Introduction

Agroforestry systems incorporating a range of tree and crop species offer much more scope for useful management of light interception and distribution than do monoculture forests and agricultural crops. The potential benefit as a result of combining field crops with trees is obvious from consideration of the waste of light resources experienced in orchards and tree-crop plantations.

Trees are commonly planted at spacings appropriate to their size at maturity. This inevitably leads to under-use of available light in the early years after planting. Even modern, productive apple orchards can intercept as little as 30% of the available light at five years of age (Jackson 1980). A coconut plantation that intercepted 90 percent of the available light at maturity intercepted 50% when three years old and 70% when five years old (Nelliat et al. 1974; reported by Nair 1983).

Even at maturity many tree crops transmit a high proportion of the available light because experience has shown that it is not beneficial to have the trees denser or more closely spaced. Apple orchards seldom intercept more than 70% of the available light, those which do so being too dense and shaded for profitable fruit production (Jackson 1980). Twenty-year-old tall coconut palms in the Russell Islands were found to transmit 40-70% of the available light, depending on planting density (Smith and Whiteman 1983) and a dense dwarf palm plantation transmitted 20%.

Okigbo and Greenland (1976) and Okigbo (1980) identified more efficient use of light resources by plants of different heights and canopy structures as one of the advantages to be gained by growing crops in mixed stands. The way in which this is achieved in one traditional agroforestry system, the village-forest-garden system of Indonesia, was described by Michon (1983). In these forest-gardens, the cultivated crop species, from small herbs to taller emergent trees, form a layered structure giving a gradient in light and humidity exploited by plants according to their ecological requirements.

It is reasonable to suppose that successful systems of tropical agroforestry evolved along the lines described by Bunting (1980) for tropical mixed cropping in general. As soon as a gap appears in the mixture the farmer, or his wife, puts something in it. A body of knowledge is thus built up as to the combinations of available plants which most nearly meet the farmer's requirements.

The effective application of the much more rapid and powerful modern scientific methods of improving agricultural productivity to these mixed crop systems depends on understanding the crop interactions, particularly in relation to use of light, water and nutrient resources and developing appropriate management strategies. This paper concentrates on light utilization in agroforestry systems and the ways in which this can be optimized.

The general theory of light penetration and shading in agroforestry systems

The characteristics feature of light interception and penetration in discontinuous canopies such as those in agroforestry is that it **cannot** be calculated as a simple function of vertically-summed leaf area index (L) and a light extinction coefficient (K) by the usual equation:

$$I/Io = e^{KL} \quad (1)$$

where I is light intensity beneath an LAI of L and Io is light intensity above the canopy.

Instead the transmission through the (discontinuous) tree canopy must include a component representing light which misses the trees altogether by penetrating directly to the ground crop through gaps between the trees or rows of trees. If such transmission is designated Tf then the total light transmitted to the ground or field crop surface (T) expressed as a decimal fraction of light above the trees is as shown in Equation (2) (Jackson and Palmer 1979; Jackson 1983):

$$T = T_f + (1-T_f)e^{-KL} \quad (2)$$

In this equation Tf represents the fraction of the ground surface which would still receive light if the trees were 'solid' or non-transmitting to light and the second term represents light actually transmitted to the ground through the tree canopy with L' being $L/(1-T_f)$.

The corresponding equation for fractional interception by the trees (F) is:

$$F = F_{max} - F_{max} e^{-KL} \quad (3)$$

where F_{max} is the decimal fraction of the available light which would be intercepted if the trees were 'solid'.

From these equations it can be seen that:

1. The partitioning of light between the trees and the crop is a function of tree LAI and also of tree dimensions and arrangements which (together with latitude, time of day and time of year) determine the cast-shadow area for direct light (F_{max} for direct light) and the corresponding interception of diffused light.
2. Addition of a unit amount of tree leaf area will result in interception of more additional light if it is done in such a way as to reduce Tf by increasing F_{max} (e.g., by placing additional trees in gaps or increasing tree dimensions so as to increase the proportion of the ground which is shaded) than by increasing leaf area within the same canopy volume. In the extreme case, with widely scattered blocks of trees, doubling tree leaf area by placing extra trees in gaps could almost double light interception. Doubling the leaf area within the existing trees would increase light interception to a much smaller extent and hardly at all if L' in Equations (2) and (3) was already high. This conclusion, which is obvious, is borne out by the simulation studies of Rook et al. (1985).

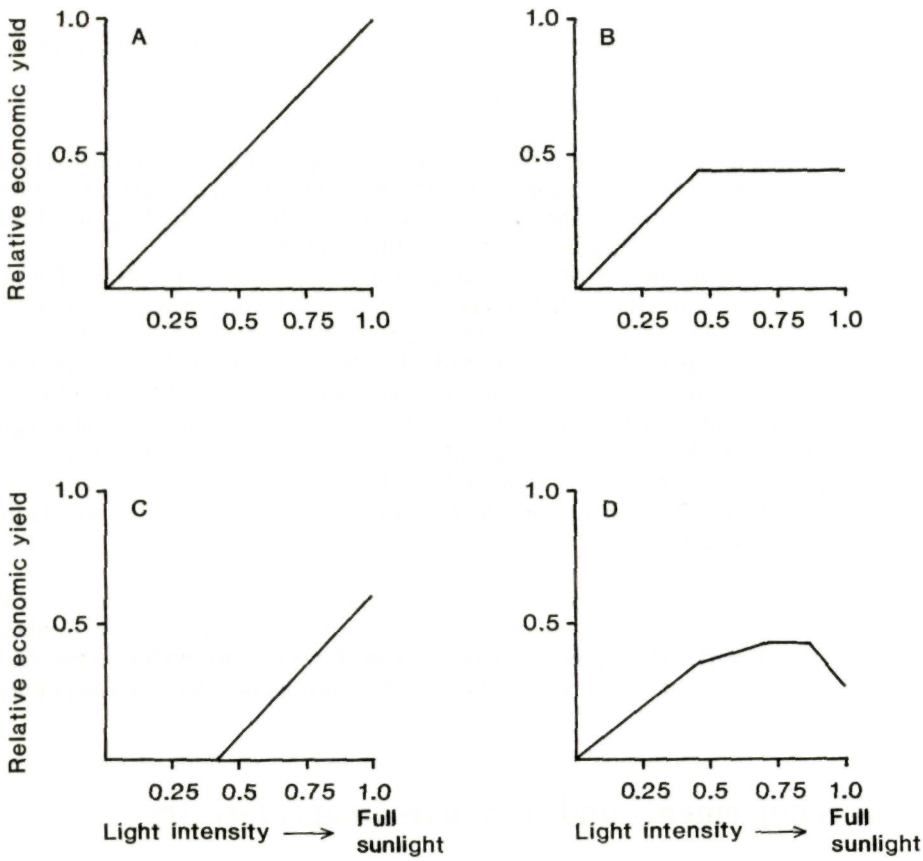
Using a modified Norman and Welles (1983) radiation interception model they calculated that under a particular set of conditions for Pinus radiata in New Zealand increasing the crown height to give a 77% increase in crown volume, with a correspondingly reduced foliage density, increased photosynthate production per tree and per unit ground area by 12%.

Light requirements and responses in agroforestry

The light requirements and responses of tree and crop plants can be categorized into four types as shown in Fig.1. In the first type (A) there is a linear relationship between intercepted light or light intensity with the regression line going through the origin.

There are many examples of dry matter production by crop plants being proportional to intercepted radiation, particularly early in the season (Biscoe and Gallagher 1977; Monteith 1977a). This does not necessarily imply a linear relationship between canopy productivity and light intensity because at least some of the variation in radiant energy interception in the data used was a consequence of variations in percentage effective ground cover (percentage of available light intercepted) rather than in light intensity. There is, however, also direct evidence that net canopy photosynthesis can be as linearly dependent on irradiance changes during a day (Biscoe and Gallagher 1977).

Figure 1 The relationship between economic yield and light intensity for four different plant types showing linear dependence (A), a degree of shade tolerance with low light saturation (B), shade intolerance (C) and shade requirement (D).



Observational studies have also shown an approximately linear relationship between the dry matter production of grass and weeds in coconut plots planted at different densities and the degree of shade. Smith and Whiteman (1983) found the mean above-ground dry matter yields of sown grasses and weeds under natural shade levels of 69, 54, 43 and 17% full sunlight (PAR) were 56, 49, 33 and 20% of those obtained from unshaded control sites.

Monteith (1972) cites crops such as maize, bulrush millet and tropical grasses in general as having this type of non-saturated light response. Subsequently Monteith (1977b) attributed this to C_4 plants in general.

The second characteristic type of crop x light relationship (B) is that in which crop canopies show light saturation at less than full sunlight intensity. In this case net photosynthesis or crop growth increases with light intensity up to a certain level and then stays at this plateau rate irrespective of further increases in irradiation (Biscoe and Gallagher 1977; Sale 1974). Mott and Popenoe (1977) show this response curve as typical of tropical legumes and Monteith (1972) shows a rather less flattened one for tropical species such as cassava and beans.

The third type of relationship (C) is one in which there is little or no economic yield at below a threshold level of light intensity although yield can be a linear function of light intensity above this point.

Cannell (1983) suggested that fruit and seed-yielding crops in general are intolerant of shade. It seems that the processes involved in flower and fruit bud formation, fruit set, fruit growth and the development of economically important visual attributes such as red skin pigmentation (anthocyanin formation) require levels of insolation much higher than those needed for vegetative growth. This was shown by within-canopy studies and artificial shading experiments on apple in which progressive increases in shade which had little effect on vegetative growth had dramatic effects on fruit yield and quality (Jackson and Palmer 1977a, 1977b; Jackson et al. 1977). From this and other work it was concluded that canopy zones receiving less than 50% of full daylight were effectively incapable of producing good quality apples and studies on peach planting systems suggest that fruit formation in this stone-fruit crop is at least as shade intolerant.

The final category (D) includes trees and crops which actually benefit from shading. Huxley (1967) showed by direct experimentation that Robusta and Arabica coffee seedlings increased in dry weight more rapidly when grown under 27, 38 or 54% full daylight than when grown in the open. This phenomenon appears widespread among tree seedlings. A rather more surprising result, in view of the generally adverse effects of shade on fruiting, was the increase in yield of top quality fruits of peppers in Israel which Rylski (1986) achieved by artificial shading. When imposed in summer, low levels of shade (12 and 26%) gave yield improvements of more than 62% over the unshaded controls while reducing light by 47% gave 30% more yield than control.

Management of agroforestry systems to maximize productivity through optimizing light utilization

Selection and management of 'high light requirement' fruit tree crops

There is ample evidence that seed and fruit producing trees are often of Type C as defined above. They cannot produce their crop in the more shaded parts of the trees and consequently there has been a pronounced move towards using very dwarfed trees giving shallow, well-illuminated cropping canopies in the commodities which have had the greatest research input. The change in apple production has been particularly dramatic with large trees replaced by more productive shallow cropping canopies of little more than a metre in depth and with orchard LAIs of around 2 or less (Jackson 1980; Jackson and Middleton 1987) compared with old style large tree orchards with LAIs of 5 or more. The productivity gain in the sole crop orchard is a result of better illumination of the fruiting wood, easier and cheaper management as a result of the reduced tree size (Jackson 1985) and a lower respiratory load in relation to photosynthetic productivity. In the agroforestry situation there would be a tremendous additional advantage of eliminating the non-productive zones of fruit- and seed-producing trees in that this would enable light currently intercepted unprofitably by the lower and inner parts of such trees to be available for growing understorey crops.

The simplest approach to meeting the specific agroforestry objective is to produce vertical columnar trees capable of producing fruits all the way down to ground level and so contained in their lateral growth that they bear fruits right back to the tree trunk, i.e. there is no unproductive inner zone. Such trees would minimize F_{max} for any given level of fruit production, minimize light interception per unit of tree LAI, and maximize availability to the inter-crop at ground level. There are two ways of achieving such tree form, by selection and breeding; and by pruning.

Selection and breeding for columnar fruit tree form

Variation in branching habit and tree form is commonplace within both coniferous and deciduous tree species, arising by mutation, but it is only recently that this variation has been exploited in a systematic way other than for purely ornamental purposes. Two common mutant forms, those generally referred to as 'pendula' and 'columnaris' can have the narrow-crowned habit which minimizes their cast shadow areas. 'Spur-types' with the main branches clothed in fruiting spurs rather than long lateral branches are also commonly found, e.g., in apple and in peach, an outstanding example being Red Delicious apple of which spur-types predominate. Such trees are, by and large, of conventional form even though the ratio of fruit yield to tree cast shadow area is obviously greatly increased.

A much greater potential for radical change in tree form has come with the identification of the gene for compact, columnar, non- branching habit and its use in breeding programmes (Tobutt 1985). Trees of this type are essentially upright poles covered with fruiting spurs without any lateral vegetative branches. The first varieties from these programmes are just now becoming commercially available. A rather similar habit is available within *Prunus,* although so far only exploited in the ornamental cherry Amanagawa. There are also prospects of compact types of a number of other fruit species (Alston and Spiegel-Roy 1985).

Pruning to produce fruit trees with a maximum ratio of fruit yield to cast shadow

Depending on natural tree branching and fruiting patterns two methods suggest themselves. Where the fruit trees crop on young wood, e.g., one-, two- and three-year-old wood, they can be pruned to produce a vertical axis with cropping laterals which are removed by cutting back to the trunk as soon as they surpass the desired maximum age. This is the basis of the 'pillar' and the 'slender spindle bush' (Wertheim 1978) and also of the 'axe' which is being used for both apples and peaches in France (Lespinasse and Delort 1986).

The major weakness exhibited by 'pillar' systems in the United Kingdom and 'axe' systems in France is that, where the trees are planted relatively close together in hedgerows only a few metres apart and growth is vigorous, the lower parts of the trees become excessively shaded by the adjacent hedgerows, are unable to produce good quality fruits and may even fail to regenerate lateral branches after pruning back to the trunk. Control of the vigour of growth of the top of the trees by careful pruning is essential to prevent this happening if vigour is not naturally controlled by genotype (scion and rootstock) or soil. In the agroforestry situation this problem is much less likely to occur because the trees or hedgerows can be spaced so widely apart that even the lowest parts of the tree receive ample sunlight for production of good quality fruits and for branch regeneration.

Where the fruit trees crop best on older spurs then either:

1. A columnar tree shape around a 'centre-leader' vertical axis can be maintained by using the 'North Holland' type of pruning system with shortening back or removal of extension shoots in both summer and winter. In this approach the lateral branches are not allowed to extend more than about a metre from the trunk.
2. As an alternative, trees of a spreading-branched form can be spur pruned so that all the fruits are borne on spurs on main scaffold limbs with gaps between these limbs for light penetration. This is, however, a much more difficult tree form to manage than are the centre-leader, vertical axis forms described earlier.

Selection and management of other tree crops in agroforestry situations

Some forest trees as well as fruit trees are shade-intolerant (Perry 1985) and Assmann (1970) concluded that mixing shade-tolerant and shade-intolerant trees led to increased productivity compared with growing intolerants alone. For example, the yield *oiPinus sylvestris - Fagus sylvatica* mixtures was up to 24% greater than that of pure *P. sylvestris*. Shade-intolerant timber trees can be regarded as ideal partners for understorey crops in the same way as fruit trees and palms and the same design requirements are relevant.

Even when the trees are Type A in their light response it is clearly advantageous in an interspersed agroforestry situation for the timber trees to have a maximum ratio of economic yield (trunk) to tree volume and cast-shadow area (F_{max}). Essentially to achieve this we need trees with strong genetically determined apical dominance (or apical control). This tree type has been sought for very different reasons in the Finnish forest tree breeding programme. In this the ideotype for conifers has stems which are straight, have small taper, thin bark, good quality timber and rapid height and diameter growth, and branches which are slow growing, are consequently small in length and diameter and subtend angles at about 90 degrees with the stems (Karki and Tigerstedt 1985). Such trees could be very suitable for row and alley cropping (see below).

The Finnish selection and breeding programmes have produced narrow crowned trees with a high, and highly heritable, ratio of standing stemwood to total above-ground fresh weight. Among the species with narrow crown forms are *Picea abies, Pinus sylvestris* and *Betula pendula*. It is noteworthy that narrow-crowned clones occurred naturally as did the Wijcik mutant of Mcintosh which is the source material for compact apple tree breeding. There seems every possibility that a systematic search for narrow-crowned or columnar types of relevant tree species for agroforestry would result in the rapid identification of suitable clones.

This argument is probably relevant in all agroforestry situations where timber is an important product. It is likely to be most difficult to put into effect where the ground crops is of Type D with a specific shading requirement. In general it is much easier to ensure an even low level of irradiation in the understorey if the trees have high F_{max} and low leaf area per unit canopy volume, grown as flat-headed (umbrella-like) trees or as very tall thin hedgerows, than if they are dense and columnar with low F_{max} and high density of shading although this can be achieved in row and alley systems with appropriate dimensions and row orientations (Jackson and Palmer 1988). The ideal understorey crop or alley crop to combine with dense columnar spaced trees is one with an Type A light response so that it can make use both of very high irradiances in unshaded areas and low irradiances close to the trees.

Fuelwood and fodder trees in an agroforestry situation

It is assumed that these have a Type A light response, with some economic product, in the form of branches and leaves, being produced even in shaded situations and trunk thickening and upward growth being a function of total light interception. There is not likely to be any intrinsic advantage from growing such trees in close, intercropping association with crops. Indeed their yield of vegetative dry matter per unit ground area may well be higher if they are grown in solid blocks with a degree of 'density stress' (Cannell 1983). If the trees are grown in such blocks, or at least in multi-rows, their productivity will be influenced by the following:

1. The upper limit to potential yield will be determined by F_{max} and reduction in this will, other things being equal, be accompanied by loss of yield.
2. Increases in leaf area index of a closed canopy or of leaf area within a given tree volume will not necessarily lead to increases in net photosynthate production. Above a certain leaf area index, which varies with the light extinction coefficient, surplus production is reduced as respiratory losses more than counterbalance photosynthetic gains (Saeki 1960; Kira and Kumura 1983).
3. As a consequence of 1 and 2 reduction in the dimensions of a fuel or fodder tree block, especially reduction in the horizontal dimension of ground area covered, will reduce its productivity to a much greater extent than will removing branches from individual trees or removing individual trees from within the stand as long as these do not leave large gaps.

In general, the techniques of clear-felling of forest trees and even of coppicing are largely determined by the specification of the end product, e.g., in terms of sawnwood potential, pole characteristics, etc., and by the economics of harvesting on a large scale. In the small-scale agroforestry situation it may well be possible to treat fodder and fuelwood as regular crops from the trees while maintaining them as photosynthetically efficient canopies. In this context it is worth noting that fruit trees, once mature, are capable of putting 70% of their dry matter increment into harvested fruit each year (Jackson 1985) and data presented by Barlow and Smith (1971) shows up to 77.5% of the total annual increment going into harvested fruit and deciduous leaves with only 22.5% going into root and trunk and branch tissues. If such a ratio of consumable to structural product could be obtained in fodder trees by appropriate selection and management then sustained annual harvesting of only that production which is surplus to the trees' maintenance needs could well replace the longer term cycles of production (Cannell 1983) which are currently common.

Effect of the light requirements of the ground crop on system design and management

Although it is possible to think of available radiant energy being partitioned up between the tree crop and the ground crop the proportionate partitioning will only have a corresponding effect on ground crop yields if this crop is Type A in its light responses. In all other cases the pattern of shade distribution over the ground could be of critical importance.

Jackson and Palmer (this volume, Section 5) show that row and alley systems can result either in relatively uniform shade across the alley or in a combination of dense shade near the trees and little shade in the alley centre or adjacent to a south-facing row (if north of the equator). Moreover, the shade pattern can change with time of year. The uniformity of shade cast by scattered or evenly distributed trees will depend on the height of their foliage above the ground as well as on its LAI. Under these circumstances the efficiency with which a crop can utilize the light which is not intercepted by the trees will depend on the combination of crop requirements and light intensity pattern over space and over time.

In order to assess the magnitude of these effects it will be necessary to obtain data on shade responses under the appropriate environmental conditions. An indication of the likely crop-specificity can be obtained from the work of Willey and Holliday (1971a, 1971b). They showed the yield of barley to be reduced by shading during the ear development phase but not by shading during the subsequent grain-filling period; whereas the yield of wheat was reduced by shading at either of those times. Yoshida and Parao (1976), in experiments involving shading to 25, 50 and 75% of full daylight, found the vegetative growth of rice to be almost unaffected by shade but the reproduction and ripening phases to show a linear dependence of yield on light intensity. Where shade is of positive benefit, as in protecting peppers from sunscald, it is unlikely that a combination of exposure to full sunlight for part of the day coupled with deep shade for another part of the day — as is achieved with some row and alley systems — will be of equal value to an equivalent average reduction in light as a result of a virtually continuous sparse overhead canopy. A combination of shade trials and computer modelling of light interception and distribution could be very valuable as a supplement and a guide to direct experimentation to optimize agroforestry design and management and the selection of appropriate trees and crops.

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The continental oases of southern Tunisia and the agrometeorological network of the Nefzaoua Project

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Abstract

The Nefzaoua Region represents the final phase in the transition from the mediterranean climate to the warm desert climate. We examine the 'agrometeorological efficiency' of the traditional oasis system and illustrate certain trends in oasis management. Finally we describe the agrometeorological network of the Nefzaoua Project.

Introduction

The Nefzaoua Project managed by the Istituto Agronomico per POltremare of Florence (IAO) and the Institut des Regions Arides of Medenine (IRA), is a cooperative project between Italy and Tunisia. Its aim is to combat desertification and to improve the traditional management of the oasis.

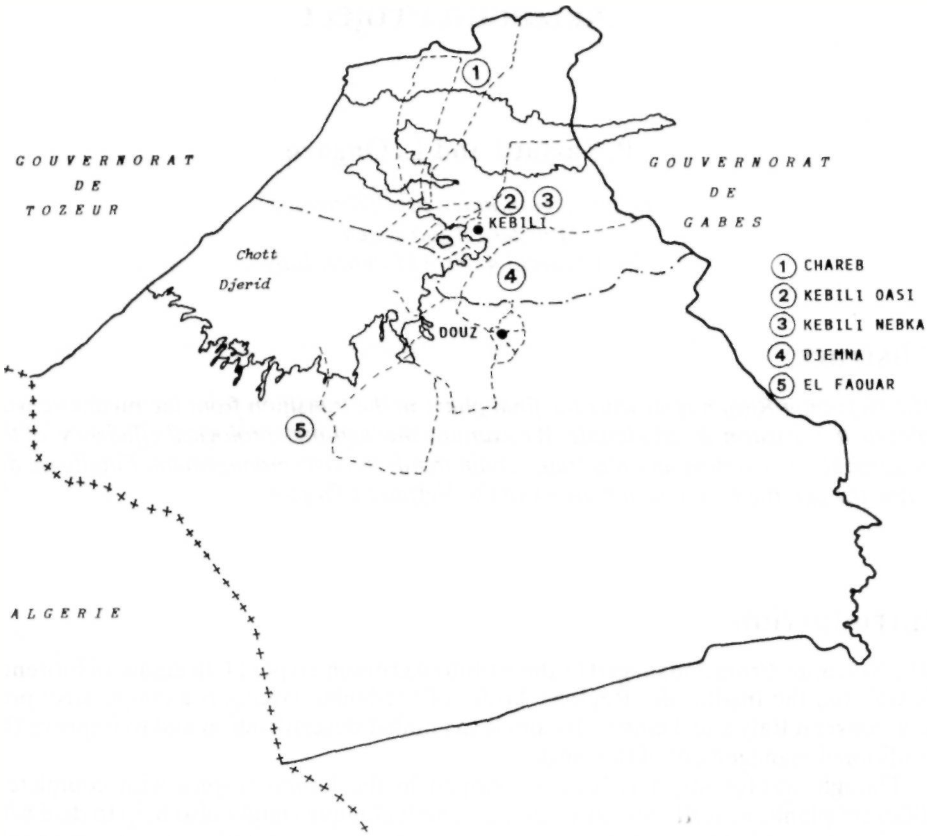
Though agroforestry has been developed in the humid tropics with completely different plants, nevertheless its principles and techniques might also help to deal with efficient use of light and water in complex multi-strata vegetation structures in arid climates, such as the continental oases of the Nefzaoua.

The region of Nefzaoua

The region of Nefzaoua in southern Tunisia lies to the south of the Chott El Fedjedj, and to the east of the Chott El Djerid, two vast salty depressions that range in elevation between + 23 and -20 m asl. Eastwards are the Matmata mountains and southwards is the Sahara desert (Figure 1).

A recent survey of the geomorphology, soils and vegetation of the area has been conducted by the Istituto Agronomico per l'Oltremare (Ongaro 1986) and a land units map has been drawn. The region has a tropical arid climate (Tave = 21 °C) with outbreaks of cold air from the Mediterranean sea; occasionally it is reached by the edges of the frontal depression systems crossing the upper latitudes. Throughout the entire zone the scanty and variable rainfall (90 mm per year) coincides with the period of lowest temperatures.

Figure 1 Agrometeorological network of Nefzaoua (1:1,500,000).



The Nefzaoua represents the final phase in the transition from the mediterranean climate to the warm desert climate dominated by tropical highs.

The oasis

Agriculture is practiced exclusively in the oasis; the surrounding steppes are grazed by camels, goats and sheep. Traditionally vegetation in the oasis is structured on three levels: 1st level, date palms; 2nd level, fruit trees (olives, figs, pomegranates, almonds and apricots); 3rd level, fodder plants (alfalfa and barley) and vegetables.

Fields are small and surrounded by hedges of palm leaves; the irrigation and drainage network is very close and plants are irrigated by submersion. The soils have a great percentage of sand and silt and, by consequence, have a very low cation exchange capacity. Therefore the manure used to maintain their fertility is a very important factor and also contributes to increased soil available water capacity. Commonly the oasis is protected from the outside by one to three shelterbelts of non-living barriers.

The components of the whole system (vegetation structure, irrigation and drainage, hedges and shelterbelts, manure) contribute to create the 'oasis effect' leading to a reversal in the ratio between turbulent latent heat flux density and net all-wave radiation flux density (Flohn 1971; Oke 1978). The traditional management of the oasis has created a very complex system with the integration of agriculture and rangelands that cope quite well with the extreme environmental conditions.

The present situation

Recently a decline in the productivity of many oases has led to a change of the system. Certain trends can be discerned:

1) abolition of fruit trees and, in some cases, of fodder plants with the consequent loss of manure;
2) new irrigation methods using closed pipes instead of the traditional open air network; and
3) larger fields of date palms with decreased plant density.

All these management modifications affect many agrometeorological parameters inside the oasis (temperature, global and net radiation, wind speed, potential evapotranspiration, etc).

On the other hand desertification in the surrounding steppes has been accelerated by climatic factors as well as by overgrazing with the consequence of increased heat advection from the areas in which the oases are embedded. Thus the traditional agroecosystem is being replaced by a more 'simple' but probably more unstable one, the long term validity of which has yet to be shown.

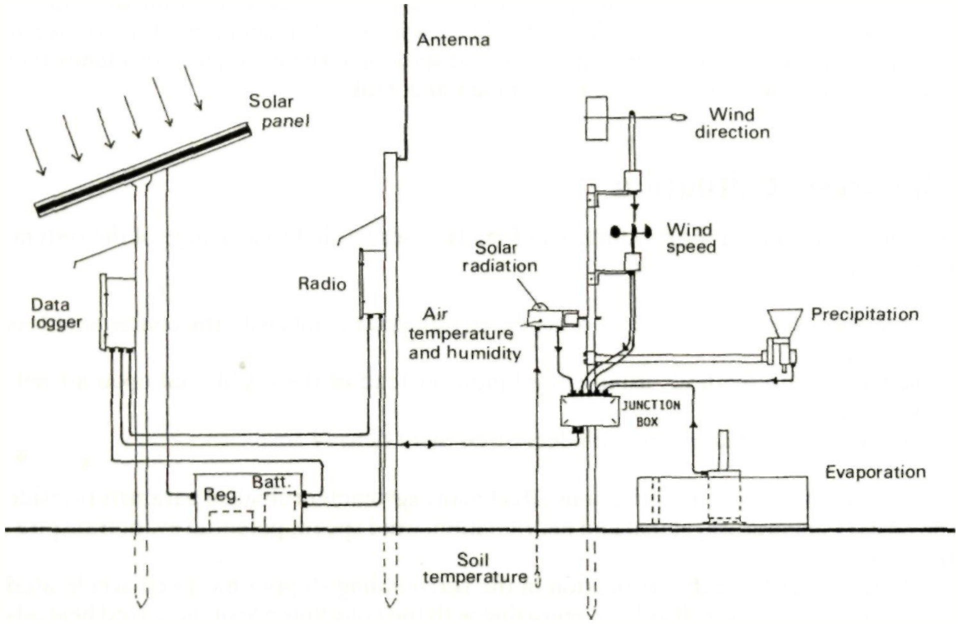
The agrometeorological network

To monitor the present situation and to assess the validity of possible new proposals, an agrometeorological network will be implemented during 1987, as a part of the Nefzaoua Project. The network will be composed of five peripheral stations and a central unit in Kebili for data processing and storage. The meteorological variables to be measured include: precipitation, air temperature and humidity, solar radiation, wind speed and direction, evaporation and soil temperature (Figure 2). Data will be sampled every two minutes, pre-processed and transmitted automatically by radio to a personal computer. Data will also be stored at the local stations on solid state memory modules with a thirty-day data capacity. Solid state modules will be interchangeable and connectable to the computer by an interface. All the peripheral components will have a working range from -50 °C to +125 °C. The stations that don't 'see' Kebili will be connected by two radio repeaters.

The network has been designed to be reliable and user-friendly (Benincasa et al. 1984; Sarfatti 1986).

The network will also provide 'ground-truth' for a long-term remote-sensing experiment that will be conducted after 1988 by IAO and by the Italian National Research Council (CNR) to monitor desertification processes and oasis 'health' utilizing Landsat TM and TIROS AVHRR images.

Figure 2 Peripheral agrometeorological station (1:30).



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The need for meteorological information to plan agroforestry on steep slopes in Ethiopia

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Abstract

Ethiopia is characterized by land features of mountains, hills, plateaus, valleys and gorges. In general, the land above 1500 m elevation is classified as highlands. The country covers 124 million hectares of land comprising 42 million people. Agriculture is the dominant sector of the economy. It contributes to 90% of the exports and an employment of more than 80% of the labour force.

On the other hand, 95% of the cultivated lands are situated in the highlands where 88% of the human population and two thirds of the livestock are found. The highlands are rugged and steep. As a result of their steepness, overgrazing overcultivation and wanton deforestation, the highlands suffer from environmental degradation.

The traditional climatic zones prevailing in the country are:

- *Kolla (arid & semi-arid)*
- *Woina Dega (semi-humid)*
- *Dega (cool and humid)*
- *Wurch (cold and moist)*

In these zones, 12 major land use and cover types were identified from satellite imagery interpretation and limited field checks.

The cropland occupies 14.8%; grazing and browsing land 51%; forests 3.6%; and currently unutilizable land 18.7%; of the country.

In the history of Ethiopian agricultural land use, agroforestry is closely related to intercropping of perennial and annual crops. It is widely practiced in the south, southwestern and eastern parts of the country. Agroforestry has also recently been recognized as impoerant soil and moisture conservation.

At present, the productivity of the highlands is declining below the food requirements of the people and the livestock. Tlie reasons are severe soil erosion and decline in the fertility of the soils resulting from poor land management practices.

In order to reverse the situation, scientifically designed and planned agroforestry farming systems are urgently needed on steep slopes. The systems should itegrate resource - conservation - based production of crops, livestock, woods and conservation of nature. However, these require basic information on climate, soils and slope classes. In Ethiopia, 6 rainfall pattern regions, 10 thermal zones, 15 length-of-growing periods, 18 major soil types, 380 land systems and 5 slope classes were identified at exploratory levels of studies.

Introduction

Ethiopia is situated between 3° and 18° north latitude and 48° east longitude (i.e., in East Africa). It is mainly characterized by land features of mountains, hills, plateaux, valleys and gorges. In general, the land above 1500 m asl is considered rugged highlands. The country has a total land area of about 124 million hectares and comprises 42 million people (FAO 1986a).

