bark, and feed for livestock. Which type of production a farmer will settle for will depend on environmental conditions and marketing prospects. Such a modernization of the shifting cultivation system may be attractive where land shortage has not become too acute or where there are particularly good prospects for selling the products from the forest fallow. In many regions in Africa, population density has already reached such a level that there is no room for any kind of shifting cultivation, even of the improved version. In such densely populated areas, methods that maintain trees as nutrient pumps while discarding the 'shifting' part of the old system offer more promise.

Within this second category various systems can be imagined, but whichever system is chosen, trees will be the pumps that recover nutrients from deeper soil layers. Once the nutrients have been incorporated into the biomass of the trees, they may be returned to the soil by two different pathways. They may either take the short route through branch mulch that is spread on the fields, or they may make a detour through livestock fed on fruits and leaves and ultimately reach the soil in the form of manure. In both cases, it is necessary that a continuous cycling of the nutrients is sustained. It is not possible, of course, to continue to lop branches off a stand of trees to use as branch mulch or feed unless some kind of arrangement is made to ensure the replenishment of the soil under the trees with nutrients. Otherwise the trees would soon pump the soil 'dry' and their growth would

Cotton growing under shea butter trees.

be brought to a standstill. It is thus a precondition for any system using tree pumps that it is devised in such a way that leached and newly released nutrients can be intercepted by the roots of the trees, thereby ensuring an almost complete cycling of those nutrients that are not carried away in the crops.

To achieve this, various spatial arrangements of the trees are possible. The simplest is an even distribution of the trees throughout the cultivated areas. This system is exemplified by the farming carried out under *Acacia albida* in Africa and under *Prosopis cineraria* in India. What these two species have in common is that they do not throw heavy shade during the crop season, particularly *Acacia albida,* nor do they develop superficial lateral roots that would compete with crops. Both are furthermore excellent fodder trees. Through research, it should be possible to identify more species that could be grown with benefit on farmland.

Trees in fields are often disliked by 'modern' farmers. They get in the way of their machinery and must therefore disappear. This conflict could be attenuated if zero tillage farming was practiced between the trees and the weed problem was solved by means of herbicides. Such a method would maintain soil fertility better than cultivation based on ploughing and harrowing, and also draw less on scarce petroleum resources.

Some otherwise valuable trees cannot be grown within fields. They throw too dense a shade, exude inhibitors, or compete too violently with neighbouring crops. If such trees nevertheless are wanted as nutrient pumps and for production purposes, the spatial arrangements of the trees can be altered. In such situations, the farm areas should be covered by a network or grid of tree rows of sufficient density to make it possible for the tree roots to intercept most leached plant nutrients. On slopes, only parallel rows along the contour lines are required. The density of the grid, or distance between the lines, should vary according to the nature of the soil, the rainfall, and the tree species selected. On slopes it may be preferable to space double or triple lines quite far apart, as the leached nutrients sooner or later are carried down to the tree line by underground flow. On flat land, on the other hand, the grid should not be made too wide. The maximum width between tree rows should not exceed twice the length of the lateral tree roots, otherwise it is impossible to maintain the nutrient cycling. As some tropical trees extend their lateral roots more than 40 metres, openings need not be made too narrow either. Intercepted nutrients that have been pumped up into the biomass of the trees, within these nonshifting tree-pump systems, must be brought out into the fields through the regular application of tree mulch or via livestock manure. It should be added that the systems proposed here, besides ensuring the necessary cycling of nutrients, would provide excellent protection against erosion and ensure favourable microclimatic conditions.

The efficiency of the tree-pump system will, to a large extent, depend on an appropriate density of evenly scattered trees or of tree grids. On the other hand, if the density of the tree vegetation becomes excessive, it will throw too much shade and, in arid regions, compete too much with the crops for scarce water. Research will thus be needed to determine the ideal stocking of different tree species under varying conditions of soil and rainfall. An interesting solution to the problem of how to maintain the humus content in the soil at a sufficiently high level to act as a barrier against leaching, without resorting to an excessively dense tree cover, might be the periodic cultivation of green manure crops. This possibility ought to be given full consideration in all research aimed at modernizing shifting cultivation.

The life sustaining surface layer of our planet, its soil, is not a renewable resource. It is a tender structure almost like a live organism. Managed with knowledge, understanding, and care, it will be able to sustain human life for generations. Overexploited through greed or ignorance, it will not last for long. May the ideas presented here enable it to support the teeming populations of this continent for a little longer.

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