Agriculture is the dominant sector of the economy. It contributes to 90% of the exports and an employment of 88% of the labour force. The farm families organized into peasant association are about seven million and the annual population growth is about 2.9% according to the 1984 national census. Ninety-five per cent of the cultivated lands are in the highlands. They contain 88% of the country's human population, two-thirds of its livestock and over 90% of its economic activity. However, the highlands suffer from environmental degradation as a result of overgrazing, overcultivation, excessive deforestation, and slashing-and-burning of the natural vegetation cover. The destruction of forests according to recent estimates is 200,000 ha per year which is over the potential capability of the existing 3.6% forest land. The sensitive arid and semi-arid vegetation of the lowlands is badly threatened by overgrazing. The present estimate of the annual country-wide soil loss rate is 2 billion cubic meters. The highlands are seriously threatened by sheet, rill and gully erosion. Sheet and rill erosion attack mainly cultivated lands and grazing lands. For these reasons, the fertility and productivity of the highlands is declining rapidly.

The traditional agroclimatic zones and slope classes

The four traditional agroclimatic zones of Ethiopia are distinguished by the linked factors of altitude, annual rainfall and temperature (Table 1).

Table 1 Traditional agroclimatic zones.

Agroclimatic zone	Climate	Altitude m asl	Average annual rainfall, mm	Area km^2
Kolla	arid & semi-arid	<1500	<800	702,755
Woina-Dega	semi-humid	1500 < 2400	800<1200	398,811
Dega	cool & humid	2400<3200	1200 < 220 0	127,954
Wurch	cold and moist	>3200	>2200	14,280

However, rainfall is related to geographical position as well as altitude. At a given. altitude, a site in Tigre or Eritrea, or in the south-eastern region towards the frontiers of Somalia or Kenya, is likely to receive less than a site in Shewa, Keffa, Elubabor or Wellega.

In order to understand in detail the agroclimatic conditions of the country, the four agroclimatic zones are sub-divided into 11 sub- agroclimatic zones based upon the distributions of the average annual total of rainfall (Table 2).

Table 2 Sub-division of agroclimatic zones.

Agroclimatic sub-zones	Climate	Altitude m asl	Annual rainfall mm
Bereha	arid	<500	<200
Dry Kolla	semi-arid	500-1500	200< 800
Moist Kolla	warm-semi-humid	500-1500	800-1400
Dry Woina Dega	semi-humid	1500-2400	<900
Moist Woina Dega	semi-humid	1500-2400	900-1400
Wet Woina Dega	humid	1500-2400	>1400
Moist Dega	cool & humid	2400-3200	900-1400
Wet Dega	cool & wet	2400-3200	>1400
Moist Wurch	cold & humid	3200-3700	900-1400
Wet Wurch	cold & wet	3200-3700	>1400
High Wurch	extreme cold & wet	>3700	>1400

The five slope classes distinguished in Ethiopia are: 0-10%, 11- 25%, 26-35%, 36-50% and more than 50%. Slope class 0-10% occupies mainly the lowlands below 1500 m elevation (about 703,000 km) and the flat highland plateau and valley bottoms. The other classes are found mainly in the highlands. Slopes greater than 50% occupy a large area compared to the other classes.

Present land use and cover types

Land use refers to the uses to which the land resources are put by man to derive the maximum benefits in order to satisfy his social and human needs. These are food, clothing, shelter, firewood and other materials such as wood for furniture (FAO 1986b). Land use involves the physical interaction between the resources and the powers of man and animal required to produce the necessary commodities. However, land cover types reflect only the natural and physical features of the resources from which man can benefit. These resources are vegetation, soils, water, cultivated land areas, salt flats and the rocks. Vegetation by itself comprises forests, woods, bushes, shrubs and grass at various levels of cover density.

In Ethiopia, a land-use/land-cover study was carried out by interpretation of Landsat imagery (1972-1979) and limited field checks (FAO 1984a). The study distinguished 12 major land cover types:

1. Urban and built-up land
2. Cultivated land
3. Afro-Alpine and sub-Afro-Alpine vegetation
4. Forest land
5. Woodland

6. Riparian woodland or bushland
7. Bushland
8. Shrubland
9. Grassland
10. Wetland
11. Bare land
12. Water bodies

The 12 major cover types were further subdivided into two to five sub-units. A further classification was made, based on main land use and main crops. Finally, the distribution of land under the major kinds of land uses were summarized as shown in Table 3.

Table 3 Classification based on land use and main crops.

Use	Area (ha)	Percent
Crop land		
Annual crops	16,413,140	13.1
Perennial crops	2,074,050	1.7
Grazing and browsing land	63,725,700	51.0
Forest, woodland, bush and shrub		
Forest	4,473,520	3.6
Other	10,135,470	8.1
Currently unproductive land	4,719,740	3.8
Currently unutilizable land	23,292,380	18.7
Total	124,834,000	100.0

The history of agroforestry in Ethiopia

In the history of Ethiopian agriculture, intercropping is a common practice especially in the south, south-western and eastern parts of the highlands. At present, it is remarkably considered as an old agroforestry practice in the perennial crop growing areas. Among the perennial crops, coffee, ensete and chat *(Chata edulis)* could be mentioned as common examples.

The history of the traditional agroforestry farming systems in Ethiopia goes back to the beginning of coffee production in the country. In general, coffee grows wild as well as cultivated in the south and south-western highlands. However, it is cultivated in pure stands in the eastern and central highlands. Wild coffee grows naturally as bushy strata under tall forest trees, while cultivated coffee is common to homesteads under the shade of irregularly scattered trees. The common shade tree genera axe *Albizia, Acacia* and *Corida.* All of these have flat and wide umbrella-shaped canopies. However, the canopies allow an optimum amount of light rays to penetrate and reach the coffee bushes.

On the other hand, since the shade trees and the coffee bushes are scattered, there is enough space to plant other crops in between. Farmers in the south till the coffee fields in the rainy season with hoes and intercrop them either with cereals such as maize and sorghum; pulses; or root crops such as taro, potatoes and cassava. Some farmers intercrop coffee with perennial crops such as ensete, lemons, oranges, limes and hops. In some other perennial crop areas, where coffee is not commonly grown, ensete and cabbage are grown in the shade of scattered trees. And in the central Ethiopian highlands, acacia trees are scattered in the cereal and pulse fields. Chat bushes in the eastern (Hararghe) and central highlands are intercropped with cabbages, sweet potatoes, shallot or onions during the growing season.

As a result, farmers derive multiple uses from their intercropping. They produce coffee, beans, seeds, vegetables, loppable browse for their cattle and firewood from the branches of the trees. Therefore the system does not very much affect or change the natural ecological balance of these areas, because the canopies of the trees and the branches of the bushy perennial crops intercept the erosive heavy rain drops. On the other hand, the root systems allow free infiltration of water by retarding surface run-off and bind the soil *in situ*. Added to that, litter from leaves and bark add organic matter, increases fertility of the soil and improve its structure and its workability.

These ecological interactions not only conserve the soil but keep the moisture and nutrient balance of the soil intact to make it reliable for crop production. Today, farmers need to produce enough for themselves and if possible a surplus to insure food and export securities for their nations. This should also be done without causing serious and irreversible damage to the resources.

In Ethiopia, cultivable land is scarce and vulnerable to degradation. Therefore, an understanding of the traditional agroforestry farming system invites us to think more scientifically about its advantages and to design scientifically-tested systems to protect our environment. This requires identification of the quality and distribution of various environments, the crops to be grown, their optimum environmental requirements, and the trees and shrubs to be integrated within the system.

It also involves the selection and breeding techniques of high yielding plant and/or crop species, proper management and conservation techniques and designs. However, identification of techniques should rely upon research findings and recommendations in order to arrive at conservation-based multiple productivity of the resources.

The need for agroforestry planning in Ethiopia

For many centuries subsistence mixed agriculture has been practiced, mainly in the highlands of Ethiopia. It integrates both livestock- rearing and the production of rainfed cereals, pulses, perennial crops, fibre crops and oil crops. Oxen and man were and still are the main sources of farm power. Cows are reared to produce oxen and some milk products. Goats and sheep are kept mainly for meat and as a source of cash in the peasant economy. Horses fulfil the need for transportation of humans and goods. However, for many centuries, land has been ploughed and grazed without thinking of soil and water conservation measures. As a result of human and livestock pressure on the land, cultivated and grazing lands are expanding at the expense of the natural vegetation. Therefore, erosion in the highlands is aggravated as a result of misuse of land and wanton destruction of the natural vegetation. Drought is a common and recurrent phenomenon, especially in the north and north-eastern parts of the country.

The environment of the Ethiopian highland is fragile because of its rugged and steep terrains. It requires wise and scientific uses for its sustained productivity. For instance, if one compares the north with the south and south-western regions of the highlands, the latter are better protected than the former because of considerable cover by vegetation and old practices of agroforestry-oriented farming. In the south and south-western regions, perennial crops (e.g., ensete and coffee) and their associated tree canopies intercept the rainfall thereby protecting the soil from its erosive power. On the other hand, soils in the northern, north-eastern and central highlands are heavily washed and the environment is degraded. Crop failures and significant yield decreases are common phenomena in these areas. The causes are serious droughts and bareness of the ground. Therefore, people and livestock are suffering from shortages of food and feed in those areas.

In order to reverse the degradation of the environment and halt the ongoing soil loss, scientifically-based agroforestry systems planning is badly needed on the steep highlands of Ethiopia. In such a system, the major concern of planning should be efficient soil- and water-conservation practices and sustained production of cereals, pulses, oil crops, fruit, fodder (browse and herbs), firewood and wood products.

Availability and quality of climatic data

In Ethiopia there are more than 506 climatic stations. All operate under the authorization of the National Meteorological Service Agency (NMSA), which is responsible for the collection, analysis and distribution of the climatic data.

Of these, 213 record precipitation; 192 stations record precipitation and temperature; 52 stations precipitation, temperature and relative humidity; four stations precipitation, temperature, relative humidity and solar radiation; 18 stations precipitation, temperature relative humidity, solar radiation, and sunshine duration; 27 stations precipitation, temperature, relative humidity, solar radiation, sunshine duration and windspeed. Many of the stations have records of more than 5 years. However, only a few stations, such as Gore and Addis Ababa, have records of more than 35 years.

The shortcomings of the climatic data in Ethiopia are the short periods of observations; the poor quality of the data due to inconsistency of records; and the relatively few stations that make comprehensive agroclimatic measurements.

Rainfall patterns and distribution

The Land Use Planning and Regulatory Department (LUPRD) of the Ministry of Agriculture studied the climatic patterns of Ethiopia sources (FAO 1984b). Six major rainfall pattern regions were distinguished.

Rainfall pattern region 'A' encompases the north-eastern and south-western parts of the country. The region receives rain in summer (i.e., in June, July, August and September). In the highland areas, precipitation exceeds one-half potential evapotranspiration (PET) at the beginning and end of the rainy season; and full PET in the middle of the rainy period. However, in the lowlands of north-eastern areas the rainfall exceeds $^1/_2$ PET only in July and August and is always below full PET. Therefore, the lowland areas suffer from shortage and insufficiency of rains.

Region 'B' encompasses the southern and south-western parts of the country. The region receives tremendous amounts of precipitation from March to early December in highland areas; and from mid-April to November in the lowland humid savanna areas. Precipitation always exceeds full PET for most of the rainy season. The region is characterized by rains occurring from spring to autumn and is ecologically stable with vigorous vegetation growth and cultivated perennial crops such as coffee, ensete and rootcrops.

Region 'C receives rain in spring, summer and autumn. The region covers the eastern and south-eastern plateaux and escarpments. The rainfall occurs from February to November in highland areas and from March to November in the low-lying areas. In most of the regions, precipitation during the rainy season is more than $^1/_2$ PET.

Except for some low-lying areas, the region does not suffer from an insufficiency of moisture for the growth of natural vegetation.

Region 'D' covers the north-eastern Red Sea coastal areas. It enjoys rains throughout the year. However, summer rain is small compared with the other three seasons. In most of the areas, precipitation is below $^1/_2$ PET. Therefore, growth of natural vegetation is highly affected by the short and zero length of the growing period. Therefore, the region is considered not climatically suitable for cultivation of crops and livestock rearing.

Region 'E' covers the whole of the Ethiopian rift valley and the eastern, central and south-eastern highlands. It receives rains from March to the beginning of October i.e. small rains in spring and big rains in summer merging together. However, there prevails a very short dry spell in May which has little effect on crops and the growth of natural vegetation. In most of the highland areas precipitation is higher than potential evapotranspiration. But in the lowlands, like in 'Dire Dawa', precipitation is always between half and full PET.

Region 'P covers the southern and south-eastern frontiers with Kenya and Somalia. It has a bi-modal rainfall distribution, with spring rainfall considerably greater than the autumn rainfall. The significant rainy months are April to the end of May and from September to November. The rains bordering region 'C of this zone are more reliable than rains in the south-west and south-east. In the highland areas near region 'C, precipitation is less than $^1/_2$ PET. In the region no major rain-fed crops are grown and the natural vegetation is dominated by thorny low shrubs.

Thermal zones

In Ethiopia, average temperature decreases about 0.6 °C for every 100 m increase in elevation. In this regard, the temperature gradient determines the distribution of annual and perennial crops, livestock and the natural vegetation in general. The LUPRD (FAO 1984b) distinguished 10 thermal zones based upon mean temperature during the growing periods (Table 4).

Table 4 Thermal zones.

Thermal Zone	Mean temperature during growing period, C
1	>27.5
2	>25.0 < 27.5
3	>22.5 < 25.0
4	>20.0 < 22.5
5	> 17.5 < 20.0
6	>15.0 < 17.5
7	>12.5 < 15.0
8	> 10.0 < 12.5
9	> 7.5 < 10.0
10	< 7.5

Source: FAO 1984b

The zones help determine the types of crops, trees, shrubs and herbs to be found and grown, produced and reserved in a certain locality.

Length of growing periods

Length of growing period is determined by the interrelated analysis of precipitation, soil moisture holding capacity, potential evapotranspiration and frost period. The growing period is considered to begin when precipitation exceeds *It* PET and end when precipitation falls below $^1/_2$ PET.

Length-of-growing period 0 to 90 days occurs in the north- eastern, eastern, south-eastern and southern lowlands. There the natural vegetation is very scanty and consists primarily of thorny- bush acacias. The highlands and the north-western, western, and south-western lowlands are characterized by growing periods longer than 90 days.

Other land resource information essential for agroforestry planning

Mapped information on the physical environment (at scale of 1:1,000:000) is available from LUPRD. Since soils are the vital medium for plants growth, their nature, and characteristics should be known to help in planning, decision making and implementation.

In Ethiopia 18 dominant soil types, 380 landscape units and 120 soil management units have been identified and characterized. This information enables planners and decision makers to identify the relevant types of agroforestry based developments to be undertaken in the areas where they should be necessary.

Conclusions

Agroforestry planning requires scientific decisions on an integration of resource-conservation-based multiple use systems. Multiple use can be interpreted as integration of pulses, cereals, fruits and firewood production; or integration of wood and fodder production; or integration of fruits, recreation and nature conservation. However, choices of species and varieties should rely upon the available natural resource information.

On the other hand, plan implementation requires data on human and livestock population and the feeding and cultural conditions of the society for whom the effort is sought. Implementation in turn requires continuous monitoring of the benefits and changes in resources and ecosystem characteristics.

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Mulching as traditionally applied by small scale coffee growers in Tanzania

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Abstract

Microclimate management of coffee farming by small holders using organic mulching is dealt with. A review of the commonly used mulch — dried grass and sometimes banana leaves, applied to each or alternate inter-row is made. The marked effect on the climate of the soil enables the farmers to practice intercropping with suitable annual crops during the first few years of the coffee plants, and increased coffee yields thereafter. The gains accrued are mainly due to improved soil and water conservation, and addition of organic matter and nutrients. Both the effects and gains are treated qualitatively due to limited availability of figures.

Introduction

The application of mulch in coffee plots by small holders may date back to the time when coffee was first introduced in East Africa by missionaries from Reunion island between 1883 and 1896 (Acland 1973). At the time, the advantages of mulching as we know them today were unknown except probably that of weed control (or suppression). The mulch, most commonly used was, and still is, cut wild grass or sorghum trash. Some few small holders however do produce napier grass for this purpose. In this respect, we shall define mulch as covering of the soil surface with cut grass or crop residue.

The use of mulch in coffee farms has been on the increase over the years especially during the first few years after planting. The enthusiasm however has slackened at times during low coffee prices such as the world economic depression of the late 1920's and early 1930's and also the inter-world-war years. Through experience, farmers know the direct relatinship between mulching and better yields, although they might not be fully aware of all the beneficial effects that lead to this relationship.

Materials and their method of application by most farmers in Tanzania will be dealt with briefly in this presentation.

Mulching materials

Mulches are generally divided into two categories, organic and inorganic (Davies 1975). Organic mulches include cut grass (wild or grown), straw, non-synthetic cloth, creeping crops, weed and crop residues. Inorganic mulches though not used by farmers in coffee crops are: ash, water, minerals (sand and stones) and synthetic materials such as opaque or transparent plastics (Stigter 1982).

The most common organic mulches used in coffee plots by farmers are cut grass, sorghum and maize trash. Wild grass is conveniently available for use in areas where there is less demand for land. It is cut at the end of the rains, baled and transported to the farms. A limited number of farmers use sown grass such as napier grass. It has a higher bulk than any other grass: up to 173 tons per hectare of green matter from two cuts per year (Acland 1971). Banana leaves, which are within easy reach when banana trees are interplanted with coffee for shade, are also used. Although it lasts longer than a year, this mulch is generally insufficient by itself.

In areas where maize and sorghum are grown for food, their trash is properly utilized for a mulch. They decompose very quickly but are only readily available at the end of the farming season. Other materials are also used if available, but they are in insufficient quantities to be of noticeable value.

Methods of application

The method of application is dependent on the planting pattern, which is usually by rows but is also influenced by the availability of land for other crops. If the same plot is intended for interplanting with other crops such as maize or beans, mulch is applied to the rows leaving the space between the rows for the annual crops. This practice of intercropping is normally carried out during the fust few years of the coffee plants, and is stopped after the first coffee harvest when mulch is applied to the whole field except near the stems to enable easy harvesting.

Mulch is also applied to interrows. This is normally the case in areas where there is high infestation of weeds. Intercropping with annual crops then is generally not practiced but interplanting with banana trees is carried out by some farmers. Others apply mulch to alternate tree rows or alternate interrows. With this practice, intercropping with annual crops is easily carried out, although it would seem that such farmers are faced with non-availability of sufficient materials in the first place. With mulch applied to the whole surface, normally no other farming activity except field works is carried out on the farm. The practice of applying mulch to the whole surface can also be observed in areas where the cultivated land is situated on a sloping terrain, in which case mulching is mainly applied to arrest soil erosion.

Time of application

For a traditional farmer, mulching materials are readily available at the end of the rainy season (wild or grown grass) and after harvesting of the annual crops for trash or crop residue. Unless advised otherwise, the practice is to apply mulch at the end of the rains. This practice is beneficial in areas with heavy rains, e.g., the slopes of Mt. Kilimanjaro where amounts greater than 800 mm usually fall in April and May, and mulch only makes the soil too wet if applied before the rains. Where the rainfall is rather low, mulch gives higher yields if it is applied before the rains start (Acland 1971), this encourages maximum water infiltration.

Planting of coffee is normally done at the beginning of the main rains. To prevent soil erosion, mulch is sometimes applied only around the stem of the young coffee plant.

Effects of mulching

Soil moisture

Mulching enhances soil moisture status through improved infiltration and reduction in evaporation, the former being more beneficial than the latter according to Webster and Wilson (1971). It is therefore desirable to apply mulch at the beginning of a rainy season in order to aid infiltration, rather than at the end of the rains when it can only reduce the rate of drying out during the following dry season. Pereira and Jones (1954) showed this to be true on coffee in Kenya (Table 1). In fact, mulching alternate rows before the rains gave better yields than mulching all rows after the rains.

Table 1 Yields of clean coffee (after Pereira and Jones 1954;)

Year	Total Rainfall (mm)	No Mulch (kg/ha)	Mulched all rows before rains (kg/ha)	Mulched alternate rows before rains (kg/ha)	Mulched all rows after rains (kg/ha)
1950	610	94	188	133	88
1951	1372	841	1492	1307	1213

Soil temperature

Mulched soil has lower average temperatures and a restricted diurnal temperature range. This effect is of minor importance under tree crops with heavy shade, but even under cocoa Smith (1954) found that mulching reduced average soil temperature slightly and the diurnal range considerably. The lowering of soil temperature reduces losses due to evapotranspiration.

Erosion and soil characteristics

Mulches protect the soil from wind and hail; and prevent breakdown of soil structure by the impact of rainfall, thus decreasing soil erosion and run-off. They also increase earthworm and termite activity which provides many channels for the percolation of water. Through increased infiltration, leaching is promoted thereby reducing soil salinity in the top layers of the soil in saline areas. Decomposition of mulch organic matter thus improves the soil structure.

Weed control

One of the main beneficial effects of mulching is weed control or suppression. It is particularly important in areas with poor rains, as weeds compete with coffee plants for water and nutrients.

Growth and yields

The outcome of the aforementioned effects of mulching together with a few minor ones, combine to give higher yields of the coffee crop. Pereira (1954) quotes field trials in Kenya with large yield increases when an organic mulch was applied before the rains, while Robinson (1964), found that a single annual application of trash mulch to coffee at 18 kg per tree significantly increased yield. High yields are not only realized in coffee but also the annuals (maize and beans) intercropped with it. Better yields of the annual crops, especially beans of the determinate-landraces variety, are realized from nearly-decomposed mulch applied to the surface before it is renewed.

The downward growth of tap roots and the development of the root system as a whole for coffee is increased by mulching (Bull 1963).

Limitations

If the mulching material is to be obtained from grown grass, then land is required for this purpose. This might prove difficult and expensive in areas with high demand for land. Also a lot of labour is involved in cutting and carrying the material from outside the plantation. To a smallholder, it might not be worth the trouble unless the crop sells at a relatively high price especially if the mulch decomposes rapidly.

Concluding remarks

In the tropics, the usual limiting factor for plant growth is moisture. The traditional farmer depends entirely on rainfall as a source of moisture in all agricultural activities. One can say crudely that the more the rainfall the better the yields. However, from time to time, particularly in the recent past, frequent droughts of varying degrees have been experienced in the tropics. This has made it absolutely necessary for the farmer to get the best out of the little rainfall. Incorporating mulching in the farming habits should definitely be encouraged in these areas to maximize the available moisture.

The difficulty with which mulching materials are obtained increases day after day. Firstly, there is no more free land where farmers can go and get wild grass at no expense. Secondly, due to high competition for land and expanding agriculture, proper planning of one's plot is required in order to be able to grow grass for mulching. It is therefore imperative that proper advice is available on the best type of grass to grow to economize on the land, taking into account the yield of mulch and the rapidity with which it decomposes.

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Agroclimatic zones of Zimbabwe and potential for agroforestry

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Abstract

Zimbabwe is considered to be divisible into five agroclimatic zones which are really agroecological zones. The paper describes the main agroclimatic features of each of these zones and evaluates the possible significance of each of the major features on agroforestry. It is recognised that only the availability of moisture in the form of rainfall, at the right time, is the main limiting factor for agriculture in general and agroforestry in particular. To a limited degree, temperatures are also considered limiting but only as far as excessively high temperatures in the arid and semi-arid parts of the country increase the possibility of moisture stress. Although frost occurs in parts of the country during the cool, dry season, low temperatures are not a serious limitation to agro-forestry.The areas that appear to be climatically most suited to agro-forestry are, for a variety of reasons, also the areas in which there seems to be the least need for it. The semi-arid and arid areas that are marginal for most other forms of agriculture appear to be the areas in which the greatest benefit could be derived from agroforestry. They are also the areas in which it would appear great difficulty may be experienced in trying to establish a useful and practical agro-forestry system. This last problem is the challange which the paper poses for the agroforestry researcher.

Introduction

The agroclimatic zones which will be used in this paper are based on a combination of Zimbabwe's rainfall map and the agro-ecological zones described by Vincent and Thomas (1960). An examination of the two maps (Figures 1 and 2) shows that the agro-ecological zones are very closely related to rainfall. The agro-ecological zonation, however, was based on several parameters such as soil type, vegetation as an indicator of agricultural potential, rainfall and, in particular, the effectiveness of the rainfall. Paramount importance is therefore attached to the availability of moisture in the right quantity and at the right time.

There is no doubt that climatic factors are a *sine qua non* for any agricultural activities but their impact will vary according to other physical as well as human conditions. For the purposes of this discussion it is proposed to put the impact of agroclimatic factors in the context of three other factors. These are:

1. the existence or absence of a tradition of agroforestry;
2. the desirability of it; and
3. the feasibility of it.

Figure 1 Mean annual rainfall.

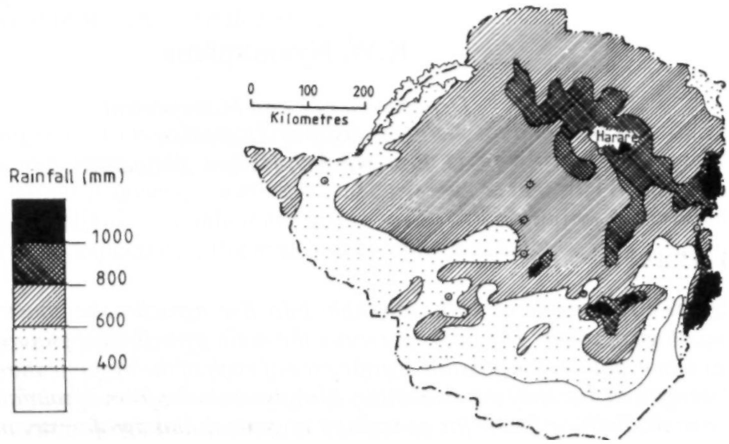
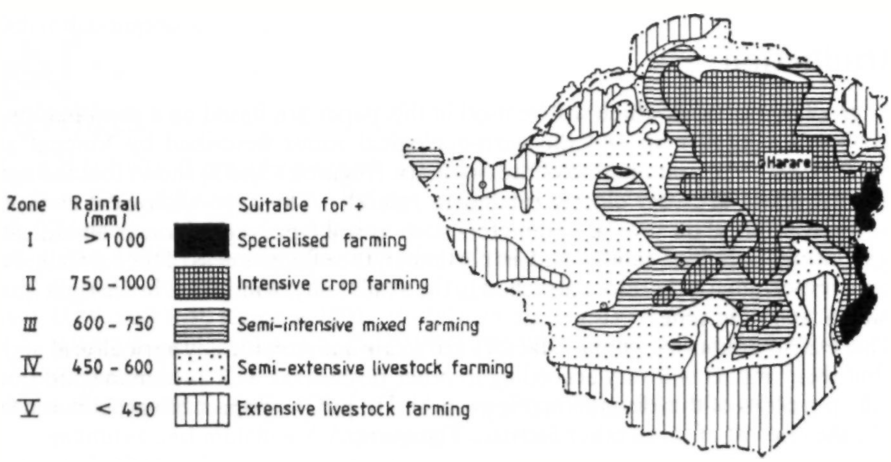


Figure 2 Agroclimatic zones.



The writer firmly believes that the existence of a tradition of agroforestry provides conditions which facilitate the re-introduction or modification of agroforestry systems and probably constitutes the most important guarantee in terms of potential for agroforestry. In many cases where there has been a tradition of agroforestry, agroclimatic conditions are often conducive to the development of a variety of such systems as is the case in most high-rainfall tropical zones.

Desirability of agroforestry has to do with those conditions in which it is perceived that agroforestry will result in a significant improvement in the physical condition of the environment or in the improvement of the social condition of the residents. This is often the case in arid and semi-arid regions. However, in such regions, agroclimatic considerations can be limiting or even overriding. It is felt that desirability of the system will create the necessary will without which no practice can be adopted regardless of how conducive the physical environment may be.

Feasibility simply refers to the presence of optimum conditions that would minimize impediments to the establishment of agroforestry, i.e., is it physically possible, socially acceptable and economically sensible?

The case of Zimbabwe

On the whole, Zimbabwe may be described as a semi-arid country in which more than 85% of the area receives less than 800 mm of rain per year. The rain is concentrated in the five months from November to March followed by a marked dry season.

Although parts of the country are susceptible to frost in the middle of the dry season, temperatures are not a major limiting factor for plant growth, except in isolated areas where ground frost can be a problem in the cooler months of the year. On the whole, therefore, Zimbabwe's potential can be considered to be largely a function of rainfall amount and distribution.

Agroclimatic zone I

This is a region of relatively high elevation with cool temperatures throughout the year and a rainfall generally well in excess of 1,000 mm per year. The rainfall is fairly reliable and although it is concentrated in the five summer months from November to March, this zone has the additional advantage that, in the dry winter months, it experiences light drizzles, called 'guti' in local parlance. This, together with the relatively cool temperatures at that time that minimize evaporation losses, means that the soil profile is moist throughout the year.

Most of the zone is on mountainous or hilly terrain with steep slopes that make soil erosion a serious hazard especially with the high silt and clay contents of the soils commonly found there. The soils are mostly Ultisols and Ultic or Oxic subgroups of Alfisols and some Oxisols. They are therefore of relatively low agricultural potential.

This combination of factors makes this zone highly suitable for agroforestry practices. Such practices are also desirable as they would ensure increased cover to protect the fragile lands. The introduction of agroforestry systems could be initiated in the areas where dairying is currently taking place with beneficial effect, especially if leguminous trees could be introduced for the benefit of the pastures. At present, the only form of agroforestry that has been attempted so far has been the growing of shrub and tree crops such as coffee and tea together with various larger trees for shade and for firewood to be used in the processing of the tea or coffee. However, one practice which has shown interesting possibilities is the practice of integrating coffee with the cultivation of silverleaf desmodium (*Desmodium uncinatum*) and fine stem stylo *(Stylosanthes guianensis var. intermedia).* These pasture species provide a thick cover on the surface which apparently helps to conserve moisture while at the same time providing the coffee crop with nitrogen. In turn, the pastures are grazed by sheep at regular intervals thus keeping their growth in check and at an acceptable level with regard to potential competition for water and other nutrients.

Although climatically this zone is ideal for agroforestry and the practice would result in desirable, beneficial effects, the zone covers only 0.4% of the total land surface of Zimbabwe. With its ideal climate, competition for land here is very high and plantation agriculture and horticulture enjoy a high preference over any other form of land use.

Agroclimatic zone II

This zone has a rainfall in the region of 800 -1,000 mm. It is also an area of relatively high elevation and concomitant cool temperatures. Rainfall is somewhat less reliable, particularly its onset. Some good, fertile soils, mainly Alfisols, typify the region. Climatically, this region is also suitable for the introduction of a wide range of trees and tree crops. However, this being probably the best agricultural land in the country, and also because of the proximity of most of the region to Harare, the capital, land here is at a premium and there has been strong resistance to any form of agroforestry.

A strong tradition of rotational monocultures revolving around maize, wheat, tobacco and, sometimes, groundnuts, is the norm here. There is also a considerable amount of dairy activity and it is in the area of dairying that some possibilities for agroforestry could be examined since this zone suffers some very high temperatures in the three months preceeding the rainy season, namely September, October and November. If nothing else, the introduction of certain tree species could provide shade during that period which is also a period when the 'veld' for grazing is of very poor quality. The selection of tree species for such a practice would have to take into account the severe frosts that occur in this zone.

Agroclimatic zone III

The rainfall here is moderate but comes mainly as infrequent heavy showers which, together with the generally high temperatures, reduces the effectiveness of the rain. The region is therefore subject to severe mid-season droughts. In their agro-ecological zonation, Vincent and Thomas (1960) point out that the region is

> '....marginal for maize and tobacco production or for enterprises based on crop production alone... The farming system in conformity with the natural conditioning factors should therefore be based on both livestock (assisted by the production of fodder crops) and cash crops, each playing a varying but approximately equal part.'

This zone probably has the most ideal combination of desirability and feasibility for agroforestry. The farming systems recommended for the zone lend themselves well to the possible inclusion of agroforestry. This could take the form of plants that have a rapid rate of growth and high nutritional value for livestock. At the same time the tree species thus introduced, if carefully selected, could, after the first few years of growth, prove to be hardier and more viable than any of the cash crops currently being produced there.

Agroclimatic zone IV

The rainfall is low (450 - 600 mm yr") and tends to be erratic. Periodic seasonal droughts and severe dry spells during the rainy season are characteristic of this region. Except for the production of some drought-resistant crops in favoured localities, this is a zone in which cattle ranching appears to be the most viable use of land possible. The potential for agroforestry here will be discussed jointly with that of Zone V.

Agroclimatic zone V

Rainfall here is too low and erratic even for the production of drought-resistant fodder crops.

Zones IV and V offer the possibility of introducing some agroforestry systems integrated with livestock production especially as these are areas of extremely high temperatures for most of the year. High temperatures are known to have adverse effects on animal metabolism and therefore on the productivity of the animals. Although rainfall is low, it would be necessary to ensure an adequate supply of water for the trees only in the first year or two because most of the area covered by Zones IV and V has extensive reserves of ground water. Trees would be able to exploit this ground water better than most other crops. In time, the change in vegetation could result in desirable micro-climatic effects.

The possibility also exists to introduce commercial tree crops in these regions. For example, in the Zambezi Valley, some of the local people have successfully grown cashew nuts for their own consumption but the possibility of larger scale, organized production on scientific lines has not been investigated seriously.

Conclusion

Zimbabwe has a wide range of both macro- and micro-climatic conditions which offer reasonable possibilities for agroforestry. In those areas where climatic conditions are optimum, agroforestry faces unfair competition from traditional farming systems which are considered to be a more intensive and more economic use of the land. Some agroforestry systems appear to be possible in the low rainfall- high temperature zones. Here the introduction of agroforestry practices can increase the diversity of agricultural practices and ameliorate the hostility of the environment for other agricultural production systems. Thus the economic potential of these otherwise inimical environments can be increased.

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Climatic zoning for agroforestry in Somalia

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Introduction

Though Somalia has a pastoral economy, with approximately one head of cattle, one camel, two sheep and three goats to every person, relatively little is known of the distributions of natural vegetation, nor has much serious consideration been given to the development of that agroforestry which already exists within the traditional patterns of agriculture and rangeland use. Investigations are still principally based on the identification of the extent, potentialities and use of indigenous species; and on the selection and possible applications of exotics. As a contribution to the resource base for agroforestry, this paper uses the method of Teel (1984) slightly modified, to establish climatic zones suitable for use in agroforestry.

Topography

Southern and Central Somalia consists of rather undistinguished relief rising from the coastal plains to a maximum altitude of 500 m asl near the Ethiopian border (Figure 1). The country's two most important rivers, the Juba and the Shabelle, dissect the western parts of the plain, but the lower reaches consist of meanders with flood plains. The Shabelle does not actually run into the sea. Just north of Mogadishu it turns parallel to the coast for a distance of some 300 km, before running out into swampland.

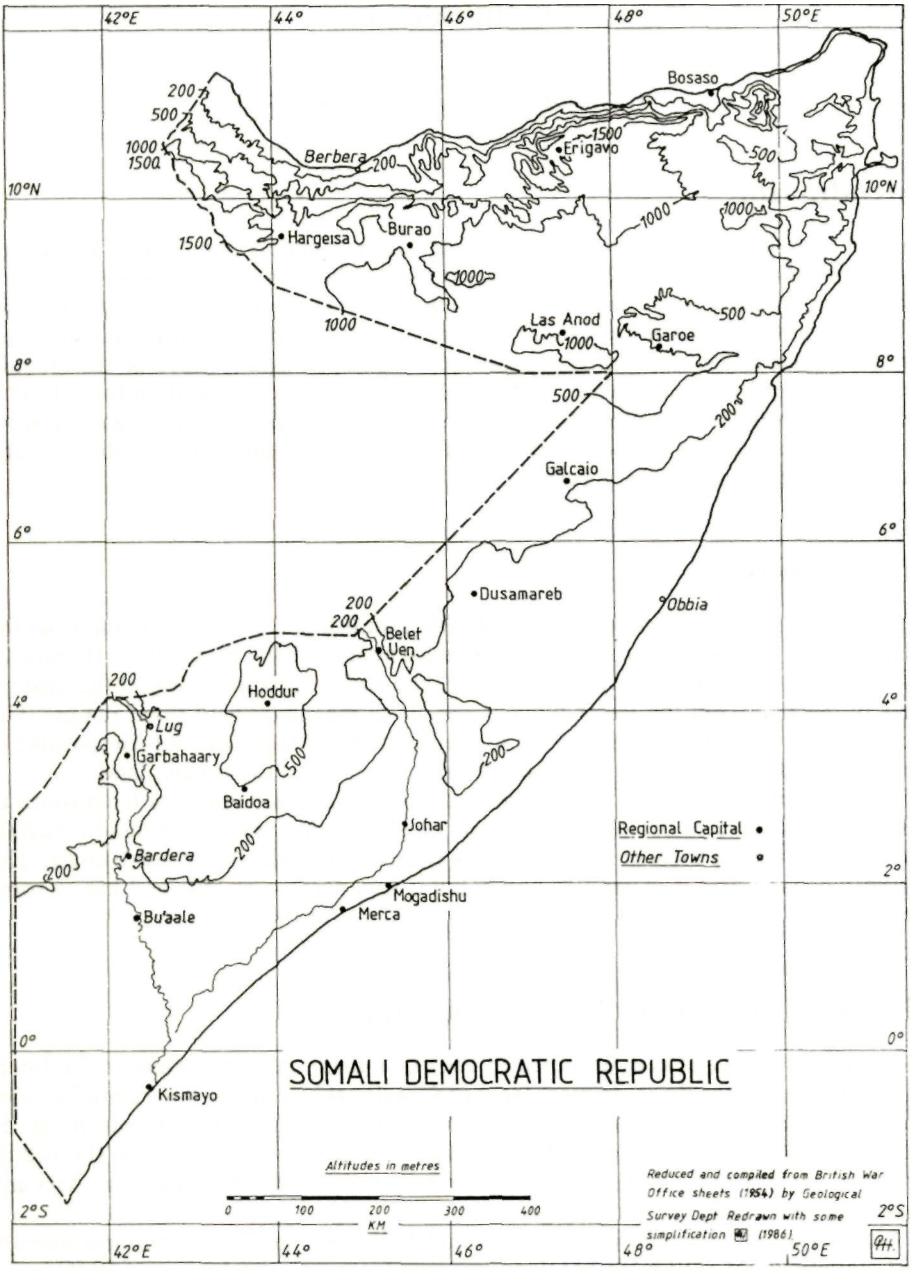
The northern regions are considerably different. The ground rises from south to north with a succession of ridges and upland plains, reaching maximum heights of 2000 m or more along the escarpment, which lies close and parallel to the north coast. The northern coastal strip is of variable width, but is very narrow, as little as 1 km, in some areas.

The synoptic climatology of Somalia

The climate of Somalia is determined by the north and south movement of the Intertropical Convergence Zone. In most areas of Somalia, this results in two rainfall season, the 'Gu' as the zone passes northwards, and the 'Der', on its southward movement. In both cases, however, the rain is produced by the moist air deriving from the Indian Ocean, in the southerly air stream. The north-easterly winds, deriving from Asia and Arabia, produce little significant rain.

Annual rainfall amounts are generally small, falling within arid or semi-arid zones of most classifications. With temperatures ranging from an annual mean of 18 °C in the northern highlands to just over 30 °C in one or two small areas. There is thus a considerable moisture deficit over the entire country.

Figure 1 Map of Somalia



Agroclimatic zonation

For the agroclimatic zonation, the method of Teel has been used, with some modification. This method is very similar to the Webb et al. (1984) system, with only the various class limits being changed. In the method, all that is required is the mean annual rainfall and mean annual temperature, though due to the limited records available, a topographic map is also needed for spatial interpolation. Rainfall and temperature are classed and overlain, to give distinct agroclimatic zones.

Rainfall

No definitive rainfall maps yet exist for Somalia, though most maps are based on the data of Fantoli (1965), British Meteorological Office (1962), and Hunt (1951), none of which is more recent than 1960. A new map of mean annual rainfall has therefore been made based on the three sources mentioned above with more recent data, including the effect of altitude in the north.

Fantoli listed all known meteorological records for eastern, central and southern Somalia, up to 1960. Eighty-two rainfall stations are included, though some of these have records too short to be useful. The British Meteorological Office report provides summaries for 28 stations in northern Somalia, using data up to 1960. Hunt carried out an intensive field study in northern Somalia with 49 rain gauges over a six years period from 1945-1950. The Department of Civil Aviation provided information on 18 stations up to the present. The Food Early Warning Department produced data for 23 stations from 1980 to the present. Thus, although the records are scattered, and often broken, it has been possible to provide enough data, at least for a first approximation, to produce an annual rainfall map.

The northern part of the country, which, as mentioned above, consists of rather broken terrain, was subjected to a simple analysis to obtain a rainfall altitude relationship. The Hunt data, which at least has internal consistency was used for this, and the relationship is shown in Figure 2. Compared to previous maps, there are a few changes. In the lower Juba region, north of Kismayo, isohyets of 600 mm and 700 mm have been added, as more recent records show four stations having 600 mm or more. In the north, there has never been any consensus as to the real maximum values. Peak values have varied between 500 mm and 1100 mm. The actual maximum mean measured rainfall occurs at Dalo, which is on the edge of the escarpment, measured at 833 mm. This is likely to be close to the actual maximum spot value.

Temperature

As with the rainfall map, data for the mean annual temperature are derived from Fantoli 1965), British Meterological Office (1962), and from the more recent sources (Figure 3). Altogether, 40 station records were used, and these exhibited good inter-station consistency. In the north, 13 stations were used to derive a temperature-altitude relationship:

$$T = 29.22 - 0.0064 \times \text{altitude (m)}$$

with $r = 0.92$. Note that the lapse rate of 0.0064 °C/m is rather more than that given in Webb et al. (1984).

Figure 2 Mean annual rainfall in Somalia.

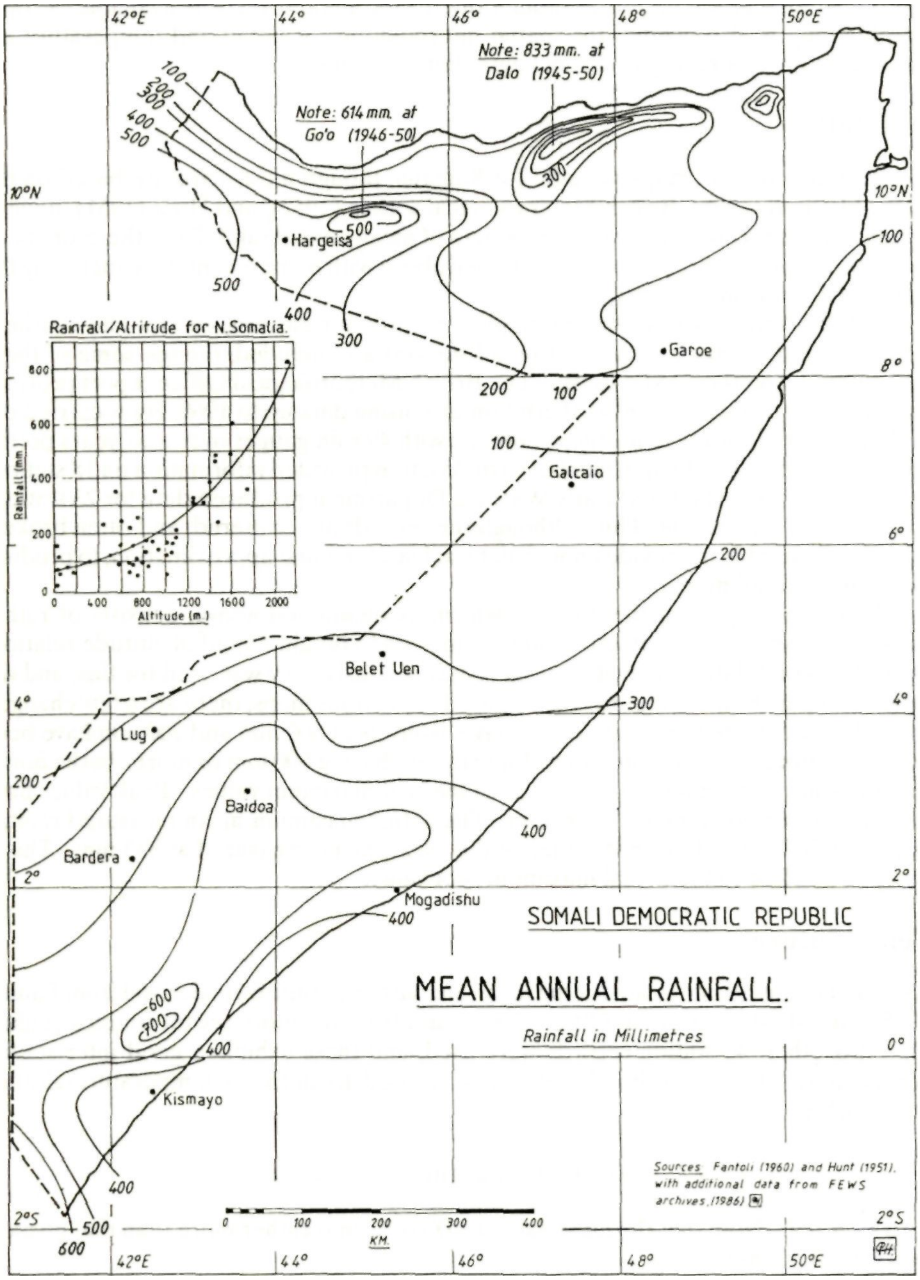
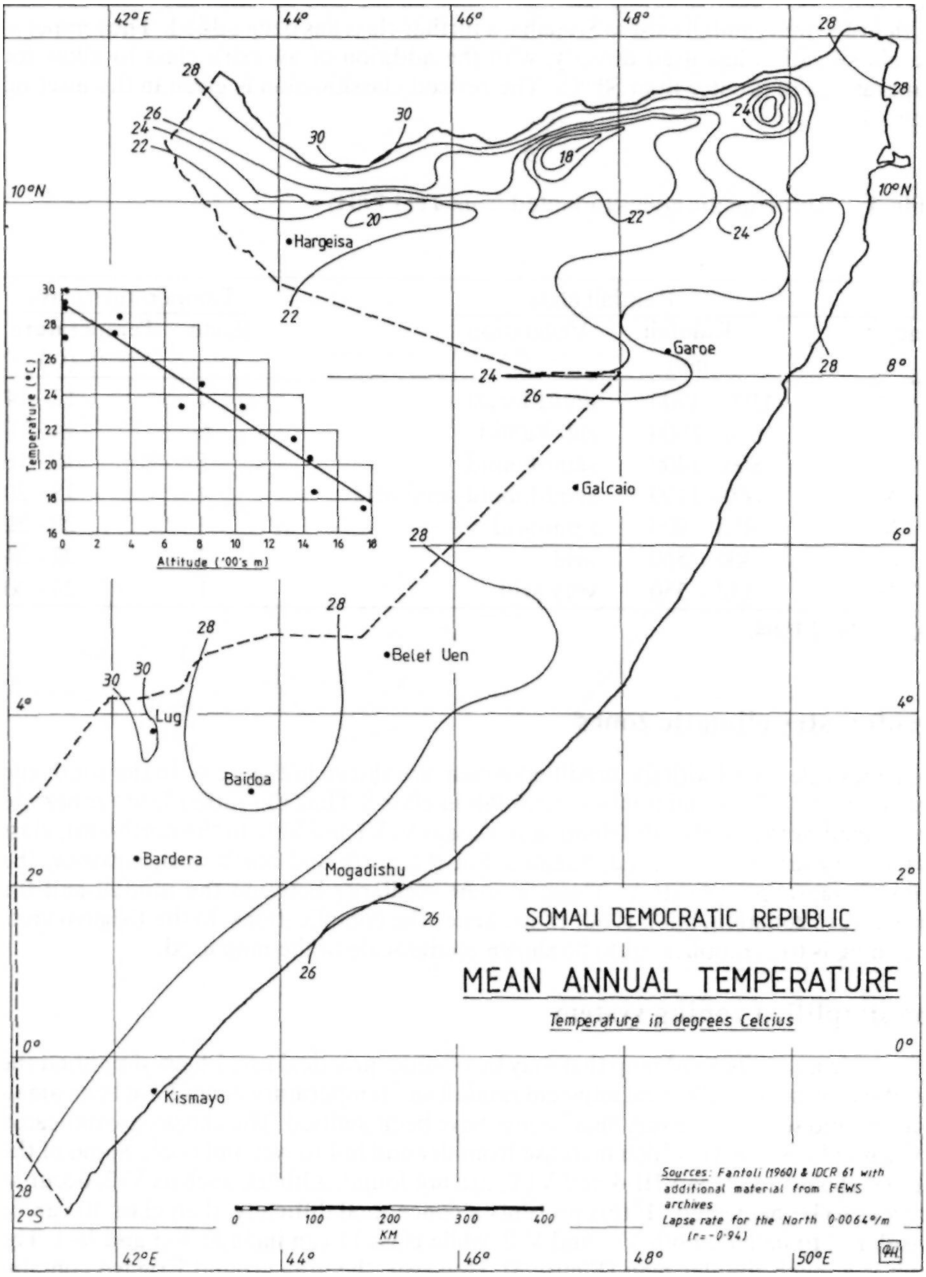


Figure 3 Mean annual temperature in Somalia.



The zoning system

Table 1 shows part of the original Teel tables. In the original, the rainfall classes are divided by potential evaporation to give unique classification. However, not enough is yet known about potential evaporation in Somalia for this to be possible. Rainfall has thus been used directly, setting class limits at 500, 325 and 150 mm. Because areas of less than 150 mm rainfall exist in Somalia, a further class has been added. The temperature classification has used directly, with the addition of an extra class to allow for temperatures of greater than 30 °C. The revised classification is given in the inset on Figure **4.**

Table 1 Agroclimatic zones (adapted from Teel 1984)

Rainfall class			Temperature class	
Zone	Rainfall mm	Vegetation	Zone	Temperature (C)
I	1100 -1700	moist forest	7	12-14
II	1000-1600	sub-humid	6	14-16
III	800-1400	semi-humid	5	16-18
IV	600 -1100	semi-humid-semi-arid	4	18-20
V	450- 900	semi-arid	3	20-22
VI	300 - 550	arid	2	22-24
VII	150 - 350	very arid	1	24-30

Source: Teel 1984.

Agroforestry climatic zones

The zones calculated with the modified system are shown in Figure 4. In the south and central regions almost all temperatures fall in class 1. Thus the rather large zones are determined by the rainfall distribution in classes V, VI and VII. In the north-east, class **VIII-**1, very dry and hot, predominates. For the north and north-west, however, the zoning is more complicated. There is some similarity between the rainfall and the temperature zonation; but it is not exact, hence the complications. In the Erigavo area, the zoning is too complicated to be shown on the scale of the map used.

The simplified zoning system

To provide an easily-read map that may be of some practical use, I have simplified the classification scheme. Several adjacent rainfall and temperature zones have been amalgamated and some of the very small zones have been omitted. The classes are indicated by the numbers 0 to 11, which increase from dry and hot to wet and cool. Some of the original classes, such as VIII-4 and VI-0, are not found. Others, such as V-2, occur so rarely as to be neglected. If this presents a conceptual difficulty, then class 10 can be considered to include both V-l and V-2, while class 11 can include V-3 and V-4. The result is a much simpler map (Figure 5). However, the area around Erigavo contains such a variety of zones that they cannot be conveniently mapped.

Figure 4 Agroforestry climatic zones (after Teel 1984).

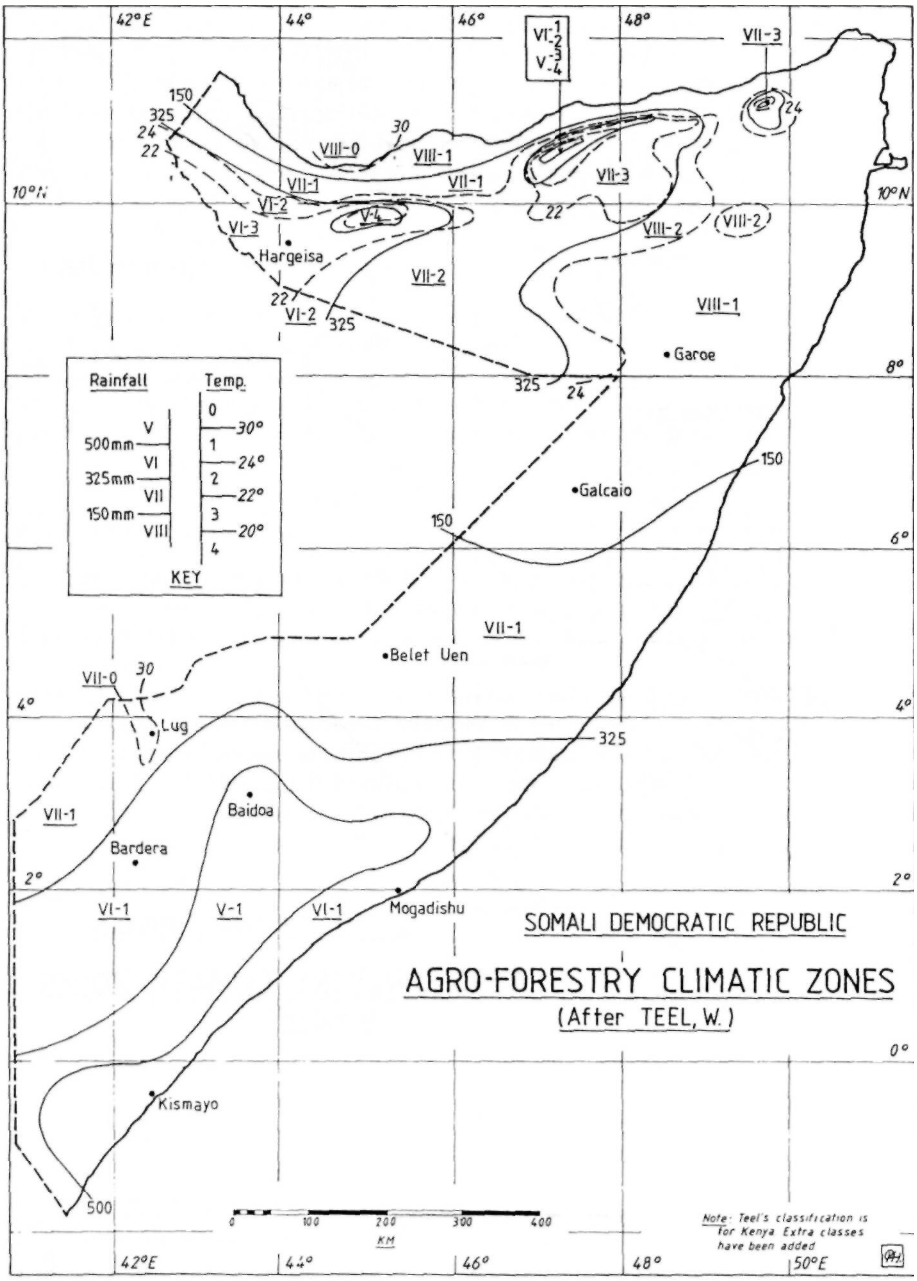
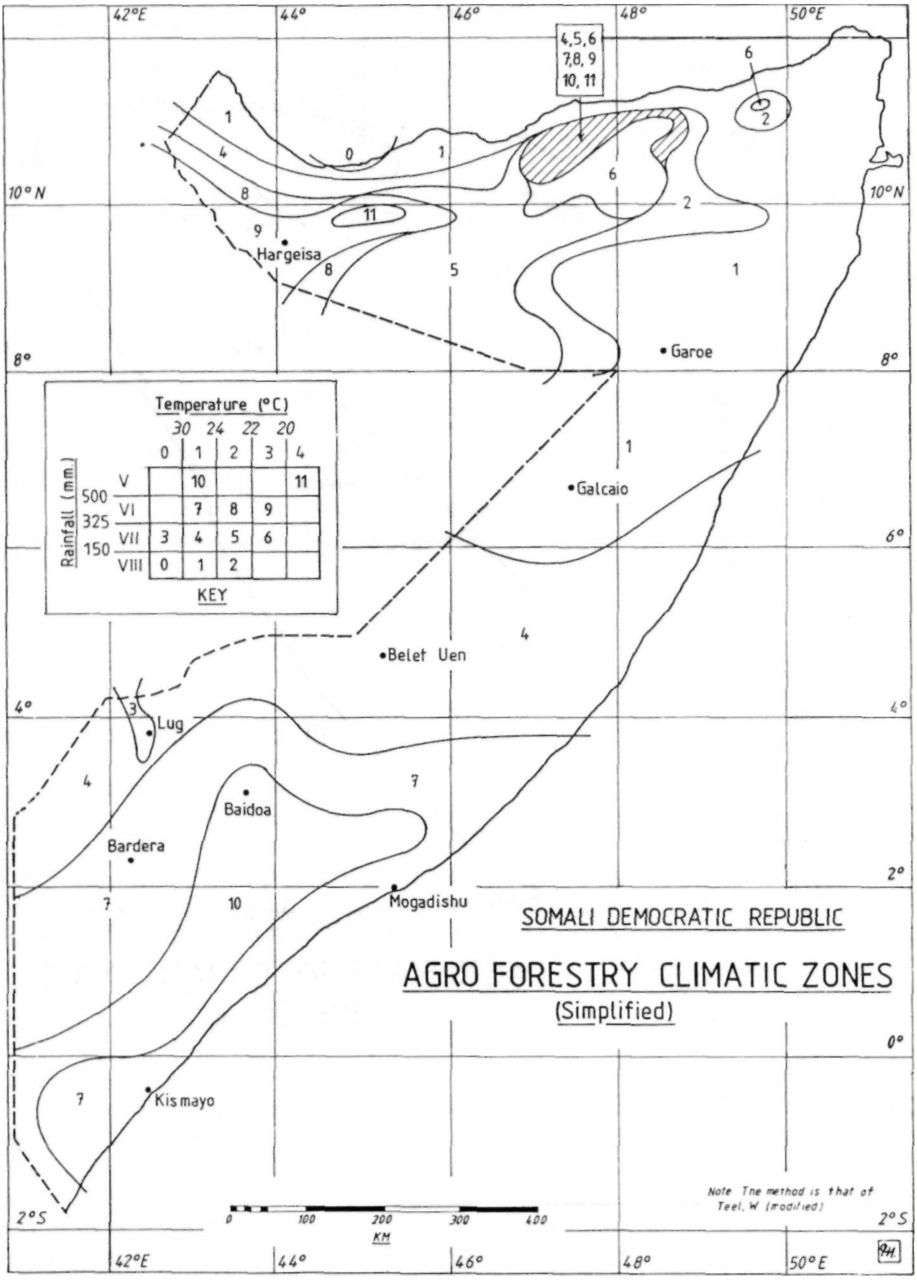


Figure 5 Simplified agroforestry climatic zones.



Discussion and conclusions

The next step should be that of confirming the validity of the zonation scheme by checking on the ground the occurrence of both native and exotic species of known climatic preferences. This would be a major study in itself. Although there is a considerable body of knowledge as to the extent of native species, this is not readily available, nor is there a complete list of the agroforestry uses of the native species. However, the need for this type of information is recognized, and some work is going ahead, principally at the National Range Agency. Until this is available, then some estimate of the potentialities and the availabilities of trees for agroforestry uses can be obtained by extrapolating information from adjacent countries, particularly Kenya.

Acknowledgements

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The influence of rainfall distribution to traditional agroforestry practices in western Kenya

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Introduction

The Kenya Woodfuel Development Programme (KWDP) is a research and development implementation programme whose mandate is to contribute towards helping farmers to plant trees on their farms for self- sufficiency in fuelwood, among other benefits. The districts of Kakamega, Kisii, Murang'a and Nakuru were identified for the programme activities because of their high population and agricultural potential. KWDP, which works under the auspices of the Ministry of Energy and Regional Development (MOERD), was initiated in 1983 following the recommendations of the Kenya Fuelwood Cycle Study (1980-82). This study was carried out jointly by the Ministry and the Beijer Institute of the Swedish Royal Academy of Sciences. KWDP is financed through a Dutch Government grant for its programmes in Kakamega and Kisii Districts where ground activities started in 1984 and 1985, respectively.

The Programme's approach towards district implementation programmes is both holistic and step-wise in nature, whereby in the first step, the district's resources, including physiological, climatic, socio-cultural, demographic and other relevant information, are inventoried to assist in realistic planning-implementation strategies. It was during this survey that the KWDP learned a great deal from farmers' knowledge tree regeneration practices in Kakamega District. One of the study's important findings was that the highlands would experience serious fuelwood scarcity earlier than projected because the rising populations would necessitate rapid land demarcation and privatization.

This brief paper will highlight KWDP's findings on rainfall distribution and its effects on traditional agroforestry practices within the district. The KWDP has indeed used the information from the findings and the observed traditional agroforestry activities and has incorporated such knowledge in its planning strategies for the Kakamega District.

The main advantage of incorporating local farmers' knowledge in any planned implementation activities is that such planned activities are both realistic and acceptable to the farmers.

Rainfall distribution in Kakamega

The average annual rainfall for Kakamega District varies from 1,200 mm to over 2,000 mm, the annual rainfall increasing from the drier northern parts of the district to the much wetter southern areas. Most of this rain occurs between March and October with monthly averages of over 120 mm during those months. Peaks occur during the long rains, April to June, and the short rains, August to October. (See App. for rainfall figures from various stations, adopted from Farm Management Handbook of Kenya, Vol.11.)

Kakamega District (especially the southern parts) has its rainfall distributed more or less uniformly throughout the year except for the months of November through February, which receive less than 100 mm.

Tree regeneration activities

The survey found that traditional tree-regeneration activities in the district are very much influenced by the rainfall pattern.

Traditional on-farm nurseries

Our surveys revealed that there are many small on-farm bare-root nurseries in Kakamega, especially in the wetter southern parts of the district. These nurseries are very variable in size, ranging from small broken pots to nurseries of up to 3 m . We estimate that about 40% of the households in Kakamega established their own on-farm nurseries in 1983 with a preference for exotic species (eucalyptus and cypress comprised about 83% of all the species found in these nurseries). The end use for these trees is marketable building poles and timber.

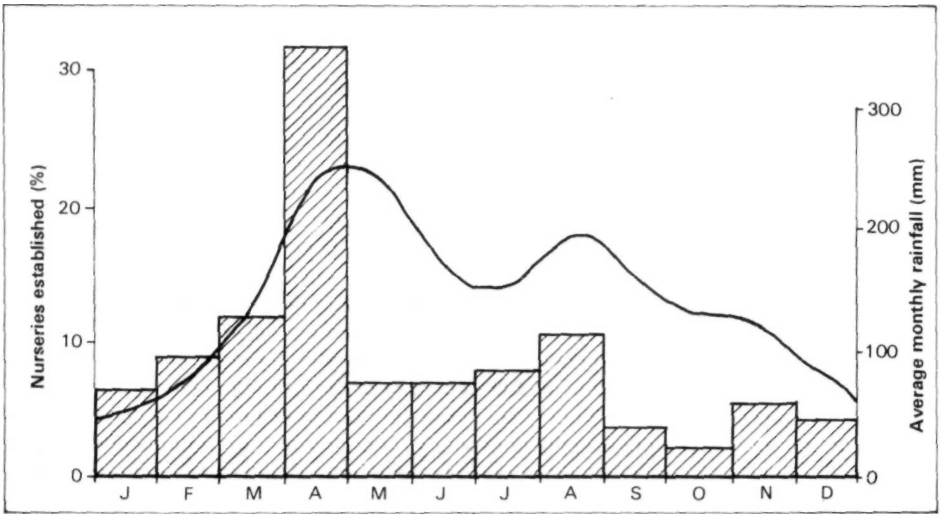
The nursery techniques practiced by farmers differ substantially from standard practices, and even within those techniques great differences occur. Farmers usually start establishing their nurseries at the beginning of the rainy season (Figure 1), although the normal forestry practice is that seedlings should be ready for planting-out with the onset of the rains. The district (especially the south) receives well-distributed rainfall, so that even with seed-sowing in March and April and outplanting in June and July, survival of outplanted seedlings is very high. Another possible explanation is that the farmers plant early to avoid the cumbersome task of having to water their nurseries during the dry months.

KWDP nursery implementation strategy as influenced by the farmers' knowledge and experience in Kakamega

The original funding proposal had recommended that KWDP establish about 600 centralized nurseries scattered throughout the district in cooperation with women groups, local chiefs and others. These nurseries were to utilize traditional forestry practices including expensive water works, polythene tubes, nursery labour, and so forth. However, following the findings of our surveys, we decided to adopt a different implementation strategy. Since farmers planted the species for which seed was readily available, we believed that we could get them to grow different agroforestry species using traditional knowledge if seed were made available. However, traditional on-farm nurseries would require some improvement in construction and management to give better survival at the time of outplanting.

Given the above situation, we prepared a pamphlet suggesting a few technical changes in nursery construction and operation. The farmers are initially issued with free seeds together with the pamphlet followed by a demonstration on how to construct such nurseries. Our initial monitoring indicates that this implementation strategy has been quite successful.

Figure 1 The initiation of farm nurseries in 1983 (vertical columns) and average monthly rainfall in Kakamega district



Tree propagation through wildlings

Tree establishment through planting of wildlings is also common in some parts of Kakamega District. Wildling collection is mainly confined to indigenous species and some fruit trees.

Collection of wildlings is determined by the seeding habit of the particular species. Most seeds ripen during the dry season. Such seeds, when they fall from the mother tree, start germinating at the onset of the rains. Two to three months after germination, most seedlings of these indigenous species and fruit trees are ready to transplant.

The KWDP plans to use this strategy to encourage the farmers in Kakamega to utilize wildlings especially for those agroforestry species whose seeds are more difficult to obtain and whose viability in storage is limited. Examples are *Grevillea robusta* and *Calliandra calothyrsus.*

Tree propagation through direct seeding

In some parts of Kakamega, farmers have traditionally propagated *Sesbania sesban, Makhamia platycalyx* and other prolific seeders either through broadcasting the seeds on their agricultural fields or through direct planting in prepared holes. This direct-seeding is controlled by the rainfall pattern. Direct seeding (especially for broadcast seeds), is done after land preparation during the dry season. Usually with the onset of rains, such seed starts to germinate. The farmers thin systematically, leaving an adequate number of seedlings, depending on the branching habit of the particular species.

KWDP intends to utilize this experience in developing tree- propagation strategies but with a number of modifications for the more prolific-seeding species.

Appendix: Rainfall figures from various stations in the Kakamega district

Table 1 Rainfall figures from various stations (Kakatnega district) having at least 10 years of records up to 1976.

No and altitude	Name of Station	Years of rec.	Kind of rec.	Annual rainf. mm	Monthly rainfall in mm Jan	Feb	Mars	April	May	June	Jury	Aug	Sept	Oct	Nov	Dec
8934001	Kakamega District	55	Average	1930	60	95	151	254	260	190	164	230	186	134	118	87
1554 mm	Office		60prob	1729	32	56	112	216	230	161	147	197	156	118	81	58
8934002	Bukura Farm Institute	52	Av.	1788	52	91	161	257	247	157	131	187	161	127	123	94
1463 m																
8934009	Kaimosi Mission	34	Av.	1815	74	100	154	259	251	165	157	198	161	120	108	78
1615 m			60%	1543	34	39	101	242	229	120	127	172	118	77	57	59
8934013	Mumias Girl's School	41	Av.	1756	58	80	155	258	258	168	136	155	164	139	115	71
1340 m			60%	1579	31	56	106	236	240	147	115	127	154	122	72	50
8934028	Kakamega Forest	38	Av.	2025	88	108	148	279	289	195	171	220	173	140	122	93
1676 m	Station		60%	1866	53	101	156	288	218	187	169	217	144	145	109	64
8934031	Yala St Mary's School	34	Av.	1832	73	89	145	277	264	150	118	165	154	136	145	116
1463 m			60%	1613	37	98	135	251	261	125	96	158	131	137	146	77
8934040.	Butere Health Center	34	Av.	1840	55	94	162	298	260	152	117	171	177	144	118	92
1435 m			60%	1649	22	44	131	270	235	144	90	144	143	117	92	51
8934061	Malava Dispensary	29	Av.	2085	55	78	164	244	294	204	212	257	205	173	115	83
1595 m				1871	25	32	85	214	251	163	162	190	147	147	65	34
8934071	Turbo Stanley 1 State	28	Av.	1332	89	42	78	157	166	142	155	225	134	82	69	52
1905 m																
8934078	Esirwa Kaimosi	30		2119	78	88	160	282	301	197	190	235	202	162	122	103
1707 m																
8934096	Kakamega	18	Av.	1918	55	111	178	240	239	150	133	224	172	169	152	98
1585 m	Station															
8934103	Vihiga, Maragoh	23	Av.	1875	91	106	169	290	242	125	102	158	144	144	161	140
1585 m																
8935015	Turbo Forest Lands	59	Av.	1258	36	43	76	151	153	141	184	229	112	60	53	21
1829 m	Estate															
8935042	Larhe Farm	38	Av.	1194	30	32	67	154	174	132	168	191	100	58	51	36
1844 m																
8935076	Turbo Selborne Estate	29	Av.	1169	35	40	72	142	148	124	147	202	108	67	43	40
1890 m																

Vegetation and bioclimate in Liberia

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Abstract

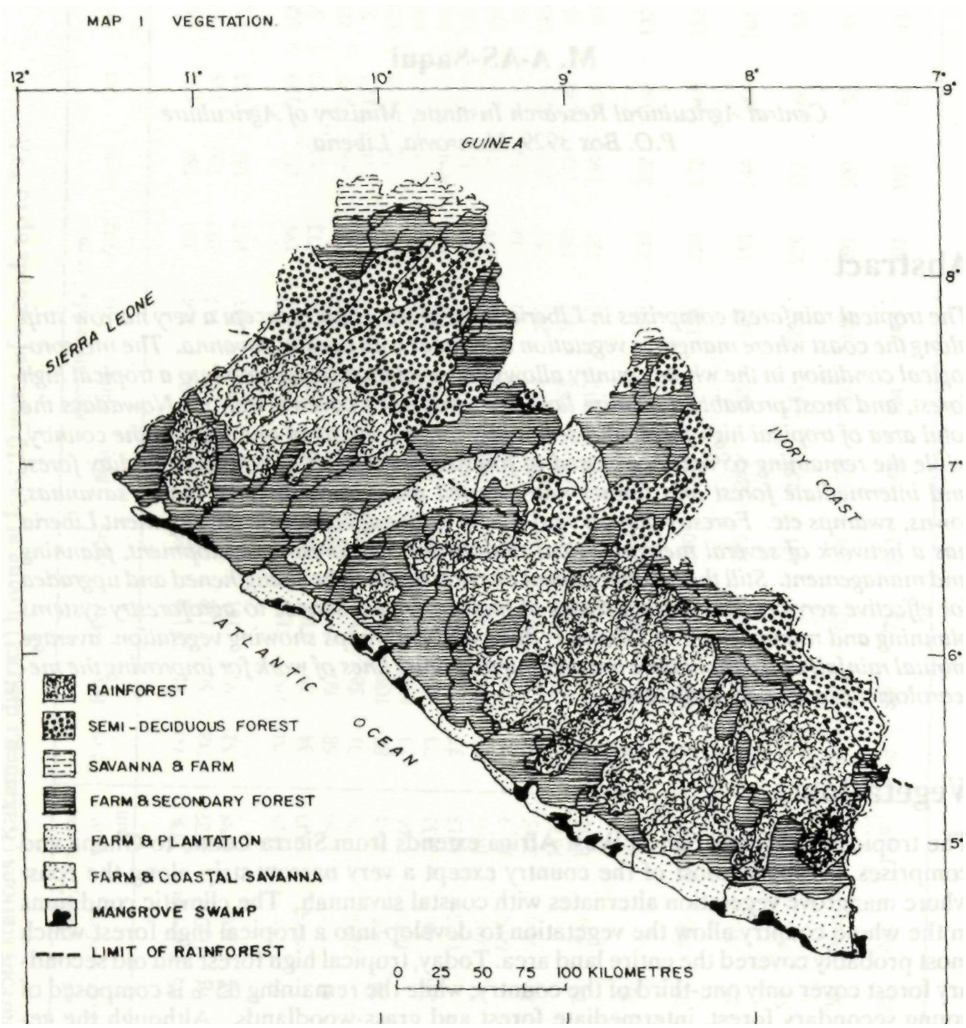
The tropical rainforest comprises in Liberia most of the country except a very narrow strip along the coast where mangrove vegetation alternates with coastal savanna. The meteorological condition in the whole country allows the vegetation to develop into a tropical high forest, and most probably the entire land area was once covered with it. Nowadays the total area of tropical high forest and secondary forest consists of one-third of the country, while the remaining 65% is composed of forested areas such as young secondary forest and intermediate forest and further non-forested areas such as farm lands, savannas, towns, swamps etc. Forestry plays a vital role in national economic development.Liberia has a network of several meteorological stations for agroforestry development, planning and management. Still the meteorological division needs to be strengthened and upgraded for effective services.The present status of meteorological service to agroforestry systems planning and management in Liberia is discussed and maps showing vegetation, average annual rainfall and temperature are presented. Future lines of work for improving the meteorological service are indicated.

Vegetation

The tropical rain forest belt in West Africa extends from Sierra Leone to Ghana and comprises in Liberia most of the country except a very narrow strip along the coast where mangrove vegetation alternates with coastal savannah. The climatic conditions in the whole country allow the vegetation to develop into a tropical high forest which most probably covered the entire land area. Today, tropical high forest and old secondary forest cover only one-third of the country; while the remaining 65% is composed of young secondary forest, intermediate forest and grass-woodlands. Although the general climatic conditions are nearly uniform throughout the country, rainfall and humidity decrease toward the interior. Consequently, vegetation is banded into zones more-or-less parallel to the coastline (Figure 1).

These zones are closely linked, but various kinds of transition occur, which are mostly influenced by topography and soil. The influence of shifting cultivation on the vegetation has been immense, and most of the high forests have at times been converted into farmlands. After farms are abandoned, natural vegetation recaptures the land and high forest gradually reappears. Several development stages can be recognized, such as 'recent farmland,' 'old farmland' and 'intermediate forest.'

Figure 1 Vegetation map of Liberia.



Bioclimate

In 1951, the Division of Meteorology was established within the Department of Public Works. It supervises a number of weather station throughout the country which measure daily rainfall and record maximum and minimum temperatures.

The equatorial position and the distribution of high and low pressure belts over the African continent and the Atlantic Ocean determine the climate of Liberia and, more generally, West Africa. Thus the climate of Liberia is marked by an even and fairly warm temperature throughout the year and above all by the very high humidity, above

90% much of the time. Unlike the temperate zones, the seasons are not determined by changing temperatures but by the prevailing precipitation. Therefore, a rainy and a dry season with transitional periods can be differentiated. Rainfall is heavy and intense. There is little year-to-year variability in the climate.

Rainfall

The Liberian coastline runs approximately from south-east to north- west and at right angles to the prevailing south-westerly rain- bearing winds. As the maritime air reaches the coast it is forced to rise, it cools, and condensation takes place which causes the extremely heavy precipitation. Consequently the rainfall is heavier than on any other part of the west coast of Africa except the Freetown Peninsula in Sierra Leone and a small isolated location near Buea in Cameroon. The annual rainfall near the coast is nearly 4550 mm (180 inches) but the amount has exceeded this in some years. Towards the interior, rainfall decreases except for the higher areas where the air is forced to rise, causing orographic precipitation. Because of its high altitude, the area around Mount Nimba receives much more rain (3225 mm = 127 inches) than would be expected from its geographical position. In the north-west there is a similar situation.

Figure 2 indicates a pronounced rainfall pattern. Generally a fairly distinct dry season extends from about November to April and a wet season the remainder of the year. The months of heaviest rainfall vary somewhat in different parts of the country, but normally are June, July and September.

In August most stations show a marked decrease of precipitation, and a short dry season known in Liberia as the 'middries' sets in for a fortnight or so. In September the rain starts with new force. The extreme south-east corner of Liberia is even noted for two distinct rainy seasons, with maxima in May-June and September-October, and with a well-defined short dry season in between.

The distribution of rain throughout the year and particularly the length of the dry periods are at least as important as the amount of rainfall. Since Liberian soils have usually low moisture-storage capacities, the amount and frequency of rainfall during the dry season becomes a limiting factor for the cultivation of many crops.

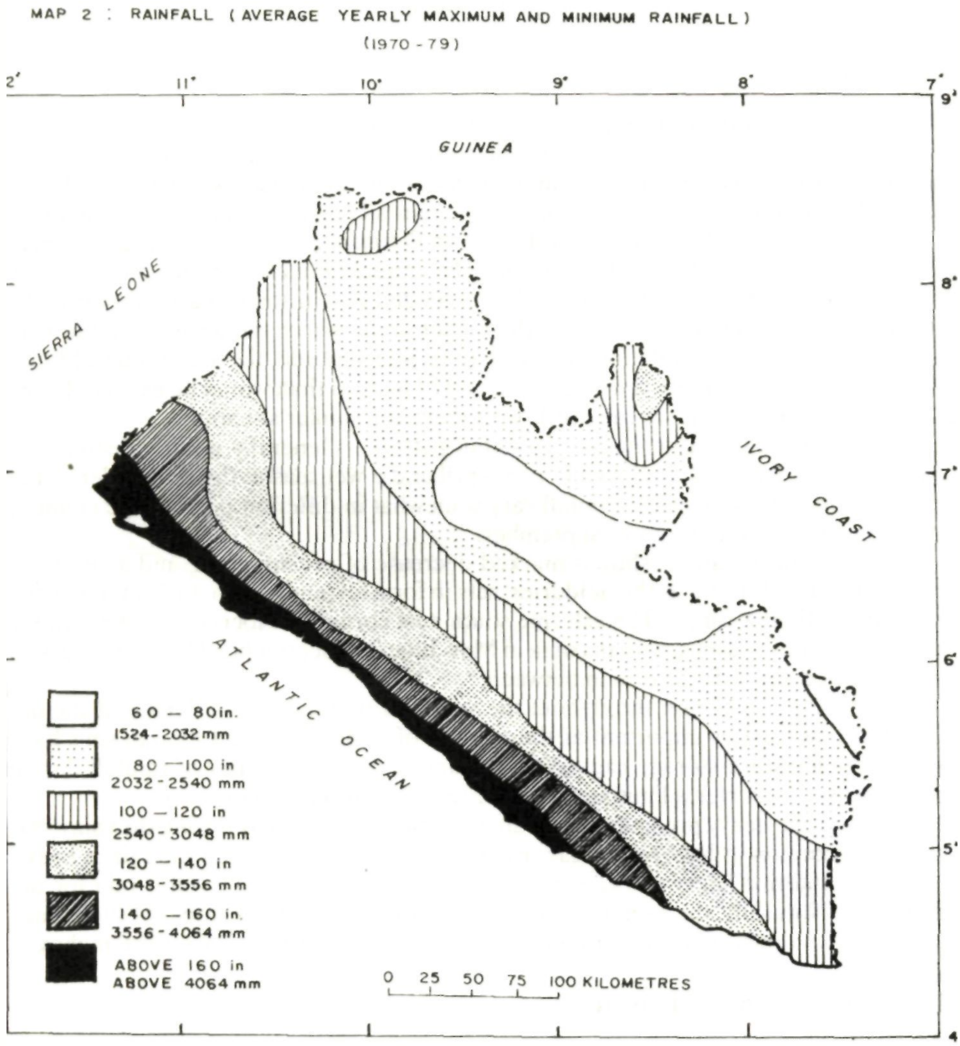
In spite of the heavy precipitation, it does not rain continuously during the rainy season. It is common to have sunny days even during the months when the rain is heaviest. In the interior heavy showers may occur, but only very rarely will it rain for the whole day. Naturally, the rain may last for a day or two without a stop. At such times the rain pours down steadily and water usually covers the ground for several inches.

Temperature and sunshine

Because of the equatorial position of Liberia the sun is almost overhead at noon throughout the year, and insolation is very intense. Therefore, high temperatures with little monthly variation should be expected. However, since temperatures are not solely dependent on insolation, but are affected by the degree of cloud cover, air humidity, rainfall and vegetational cover, temperatures in fact are much lower than anticipated.

Along the coast, the Atlantic Ocean has a moderating effect on the temperatures, and annual and daily variations are evenly balanced; while toward the interior the continental influence becomes more dominant, the range of temperatures widens, and the variation of minimum and maximum increases markedly. It is difficult to quote figures for temperature, since they vary considerably with location and altitude, but 27 to 32 °C (80 to 90 °F) during the day and 21 to 24 °C (70 to 75 °F) at night seem to be fairly representative. Because of the uniform and high humidity — the relative humidity ranges

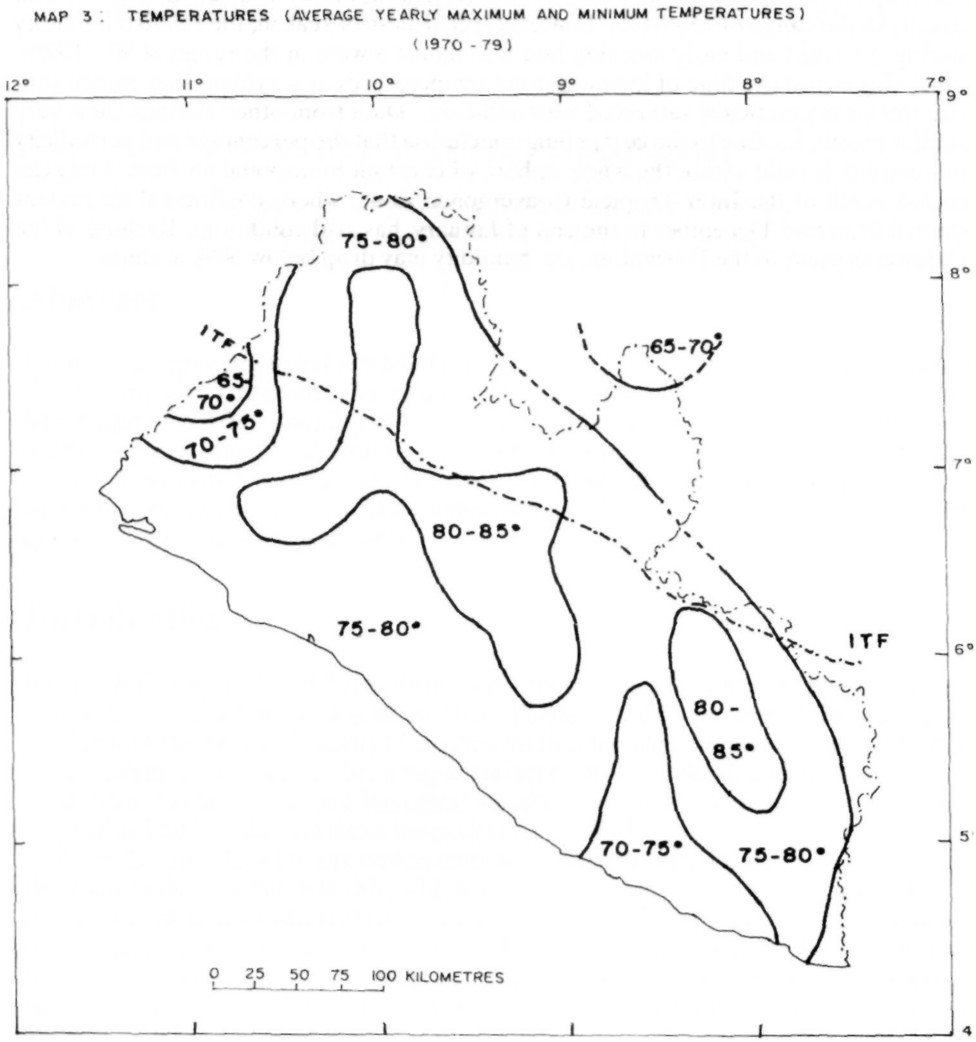
Figure 2 Average annual rainfall.



generally between 85 and 95% within the coastal area — temperatures seem much higher than they actually are. Only in the higher regions near the Guinea border, where the average altitudes are between 550 and 610 m (1800 and 2000 ft), is the climate more pleasant, since temperatures are much lower during the entire year. At times the inhabitants of these regions even suffer from the cold nights.

Figure 3 shows the average annual temperatures of Liberia. They range in the coastal area from 24 to 27 °C (75 to 80 °F) while in the interior they are usually several degrees higher except for the mountain regions. Although the country is situated north of the equator, the highest temperatures occur between January and April and the

Figure 3 Average annual temperature.



lowest ones are usually recorded during the months of August and September. These low temperatures are mainly caused by the large amount of cloud cover common over much of coastal West Africa during these months.

Sunshine is at a minimum during the wet months, particularly June to September, with a definite minimum in August. Days of long and bright sunshine occur between December and March, and an average of 6.3 or even 7 hours per day is not exceptional. During June and September only a few hours sunshine are recorded, and during August sunshine is particularly low, rarely exceeding the average of 1.3 hours per day. Sunshine and cloudiness therefore do not necessarily correlate with the rainfall; especially since August, when 'middries' occur, is the time of highest cloud cover.

The equatorial maritime air masses brought on the south- westerlies cause the very high humidity of Liberia. A relative humidity of 90 -100% during the rainy season is common, while during the dry season the average humidity is somewhat lower and usually in the range of 85 - 95%. However, regardless of season, the relative humidity during the night and early morning hours is almost always in the range of 90 -100%. Since this is also the time of lowest diurnal temperatures, it is evident that before sun-rise the air is practically saturated with moisture. Data from other stations show very similar results, leading to the compelling conclusion that the percentage and periodicity of humidity is valid within the whole sphere of constant monsoonal air flow. Only the region north of the Inter-Tropical Convergence Zone, where continental air masses prevail from mid-December to the end of January, has arid conditions. Because of the extreme dryness of the Harmattan, the humidity may drop below 50% at times.

Environmental driving variables of ecosystems and their distribution on a complex terrain

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Abstract

Using an example of general model of ecosystem productivity, the role of environmental driving variables is stressed. Use of the particular model when only light is the limiting factor is presented for a few places in Slovenia, Yugoslavia. The importance of other limiting factors, e.g., water, is illustrated; and simple methods of how to incorporate it in the model are presented. Several examples are given of how to assess the peculiarities of the environmental driving variables in a complex terrain which must be known for assessment of ecosystem productivity of an area.

Introduction

Since the first agricultural fields were established in ancient times, their productivity has been monitored in one way or another. Farmers and foresters and their ancestors tried to increase the productivity of ecosystems they manage. At first the understanding of ecosystem functioning has been vague and more or less at the descriptive level. Later on statistical relations among biological variables and environmental ones have been determined and models on these bases developed (Robertson 1983).

In the last two decades, the understanding of ecosystem functioning has been one of the main goals of research in this field. A further development is dynamic modelling of the ecosystem and its simulation on computers (de Vries 1982). These models are based on biological, physical and chemical principles. They try to explain the ecosystem functioning by selection of main variables and by the study of their interrelations. They have been applied in various versions at many locations throughout the world (Robertson 1983).

In the present contribution we extend the concept of ecosystem modelling from a particular location to an area with mesoscale dimension. To illustrate this we present a general model of ecosystem productivity and a particular model when light is the limiting factor. The model is applied to locations in north-western part of Yugoslavia. The importance of another limiting factor — water — is stressed and simple methods of incorporate it in the model are presented and the obtained results discussed.

General models

The productivity of a plant canopy ecosystem (P) is a function of biotic parameters describing phytometrical, physiological and optical characteristics of a plant canopy;

and abiotic parameters describing the soil and meteorological environment. The influence of management is implicitly included in the biotic and abiotic parameters. Since all parameters are interrelated, for producivity (P), we can write:

$$P = f(B,, S_m, M_n) \qquad (1)$$

where 1, m and n are the numbers of biological, soil and meteorological parameters, respectively.

According to Gaastra (1963), the productivity sought as net photosynthesis is a function of weather. It can be separated into photochemical processes driven by photosynthetically-active radiation, biochemical processes governed by temperature of the plants and transport phenomena among the plants and their environment as determined by morphological and physiological characteristics of plant canopy, and the wind and temperature regime in and above the canopy.

Some interrelations of this function are already known but a complete knowledge of these complex relations is still far ahead. Models based on realistic simplifications of the ecosystem have been derived and many of them are at work in the world (Robertson 1983). Among simplified dynamic models we can distinguish four types: when light is the limiting factor (level 1); when water is the limiting factor (level 2); when nitrogen is the limiting factor (level 3); and when phosphorus is the limiting factor (level 4) (de Vries 1982).

A schematic presentation of a general model of plant production in relation to weather (production level 1) is given according to Landsberg (1981) on Figure 1.

Models used at various locations in north-western Yugoslavia

For calculation of net photosynthesis of plant canopies in north- western Yugoslavia we used the modified computer program CALPROD (Band et al. 1981; Hocevar and Kajfez-Bogataj 1984). The basis of it is that net photosynthesis of a leaf is a known function of absorbed solar radiation and leaf temperature. The model belongs to level 1 and assumes healthy plants. The simplification is justified by the fact that at the studied locations, precipitation exceeds evapotranspiration during the growing period. The flow chart of this program is given in Figure 2.

Results obtained by this model for five locations in northern Yugoslavia using climatological data for submodels 1, 2 and 3 which take into account different plant response curves are shown on Figure 3 as daily net photosynthesis by month. Production viewed as net photosynthesis is largest at Koper, a warm and sunny place on the coast; and lowest in the mountainous Planica at a height of 850 m asl.

Figure 1 Schematic presentation of a model of plant growth in relation to weather. Solid lines represent flows of material, dotted lines flows of 'information.' Valves represent rates, boxes represent states and circles enclose the environmental driving variables. Numbers indicate the sequence of calculations for programming purposes, i.e., calculate (1) energy interception; (2) stomatal conductance — feed forward to net photsynthesis, transpiration; (3) transpiration; (4) leaf water status— geed back to stomatal conductance (iterate), xylem water potential — feed forward to partitioning equations; (5) net photosynthesis; (6) respiration;

(7) partition accumulated assimilates; (8) update mass of component parts (convert assimilates to leaf area, root length, etc.); (9) volume of soil exploited by roots; (10) update soil status in root zone — feed back to tranpiration. (After Landsberg 1981).

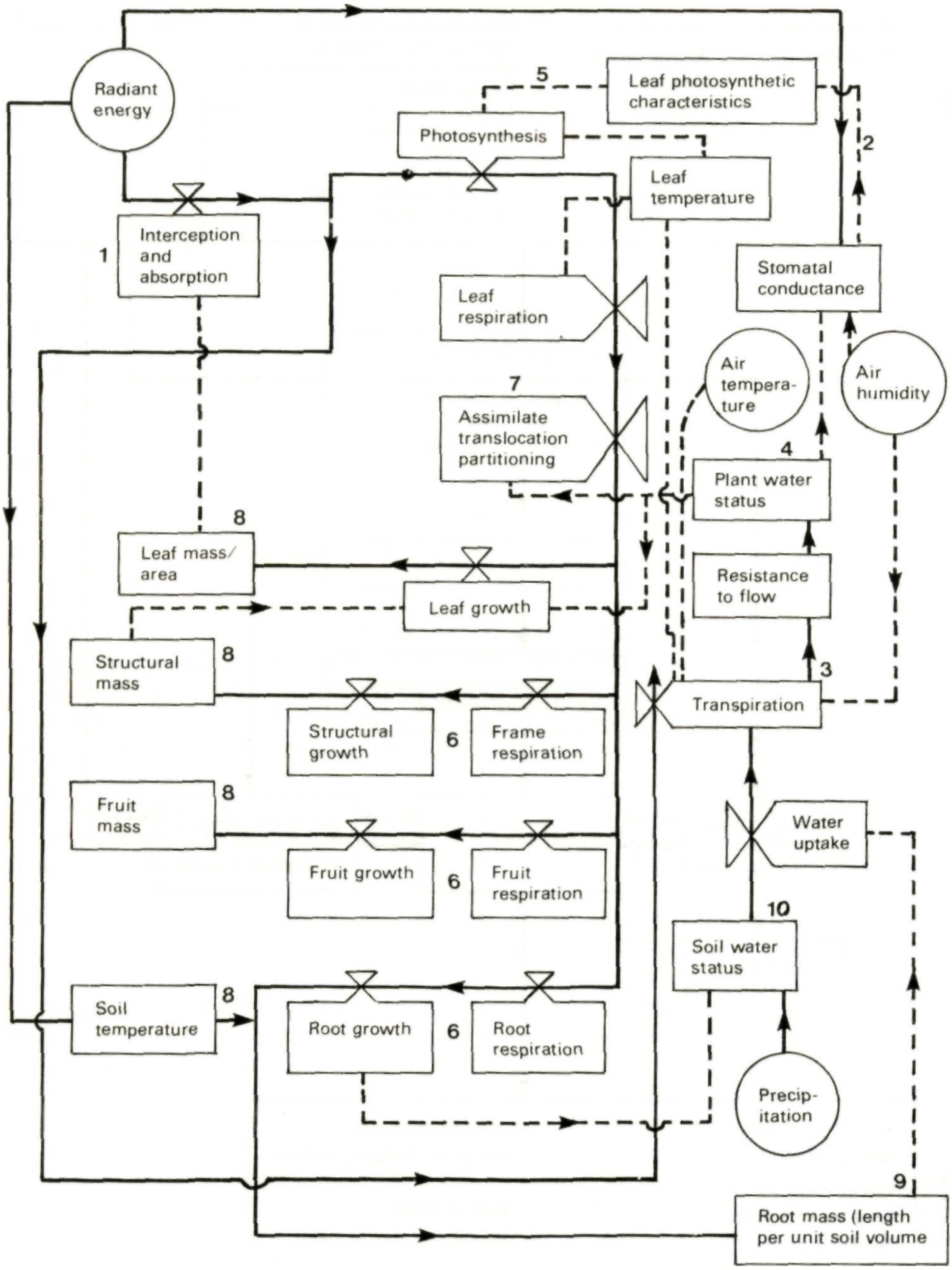


Figure 2 Modified CALPROD program flow chart, emphasizing input and output including water as limiting factor.

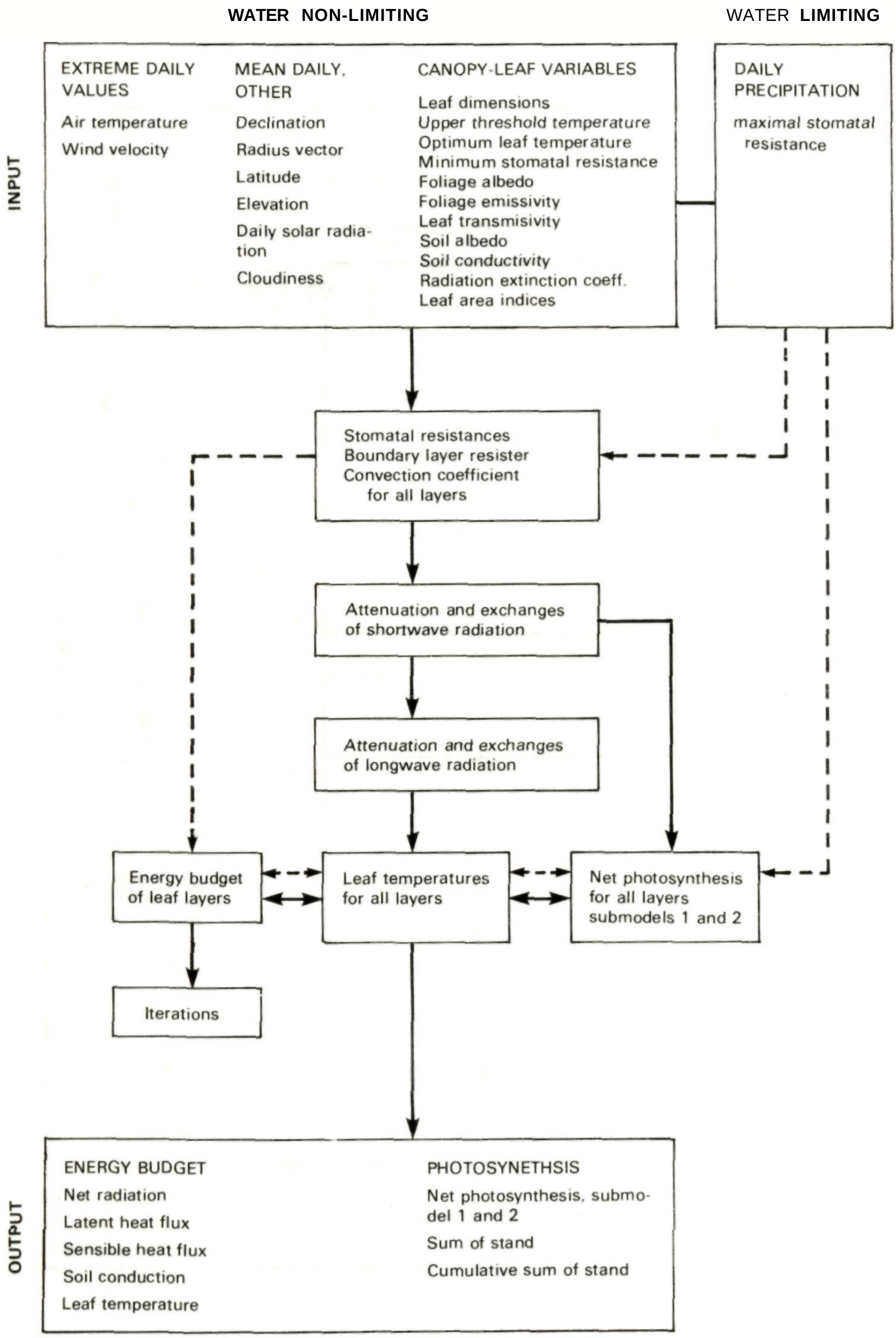
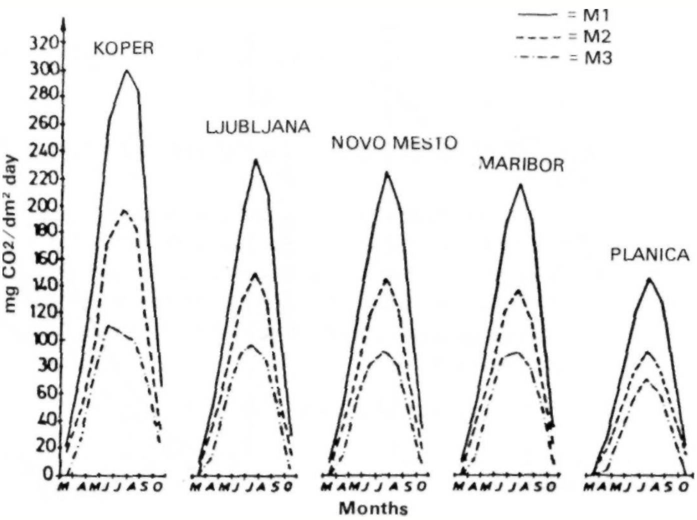


Figure 3 Daily course of mean net photsynthesis according to submodels Ml (high temperature plants), M2 (agricultural plants) and M3 (woody plants), for five locations in Slovenia for the vegetative period, March through October.



With the same CALPROD model we calculated also the productivity of buckwheat plant canopy using appropriate input data and photosynthetic response curves for *Fagopynim esculentum* (Moench) (Kajfez-Bogataj and Gaberscik 1986). For the year 1984 the comparison of observed and calculated results shows a very good agreement (Figure 4). More information about this research can be found in Kajfez-Bogataj and Hocevar (1986).

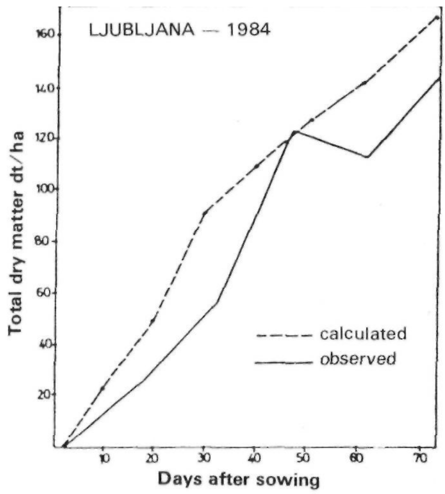
With the same model we also calculated net photosynthesis of a beech forest at two elevations using biological variables for locations at Ljubljana and Planica. Comparison of observed and predicted net photosnynthesis shows fairly good agreement in spite of being the first trial (Figure 5) (Kajfez-Bogataj and Robic 1985).

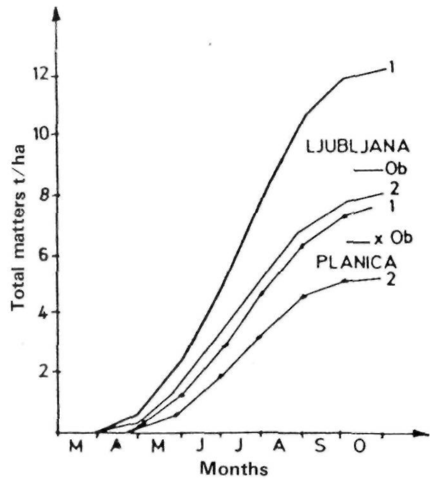
In general, the north-western part of Yugoslavia with large amounts of precipitation (yearly amounts 1250-1750 mm) does not experience drought although some years may show a shortage of water. During these dry years, there are negative effects on plant canopy productivity, viz., stomatal resistance will be larger, transpiration will be smaller and therefore temperature of leaves will be higher, diffusion of CO2 into stomata will be smaller and so net photosynthesis will decrease.

We incorporated the shortage of water in CALPROD by using a minimum stomatal resistance calculated as a function of water balance. Thus, additional input data and additional computations are needed for the maximum stomatal resistance and the main terms of water balance equation, daily precipitation and daily evapotranspiration (Bringfeld 1980; Maticic 1977). Additional input data and their influence on particular computation steps of the computer program are schematically presented on the flow chart by dashed lines (Figure 2).

Figure 4 Comparison of observed and simulated total dry matter production of buckwheat for Ljubljana, 1984.

Figure 5 Comparison of predicted and observed dry matter production of forest calculated by submodels 1 and 2 at Ljubljana and Planica.





From data on daily precipitation and daily evapotranspiration we calculated minimum stomatal resistance as a linear function of time, the factor of proportionality being on the order of 2-7 s cm" day " beginning on the day when all the precipitation was used for evapotranspiration. Until this day, stomatal resistance had the minimum value given by the input data.

An efficiency parameter was calculated from the minimum and the maximum stomatal resistance and the calculated minimum stomatal resistance for particular day. Since its value has to be between one and zero, we applied the cosine-squared function.

Preliminary results obtained by the modified program which includes light and water as limiting factors show rather small changes in comparison with the previous ones except in Koper which is located on the Mediterranean coast. We speculate that the differences in water regime are not large enough from year to year and the model not sensitive enough to show a well-expressed influence of water shortage on net photosynthesis. In regions with large water shortages, we can expect that the mentioned modifications of the model will be of greater significance.

Extension of prodcution model to an area

The model can be applied to a large area if all of its parameters do not change very much over the area or to a smaller area in complex terrain. In nature, an ecosystem of an area normally consists of (j) elementary parts (Figure 6) which are defined by different values of parameters and therefore different productivities (Pk)

$$P_k = f(Bi_{k)} S_{mk}, M_{„k}) \qquad (2)$$

To obtain the productivity of an area we have to sum up the productivities of elementary parts:

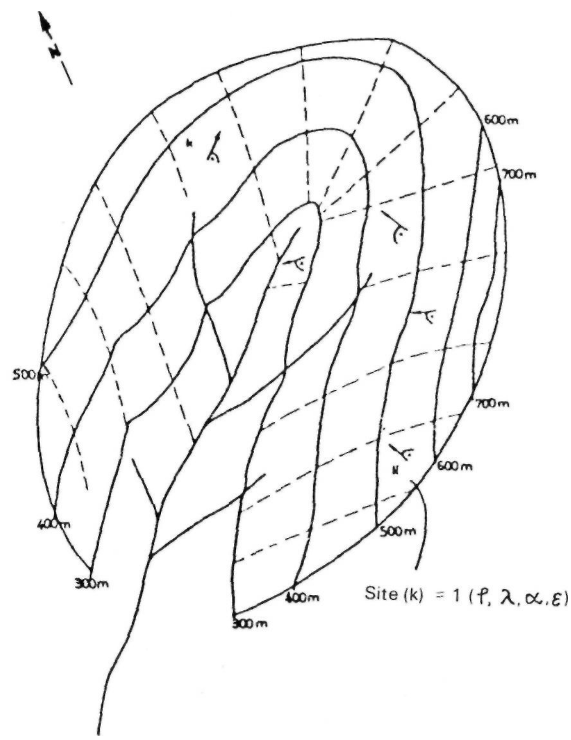
$$P = \sum_{k=1} P_k$$

where the area is divided in j homogeneous areas.

Environmental driving variables in the mesoscale

To calculate the production of a whole ecosystem in complex terrain we have to know how the values of its parameters vary over the area. In particular, the atmospheric parameters change their values very much from one elementary part of the ecosystem to the other. Complex terrain is very common in Slovenia; therefore its influence on the distribution of atmospheric variables values has been studied extensively. Some of

Figure 6 Ecosystem of a watershed and its elementary parts.



these studies will be discussed giving methods for evaluation of atmospheric variables as a function of terrain or site.

One such atmospheric variable is minimum temperature. It shows very distinctive features in valleys and basins on mornings after clear and calm radiation nights. A temperature inversion develop with air minimum temperature increase from the bottom of cold air lake basin. The rate is between 4.4 °C/100 m and 6.2 °C/100 m height along the slopes. These values resulted from measurements in Slovenia (Petkovsek et al. 1969) and in Pennsylvania, U.S.A. (Hocevar and Martsolf 1972) and are theoretically explained by Hocevar (1973).

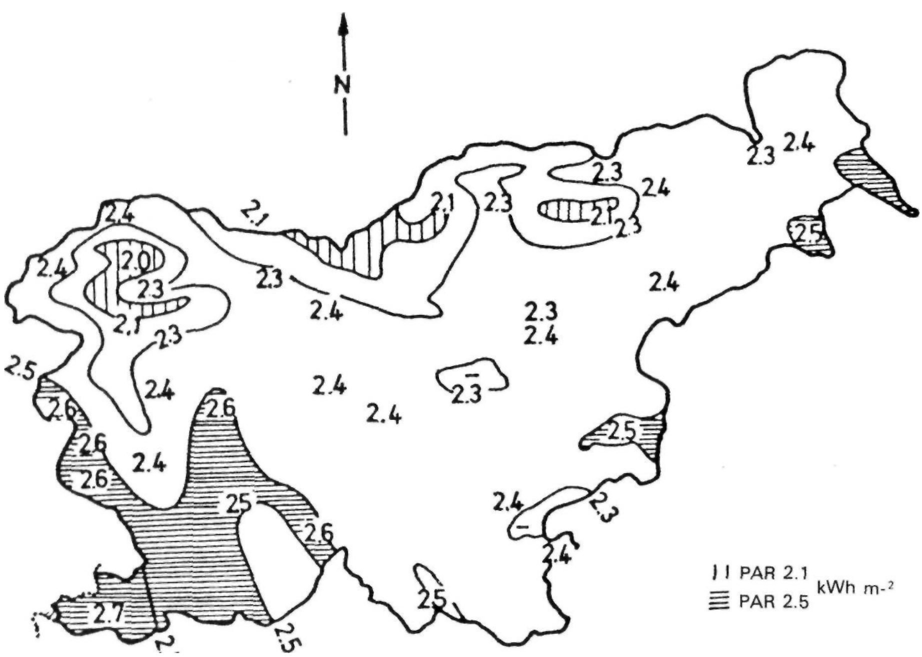
Photosynthetically—active radiation (PAR) determines photochemical processes (Gaastra 1963). We developed a method for estimating PAR for any site in complex terrain (Hocevar and Rakovec 1981). The method has the following steps: First, a map showing the areal distribution of PARh on a horizontal surface in the chosen period is prepared based on calculations from hourly measurements os sunshine duration at climatic stations (31 in Slovenia) and spatial features of convective cloudiness, fog and air pollution in the same time intervals. This is done for a typical day of every decade and every month of the year (Figure 7).

Second, PAR of an element of sloping surface (PAR_S) is calculated as the product of ks and PARh, where ks is a function of azimuth and inclination of the surface. Both ks and PARh are functions of the treated time period, as well.

$$PAR_S = ks\,(PARh) \tag{4}$$

A matrix of coefficients k$ was obtained from known values of $PAR_s$and PARh at locations observing meteorological parameters (Hocevar and Rakovec 1979).

Figure 7 Spatial distribution of PAR gained by a horizontal surface in Slovenia on a typical July day.



The third step is to account for obscuration of the sun by obstacles along the solar path. In our calculations, we reduced PAR by 80% when a site was so obscured and only diffuse PAR was present.

Model calculations of the three atmospheric variables, PAR, air temperature and soil surface temperature were made for an idealized basin with slopes of 20° and the

Figure 8 Daily course of PAR, soil surface temperature (Tg), air temperature (T_a), and mean sunshine duration on various sites in an idealized basin with 20° slopes using meteorological data for Dolenjska, Slovenia, on 17 June. Shaded portions of sunshine circles indicate fraction of hour that sky is cloudy.

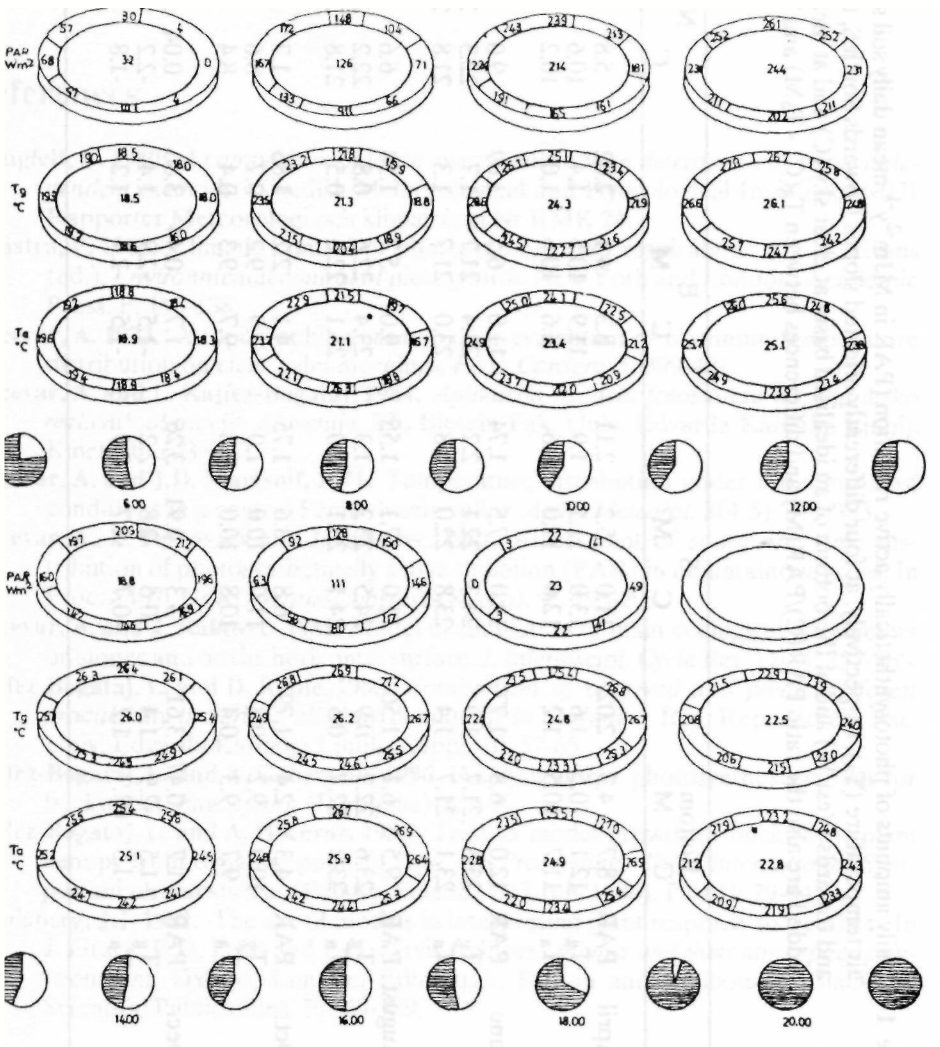


Table 1 Daily amounts of photosynthetically active radiation (PAR in $MJm^{-2}y^{-1}$ mean daily soil surface temperature (T_g) mean daily air temperature (T_a), respectively, at four differently oriented slopes (towards South S, towards East E, towards North N and towards West W) and at the bottom of an idealised basin at clear sky (C) and at mean sunshine duration conditions (M). Added are also the ratio PAR(C)/PAR(M) and differences between T_g(C) - T_aM) and T_a(M), respectively.

		Bottom			S			E			N			W		
		C	M		C	M		C	M		C	M		C	M	
17. April	PAR	8.7	4.3	2.02	11.0	5.2	2.11	8.3	4.1	2.02	5.8	3.0	1.93	8.2	4.0	2.0
	T_g	12.1	10.5	1.6	13.0	11.1	1.9	11.9	10.5	1.4	10.6	9.6	1.0	11.9	10.3	1.6
	T_a	11.7	10.5	1.2	12.6	11.0	1.6	11.6	10.6	1.0	10.2	9.6	0.6	11.5	10.3	1.2
17. June	PAR	12.0	6.8	1.77	13.0	7.5	1.74	11.0	6.5	1.69	9.0	5.3	1.69	11.0	6.4	1.72
	T_g	23.6	21.7	1.9	24.3	22.1	2.2	23.4	21.7	1.7	22.3	21.0	1.3	23.3	21.5	1.8
	T_a	23.1	21.7	1.4	23.8	22.0	1.8	23.0	21.7	1.3	21.8	21.0	0.8	22.9	21.4	1.5
17. August	PAR	9.5	6.1	1.56	11.0	7.1	1.55	9.0	5.7	1.58	6.6	4.3	1.53	9.0	5.8	1.55
	T_g	23.6	22.7	0.9	24.5	23.2	1.3	23.4	22.6	0.8	22.2	21.8	0.4	23.4	22.6	0.8
	T_a	23.2	22.7	0.5	24.1	23.1	1.0	23.1	22.6	0.5	21.8	21.8	0.0	23.0	22.6	0.4
17. Oct.	PAR	4.3	2.4	1.79	6.8	3.6	1.75	4.1	2.2	1.86	1.7	1.0	1.70	4.1	2.4	1.71
	T_g	10.0	9.2	0.8	11.0	10.0	1.0	9.9	9.2	0.7	8.6	8.2	0.4	9.9	9.3	0.6
	T_a	9.7	9.3	0.4	10.8	10.0	0.8	9.7	9.3	0.4	8.4	8.4	0.0	9.7	9.4	0.3
17. Dec.	PAR	1.7	0.47	3.61	3.3	0.91	3.26	1.7	0.44	3.86	0.04	0.01	3.16	1.7	0.47	3.62
	T_g	-1.5	-2.9	1.4	-0.6	-2.8	2.2	-1.5	-2.9	1.4	-2.2	-2.8	0.6	-1.5	-2.8	1.3
	T_a	-1.5	02.7	1.2	-0.7	-2.7	2.0	-1.5	-2.7	1.2	-1.8	-2.8	0.7	-1.5	-2.6	1.1

observed mean duration of sunshine at Dolenjska, Slovenia. The results are given as daily courses (Figure 8). Daily mean values are compared with clear sky values in Table 1.

Conclusions

The results of modelling indicate that it can be a powerful tool for estimating ecosystem productivity. Dynamic modelling can be extrapolated from a point to an area. If the ecosystem is represented by its elementary parts, parameters defining those elementary parts must be known. This is especially true for highly changeable atmospheric variables in complex terrain. Some of the methods for evaluation of time and space distribution of those vital ecosystem parameters for which we give some practical examples have proved useful.

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Traditional agroforestry practices under the edaphoclimatic parameters of Cyprus

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Abstract

Various forms of agroforestry have been practised in Cyprus since time immemorial and many of them continue to be practised to the present day. Agroforestry was culturally, socially and economically imperative for the well-being of the rural household in that it provided a good variety of products on the limited land of the farmer, that made the family self- or almost self-sustained. Under the unpredictable and most frequently adverse (to annual crops) climatic conditions of Cyprus, this variety of crops was also of great significance in that it provided a buffering effect to the household budget and averted starvation in cases of failure of one or other of the crops.

Under such conditions, economic analysis, cost-benefit ratios and alternate rates of return from the land did not come in. Hence no serious attempt has ever been made to evaluate the inter-relations between ligneous plants and other associated plant or animal production on the same land.

In Cyprus there has been a gradual reduction in the practice of agroforestry in favour of intensive monocultural practices. This has come about as a result of a combination of factors, as follows:

- *Increased income and rising standards oflivingin rural areas enabled the farmer to become a partner in the nationwide economy, in contrast to the self-sustained household economy of his fathers. His purchasing power has increased and what he does not grow he can purchase. Under such conditions he finds monocultures easier.*
- *The increasing use of water for irrigation stimulated intensive monoculture practices with non-ligneous crops of high cash-earning value.*
- *Under rainfed conditions, short-rotation crops (annuals) lost their value due to climatic adversities, in favour of the ligneous, longer rotation crops, resulting in ligneous monocultures.*
- *High wages for manual work necessitated mechanization in agricultural operations and this favoured monocultures.*
- *Consolidation of small scattered holdings in many communities also favoured monocultures.*
- *The easy availability and increased use of fertilizers reduced the importance of crop variety in maintaining soil productivity and favoured monocultures.*
- *Lack of quantitative data and information on the values of agroforestry also favoured monocultures.*

Research and education on agroforestry are necessary in order to establish its value as an economic and ecological land use practice, especially in countries with sensitive agronomic conditions and adverse climatic patterns.

Introduction

There are indications that Cyprus was covered with very dense forests in prehistoric times. Homer refers to Cyprus as the Green Island (Dasoessa) and Strabo who visited Cyprus more than one thousand years later (in 45 A.D.) writes thus about Cyprus in his Geographica (Cobham 1908):

> Such then is Cyprus in point of position. But in excellence it falls behind no one of the islands: for it is rich in wine and oil, and oil, and uses home- grown wheat. There are mines of copper in plenty at Tamassos, in which are produced sulphate of copper and copper-rust useful in the healing art. Eratosthenes talks of the plains as being formerly full of wood run to riot, choked in fact with undergrowth and uncultivated. The mines were here of some little service, the trees being cut down for the melting of copper and silver; and of further help was shipbuilding, when men sailed over the sea without fear and with large fleets. But when even so they were not got under leave was given to those who would and could cut them down to keep the land they had cleared in full possession and free of taxes.

Clearing and destruction of the forests continued throughout the long years that followed, until the year 1880 which became the turning point with the establishment of the forestry service and the beginning of rational forest management.

Forestry and food production were always competitive land use systems and there was hardly ever amicable symbiosis.

Foresty and food collection

For thousands of years, before man felt the necessity and had the capability to clear the forest and practise agriculture, he lived in harmony with the forest environment and fed himself with wild fruits seeds, roots, plants and honey that mother nature provided. He collected his food and moved about in search of it.

Collection of food from the forest was the earliest agroforestry practice. In Cyprus this practice survives to the present day with a big scope for increase. The modern Cypriot has preserved his rural habits through the ages and he takes great pleasure in the collection of food from the forest, though no longer for his subsistence but for a hobby and instinctive satisfaction.

Fruits like the berries of bramble *(Rubus fruticosus)* and the strawberry tree *(Arbutus andrachne* and *A. unedo)* and the fruit of the hawthorn *(Crataegus azarolus)* are delicacies of high esteem not only among the rural population but also among city dwellers. So are many herbs and vegetables that are eaten raw, cooked, or pickled; or are used to give flavour to food. A big number of plants is also widely used in herbal medicine and in extraction of essential and other oils.

Mushroom collecting from the forest is a very enjoyable hobby for the city dweller and a very profitable side-job for the villager. In 1986 the 'red mushroom' *(Lactarius* *deliciosus)* of the pine forests reached the price of CY3.5 (U.S.$7) per kilogramme in the city markets and it was a significant source of revenue to those villagers whose area was favoured with the right rainfall and temperature for the growth of the mushroom. Truffles *(Terfezia spp.)* are another valuable mushroom that grows in symbiosis with roots of various trees, but good production years occur very rarely, as the fungus grows only if there are late spring or early summer rains, that occur very rarely in Cyprus.

Snails of various species are also a delicacy. They are collected from wooded and other rural areas when there is sufficient rainfall or atmospheric moisture to bring them out of their underground hibernation.

Honey, collected from the cavities of tree trunks was perhaps the earliest form of sugar used by man. In Cyprus, wild honey is not collected today. Instead there is a well-organized scientific production through intensive methods of apiculture. Honey provides subsidiary income to many farmers and saves foreign exchange through reduction of sugar imports.

The forests of Cyprus are also good biogenetic reserves inasmuch as many of the cultivated varieties of fruits and cereals are found therein in their original wild form. Examples of such plants are wild apple and pear trees, wild wheat and oats, and wild carrot and cabbage. The latter *(Brassica hilarionis)* is endemic to Cyprus. These wild varieties are important sources of genes in the effort to rear cultivated varieties which will show increased resistance to environmental adversities such as drought, frost and disease that are frequent in the Cyprus environment.

Forestry and hunting

After food collection, hunting was probably the oldest of man's activities in his long struggle to feed and clothe himself. Excavations in Cyprus have shown the existence of such animals as the fallow deer *(Dama mesopotamica)* and the wild boar *(Sus scrofa)* that were hunted for their meat and their skins. The wild sheep (moufflon) of Cyprus *(Ovis amnion orientalis* — Cyprus variety) was also hunted, as has been confirmed by bones of the animal found at Khirokitia in neolithic settlements dating back to 7,000 years B.C.

In 1396, A.D.O. D'anglure wrote (Cobham 1908):

> The following Sunday, the ninth day of January, the King sent us again presents, to wit one hundred partridges, sixty hares, and five wild sheep, a sight fair to see. He was a prince who greatly loved hunting. He had a little beast no bigger than a fox. It is called 'carable', and there is no wild animal but this little beast will catch it, especially the animals named above.

Hunting of the moufflon is also depicted very vividly in mosaics of the Graeco-Roman period excavated at Paphos. The animal today is protected and its hunting is strictly prohibited.

Hunting in Cyprus today is not done for the sake of obtaining food, but for sport and recreation. Cyprus, with a population of about 600,000, has a hunter population of about 40,000, perhaps one of the highest proportions in the world. The most common species hunted are partridge *(Alectoris graeca Cypriotes);* hare *(Lepus europea);* wood pigeon *(Columba palumbus palumbus);* thrush *(Turdus spp.);* turtle dove *(Streptopelia turtur turtur);* and to a lesser degree, woodcock *(Scolopax rusticola)* and various species of ducks and waterbirds that come to Cyprus as winter visitors.

The catching of small birds on limesticks and nets has been reduced considerably the last three years through a government decision for strict enforcement of the law.

The catching of eels from forest streams and other inland waters has come almost to a halt, as eels have almost disappeared due mainly to the widespread use of insecticides, herbicides and fertilizers. Stream fishing is non-existent. However, through the good work of the fisheries service, the sport of fishing for trout and other fish in reservoirs that are artificially stocked with spawn, has gained ground in the last ten years. Rearing of trout and other fresh-water fish in farms is also practised. A prerequisite for trout rearing is cool, clear water that is secured only through the existence of forests and the absence of debris caused by erosion.

Forestry and grazing

The taming of animals by man and the practice of grazing in Cyprus are almost as old as the practice of hunting. Although extensive free range grazing on land that does not belong to the grazier is a primitive mode of subsistence, it survives to the present day. It was an easy method of providing meat, milk, cheese, wool and other products for the household and for trading. In the xeroclimatic conditions of Cyprus, grazing in the forests on ligneous maquis was a secure land-use practice, in that it was not affected by the frequent droughts that severely affect annual crops such as wheat, barley and legumes that provide forage in areas outside the forests.

Free-range goat grazing in the forests of Cyprus was common practice. However, after many years of experience and careful study and considerations, it was decided that free-range goat grazing and sound forest management on the mountain forests of Cyprus could not co-exist. At the same time, with rapidly rising living and social standards, the life of the landless shepherd did not appeal to the new generation. Through a series of measures initiated in 1880, forest grazing was continually reduced; and by the year 1940 almost all free-range goat grazing was eliminated from the mountain forests, through methods that generally met the consent of the graziers themselves. Today there is controlled goat grazing only on an area of lowland forest (maquis) which is about 5% of the total area of state forests.

To replace free-range grazing, intensive animal husbandry methods with better breeds of animals have been initiated and encouraged by government action. These methods have proved to be rewarding from both economic and social aspects.

Foresty and food production

The process of clearing the forests to produce food crops was intensified as man settled down and became a farmer and as the human population increased. It was only natural that in the long struggle of man to feed himself and survive, production of food would receive top priority. Man thus went on clearing the forests and extending the agricultural land. Notions of ecological balance, soil and water conservation, soil fertility, indirect influences of forests, let alone agroforestry, could not be even dreamt of. There was cut- throat competition between the people's needs for natural ligneous vegetation and for cleared areas suitable for cultivation and food production.

There is bitter evidence in Cyprus that man went too far in his uncompromising fight against the forest. He clear-felled forests and established food crops on steep slopes and other sites that were suited only for forest. The result did not take long to come and is evident today in the extensive areas of hilly land that lie derelict and devoid of any vegetation, deteriorating through constant erosion and constituting a wasting asset through desertification. Derelict stone terraces and abandoned vineyards are still to be seen, as evidence of irrational human activity. In many such cases the forest is creeping back to occupy its ground.

Today more wisdom has prevailed in land use. Very steep, rocky ground has been left to forestry; and crop production has been restricted to the better soils, mainly in small patches along streams, where irrigation makes crop production feasible. The crops are usually deciduous fruit trees such as apple, pear, plum and peach; with annual field crops such as runner beans and potatoes grown before the canopy of the fruit trees closes. There is generous application of fertilizers. Under these circumstances, ligneous crops are not beneficial to the food crop and the two are not therefore mixed on the same ground.

Many lowland, flat areas where the forest cover has been removed, have been converted today to very productive agricultural land, where water for irrigation is available. Examples of such forest land that is used today exclusively for agriculture are to be found in the Kokkinochoria (Red-Soil Villages) which are the granaries of Cyprus for potato production. These lands are very near to sea level, the climate is very mild and they are ideal for late winter production of potatoes that earn the highest foreign exchange of any agricultural crop of Cyprus. There are two crops of potatoes every year on the same land. The limiting factor to more production is water for irrigation.

All this 'potato land' is leased to farmers by the Forestry Department at nominal rent. The farmers see no place at all for any ligneous production in combination with potatoes. Even where shelter is needed from the blasting effect of the sea, the farmers use mechanical wind barriers, e.g., fences with canes or nets and, rarely, windbreaks of lines of cypress trees. The reason for the mechanical windbreaks is that water and light competition between the trees and the field crops reduce yields considerably.

Forestry and water for agriculture

As was mentioned in the previous section, forests in Cyprus are today restricted to very poor soils on what may be termed absolute forest ground, where agricultural crops (which are more exacting to soil conditions) could not survive. Even so, there exists in Cyprus a very special form of agroforestry practice based on water relations. Through very extensive dam construction, large quantities of rain water are collected from forest areas and stored in reservoirs. This water is transported over considerable distances — as far as 120 km in the case of the Red-Soil Villages mentioned in the previous section — and used very profitably for the irrigation of agricultural crops.

Though in this case the forests and the agricultural crops are not on the same ground but hundreds of kilometers apart, there can be no doubt about their interrelation and about the importance of this system of agroforestry (which could perhaps be termed teleagroforestry). It can even be said that this system possesses advantages over the system of trying to grow both ligneous and agricultural crops simultaneously on the same ground.

Forestry and agricultural protection

The essence of this system of agroforestry is that forest trees are used to provide protection to agricultural crops.

Shelter-belts

The small size and wide distribution of rural holdings in Cyprus is a limiting factor to the establishment of shelterbelts. There are no large continuous holdings of agricultural land; practically all households in the rural community own a share of the land. The average size of holding is 3.8 ha, but varies according to region from 1.3 to 6.3 ha. Each holding is scattered in many small areas around the village. It is obvious that under these conditions the establishment of shelterbelts is not easy.

It can however be said that the existence of large continuous stretches of State Forests on the upper catchments of practically all the watersheds in Cyprus provides a huge continuous shelterbelt that affords protection to agricultural lands lower down in the watershed and especially to the land in the neighbouring foothills. The protection consists in the amelioration of the microclimate; by the reduction of extremes in low and high temperatures; the protective effect on plants and animals from the cold winds and the frost of winter; and the protection against soil erosion through the action of water that would come down the steep slopes dangerously had they not been clothed with the forest vegetation.

Windbreaks

The use of windbreaks to afford protection to agricultural crops is very common in certain parts of Cyprus. Their use is more frequent in western Cyprus, to protect crops from the cold spring winds during the flowering season, from the strong westerly winds throughout the year and from the blasting effect of the sea.

The trees most commonly used as windbreaks are cypress *{Cupressus sempervirens)*, various species of eucalyptus, casuarina, tamarix, the wattle tree *{Acacia cyanophylla)* and, to a lesser degree, pines. The planting is usually done in two rows along the boundary of the holding and the trees are staggered in the two rows. The planting distance between the trees varies from 0.5 to 2.0 m depending on species and on the degree of protection required.

The most conspicuous examples of the use of such windbreaks are:

1. Extensive lines of cypress in the Limassol area to protect citrus groves from the effects of the sea winds;
2. Lines of poplars along irrigation channels in the mountain villages;
3. The relatively young windbreaks of tamarix in the areas of Argaka and Yialia, which make possible the establishment of banana plantations right on the sea shore; and
4. The cypress windbreaks that are being established at a very fast rate in the south coastal areas of Paphos, to shelter the plantations that are coming up in the newly irrigated areas of a big irrigation project.

Ligneous crop trees with annuals

The growing together in the same field of ligneous crop trees with annual crops is one of the oldest forms of agroforestry practised in Cyprus. Carob *(Ceratonia siliqua)* and olive *{Oka europea)* trees are indigenous to Cyprus and they grow naturally almost everywhere from sea level to about 1200 m asl. The fruit of these trees has been harvested and utilised in Cyprus since time immemorial. The carob fruit was known as the black gold of Cyprus as late as the 1940s, due to the significant foreign exchange that was earned from its export; whilst olives and olive oil constitute a basic diet of a large majority of the population.

It was only natural that many farmers would utilize the crop from those trees that grew naturally on their land. In the same way they utilized the annual growth of grasses and other plants for the grazing of their animals — mainly sheep and goats. With the advent of agriculture and the evolution of cultivated varieties of annuals such as wheat, barley, oats, various vetches, etc., it was again natural for the Cypriot farmer to try to obtain the benefit of two or more crops on the same field, i.e. the fruit of the carob and/or the olive and a cereal or leguminous crop which he sowed annually. The latter crops are harvested as grain, or used as green fodder for grazing or for cutting and transporting to animals in the pen. In years of abundance, green fodder is also dried and used as hay.

After the harvest, a third 'crop' is left in the field: the stubble, which provides good grazing material in late summer and early autumn when little other forage is available.

A fourth crop, of a much longer rotation, are the woody parts of the trees obtained through pruning or, rarely, through the felling of overmature or dead trees. They are top quality wood and fetch prices as high as CY40 per ton, for use as luxury fuel for heating in open hearths in urban households, or for charcoal manufacture. This system of multiple agroforestry is very advantageous as it secures at least a basic subsistence income to the farmer under the unstable and often adverse climatic conditions of Cyprus, where droughts very frequently bring about complete failure of the annual crops of cereals and legumes. The revenue from the tree crops is not affected much by the annual whims of climate, and has a buffering effect on the farmer's income, which helps him go through adverse years.

A very intensive and very productive system of this form of agroforestry is practised when there is water available for irrigation. The extensive use of fertilizers also brings about increased production under this system. However, when water is available, the tree used is no longer carob and olive but mainly citrus, which is more profitable. Also the undercrops, if they exist at all, are not cereals and legumes for animal food, but strawberries, peanuts, beans, carrots and other vegetables that bring in high cash returns to the farmer.

Trees for shade

Summer temperatures in the flat, fertile plains of Cyprus may rise as high as 40 °C during the hot dry season from June through August. Under such conditions, the presence of trees with a large, dense canopy to provide shade for the farmer and his animals becomes invaluable. It is thus a very common phenomenon in Cyprus to see large isolated trees on agricultural and grazing lands. These trees and their surroundings are very lonesome and isolated during the cold season; but their shade makes them an oasis during the hot season, when man and animal seek refuge beneath their branches to find shelter from the scorching heat of the overhead sun.

The traditional trees used for shade are carob, mulberry *(Moms alba),* Persian lilac *(Melia azedarach),* oak *(Quercus lusitanica)* eucalyptus of various species, wattle (-*Acacia cyanophylla),* pines and fig trees *(Ficus carica).*

Conclusions

Various forms of agroforestry have been practised in Cyprus since time immemorial and many of them continue to be practised to the present day. Agroforestry was culturally, socially and economically imperative for the well-being of the rural household in that it provided a good variety of products on the limited land of the farmer, that made the family essentially self-sustained. Under the unpredictable and most frequently adverse (to annual crops) climatic conditions of Cyprus, this variety of crops was also of great significance in that it provided a buffering effect to the household budget and averted starvation in cases of failure of one or other of the crops.

Under such conditions, economic analysis, cost-benefit ratios and alternate rates of return from the land did not come in. Hence no serious attempt has ever been made to evaluate the interrelations between ligneous plants and other associated plant or animal production on the same land.

In Cyprus there has been a gradual reduction in the practice of agroforestry in favour of intensive monocultural practices. This has come about as a result of a combination of factors, as follows:

1. Increased income and rising standards of living in rural areas enabled the farmer to become a partner of the nationwide economy, in contrast to the self-sustained household economy of his father. His purchasing power has increased and what he does not grow he can purchase. Under such conditions he finds monocultures easier.
2. The increasing use of water for irrigation stimulated intensive monoculture practices with non-ligneous crops of high cash-earning value.
3. Under rain-fed conditions, short-rotation crops (annuals) lost their value due to climatic adversities, in favour of the ligneous, longer rotation crops, resulting in ligneous monocultures.
4. High wages for manual work necessitated mechanization in agricultural operations and this favoured monocultures.
5. Consolidation of the small scattered holdings in many communities also favoured monocultures.
6. The easy availability and increased use of fertilizers reduced the importance of crop variety in maintaining soil productivity and favoured monocultures.
7. Lack of quantitative data and information on the values of agroforestry also favoured monocultures.

Research and education on agroforestry are necessary in order to establish its value as an economic and ecological land use practice, especially in countries with sensitive agronomic conditions and adverse climatic patterns.

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Water-harvesting based agroforestry in the arid regions of Israel

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Abstract

A long-term project was initiated to develop sustainable agroecosystems for the production of food, fodder and firewood under rainfall-harvesting conditions in an arid region.

The study is conducted in the Negev desert at the experimental sites of the Desert Run-off Farms Unit in Wadi Mashash andAvdat, where the mean annual rainfall amounts to only 115 and 80 mm, respectively.

Relying entirely on run-off water, research is carried out along the following lines:-

- *Plant introduction, with particular emphasis on* Prosopis, Eucalyptus, Acacia *and* Atriplex spp.
- *developing appropriate cropping systems based on the agroforestry concept, whereby the following aspects will be monitored in relation to water use efficiency.*
  - *combinations of trees, shrubs and annuals*
  - *plant densities*
  - *optimum coppicing cycles*
  - *fertilization at planting*
  - *animal studies.*

Introduction

For nearly thirty years, the Desert Run-off Farms Unit of the Ben Gurion University of the Negev and the Hebrew University of Jerusalem have studied methods to recreate and improve the rainfall harvesting methods developed 2400 to 1500 years ago. These studies have been carried out at experimental sites in Shivta and Avdat (mean annual rainfall 80 mm), located 70 km respectively south-west and south of Be'er Sheva (Evenari et al. 1982).

Based on obtained results a pilot farm was established in the early 1970s at Wadi Mashash (mean annual rainfall 115 mm, located 20 km south of Be'er Sheva, 31° 08'N, 34° 53' E, elevation 400 m asl, 60 km from the Mediterranean. All three locations are characterized by Koppen climate BWhs and BShs (winter rainfall in hot deserts, hot steppes) and by Thornthwaite moisture index, 40 - 60.

Starting with the successful cultivation of a wide variety of orchard and field crops, a major effort is now under way to develop new crops, cropping systems and applications of water-harvesting techniques, with particular emphasis on the needs and problems of people inhabiting the arid and semi-arid regions of the world. With water as key factor a well-defined relationship needs to be established between **water supply** — the water-harvesting system, and **water use** — the management of various intensified agrosystems to achieve maximum biomass production per unit of time, area and water.

Water harvesting

Farming based on rain-water harvesting is a system which allows agricultural activity in areas that normally do not receive enough rainfall, by concentrating rainfall-induced runoff from a catchment area into a smaller cultivated area. When rain intensity exceeds the infiltration rate of the soil, water is not absorbed by the soil and hence runs off along the surface to the low-lying parts. A catchment area is therefore characterized by sloping surfaces with low infiltration rates. The cultivated area, however, often comprises a similar soil type and earthen walls need to be erected to retain the accumulated runoff water, allowing for deep infiltration. This requires deep soils with a high water-holding capacity, storing enough water to support plant production during the dry season.

Based on this principle, various water-harvesting systems are in use, such as:

- terraced wadis (dry river beds, carrying water during high- intensity rains), sometimes constructed with conduit channels, tapping runoff water efficiently from adjacent hill slopes;
- diversion systems, where erratic flash floods in wadis are partly diverted to adjacent fields using diversion channels;
- macro-catchment basins ('limanim'), where runoff is collected from tributaries and artificially trapped in natural depressions with areas ranging from 0.3 ha to 0.5 ha; and
- micro-catchments, where runoff from a relatively small catchment area is harvested for the support of single trees.

Relying entirely on locally available materials, research is carried out to obtain higher run-off efficiency rates as well as to design water-harvesting schemes with a minimum amount of maintenance and repair.

Plant introduction

Plants, mainly those native to arid lands, are screened for their potential for production of food, fodder and firewood, the three most pressing needs in arid and semi-arid regions of many developing countries. The criteria for selection include: capacity for rapid growth; reliable regrowth after harvesting by coppicing (in the case of fodder trees and shrubs); acceptability as food and/or fodder, especially under current conditions; and finally, ecological adaptability to prolonged droughts, and brief, intermittent periods of flooding in the catchment basins. Most promising species are *Prosopis spp.* and *Acacia salicina* for fodder and firewood; *Eucalyptus occidentalis* and *E. camaldulensis* for firewood; *Leucaena leucocephala* for food, fodder, firewood and timber; *Atriplex barclayana, A. nummularia* and *Cassia sturtii* for fodder; and *Phaseolus acutifolius* (-tepary bean) as food crop.

Cropping systems

Once promising plant candidates are identified, more agronomical studies are carried out. Based on the agroforestry concept various combinations of trees, shrubs and annuals are established in various densities to assess overall biomass production in relation to water use. Deep-rooting trees may exploit the deeply infiltrated runoff water, while annuals extract water from the shallow soil layers. As different plant species show different demands of water at different seasons over the year, a temporal and spatial arrangement is thus created in water uptake. Furthermore, trees, because of their solar radiation-intensity-reducing and wind-breaking properties, can create favourable growth conditions for various under crops. For this purpose *E. occidentalis* and *A. salicina* are grown separately or mixed with sorghum and chickpea in different densities. Soil moisture depletion from the various soil layers is recorded through a comprehensive network of neutron access tubes, and water use by the different plant species is calculated. These are related to biomass production and plant development stage. Finally a crop simulation model will be assessed.

The above-mentioned trees are also tested for optimum coppicing cycles of 2,3 and 4 years (Zohar 1974) under different plant densities of 600-1200 trees/ha. Depending on the regeneration capacity of the coppice shoots, an optimum harvesting management scheme can thus be determined (Zohar et al. 1986).

Additional experiments involve initial fertilizer application during planting to boost yield and soil tillage.

Animal studies

Animals such as sheep, goats and camels are integrated with these cropping systems. Grazing trials are performed to check fodder quality of different plants, fodder quantity uptake, timing of fodder application, and grazing conditions in relation to food conversion rates.

Conclusion

With a more concentrated water supply, management practices can be more intensified, creating possibilities for the development of agroforestry in arid and semi-arid lands.

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Meteorology applied to agroforestry systems in the Brazilian Amazon region

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Abstract

Although there is growing interest in Brazilian Amazon region towards the adoption (mainly in upland; unflooded 'terra firme' area, once covered by tropical rainforest) of agroforestry systems, since those represent a promising option from the economical, ecological as well as social viewpoint, the need for intensifying research in several disciplines, including agrometeorology, in order to reduce the risks on this kind of enterprise is evident. This paper aims to contribute towards the orientation of research on this subject, by presenting:

a) general characterization of the area;
b) main agroforestry systems presently practised;
c) presently available agrometeorological information and
d) research priorities on meteorology applied to agroforestry.

Introduction

Although agroforestry systems are commonly and successfully practiced in native communities in the Brazilian Amazon (Peck HI 1979; Dubois 1982), this type of land occupation was not motivated by the early settlement projects planned for this region. This was due to the short term interests of these projects and the scarcity of experimental results for this type of agricultural exploitation. In recent years, however, there has been a growing interest among different categories of Amazonian agricultural professionals (researchers, planners and growers) in the assessment, refinement and adoption of agroforestry systems. This sudden popularity is due to several factors:

1. The low yield obtained in crop as well as animal husbandry projects established on Oxisols and Ultisols previously covered by rainforest, with the adoption of traditional crop and grazing management systems;
2. The recognition of the economic ecological and social advantages of agroforestry systems as compared with others, especially for humid tropical area of underdeveloped or developed countries with chemically poor soils (Peck III 1979; Dubois 1979a, 1979b; Alvim 1981; Combe 1982; Brienza Junior 1982a; Kitamura 1982; NAS 1982; Fearnside 1983);
3. The awareness of the increasing rate of deforestation occurring notably in some of the most recent regional agricultural frontiers, such as Rondonia State (Fearnside 1982,1985; Buschbacher 1986);

4. The concern about the widespread ecological disturbances expected to be caused by forest removal, especially modifications in the water environment interactions in macro- as well as in micro-scales (Molion 1975; Salati 1983,1985; Henderson-Sellers 1985);
5. The observed efficiency of some agroforestry systems in controlling pests, diseases and weeds, all of which represent serious constraints for traditional monocropping as well as multiple cropping in this region;
6. The more efficient use, by agroforestry systems, of solar energy which is predominantly available in diffuse form in this region.

The intensification of interdisciplinary agroforestry research is essential in order to support the expansion of this activity in the region. There is an urgent need for a careful survey so that suitable systems can be assessed for the different combinations of climate and soil found there, since the complex interactions among the distinct plant species which are part of these systems exhibit a local pattern which makes it difficult to extrapolate results obtained in isolated studies carried out in other regions.

Agrometeorology is one of the research areas deserving more intensive consideration in order to allow more efficient planning and management of agroforestry systems both because of its role in helping to find solutions for agroforestry questions and the incipient knowledge of the spatial and temporal distribution of many important meteorological variables; the little information on the climatic requirements of most of the native and some of the introduced crops, woody plants and pastures adopted in the region, and their various pests and diseases; and the almost complete non- existence of a micrometeorological characterization of these systems as compared with other systems of land use and to original vegetation conditions.

The aim of this paper is to provide a basis for the discussion and proposal of guidelines for the application of meteorology to agroforestry in the complex region of the Brazilian Amazon. It presents:

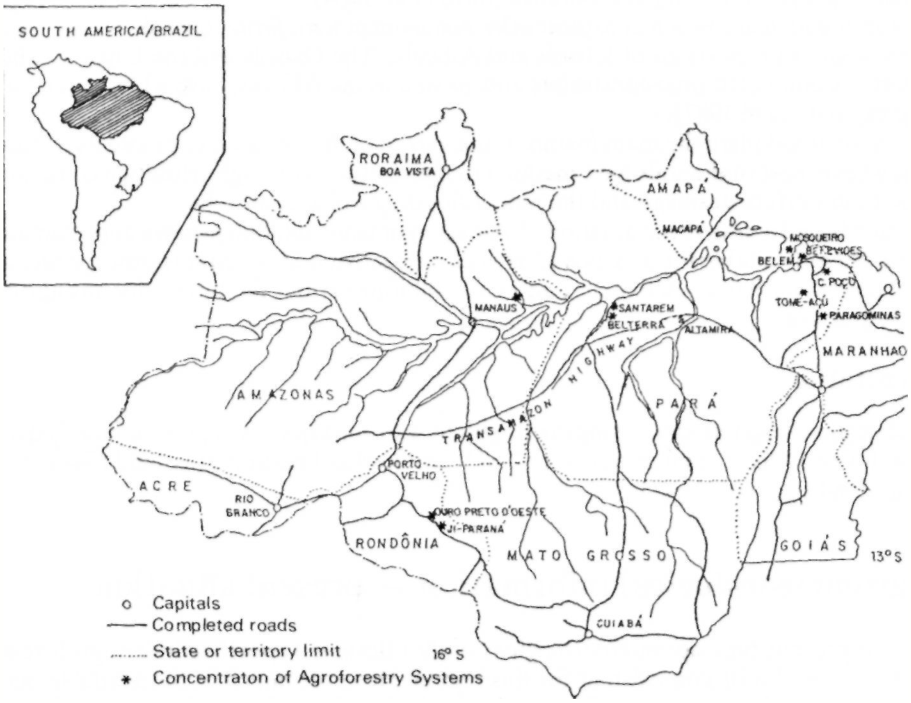
- A general characterization of the area
- The principal agroforestry systems now practiced
- Agrometeorological information at present available
- The main research priorities for meteorology as applied to agroforestry

Characterization of the area

Geographical situation

The Brazilian Amazon region referred to in this paper is the so-called Legal Amazon Region which covers approximately 5,145,000 km , corresponding to nearly 60% of the Brazilian territory and includes the whole of the states of Acre, Rondonia, Amazonas, Para, and Mato Grosso and the Federal Territories of Amapa and Roraima, and part of the states of Goias (north of 13° S latitude) and Maranhao (west of 44° W longitude) (Fig.l).

Figure 1 Localization map of Brazilian Amazon with indication of areas of agroforestry sustems concentration.



Climate

The most significant spatial climatic differences found in this region are due to rainfall. In a broad sense, the average annual rainfall ranges from 1,500 mm to 3,500 mm (SUDAM 1984), and has a bimodal distribution. The main rainy period is from December to May. The second period with lower rainfall (but greater variability), is from July to November. The northern portion of the federal territory of Roraima (located in the northern hemisphere) has a rainy season from April to August (Bastos et al. 1984).

The thermic conditions of the region are characterized by the occurrence of large diurnal fluctuations and insignificant annual fluctuations. The average annual mean temperature ranges from 22 °C to 24 °C and the average annual maximum and minimum temperatures range, respectively, from 28 °C to 32 °C and from 17 °C to 23 °C (Bastos et al. 1984).

The spatial distribution of sunshine duration shows annual averages ranging between 1,400 hours and 2,500 hours, while present information on the global solar radiation distribution suggests annual average values between 8.4 MJ m^{-2} day^{-1} and 10.2 MJ m^{-2} day^{-1} and monthly average values between 7.2 MJ m^{-2} day^{-1} and 12.6 MJ m^{-2} day^{-1} (Bastos et al 1984).

Physiography and soils

The Amazon region is divided into two main physiographic sections i.e. the Amazon *plateau* and the alluvial flood plain. Other physiographic units also exist but in a much smaller proportion in higher altitudes (Silva et al. 1984).

On *the plateau,* which constitutes the Amazonian *terra firme,* Oxisols predominate, with smaller proportions of Utisols and Alfisols. The Oxisols and the Ultisols exhibit chemical and nutritional constraints and, as well as the Alfisols, have a low water-holding capacity (Lai 1987).

In the flood plain the main feature is the varzea of the Amazon river and its tributaries, where most of the soils have medium to high fertility although exhibiting constraints due to imperfect drainage and the risk of flooding (Silva et al. 1984).

In a broad sense, the evaluation of Amazonian land suitability shows approximately 72% of land suitable for all kinds of agricultural activity; 15% suitable only for forestry and animal husbandry activities; and 13% exhibiting serious limitations for any agricultural purpose

Vegetation

The original vegetation covering the Brazilian Amazon region was predominantly dense rain forest (49%); open rain forest (27%); and lowland natural grassland (7%) (Silva etal. 1984).

Agrometeorological information — present situation

At the present time agrometeorological studies designed specifically for agroforestry systems are almost non-existent for this region. However, much of the available agrometeorological information, if properly manipulated, can be useful for agroforestry purposes. The knowledge gained over the last ten years about the distribution patterns of meteorological variables, such as rainfall, solar radiation and wind, can at least guide the selection of suitable areas for different agricultural activities.

The bioclimatic requirements and phenological behaviour of the species that have been adopted in agroforestry systems are largely unknown since most of these species, especially perennial crops and woody plants, are of recent introduction. Present knowledge of the bioclimatic requirements of most of the tree species adopted in these systems is limited to the superficial evaluation of the climatic conditions in the natural range of a small number of species (Golfari et al. 1978). The same is true for most of the industrial perennial crops as well as for regional fruit crops (Falcao 1979; Ortolani et al. 1982; Diniz et al. 1984).

Micrometeorological studies have only recently begun in this region and have been carried out in areas of natural rain forest (Leopoldo et al. 1984; Shuttleworth et al. 1984, 1985). A study is currently being carried out in rubber-tree stands (O.M.R. Cabral, personal communication). Concerning the pests and diseases that affect agroforestry in the region as related to weather and climatic conditions, the most significant progress has been achieved with rubber-tree and cocoa crops.

Main agroforestry systems now practiced

In the region there are several types of agroforestry systems involving a high percentage of native species. These systems are planted in experimental and/or producer areas located mainly in the states of Amazonas, Rondonia and Para (Fig. 1; Tables 1 and 2) where distinct climatic conditions exist, particularly from the hydric view point (Table 3). Within the region, however, the most important concentration of plant combinations classed as agroforestry systems is found in the agricultural colony located in Tome-Acu, state of Para (Table 1), where systems have been adopted starting with the planting of medium cycle crops (papaya, banana, passion-fruit and black pepper) in association with annual species in intercropping (cowpea, rice, watermelon, melon and pumpkin). These systems then become bi-stratified agroforestry systems (such as cocoa vs. forestry species) through the introduction of long-cycle species (cocoa, coffee, guarana, rubber-trees, freijo and andiroba as well as many other forestry or fruit species) (Yared and Veiga1985).

In this region, predominantly settled by Japanese immigrants and their descendants, the adoption of this kind of system is consequence of the search for new alternatives to overcome disease control and market constraints (Yared and Veiga 1985). The most widely used systems in this region are black pepper/cocoa and passion fruit/cocoa. In the former, black pepper is planted first, followed by cocoa three to four years later (Taketa 1982).

Among the systems which include forestry species the most widespread is black pepper/freijo following a variable spatial and sequential pattern which reflects the evolution they undergo (Yared and Veiga 1985).

In Capitao-Poco, Altamira and Prainha, in the state of Para (Table 1), double systems associating shading crops (Brazil nuts, rubber tree) and shaded crops (black pepper, cocoa and guarana) are grown at an experimental level. Other experiments are: a rubber-tree vs. black-pepper combination carried out in a producer area located on Mosqueiro Island, Para (Viegas 1982); the cultivation of corn followed by cowpea intercropped in oil palm rows in Capitao-Poco (Stolberg-Wernigerode 1983); Guarana crop associated with other economically viable crops carried out in Manaus, Amazonas (Canto 1982) where there are also systems such as regional perennial fruit crops planted after a sequence of short-cycle staple crops; and systems associating shading plants and cocoa planted by CEPLAC in many parts of the region (Silva and Santos 1982).

In the Tapajos region, Santarem county, state of Para, there is a notable use of forestry species (freijo, mahogany, andiroba and urua) in systems which include food crops (maize, cassava and banana) (Brienza Junior et al. 1983).

As far as silvopastoral and agrosilvopastoral systems are concerned there are some impressive experiences such as: the planting of Pinus caribaea in pasture areas covered by 'coloniao' (green pannic) and Amazon quicuio carried out at the level of a large enterprise, in Monte Dourado, Almerim county, Para (Lins 1982; Brienza Junior 1982); the combination of pastures for cattle husbandry in a rubber-tree plantation located at Benevides, Para (Dubois 1979b); and the association of forest species, pastures and short cycle crops that is being studied in Paragominas, Para (Marques et al. 1985).

Table 1 Presentation of species found in the concentration areas of agroforestry systems in the Brazilian Amazon.

Annual Crops

Location	Cowpea	Soybean	Rice	Beans	Pumkin	Melon	Watermelon	Cassava	Corn	Sweet-potato
Tomé-Açu		*	*	*	*	*	*	*		
Capitao-Poço	*		*					*	*	
Belterra	*									
Manaus	*			*				*	*	*
Altamira	*			*				*	*	
Santarem			*					*	*	
Benevides										
Almeirim										
Paragominas	*								*	
Prainha										
Mosqueiro										
Cameta										
Rodônia (Ariquemes, Ji-Parana Cacoal e Ouro Preto)			*	*				*	*	

Forestry species

Location	Andiroba	Cedro	Freijo	Macacauba	Mahogany	Parica	Pau-d'arco	Terminalia	Urua	Faveira	Pinus	Eucalyptus	Tatajuba
Tomé-Açu	*	*	*	*	*	*	*	*					
Capitao-Poço			*										
Belterra			*										
Manaus			*							*			
Altamira													
Santarem	*		*		*				*		*		
Benevides													
Almeirim											*		
Paragominas						*						*	*
Prainha													
Mosqueiro													
Cameta													
Rodônia (Ariquemes, Ji-Parana Cacoal e Ouro Preto)									*				

Pasture

Location	Guandu	Quicuio	Desmodium	Andropogon	Pueraria	Centrosema	Coloniaõ
Tomé-Açu							
Capitao-Poço							
Belterra		*	*	*	*		
Manaus	*	*					
Altamira							
Santarem							
Benevides		*					
Almeirim		*					*
Paragominas		*	*	*		*	
Prainha							
Mosqueiro							
Cameta							
Rodônia (Ariquemes, Ji-Parana Cacoal e Ouro Preto)	*						

Fruit Crops

Location	Matapi	Jaca	Pupunha	Avocado	Biriba	Banana	Bacuri	Cupuaçu	Graviola	Orange	Limon	Passion fruit	Papaya	Bread fruit
Tomé-Açu				*		*	*	*	*	*	*	*	*	
Capitao-Poço						*								
Belterra														
Manaus	*	*	*		*	*			*			*	*	*
Altamira						*								
Santarem						*								
Benevides														
Almeirim														
Paragominas														
Prainha														
Mosqueiro														
Cameta														
Rodônia (Ariquemes, Ji-Parana Cacoal e Ouro Preto)						*							*	

Shade spec. / Perennial and semi-perennial/indust. species

Location	Erythrina	Gliricidia	Açai	Cocoa	Coffee	Sugar-cane	Castanha-do-B.	Coconut	Guaranâ	Black Pepper	Rubber-tree	Oil palm	Cotton	Cashew nuts	Source of reference
Tomé-Açu	*		*	*	*	*	*	*	*	*	*				Stohlberg-Werniegerode & Flohrschütz 1'982, Brienza Jun.,1982b Dubois, 1979, Taketa 1982
Capitao-Poço				*			*		*	*	*				Brienza Jun.1982b Stohlberg-Werniegerode, 1983 Frazao et al. 1982
Belterra				*											Brienza Jun. 1982
Manaus		*		*	*			*	*		*				Brienza Jun.1982b Canto 1982, Arkoll 1982 Silva & Santos 1982
Altamira				*		*	*		*	*	*		*		Andrade s.d. Andrade et al. 1982, Frazão et al. 1982, Paiva 1985
Santarem															Brienza Jun. 1982b Brienza Jun. et al.1983
Benevides											*				Dubois, s.d.
Almeirim															Brienza Jun. 1982 Lins 1982
Paragominas															Marques et al. 1985
Prainha				*						*	*				Andrade s.d.
Mosqueiro										*	*				Viégas, 1982
Cameta				*			*								Silva & Santos, 1982
Rodônia (Ariquemes, Ji-Parana Cacoal e Ouro Preto)		*		*	*						*				Peck III, 1979 Silva & Santos, 1982

Table 2 List of vulgar and scientific names of the species found in agroforestry systems located in the Brazilian Amazon.

Vulgar Name	Scientific Name
Avocado	*Persea americana*
Acai	*Euterpe oleracea*
Cotton	*Gossypium herbaceum*
Andiroba	*Carapa guianensis*
Andropogon	*Andropogon gayanus*
Rice	*Oryza sativa*
Bacuri	*Platonia insignis*
Banana	*Musa paradisiaca*
Sweet potato	*Ipomoea batatas*
Biriba	*Rollinia mucosa*
Cocoa	*Theobroma cacao*
Coffee	*Coffea arabica*
Cashew nut	*Anacardium occidentalis*
Sugar cane	*Sacchamm officinanun*
Brazil nut	*Bertholletia excelsa*
Cowpea	*Vigna ungidculata*
Cedro	*Cedrela odorata*
Centrosema	*Centrosema pubescens*
Coconut	*Cocos nucifera*
Coloniao	*Panicum maximum*
Cupuacu	*Theobroma grandiflonim*
OilPalm	*Elaeis guineensis*
Desmodium	*Desmodium ovalifolium*
Erythrina	*Erythrina spp.*
Eucalyptus	*Eucalyptus tereticornis*
Faveira	*Parkia sp.*
Beans	*Phaseotus vulgaris*
Freijo	*Cordia goeldiana*
Bread-Fruit	*Artocawus a tilis*
Gliricidia	*Gliricidia sepium*
Gravida	*Anona muncata*
Guandu	*Cajanus cajan*
Guarana	*Paulinia cupana var. sorbilis*
Jaca	*Artocarpus integrifolia*
Pumpkin Orange	*Cucurbita maxima*
Lemon	*Citrus sinensis*
Macacauba	*Citrus limon*
Papaya	*Platymiscium sp.*
Cassava	*Canca papaya*
Passion fruit	*Manihot utilissi/na*
Watermelon	*Passiflora edulis*
Melon	*Citrullus vulgaris*
Corn	*Cucumis melo*
Mahogany	*Zea mays*
Matapi	*Swietenia macrophylla*
Parica	*Schizolobium amazonicum*
Pau-d'arco	*Tabebuia serratifolia*
Black pepper	*Piper nigrum*
Pinus	*Pinus caribaea*
Pueraria	*Pueraria phaseoloides*
Pupunha	*Guilielma gasipaes*
Quicuio	*Brachiariaixumidicola*
Soybeam	*Glycine maxima*
Rubber-tree	*Hevea brasiliensis*
Tatajuba	*Bagassa guianensis*
Terminalia	*Terminalia ivorensis*
Urua	*Cordia alliodora*

Table 3 Average values of climatic variables in some agroforestry systems areas in the Brazilian Amazon region

	Manaus, \M						Ouro Preto d'oeste, RO				
Month	TX	TN	TM	IN	UR	PP	TX	TN	TM	UR	PP
J	30.9	22.4	25.5	130.2	86	232	29.7	21.7	25.3	88	290
F	30.6	22.4	25.4	106.8	87	273	29.4	21.6	25.1	88	292
M	30.8	22.5	25.4	113.0	87	295	30.0	21.4	25.2	87	280
A	31.2	22.5	25.4	119.2	87	296	30.0	21.8	25.2	86	196
M	31.1	22.3	25.5	150.4	87	268	29.6	20.3	24.5	84	97
J	30.9	21.8	25.3	182.8	85	ISO	29.1	18.8	23.5	83	30
J	31.3	21.3	25.4	216.8	82	128	30.6	17.5	23.6	76	4
A	32.6	21.4	25.8	228.7	80	104	32.2	18.8	25.0	73	43
S	33.0	22.0	26.3	205.0	80	102	31.7	20.2	25.6	76	100
0	32.8	22.3	26.4	187.8	81	164	31.4	21.0	25.8	80	176
N	30.3	22.7	26.4	169.3	82	150	32.1	21.6	25.8	84	225
D	31.6	22.3	25.7	127.2	85	243	31.3	21.7	25.2	87	259
Year	31.4	22.2	25.7	1936.2	84	2405	30.6	20.5	25.0	83	1992

	Tome-Aqu ,PA				Altamira, PA					Belterra, PA			
Month	TX	TN	TM	PP	TX	TN	TM	UR	PP	TX	TM	IN	PP
J	32.6	22.3	25.8	323	29.9	22.4	25.2	85	310	29.9	25.1	143.7	214
F	32.0	22.4	25.5	354	29.8	22.3	25.2	87	332	29.4	24.9	114.1	169
M	33.0	22.5	25.5	444	30.5	22.4	25.4	86	341	29.5	24.9	123.4	280
A	32.3	22.8	25.6	376	31.0	22.4	25.7	84	303	29.6	25.0	145.1	258
M	32.7	22.7	25.6	247	31.3	22.4	25.8	83	167	29.6	24.8	195.2	233
J	32.6	21.9	25.4	131	31.6	21.6	25.8	81	100	29.9	24.6	234.8	126
J	32.6	21.4	25.4	109	32.1	21.2	25.7	78	53	30.1	24.5	261.9	87
A	33.0	21.2	26.2	64	32.2	21.5	26.0	77	34	31.0	25.0	268.0	54
S	33.3	21.4	26.7	58	32.7	22.0	26.5	76	29	31.7	25.6	236.6	39
0	33.6	21.7	27.0	56	32.5	22.7	26.6	75	44	32.1	26.0	245.2	42
N	33.7	22.0	26.9	97	32.1	22.7	26.5	75	66	32.2	26.0	220.4	79
D	33.3	22.2	26.5	173	31.4	22.5	26.0	78	136	31.0	25.5	194.5	166
Year	32.9	22.0	26.0	2352	31.4	22.2	25.9	80	1914	30.5	25.2	1375.5	1847

Fonte:
EMBRAPA-UEPAE Manaus (1971/82) — CEPLAC (1976/83) — INATAM (1968/83) — EMBRAPA-UEPAE Altaminra (1974/83 — 1NEMET (1972/83)

TX = Maximum temperature (°C.)
TN = Minimum Temperature (°C.)
TM = Mean Temperature (°C.)
IN = Sunshine duration (hours and decimals)
UR = Relative Humidity (%)
PP = Rainfall (mm)

Research priorities in meteorology as applied to agroforestry

Considering the small amount of agrometeorological information available to support agroforestry activities in the Brazilian Amazon, the following list of research priorities is recommended:

1. Climatic analysis of the areas for the establishment of present or future agroforestry systems. These studies should include statistical and other approaches suitable for limited-data areas. In this context remote-sensing techniques are becoming important tools for guaranteeing the spatialization of point observations, indispensable for suitability-assessment purposes.
2. Identification of edaphoclimatic requirements of the species used in agroforestry systems. For this purpose there must be interdisciplinary team work in which agrometeorologists work hand- in-hand with pedologists and eco-physiologists to determine the demand for the different components of the systems; and then to allow the planning of combinations of species which make it possible to optimize the use of the environment.
3. Identification of suitable periods for agricultural operations and practices. This topic should also include studies on the identification of periods of fire danger as well as pest and disease risks to aid prevention.
4. Micrometeorological characterization of different agroforestry systems, including micrometeorological monitoring of the heat and momentum fluxes as well as light and rainfall distribution for such heterogeneous systems. These studies will provide useful indications of the choice of plant combinations suitable for different systems; the evaluation of the impact of these systems on the area in regard to the original vegetation or other systems; and the genetic manipulation of the species involved.
5. The use of modelling in agroforestry stands, including the adoption of modelling techniques for the determination of water budget and light distribution within these systems.

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Agroforestry systems for the cerrado region of central Brazil: potentials and constraints

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Abstract

The Cerrado region of central Brazil extends over 180 million ha and is characterized by a prolonged dry season which limits agricultural production. Less than 10 million ha were under field crops until recently whereas more than 100 million ha were under cultivated or native pasture. Irrigation is not yet widespread. Besides the long dry season extending from May to September, wet season dry spells, known locally as veranicos, also limit the yields of field crops.

The water storage in the surface layers of the soil is often insufficient to meet the evapotranspiration demand of shallow rooted field crops because of the low waterholding capacity of the latosols and the very deep water tables. Deep well drained latosols which account for about 50% of the Cerrado region also present very severe limitations of aluminium toxicity, phosphorus deficiency and low base saturation. Soil erosion is a severe problem in most areas because of soil compaction and reduced infiltration rates resulting from the use of heavy machinery and overgrazing.

Agroforestry is not yet a common practice in the region whereas extensive areas are utilized for eucalyptus and pine plantations. The potentials for agroforestry systems in the Cerrado region are discussed in the present paper. Well-planned agroforestry systems in central Brazil should minimize the risks of

(1) economic losses due to dry season crop failures,
(2) degradation of pastures due to overgrazing
(3) soil erosion and
(4) unemployment and/or underemployment of family labour, especially in case of unskilled rural families.

Introduction

The cerrado region of central Brazil extends over more than 180 million ha, accounting for nearly one-fifth of the total area of the nation. The region is heterogeneous in terms of potential for agriculture, pasture management, silviculture and agroforestry systems but is often considered to be a savanna-type ecosystem. It is interesting that the development of the Amazon region of Brazil and the possible consequences of destruction of the native vegetation of evergreen tropical humid forests there are being discussed at national and international levels with great alarm whereas the destruction of the equally fragile ecosystems of the cerrado region continues without ample discussions on viable alternatives of safe management of natural resources like soil and native vegetation (Alvim and Silva 1979; Goodland and Irwin 1975).

Intensive agriculture in many parts of the cerrados is a very recent phenomenon. Since the region of cerrados is not an administrative unit, it is very difficult to obtain statistics of economics, population growth, agricultural production and productivity for the region as a whole. Any generalization of policy recommendations is also difficult because of the enormous size, variations in climate, soils, vegetation and geomorphology, and uneven pattern of population growth. However, in the present paper I shall examine the possibility of agroforestry management in the region in very general terms.

Natural resouces of the region

Climate

The cerrado region may be divided into five principal subregions on the basis of climatic variations (Azevedo and Caser 1979):

1. The central (core) subregion with an annual precipitation of 1400-1700 mm and a dry period of 4-5 months,
2. The north-eastern subregion with an annual precipitation of 500- 800 mm and a dry period of 8-9 months,
3. The north-western subregion with an annual precipitation of 2000- 2300 mm and a dry period of 3-5 months,
4. The south-eastern subregion with an annual precipitation of 1400-1700 mm and a dry period of 4-5 months, and
5. The south-western subregion with an annual precipitation of 1100-1400 mm and a dry period of 2-3 months.

Subregions 4 and 5 occupy relatively very little area. Azevedo and Caser (1979) subdivide these subregions into forty smaller geographical units on the basis of geomorphological characteristics. Detailed data on rainfall, temperature, evapotranspiration and radiation can be found in Hargreaves (1976) and Golfari et al. (1978). Johnson (1982) and Reddy and Amorim (1984) discuss the paucity of climatic data for the region and suggest modifications for calculations of potential evapotranspiration and radiation for the region, taking into account altitude, latitude and longitude for the different stations. Further refinements of the models can be achieved only when more careful measurements are available for longer periods.

Probably the least variable component is the average monthly temperature which oscillates around 20 °C in the core region. Maximum temperature oscillates around 27 °C and minimum around 16 °C. Day length and radiation are not limiting factors for plant growth during any time of the vear. For example, mean monthly values of solar radiation is always above 15 MJ $m^{-z}d^{-1}$ in Brasilia with maximum values exceeding 18.5 MJ $m^{-Z}d^{-1}$,

The most limiting factors for agricultural production are the variations and uncertainties in the rainfall distribution. Wolf (1977) discusses the occurrence of dry spells during the rainy season in Brasilia. These wet season dry spells, known locally as 'veranicos', may last over three weeks once in seven years. There is a 50% chance that the longest dry spell in any year will be 14 days or longer and a 15% chance that the dry spell will exceed three weeks. Thus, even if the total rainfall during the season is satisfactory, crop failure due to water stress is a common occurrence in the cerrado region. In shallow rooted crops like soybeans, evapotranspiration may be reduced from a high value of 4 to 5 mm/day during the first week of veranico to 1 to 2 mm/day by the end of the third week, mainly because of low water potentials in the top layers of the soils (EMPBRAPA1981, p. 64-65). Monthly averages of rainfall do not bring out the variations in precipitation but averages for 10-day periods might be sufficient to indicate periods of water stress (Wolf 1977). Deep rooted cerrado trees and shrubs, however, show no apparent signs of water stress during these dry spells.

Soils

Soils of the cerrado region do not fall into any distinct category as different from soils of other climatic regions of the country. Latosols are the most extensive soils in the cerrado region. These are, as a rule, well-drained very deep soils with a clayey texture and very little horizon differentiation. The most interesting feature of these soils probably is the very fine microaggregate structure of the subsoil (B) horizons, which, *in situ*, present a massive appearance. The microaggregates are very water-stable and make these soils highly permeable. Infiltration rates measured under native vegetation generally exceed 15-20 cm/h. The surface (A) horizon often has a stable granular structure under native vegetation but, devoid of a vegetation cover, is susceptible to compaction and erosion by water. Once the surface layer is eroded, the massive B horizons succumb very easily to formation of very deep U-shaped gullies. Under native vegetation the bulk density of well-drained soils is often less than 1 g cm" because of very intensive termite activity. Deforestation using heavy machines; and cultivation, as well as grazing by cattle, generally lead to soil compaction and reduced infiltration rates. Also, water retention capacity is reduced because of the destruction of the original highly porous structure.

The water retention capacity of cerrado latosols is very low (Wolf 1977; Lopes 1983; EMBRAPA1982). This is attributed to the nature of the clays and the microaggregate structure which makes the soils behave as if the texture were more sandy. The very low water retention capacity makes the effect of wet season dry spells very severe. Once the soil becomes unsaturated, hydraulic conductivity of the soil decreases sharply (-EMBRAPA 1981, p. 71-72) and shallow- rooted crops will not have enough water flowing to the root zone from deeper layers with high water content.

Most of the discussions in the literature focus attention on fertility aspects (Lopes and Cox 1977; Goedert 1983) and response of crop plants to fertilizer application and liming. The most serious impediment to root growth in lower layers of the soil profile is probably deficiency of calcium (Ritchey et al. 1980,1982) since calcium is not translocated to growing root tips if it is not available in the rhizosphere of growing rootlets. However, native shrub and tree species have very deep roots which help them extract water even during the dry season when top layers of the soil profile hold very little water.

Agronomic experiments during the last decade (EMBRAPA 1979,1981,1982) have shown that most of the crop plants respond well to liming and fertilizer application in the cerrado soils. However, the economic aspects of liming and fertilizer application do not seem to have received the attention the problem merits.

Also lacking is definite proof in many cases that it is the applied nutrient that is responsible for better growth and higher yields. It is not just one element that is lacking in cerrado soils. Response to liming could be due to higher availability of magnesium (Bataglia et al. 1985); that attributed to phosphorus could also be due to higher availability of calcium from superphosphate. Until we have more information from these experiments on nutrient uptake by analyzing plant tissues we cannot determine responses involving different nutrient elements. Until then any economic analysis of the fertilizer recommendations will not be very meaningful. For example, at least in the case of two eucalyptus species, soil acidity and high exchangeable aluminium levels do not seem to pose any limitations, if other nutrients like phosphorus, calcium and magnesium are adequate (Haridasan 1985). Managanese and iron toxicities do not seem to pose serious problems in well-drained soils but may become crucial in water-logged soils. Micronutrient deficiencies may have to be corrected in intensive agriculture when high doses of fertilizers and lime are applied. Goedert (1983, p. 424-425) summarizes succinctly the need for basic research in soils and plant physiology to understand better the processes of nutrient uptake and crop growth in these nutrient-deficient soils.

The other classes of soils which occur in the cerrado region include podzolic soils, terra roxa soils, cambisols and waterlogged soils. Since there is no well-defined hierarchy in the Brazilian system of soil classification it is difficult to place these soils in other soil classification systems. Equivalent class names in other systems of classification such as that of Soil Taxonomy and FAO/UNESCO in the case of soils of the Federal District in the core region of the cerrados are indicated in Table 1. One of the main limitations is the lack of definition of criteria for a hierarchical classification. Many surveys utilize native vegetation or slope classes as criteria for subdivision of higher order categories without any definition of the variation in soil properties among different subclasses (Haridasan 1988). There is very little information available on the moisture and temperature regimes of these soils to place them correctly in Soil Taxonomy. In general, most of the well- drained latosols have an Ustic moisture regime.

Native vegetation

The cerrado region comprises of widely varying physiognomic forms of vegetation, which vary from tall closed canopy forests to grasslands devoid of any trees and shrubs. Eiten (1972) provides an excellent review of existing information on these physiognomic forms. The most common of these formations is an open tree and scrub woodland known locally as the cerrado, *sensu stricto.* The question of comparing the cerrado ecosystem(s) with other similar tropical ecosystems, especially the so-called grasslands and savannahs, always involves controversies and myriads of conflicting opinions as to the definition of different physiognomic forms of vegetation (Eiten 1978, 1986). Botanists have often worried about providing details of species composition and phytosociology but very little information is available regarding the adaptability of the cerrado species under different edaphic and climatic conditions. Interestingly, agronomists and soil scientists have seldom participated in this discussion, leaving it entirely to botanists to argue about the adaptive strategies of native plants. The only welcome exceptions were probably the surveys conducted by some British teams (Askew et al. 1970a, 1970b, 1971; Ratter et al. 1977,1978). Even in their work the only information provided is on variations in physiognomy and species composition of vegetation communities in relation to soil fertility and other edaphic factors such as the occurrence of water table.

The role of climate, edaphic factors such as soil depth, water regime and soil fertility, and fire in the origin and maintenance of the cerrado, *sensu stricto,* is discussed by Eiten (1972). The consensus at the moment is that cerrado, *sensu stricto*, is more a consequence of the dystrophic nature of the soils on which they occur than a consequence of the climate (the long dry period) and intermittent fires which are common in the region.

The cerrado, sensu stricto, occurs exclusively on deep, well- drained dystrophic soils. When the soil becomes shallow as in the case of cambisols on slopping terrain the trees

Table 1 Classification of the soils of the Federal District in the cerrado region of Brazil

Brazilian system	Soil Taxonomy	FAO/UNESCO
Latossolos	Oxisols	Ferralsols
Latossolo Vermelho Escuro	Ustox	Rhodic/Acric Ferralsols
Distrofico	Haplustox/Acrustox	
Eutrofico	Eutrustox	
Latossolo Vermelho Amarelo	Ustox	
Nao concrecionario	Haplustox	
Concrecionario	Acrustox	
Podzolico Vermelho Amarelo	Haplustalfs	
Eutrofico	Oxic Haplustalfs	Luvisols
Distrofico	Oxic Haplustults	Acrisols
Terra Roxa Estruturada Similar	Oxic Haplustults	Nitosols
Litossolos/Cambissolos	Entisols/Inceptisols	Cambisols
Eutrofico		Eutric cambisols
Distrofico		Dystric/Ferralic Cambisols
Areia Quartzosa	Typic Quatrtzipsamments	Ferralic Arenosols
Solos hidromorficos		
Sem plintita	Inceptisols (Aquepts)/Entisols (Tropaquents/Fluvaquents)	Dystric/ humic gleysols
Com plintita	Plinthaquox/Plintaquolt	Plinthic gleysols

and shrubs become sparse to give rise to a more open vegetation form known locally as 'campo sujo'. When the soil is waterlogged permanently or at least during three to four months of the year the vegetation form is a pure grassland, called 'campo limpo'. Tall closed canopy forests occur in different situations such as along streams in valley bottoms (gallery forests), on well-drained mesotrophic soils (semi-deciduous forests), on calcareous soils (deciduous forests), and on dystrophic soils (cerradao). There is no consensus of opinion as to the contribution of edaphic factors in the formation of 'cerradoes' on dystrophic soils alongside more open form of cerrado when both occur on equally poor soils. Ratter et al. (1977,1978) discuss the species composition of forests on dystrophic and mesotrophic soils. Some species occur only on dystrophic soils; others only on mesotrophic soils. And there are species that are indifferent to soil fertility. Physiological basis of this preference of soils in native species has not been investigated in any detail yet (Haridasan and Araujo 1987). Goodland (1971b) suggested that cerrado-native species were adapted to high levels of available aluminium in the soil and exhibited sclerophyllous nature not only because of low fertility of the soils but also due to aluminium toxicity. Haridasan (1982) reported that several species of the cerrado vegetation accumulate aluminium in large quantities in their leaves but high levels of aluminium in the leaves of these plants are not associated with low levels of other cations. Besides high levels of aluminium in the soil, what limits plant growth in these soils are the extremely low levels of phosphorus and exchangeable cations, calcium, magnesium and potassium.

Present land use

The more optimistic estimates put the extent of land suitable for intensive mechanized agriculture in the cerrado region to be more than one-third of the total geographic area (Goedert 1983)- However, intensive agriculture in many parts of the region is a fairly recent phenomenon. The area under field crops is less than 10 million ha (Table 2). More than twice this area is under cultivated pastures. The area under native pastures is estimated to be nearly 120 million ha which accounts for almost 60% of the total land area of the region. Most of the area cultivated are under monocropping. Crop rotation is common. However, agroforestry or agrisilviculture is not a common practice. Until intensive agriculture with field crops like soybeans, maize, wheat and sorghum was introduced, a common practice was to grow upland rice for two or three years after deforestation and burning and then use the land for pasture.

Table 2 Land use in the cerrado region of Brazil

Use	Area (thousand ha)
Native pastures	119686
Cultivated pastures	20000
Perennial crops and forest plantations	682
Cultivated	8978
Native vegetation	23717
Total	173063

There are only very few systematic, long-term studies reported in the literature on the decline in productivity of the cerrado soils. Research on many aspects of soil management began only about 25 years ago at the Instituto Agronomico de Campinas and later at the Centro de Pesquisa Agropecuaria dos Cerrados in Brasilia (Goedert 1983). It is estimated that less than 10% of the total cultivable area in the cerrado region has mesotrophic soils where soil fertility is not a limiting factor. Most of this land is already under cultivation. Therefore any expansion of area under cultivation would essentially be in dystrophic latosols.

Leite and Furley (1985) who studied one of the settlement colonies of small scale farmers concluded that low productivity of traditional crops was one of the detrimental aspects that caused the project to fall short of its crop and livestock production targets. Evaluating the success of the Sagarana Colonization project which started settling farmers in 1973, these authors reported that the productivity of the traditional crops such as rice, beans and maize was below the targets established at the beginning of the project and none of the fruit crops like citrus, mango, guava and avocado was ever cultivated. The original assumption was that the farmers would utilize an integrated management system involving liming and fertilizer application and soil conservation measures such as contour planning and terracing. The original target for establishing pastures was also not fulfilled because of the low productivity of the pastures.

One of the most serious land management problems in the cerrados is the degradation of pastures due to overgrazing and low primary productivity of the ground layer due to poor soil fertility. The prolonged dry season adds to the constraints, limiting stocking rates to 0.2 animals ha^{-1}. Once the land has been under native pasture for 15 to 20 years many areas are simply abandoned because it is not economically viable under the present set up to continue to raise beef cattle. Land recuperation in these areas is a very severe challenge because of the impoverishment of the surface layers of the soil not only from overgrazing but also because of soil erosion damage. Invasion of these areas by native species to form a secondary forest vegetation is often a very slow process unlike in small holdings which are abandoned by settlers after deforestation and cultivation for two or three years in the Amazon region (See for example, Leite and Furley 1985).

An important aspect of the land use pattern in Brazil is the size of individual land holdings. Nearly 45% of the total land area in the country is accounted for by individual holdings of more than 1000 ha (Table 3). Another 35% of the area is accounted for by holdings of 100-1000 ha. Only less than 2.5% of the area is owned by individuals who possess fewer than 10 ha though they account for more than 50% of the total number of individual properties.

Table 3 Size of individual land holdings in Brazil in 1980 (IBGE,1980. Censo Agropecuario do Brasil).

Size of holding (ha)	Individual holdings (thousands)	%	Total area Million ha	%
less than 10	2598.0	50.40	9	2.5
10 - 100	2017.0	39.20	64	17.5
100 - 1000	489.0	9.50	127	34.8
1000 - 10000	45.0	0.90	105	28.8
above 10000	2.3	0.04	60	16.4
Total	5151.3	100.04	365	100.0

The population in the cerrado region was estimated to be 15 million in 1970 and nearly 21 million in 1980, with a 3.3% annual growth rate during the last decade (Goedert 1986). More than 60% of this population lived in urban areas in 1980. In the early 1970s less than 50% of the population lived in urban areas. With migration to urban areas increasing while more area is being brought under cultivation, availability of skilled labour for agriculture in rural areas will be scarce in the future. This might increase the need for mechanization and lead to faster deterioration of soil in cultivated land.

The reality is that the big farmers, at least for the present, are not concerned about long term damage that can result from the use of heavy machinery and excessive quantities of fungicides, pesticides and herbicides. Soil conservation and preservation of natural ecosystems, especially of native plant species that might be of economic use in the future, seem to be only concepts idealized in many federal laws and regulations. Adverse effects of indiscriminate deforestation in the catchment areas of big rivers is always evident in frequent flooding of low-lying areas during the monsoon season on the one hand and the shortage of water in the reservoirs of major hydroelectric projects in the country during the dry season on the other hand.

Potential for agroforestry systems

The most interesting aspect of agroforestry systems is that it was once the essence of subsistence agriculture with very low inputs, especially in the tropics. Intensive monoculture involving mechanization and heavy input of fertilizers and other agrochemicals following the model of temperate zone agriculture is a fairly recent phenomenon, especially in the more extensive oxisols and ultisols. In the case of Brazilian cerrados, it is only in the last several decades that intensive monoculture has been replacing extensive pastures. Some of the peculiarities to be considered with regard to any discussion of possible agroforestry in the region are the following:

1. The very large extent — more than 180 million ha — and the low population density of the region: there is no great pressure on land in the cerrado region as in the more developed southern states of the country or the overpopulated regions of other tropical countries of Asia or Africa.
2. While tropical countries in Asia and Africa have already come to the stage of realizing the adverse effects of overexploiting soil and water resources in intensive monocultures, Brazil is just venturing into intensive monoculture on a large scale in the cerrado region.
3. The emphasis on agriculture in Brazil has not been on self-reliance of the country in food production or on small scale operations by individual families or cooperatives. Export-oriented crops such as coffee, cacao and soybeans have received precedence over other essential crops like wheat because of the necessity of earning foreign exchange.
4. Agriculture in the region is heavily dependent on credit from banks at all stages, including the purchase of products after harvest by the state. This is true of big farmers who own several thousand hectares as well as landless labour receiving new land from the government for the first time in settlement colonies.

What this means is that there is very little change possible in the existing pattern of land use without the government advocating it. At present there is no practice of any agroforestry system worth mentioning in the cerrado region unlike in other regions of the country such as the ones described by Alvim and Nair (1986) in southern Bahia; by Johnson and Nair (1986) in the northeast; and by Baggio (1986) in the south.

I shall therefore discuss the potentials of agroforestry systems in the cerrados with emphasis on overcoming important natural limitations of intensive agriculture in the region.

Reducing economic losses due to dry spells

As mentioned earlier one of the more serious limitations in agriculture and pasture management in the cerrado region is the occurrence of wet-season dry spells which may last from a few days to more than three weeks. These dry spells cause severe damage to field crops and grasses which have shallow root systems because they occur when evapotranspiration demands are high (Fageria 1980; Espinosa 1979; Garrido et al. 1979). Though there is often sufficient water lower in the profile, surface soil layers have very little water because of low water retention capacity. Tree species are generally capable of utilizing the subsoil moisture unlike the shallow-rooted crops and grasses.

It is only within the last few years that the Federal Government announced plans to implement large-scale irrigation schemes in the cerrado region to increase agricultural production. However, it is unlikely to be a universal practice in the immediate future because of limited water availability. It is estimated at present that the potential for irrigation in the cerrados is only about one million ha. Wet-season dry spells could be very damaging if they coincide with critical growth stages such as flowering. The most serious problem in this regard is the adoption of monocropping systems by the farmers mainly because no alternative systems are known to them. Suitable agroforestry systems should offer some security against total loss of income, especially in the case of small farmers. Selection of suitable perennial crops tolerant to water stress and adapted to low soil fertility and high soil acidity could be one of the useful strategies in this regard. Traditional fruit trees like mango, citrus and guava as well as other native species which could be exploited on a commercial scale should be one of the options. Settlers in new colonization projects with relatively little experience in farming should find this option more secure than risking everything in shallow-rooted field crops.

Besides guaranteeing an alternative source of income, one of the possibilities that should be exploited in agroforestry systems for the cerrado region is minimizing evapotranspiration demand by providing shade or reducing wind velocity.

Since the low water-holding capacity of the cerrado soils is one of the limiting factors contributing to crop failures during wet season dry spells, improving the water retention characteristics of these soils should be one of the aims of better management systems. Long-term crop rotations with fast growing trees species which could increase the organic matter content of these soil should eventually help increase the water holding capacity of these soils and thus minimize the risk of wet-season dry spells.

In spite of the serious lack of fodder in native pastures of the region during the long dry season, very little has been done to utilize alternative sources of forage to supplement the limited grass supply. Silvopastoral combinations involving forage shrubs and trees should be a viable practice in this respect.

Avoiding deterioration of pastures

The main factors contributing to the complete deterioration of pastures within ten to fifteen years are poor soil fertility and overstocking. Any viable alternative to 100% utilization of such lands for animal husbandry on a long-term basis should involve fallowing the land periodically. Fertilizer application and liming are expensive options to increase the productivity of native pastures because the potential response of native grasses to fertilizer application is as yet unknown. In such cases economically viable management systems might incorporate forestry or fruiticulture alternating with animal husbandry. With ten- to fifteen-year cycles, degraded pasture lands might recover organic matter content and nutrient status if fast-growing tree species which would furnish plenty of leaf litter could be utilized. Grass-legumes mixtures are advocated in the cerrado region on the following grounds:

- better productivity per animal per ha per year;
- better reproductive capacity of the animals;

- reducing the adverse effects of dry season; and
- improving soil fertility, especially soil nitrogen status.

One of the serious handicaps in adopting this system is the high cost of establishing cultivated pastures in the cerrado region. Large areas of the region are expected to remain as native pastures for many years (Couto et al. 1983). One of the viable alternatives should be the adoption of agroforestry systems involving legume trees with the same objectives but with the additional advantage of better soil conservation.

Use of leguminous nitrogen-fixing species and those with associated micorrhyzae capable of solubilizing phosphorus should have the greatest potential in this regard (Faria et al. 1984; Lopes et al. 1983; Nair et al. 1984). Faria et al. (1984) made an extensive search for active nitrogen-fixing root nodules amongst Brazilian forest legumes and reported seven new nodulated species, including two new nodulating genera from *Caesalpinioideae;* 18 new species from *Mimoisoideae;* and 30 new species, including four new genera, from *Papilionoideae.* All these species have the potential for use in agroforestry systems in the cerrado though some of them are not native to the region.

One important aspect that should be investigated in this connection is the adaptability of native species with economic potential in dystrophic acid soils. It should be borne in mind that the predominant native vegetation of the cerrado is a consequence of poor soil fertility and not of climate alone. Other than the reports of Ratter and coworkers (1971, 1977, 1978), there is very little information in the literature on the distribution of cerrado species in different soils. Recent reports (Araujo and Haridasan 1988; Haridasan and Araujo 1987; Machado 1985) have shown that resistance or tolerance to high aluminium levels in the soil may involve more than one mechanism. While some aluminium-accumulating species occur only a dystrophic acid soils, others occur only in mesotrophic soils with near-neutral pH. A few occur on dystrophic as well as mesotrophic soils but grow better on mesotrophic soils.

Besides furnishing foliage for animal feed and improving soil fertility, another important use of trees in pastures is to provide shade and shelter for animals, especially on hot dry days. In many cases, farmers leave isolated trees in the middle of pastures, which is not an ideal solution. This practice often creates the problem of aggregation of animals. Also, individual isolated trees succumb more easily to strong winds. Another practice is to provide isolated patches of trees, especially around artificial lakes which provide drinking water. A better solution for providing shade and shelter for animals, at the same time providing forage and helping in soil conservation, would be to develop silvopastoral systems with overstorey tree species and understorey fodder species. Many species of the native tree vegetation such as *Taipirira guyanensis, Copaifera langsdorfii, Callisthene major, Siphoneugenia sp., Hymenaea stigonocarpa* (-jatoba), *Dipteryx alata* (baru), and *Plathymenia reticulata* have the potential to be used as shade trees (Machado, personal communication). Exhaustive lists of indigenous tree species that can be used in agroforestry systems are easy to compile but experimental evidence is yet lacking to make any definitive recommendations for farmers. For example, several species which occur in the gallery forests in the Federal District have the potential for commercial-scale exploitation.

Soil conservation

Soil erosion is a severe problem in the cerrado region. Many publications erroneously state that soils of the cerrado region are not easily erodible. Sheet, rill and gully erosion pose severe problems in the cerrado soils because rainfall intensity is generally very high. The problem is worsened by the use of heavy machinery in latosols which after compaction loses its originally-high porosity and infiltration capacity. The fact that the soil is left without adequate vegetative cover at the end of the long dry season makes the soil extremely vulnerable to early torrential rains.

The problem becomes more severe when Class IV to VIII lands are left without any vegetation cover after fire or deforestation to utilise available wood for charcoal production. Though existing laws prohibit destruction of gallery forest along rivers and streams in valley bottoms, indiscriminate deforestation of such vegetation is very common leading to not only erosion and increased runoff during the wet season but also to the drying of the streams in the dry season making little water available to cattle. Suitable agroforestry systems should therefore aim at not only conserving soil where it has not yet been degraded but should shift the emphasis in many cases to recuperation of degraded soils. Most discussions on agroforestry systems usually depend on references to publications from elsewhere to justify the possibility of utilizing exotic species for such purposes. What should be done in the cerrado region is to exploit the possibility of utilizing the native species which are adapted to the climate and low soil fertility. It is well established that the cerrado tree and shrub species have extremely deep root systems capable of utilizing subsoil moisture during the dry season and have several adaptive strategies to resist fires which are frequent in the region.

The main forest plantations in the region are eucalyptus and pine. Because of the present economic conditions in the country, indiscriminate destruction of the native vegetation and planting of eucalyptus and pine were encouraged. The long term effects of repeated cultivation of eucalyptus and pine are still unknown but depletion of soil fertility and accelerated erosion, especially on Class VI to VII lands are certain consequences. One way to avoid total deterioration of such lands would be to develop suitable covercrops in such plantations and follow fallowing or crop rotations with tree crops which help recuperate soil fertility, for example by nitrogen fixation. Another viable alternative would be to think of agrosilvopastoral systems with multiple objectives if we should conserve natural resources of the region. Such arguments apply not only for the conservation of soil resources but also for the conservation of genetic resources of native vegetation as well as native fauna. The extinction of many animal and bird species in the region are often attributed to large-scale eucalyptus and pine plantations.

Better utilization of rural family labour

One of the most serious social problems in Brazil is the very low income of rural families who do not own any land but work on the farms. Even those who own some land and those who receive land from the government as a consequence of agrarian reforms often abandon the land after one or two crop failures. This happens often because of low inputs such as good quality seeds, fertilizers and pest and disease control. Often the farmers have no income in such cases because they depend on monocultures. After deforestation, they cultivate rice or other field crops for one or two years and then abandon the area to fallow or pasture.

One of the serious consequences of such irregular productivity of cerrado soils is the abandoning of rural lands by small-scale farmers who migrate to urban centres. Furley and Leite (1982), for example, state that 50 families out of 208 who had received between 65 and 240 ha of land under the Sagarana colonization project abandoned their property within the first couple of years. They could not cope with officially-established targets for land clearing, planting of crops and repayment of loans. Diversification of crops and adoption of suitable agroforestry systems should provide a better chance of success in such cases. The development of agrosilvopastoral systems in such cases should be based on the utilization of available family labour throughout the year providing full-time employment but at the same time avoiding overburdening. Small-scale animal husbandry is one of the possibilities to be considered in this regard in agroforestry systems in the cerrados, besides options such as apiculture and inland fisheries where the facilities exist.

Constraints and research needs

It is interesting that during the review of literature for writing this article, I encountered more articles on the possibility of agroforestry in the Amazon region than in the cerrados (for example, Hecht 1982; Eden 1982). The main limitation for the adoption and development of agroforestry systems in the cerrado region seems to be the lack of planning and forethought on the part of government agencies. The need for soil conservation on a long-term basis and welfare of rural families seem to be ideals advocated only on paper. The emphasis on monocropping and intensive agriculture in the region is in many ways artificial, sustained only by the eagerness of the government to support export-oriented crops with no concern about soil and water conservation or environmental protection.

There is no careful planning in the management of forests or pastures in the cerrado region. There is no replanting in degraded lands and there is no attempt to replenish the stock of felled forests. Eucalyptus and pine plantations are intended only to furnish wood for industrial purposes and are monopolies of large firms.

Some of the existing models can serve successfully for small farmers who may get to own land as a result of the proposed agrarian reforms (Furley and Leite 1982). Agroforestry should provide viable alternatives to existing models in such cases.

Yet another argument in favour of agroforestry systems in such cases is that the possibility of intensive agriculture does not exist because:

1. energy costs are very high: small farmers do not have the capital to invest in heavy machinery and other infra-structure essential for intensive agriculture;
2. there are no financial incentives or insurance against risks for small farmers to try new farming systems; and
3. government policy favours export-oriented crops because of the heavy debt crisis in spite of the food shortage within the country.

There has been no serious attempt to evaluate the potentials of agroforestry systems in the cerrado region. One of the serious handicaps seems to be that none of the more prestigious agricultural colleges in the country is located in the cerrado core region. Post-graduate courses in agronomy, soil science, animal husbandry and forestry should be encouraged in different universities in the region if new farming systems are to be experimented with. Research centres of the federal agricultural organization (EMBRAPA) are geared to attend research needs of individual crops; and, in some cases like the CPAC, to specific needs of the region. However, there is very little attempt to try novel ideas.

As mentioned earlier, there are several native species which have the potential for utilization in agroforestry systems. There are many fruit trees that have the potential for commercial exploitation. Herringer and Ferreira (1972, 1973a, 1973b) list several of these species. However, very little information is available on the agronomic aspects of these plants. Incorporation of these in agroforestry systems would warrant agronomic research on the following aspects:

1. Survey of genetic resources, which should include studies of natural distribution of these species in different climatic regions and adaptability to different edaphic conditions like soil fertility and water regimes.
2. Collection and preservation of germplasm since native vegetation is fast disappearing in the region with the extension of agriculture and pastures.
3. Agro-silvicultural trials to increase the productivity of the species for commercial exploitation.
4. Exploration of the possibilities of multiple uses such as controlling erosion, use as shelter belts, use for firewood or charcoal, use as animal feed, and nitrogen fixation.

There are no worthwhile attempts made to utilize native species in reforestation or agroforestry systems at present though there are isolated suggestions regarding the utility of several native species. For example, Escuder (1980) reports that leaves of many tree and shrub species such as *Kielmeyera coriaceae, K. obtida, Ouratea hexasperma, Syagms spp., Palicouria riff da, Borreira spp.* and *Didymopanax macrocarpum* are common in the diet of sheep. Castro and Junior (1984) found that *Dispyros hispida, Ouratea hexasperma* and *Byrsonima coccolobifolia* foliage was consumed in great quantities and *Dalbergia violacea, Blepharocalyx suaveolens, Erythroxylum tortuosum, Davilla elliptica* and *Styrax ferrugjineus* leaves in smaller quantities, especially during the dry season. Utilization of these species to supplement the ration of sheep and of other tree and shrub species to supplement the ration of cattle and goats are possibilities that should merit attention in the cerrado region.

Conclusions

Whatever the prospects for agroforestry systems in the cerrado region, no progress will be possible until the philosophy of conservation of nature — soil, native vegetation, regional fauna and environmental quality — is accepted by the community. This dilemma is well expressed in a recent publication of the Ministry of Agriculture (Downes 1983) regarding the necessity for institutionalization of soil and water conservation in the country. Once this philosophy is accepted by the government and the farmers, adoption of agroforestry systems is only the next logical step because some kind of multiple use and periodic fallowing of agricultural land seem to be a must in tropical oxisols. The present outlook that Brazil still possesses land that can be yet brought under intensive mechanized agriculture just doesn't seem right if land deterioration is not to be our goal.

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Interaction of climatic components on agroforestry systems by management practices in Pakistan

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Introduction

Pakistan having a total land area of about 88 million hectares is blessed with a variety of climates. Being predominantly an agricultural nation it is located between latitudes 24°N and 37°N and longitudes 61°E and 76°E. The area under agricultural use is about 25 percent while about sixty million hectares constituting about 68 percent of the total land area have been classified as rangelands. The forests cover about 4.37 million hectares which is about five percent of the land area.

Fuelwood production from farmlands

In Pakistan about 70 percent of households use wood as fuel which is usually supplemented by cowdung and agricultural residues (Sheikh 1985). The present consumption of fuelwood in the country is difficult to determine precisely but it has been estimated to be about 19 million m^3 annually. This requirement is met partly from the government forests which produce only 10 percent. The remaining 90 percent is produced from the farmlands. With per capita consumption of 0.4 m^3 annually, the country would need about 42 million m of fuelwood by the year 2000 when the population would have increased to 152 million. Thus an additional 23 million m of firewood requirements are met from the farmlands managed by the farmers. Therefore, these private lands offer considerable potential for planting trees in conjunction with agricultural crops.

Climatic regions

Climatically the country can be divided into the following major forest ecozones.

Mountainous regions

Mountains occupy the northern and western parts of the country. The northern mountains are the termination of Himalayan range with a number of small and large peaks which remain covered with snow. On account of this the climate is undifferentiated. In summer the mean daily maximum temperature is about 35 C and in winter the mean daily winter temperature is 0-4 °C with cold spells. The mean monthly rainfall in summer is about 236 mm and in winter 116 mm. Only about 25 percent of the area is under rain-fed agriculture with main crops as maize and wheat. Rice is grown in small areas which are irrigated through springs (PARC 1980). The forests in mountainous regions are characterized by the following types.

Subtropical pine forests

These forests occur from a little below 900 m elevation up to 1650 m on the mountain slopes. The principal species is *Pinus roxburghii* mixed with *Quercus incana, Xylosma longifolium* and *Pyrus pashia.* The chir pine (*Pinus roxburghii*) however, occurs almost in purely dense form with undergrowth of *Myrsine africana, Carissa opaca* and *Dodonaea viscosa.* Fires are generally of frequent occurrence in these forests resulting in elimination of shrubs. These forests are subjected to heavy population pressure.

Temperate forests

The temperate forests range in altitude from 1650 m up to about 3000 m. These limits depend largely on the aspects of slopes. The principal commercial species are *Cedrus deodara, Pinus wallichiana, Abies pindrow* and *Picea smithiana. Taxus baccata* also occurs in the form of scattered trees or small patches. The trees are generally very large in size due to selection system of management and long rotations. The broadleaved species in these forests include *Aesculus indica, Quercus dilatata, Juglans regia, Acer caesium, A. pictum, Ulmus wallichiana, Viburnum nervosum, Lonicera quinquelocularis, Populus ciliata, Indigofera gerardiana.* The stocking rate in these forests varies with the extent of degradation largely due to expanding agriculture and summer grazing of alpine pastures. Most of these forests grow on very steep slopes. It is not uncommon to see slopes up to 80 percent which have been terraced for crop culture.

Dry temperate forests

The mountains located towards the west of the Indus are not very high and are associated with plateaus, semi-arid valleys and plain lands. The monsoon rains do not reach here and the low precipitation is confined to some winter rains and mostly snow. During winter the mean daily minimum temperature varies from 1 C to -7 C with occasional prolonged cold spells. The mean monthly summer rainfall ranges from 5-95 mm and in winter it is 30-35 mm. The summer is mild with mean daily maximum temperature being about 32 C. The winter is cold with mean daily temperature around -0.2 C with frequent cold spells. Parts of the loamy soils are used for growing maize, wheat and alfalfa. Fruit orchards of apples, peaches, plums, apricots and grapes are common. The coniferous species in these forests include *Pinus gerardiana andJuniperus excelsa.* Broadleaved species include *Fraxinus xanthoxyloides, Pistacia mutica, Caragana ambigua.* The canopy in these forests is open and trees generally remain stunted.

Alpine forests

The alpine forests occur between 3,000 m and 4,200 m. The forests consist of *Betula utilis* either with or without *Abies spectabilis, Pinus wallichiana, Salix spp., Juniperus squamata, J. communis, Rhododendron hypenanthum* and other herbaceous vegetation. The crop is very open and stunted. These forests are of little economic importance due to their poor stocking and inaccessibility.

Tropical thorn forests

The tropical thorn forests are also known as the desert scrub. The climate is arid and hot, subtropical continental. The mean monthly maximum temperature ranges from 45°5DC to 48 °C in summer and from 5 °C to 8 °C in winter. The mean monthly rainfall in winter is about 33 mm while in summer it is about 21-38 mm. The main crops in this region are wheat, sorghum, millet and gram (PARC 1980). A number of thorny species like *Prosopis cineraria, Capparis aphylla and Acacia modesta* are representative of this type. *Tamarix articulata, Salvadora oleoides* and *Prosopis juliflora* also grow commonly in these degraded lands. These forests provide firewood to the local communities and forage to the livestock. They consist of small patches of short-boled, low-branching tree species and a variety of shrubs scattered over a total area of 1.1 million hectares in the plains which offer great potential for development of rangelands.

Dry subtropical evergreen forests

The dry subtropical region has two distinct parts. A small narrow belt lying along the foot of the mountains is nearly humid with hot summer and cold winters and has a short dry season in early summer. The south-western portion is semi-arid and hot. The mean monthly maximum temperature is around 40 °C while the mean monthly lowest minimum temperature ranges from 0 to 15 °C. The mean monthly rainfall is about 200 mm in summer while it is about 50 mm in winter. Rain-fed cultivation is the main land use. The important crops include millets, maize, wheat, oilseeds, pulses and fodders.

The formations are constituted by evergreen species of small sized trees and shrubs and grow up to about 1,000 m altitude on the hill slopes. Typical tree species include *Olea cuspidata, Acacia modesta, Mallotus phillipensis, Flacourtia indica, Sageretia theezans, Gymnosporea royleana and Adhatoda vasica.* A large part of these forests has been degraded by heavy grazing, browsing, lopping and over-exploitation for firewood. These play an important role as vegetative cover of the main water catchments.

Indus plain

The Indus plain is the western part of the Indogangetic plain which forms one of the most prominent and extensive physiographic division of the subcontinent. The plain is believed to be more than one thousand m deep and is formed by large quantities of alluvial material deposited since time immemorial by the Indus and several of its tributaries. The Indus plain is composed of silt, sand, clay and rarely gravels. Much of the land in this basin was desertic and has been developed by irrigation. The land is fertile and heavily populated.

The eastern half of this region is semi-arid while the south western part is arid subtropical continental. The mean daily maximum temperature during summer is 40-42 °C and in winter the mean daily minimum temperature is 6 °C. The mean annual rainfall is 200-300 mm. Canal-irrigated cropping is the main land use and the major crops grown are rice, wheat, sugarcane, cotton, maize, berseem, millets, oilseeds and lemons. Fruit orchards of citrus and mango are also important especially in the central part (PARC 1980). Irrigated plantations comprising largely of *Dalbergia sissoo* and *Morus alba* over an area of 0.23 million hectares have been developed.

Riverine forests

Riverine forests also occur in the Indus plain within the protection embankments of the Indus river over an area of 0.3 million hectares. These are subject to seasonal flooding with erosion and deposition. Typical plant species include *Acacia nilotica, Prosopis cineraria, Populus euphratica, Tamarix dioica* and *Salvadora persica.*

The climate is arid sub-tropical continental with hot summers and mild winters. The mean daily maximum summer temperature varies between 40-45 °C and the mean daily minimum temperature in winter is about 8.5 °C. The mean monthly summer rainfall is about 16-20 mm in the northern parts while in the southern areas it is about 45-55 mm. Canal-irrigated agriculture is the predominant land use of the region. Cotton, wheat, mustard, sugarcane, berseem, rice, gram and sorghum are the main crops (PARC 1980).

Coastal zone

The climate in the coastal zone is arid tropical marine with moderately hot summer and very mild winter. Mean daily maximum temperature ranges from 34-40°C and 19-20°C, in summer and winter respectively. The mean monthly summer rainfall is approximately 75 mm while in winter less than 5 mm rainfall is received. Due to the sea breeze the relative humidity is generally high. It is not possible to cultivate any crops due to high tides from the sea.

The mangrove forests are located in the shallow waters along the coast near the mouth of the River Indus. These forests mainly comprising *of Avicennia officinalis* cover an area of 0.35 million hectares. Where accessible these forests are heavily cut for fuel-wood and are mostly shrubby. The leaves serve as a valuable fodder. These forests have little commercial value except for small quantities of firewood and grazing.

Agroforestry systems

In Pakistan, farmers grow woody perennials in conjunction with field crops, vegetables and horticultural crops to meet their domestic needs. The aims and rationale of most agroforestry systems at the farm level are to optimize the positive interactions in order to obtain a higher sustained and more diversified productivity from the available resources. Following are some of the examples of prominent agroforestry systems and practices in Pakistan.

Agrisilvicultural systems

Tree gardens

Common in all ecological regions of the country depending upon the choice of the farmer which is generally very varied but largely for firewood, fodder and to meet the domestic timber needs.

Multipurpose trees and shrubs on farmlands

Found in several forms both in low and high altitude areas, e. g., hill farming in temperate regions. This is common both on private and public lands either through the resources of farmers themselves, or financed through sponsoring agencies.

Crop combination with plantation crops

Integrated production systems in small land holdings, shade trees in plantations and other crop mixtures including various tree species in the form of household or community forestry.

Agroforestry fuelwood production

Common in various forms including some forms of social forestry.

Shelterbelts and windbreaks

In the arid regions of southern parts of the country where strong winds damage the agricultural crops, use of eucalypts and casuarina as shelterbelts and windbreaks of different kinds are very common.

Silvopastoral systems

Protein bank (cut-and-carry fodder production)

Multipurpose fodder trees on or around farmlands are frequently planted especially in high hills to meet the feed requirements of livestock during the fodder deficit period in winter.

Living fence of fodder trees and hedges

Planting of fodder trees as live fences and hedges like *Sesbania, Euphorbia, Acacia,* etc., to protect the property from stray animals or other biotic influences.

Trees and shrubs on pastures

There are several tree and shrub species being used very widely on pastures and rangelands in all ecological regions to supplement forage production.

Agrosilvopastoral systems

Woody hedges for browse, mulch, green manure, soil conservation, etc.

Very common in different forms especially in arid and semi-arid regions to provide browse or serve as mulch or litter to conserve the available moisture.

Homegardens

Common in all ecological regions especially the temperate regions where fruit orchards are very profitable enterprise.

Other systems

Aquaforestry

Silviculture in mangrove areas and trees on banks of fish-breeding ponds.

Apiculture with trees

Raising of honeybees on different tree species for production of honey is very common in all ecological zones.

Current research status

Very little scientific work has been carried out in Pakistan on agroforestry. Studies on windbreaks of *Eucalyptus camaldulensis* carried out during 1980-83 in the arid regions of Pakistan have indicated that after 3-4 years, quicker wood yields are available from the farmlands through thinnings. The net increase in yield of wheat, cotton and maize is negligible at this early stage of tree growth (Khalique and Sheikh 1985).

In another study, Rahman (1978) measured the yield of wheat grown in unprotected fields and that grown in fields protected by either a single row of *Tamarix gallica* or two rows of *T. gallica* and one row of *Calligonum polygonoides.* He found that the wheat grain yields were increased by 7.5,15 and 13.5 percent, respectively, over the unprotected fields.

The wood-deficient areas, particularly the arid and semi-arid regions, offer considerable potential for planting of trees through cultural and management practices and modifying the micro- and macroclimate of the region. It is possible to reseed the arid and semi-arid regions with grasses like *Cenchrus ciliaris* and *Lasiurus sindicus* besides growing multipurpose fodder trees and shrubs including *Acacia albida, A. aneura, A. modesta, A. tortilis, A. victoriae, Ceratonia siliqua, Parkinsonia aculeata* and *Tecomella undulata.* Maximum survival of these species is obtained in sloping catchments without trench. Contour trenches give rather low survival due to flooding from flash rains causing long submersion of plants under high desert temperatures (Sheikh 1985).

Recommendations

As in other parts of the world, in Pakistan the beneficial effects of shelterbelts and windbreaks are quite convincing. The biological effects of windbreaks are numerous for agricultural purposes and in regions affected by strong and frequent winds especially in arid regions. Conventional design and composition of tree plantings either isolated or in the form of windbreaks have led to variable results in different climatic regions and cropping patterns.

Agrosilvopastoral systems need to be encouraged. Multipurpose tree species which not only provide wind protection, but other commodities such as timber, fuelwood, fodder, fertilizer, etc., should be planted. This would also provide plantings where interactions between shelterbelt trees and crops could be studied.

Besides technical problems, socio-economic factors such as land use and tenure, community involvement and organization, long term understanding of cost-benefit appraisal, public motivation and education are important particularly in the arid and semi-arid regions.

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Climatic resources for agroforestry in Vietnam

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Abstract

In Vietnam forests cover about 75% area of the country. They play a very important role in the formation of climate, water resources, soil, environmental conditions, and forest ecological systems and they are greatly influenced by hydrometeorological conditions too. In forest zones of Vietnam with different ecological conditions there is a meteorological and agrometeorological station network founded long ago. The application of meteorological and agrometeorological information to planning and management of agroforestry systems has gained in importance as it has intensified day by day. The humid and tropical climatic resources in the forestry of Vietnam, especially in mountainous areas of Toy nguyen (the Highland of the Central part of Vietnam), the East of South Vietnam, North East and North West of North Vietnam are multiform and rich. That is why forest flora has high potential productivity.

Unfavourable conditions such as dry and hot wind, drought, heavy rain, flood, fire, landslide, erosion and unrational exploitation have caused remarkable changes in hydrometeorological regimes. Here, there are also proposals in the directions of the study and methods of the applications of agrometeorological information (methods forecast of forest fire and methods of forecast of biomass growth of forest trees in every year) in the planning and management of agroforestry systems, especially in new planting and regeneration of forests.

Introduction

In Vietnam, forests and mountains cover about 75% of the country. Climatic resources of Vietnam are multiform and play a decisive role in the formation of forest systems and their yield. The estimation of climatic resources is of great significance in planning, management and exploitation of agroforestry systems.

In the various forest zones, the Hydrometeorological Service of Vietnam has founded a meteorological and agrometeorological station network long ago. Since 1960, hydrometeorological and agrometeorological data have been actively used in the planning and management of the forest zones.

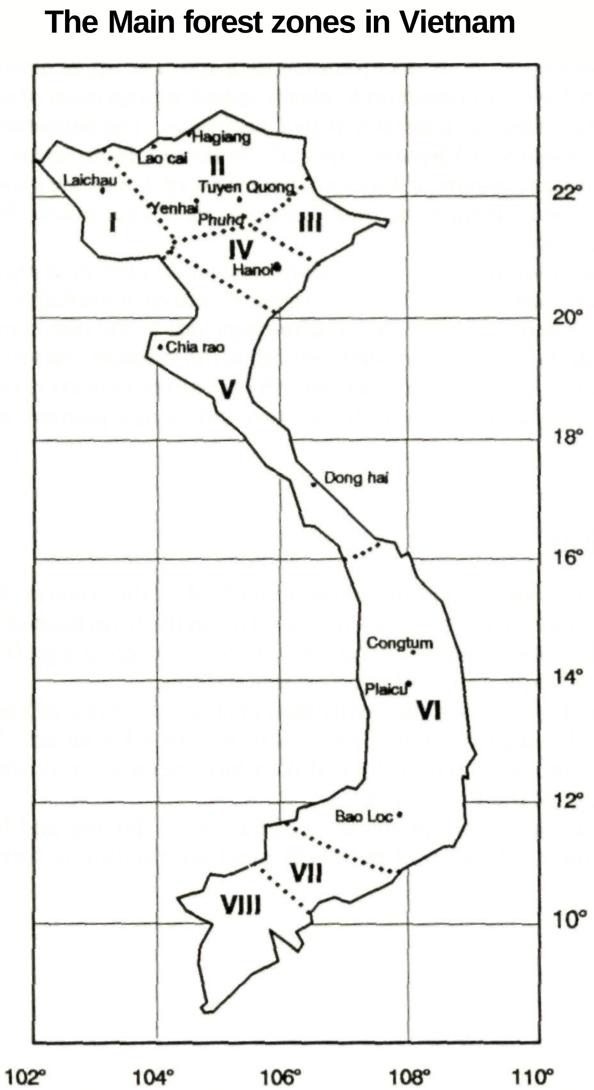
This paper discusses two problems: estimation of climatic and forest resources of Vietnam; and the application of meteorological information in forecasting forest-fire danger.

Bioclimatic resources

Forests in Vietnam are divided into eight main zones:

I	North-western zone, 9% forested;
II	North zone of north Vietnam, 20% forested;
III	North-eastern zone, 15% forested;
IV	Red River delta, 5% forested;
V	North zone of central Vietnam, 15% forested;
VI	Maritime provinces and central Vietnam, 20% forested;
VII	Eastern zone of south Vietnam, 10% forested; and
VIII	Mekong delta, 6% forested; (Figure 1)

Figure 1 Main forest zones of Vietnam.



The following are average meteorological data of two characteristic forest zones:

Laichau (Zone I): 244 m asl; 22° 03' N; 103° 09' E.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp. (°C)	17.3	18.8	21.6	24.6	26.5	26.5	26.5	26.6	26.1	23.9	20.7	17.2
Rain (mm)	16	42	61	122	278	413	409	246	156	66	39	1

Congtum (Zone VI): 536 m asl; 14° 20'N; 107° 59' E.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp. (°C)	20.9	22.6	24.8	25.5	25.4	25.0	24.3	24.3	24.1	23.6	22.9	20.7
Rain (mm)	3	9	40	107	204	248	342	352	325	151	59	11

Degree-days above the base 15 °C, representing the growth period for forest trees, are calculated for twelve forest locations and presented as frequency distributions in Table 1. Rainfall sums during the growth period are also presented. In forest zones I, II and III in north Vietnam, degree-day sums indicate favourable conditions for forest growth (due to the long winter), but rainfall in this period is very small. Moreover, rainfall is not regularly distributed in the year. It occurrs mainly in a rainy season that brings the danger of serious floods which cause severe soil erosion and landslides.

Results of analysis and calculation show that the hydrothermal coefficient of Xelianinov (Trung 1970) is suitable for determining forest zonation in Vietnam. It can also be used planning and management of agroforest systems. The hydrothermal coefficient is calculated as:

$$HC = R / (0.16 + T15)$$

where R is the sum of rainfall (mm) in the period with temperature above 15 °C; T_{15} is the sum of average daily temperatures above 15 °C; and 0.16 is an experimentally-determined coefficient for Vietnam.

Distribution of the hydrothermal coefficient has a seasonal character. In nearly all forest zones in the rainy months, June through September, the coefficient is high (Table 2). In winter and spring months, it is very low. If we assume that a monthly hydrothermal coefficient (HC) equal to 1 means a deficiency of moisture, and HC equal 0.5 means a great deficiency of moisture, then there are 8 out of 10 years very deficient in zones I, III, IV and VI. Thus the hydrothermal coefficient can be used in the planning of new forest plantations and the determination of techniques for intensive farming.

Number of rainy days

Beside a total rainfall in the period with temperature greater than 15 °C, the number of rainy days is an important climatic parameter for the planning of forestry systems. A harmonious occurrence of rainy days and sunny days is optimal for the growth and the formation of biomass of forest trees.

In general, in the growing period of forest trees (from February to November), the number of rainy days in zones I, II and III is rather regularly distributed with 14-20 rainy days per month. In such months each two days has one rainy day, especially in central part of Vietnam (zone V) the number of rainy days in every month from March to June is less than the one of other months. In Playcu (zone VI), the number of rainy days in spring months is very small: 0.1-0.9 days per month.

Table 1 Probability of exceeding sums of temperature > 15 °C and rainfall in months with average temperature > 15 °C (base 1960 -1980).

Location		Probability of exceeding tabular values (%)										
		5	10	20	30	40	50	60	70	80	90	95
Moc chau	R	2150	2020	1865	1775	1705	1640	1570	1500	1430	1350	1280
(zone I)	T	6160	5940	5700	5510	5480	5260	5140	5000	4860	4620	4560
Bac can	R	1910	1820	1690	1590	1500	1425	1363	1305	1250	1300	1133
(zone II)	T	8200	7920	7600	7400	7200	7080	6950	6840	6730	4680	6453
Thai nguyen	R	2660	2520	2320	220	2100	1970	1860	1760	1640	1500	1400
(zone II)	T	8620	8520	8360	8220	8080	7960	7820	7680	7550	7350	7240
Phu Ho	R	2870	2330	2060	1920	1840	1750	1680	1600	1510	1400	1300
(zone II)	T	8900	2660	8400	8220	8100	7960	7830	7680	7560	7400	7280
Ha giang	R	3090	2940	2780	2620	2530	2430	2330	2200	2080	1910	1770
(zone II)	T	8500	8280	8000	7840	7720	7620	7520	7420	7300	7160	7040
Tuyenquang	R	2270	2150	1865	1880	1780	1660	1550	1470	1390	1280	1190
(zone II)	T	8640	8500	8320	8100	8040	7900	7760	7620	7500	7360	7250
Van chan	R	2120	1970	1790	1670	1380	1480	1410	1350	1286	1180	980
(zone II)	T	8260	8020	7780	7650	7500	7480	7260	7120	6970	6780	6600
Daitu	R	2890	2600	2280	2090	1940	1800	1660	1550	1440	1330	1250
(zone II)	T	8540	8360	8140	7960	7820	7650	7500	7340	7160	7940	6820
Do luong	R	2720	2420	2180	2060	1930	1800	1660	1510	1340	1140	1020
(zone V)	T	8940	8800	8600	8520	8260	8120	7960	7820	7660	7500	7400
Tay hieu	R	2750	2450	2040	1800	1670	1550	1450	1350	1175	930	750
(zone V)	T	8740	8600	8420	8260	8120	7980	7840	7660	7550	7160	6940
Bao loc	R	3600	3350	2950	2800	2650	2550	2450	2300	2150	1880	1700
(zone VI)	T	X	X									
Playcu	R	3110	2875	2600	2400	2230	2100	1980	1860	1750	1630	1520
(zone VI)	T	8260	8160	8050	7980	7940	7900	7820	7760	7680	7560	7460

Total rainy days in forest zones show small differences. Maximum is 154 days in the north (Bacquang, zone II) and 189 in the south (Bao loc, zone VI). However in order to estimate more correctly we calculated the number of rainy days with probability 80% in the period with temperature greater than 15 °C and found that there are 8 out of 10

Table 2 Average monthly hydrothermal coefficient in different forestry zones of Vietnam.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Phuho	0.64	0.85	0.60	1.61	2.22	2.90	2.59	3.30	2.25	2.33	0.94	0.42
Daitu	0.56	0.70	0.63	1.61	2.78	3.37	3.62	4.68	3.17	2.62	0.70	0.49
Bac giang	1.41	1.49	1.28	3.60	1.04	1.18	11.58	7.60	5.12	5.32	1.32	1.96
Thai nguyen	0.48	0.71	0.69	1.87	2.62	4.24	4.38	4.26	3.28	2.02	0.62	0.56
Bac can	0.42	0.60	0.71	1.67	2.19	3.63	3.56	3.74	2.06	1.25	0.62	0.46
Van chan	0.35	0.52	0.57	1.38	1.86	3.04	2.60	3.86	3.44	1.92	0.53	0.36
Playcu	0.85	0.68	0.38	1.30	3.66	4.84	5.98	6.95	4.99	2.09	0.87	0.13
Tay hiu	0.42	0.47	0.44	0.96	1.76	2.01	1.78	3.52	4.94	3.60	1.02	0.44
Moc chau	0.42	0.70	0.99	1.71	2.84	3.49	3.67	4.88	4.94	2.44	1.10	0.35
Yen bai	0.75	1.01	1.20	1.93	3.01	3.46	3.58	4.40	3.93	2.40	1.11	0.63

years in which the number of rainy days in zones I, II, III and IV is no more than 120 days; and in zones V and VI is no more than 140 days. Reality shows that the period with average temperature more than 15 °C in Vietnam is usually year-long. Therefore, the greater the number of rainy days with probability of more than 80%, the greater the productivity and biomass of the forest zones.

Number of hot-and-dry days

In 1968,1969,1970 and 1971, climatic surveys in many forest zones showed that hot and dry winds cause great damage to forest trees. The meteorological factors causing the damage are high temperature, low atmospheric humidity, and low soil moisture resulting from low rainfall. The criteria for a hot-and-dry day are $T_m$ax > 37 2 8M C, Rmin < 50% and rainfall in the previous two days < 5 mm. In the forest zones of Vietnam, hot and dry days are common from March to October (Table 3), and are the main cause of forest fires.

Table 3 Number of hot and dry days (T_{max} 37 °C; R_{mjn} 50%) in forestry zones of Vietnam.

Location	Zone	March	April	May	June	July	Aug.	Sept.	Year
Yen chau	**I**	4.7	10.7	14.7	5.5	**4.0**	1.7	0.2	41.3
Dien bien	**I**	1.5	3.8	5.0	1.7	0.2	0.3	0.2	12.7
Lai chau	**I**	1.7	6.2	10.0	4.2	1.7	3.2	2.3	29.3
Laocai	**II**	0.0	0.7	4.7	4.5	3.5	2.7	1.3	**17.4**
Langson	**III**	0.0	0.0	1.0	1.0	0.5	0.2	**0.0**	2.7
Bacgiang	**III**	0.0	0.0	1.8	2.6	1.8	**0.2**	0.0	6.4
Hanoi	**IV**	0.0	0.0	1.5	4.5	2.5	0.3	0.0	8.8
Donghoi	V	0.0	2.4	4.8	7.6	7.6	5.6	1.2	29.2
Vinh	V	0.4	2.0	6.6	9.6	8.1	4.4	**0.5**	31.6
Cua rao	V	0.7	7.7	16.5	10.0	13.0	7.0	0.7	55.6
Thanh hoa	V	0.0	0.2	2.2	4.8	3.7	0.7	0.0	11.6

Forest resources

Forest land in Vietnam comprises more than 20 million ha, of which land with forest trees is about 7.8 million ha. In general, the forest is poor, the quality and quantity are low, and the capacity of the forest for commercial exploitation is limited. This is so because much of the forest is in a primitive and unmanaged state. Although the total biomass is large, the quantity of usable material is very small. On the average, annual growth of natural forest is only 1-2 m /ha although pine shows a growth of 3-5 m /ha. The calculation of potential productivity shows that with the same forest trees, the productivity would be 10-15 times greater if the forest were better managed.

Knowledge of yearly growth of forest trees allows management to devise an exploitation plan. In each of the last 20 years, 15-16 million m of wood was removed, 3-4 times more than the natural growth of the forest.

Forecasting forest fire weather

Forest fires have rapidly reduced the forest area of Vietnam. In the last 20 years fire has damaged about 10 million m of wood. Forest fires from natural causes are rare and appear only in meteorologically favourable conditions. The forest fire season is usually from November to April in the highlands of central Vietnam. In the north it is from May to October. Forest fires usually occur in the time from 1300 to 1900.

In order to effectively and actively defend the forest resource, it is necessary to predict the potential for fire in each zone. In Vietnam, it was determined that the main meteorological factors that cause forest fire are air temperature and humidity, wind, and soil moisture. We have used two methods to forecast fire danger: the methods of Nesterov and Trung (Trung 1970).

According to Nesterov, the complex index, D, is the sum of products of saturation vapour pressure deficit and the air temperature at 1300 of all days since the last rain:

$$D = K x D.i + T_a x Td$$

where D_{-1} is the value of the index on the previous day; K is a rainfall coefficient which has the value 0 for a rainy day and 1 for a dry day; T_a is the air temperature at 1300; and T_d is the dew point temperature at 1300.

The index is divided into the following classes:

Class	Level of danger	Index
I	no danger	0 — 150
II	average danger	15 — 250
III	high danger	25 - 500
VI	very dangerous	50 — 2000
V	the most dangerous	> 2000

In Vietnam, we also use the drought index of Trung (1970) for the determination of forest fire seasons:

$$X = S x A x D$$

where X is the drought index; S is the number of dry months with real rainfall < 2 x average temperature; A is the number of months with rainfall < 1 x average temperature; and D is the number of months with rainfall < 5 mm.

Outlook

In the future, the Hydrometeorological Service of Vietnam plans the following services to forestry:

1. Study the relationship between the growth of biomass of forest trees and different climatic and ecological conditions.
2. Estimate climatic and hydrological resources for planning and management of forestry zones.
3. Forecast capacity of yearly growth of forest trees in different forestry zones to establish yearly exploitation plans.
4. Develop methods of forecasting forest fires in Vietnam.

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The need for climatic information for agroforestry systems in the Philippines

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Abstract

The paper presents the status and extent of use and the need for climatic information for agroforestry systems in the Philippines and hopes to draw suggestions from the participants for a better system of implementation of our programme in agroforestry.

Existing agroforestry systems in the Philippines have no sustained productivity because aside from being still in the experimental stages, the lack of acceptance by the upland farmers and considerable support from the government, environmental factors like climate which directly affect plant/animal growth and survival have not been significantly considered.

Moreover, there are not enough meteorological stations which could provide climatic information. Many existing ones do not have the necessary instruments. Most of the existing meteorological stations are providing data for their own projects or other linked agencies' consumption. There is very minimum effort of trying to provide such useful information to the upland farmers to assist or guide them in the selection of site, selection of plant or animal species, proper combination of agroforestry crops, timing of cultural treatments, pest and disease control, conduct of development activities and other actions aimed at improving the productivity of their agroforestry farms.

Because of this present situation there is a dire need for agencies in gathering and monitoring climatic information to coordinate with agencies implementing agrofrestry programmes to come up with a better plan and effective implementation of the programmes. There is a need to increase the present number of stations and the kind of instruments presently used to efficiently provide agrometeorological information necessary to support developmental efforts of the government to increase the level of productivity especially in the hillside farms.

Introduction

Information on various weather elements are being monitored for use from specific areas relevant to agricultural planning to information required in the construction of infrastructure; for the development of alternative sources of power, e.g., water, wind, and sun; for the safety, efficiency and regularity of all types of transportation and movement of perishable merchandise; and information required by legal authorities and insurance companies in resolving cases.

In agriculture and forestry, climatic information has as much importance as in other fields. From the time the seeds are sown until the plants are harvested and stored, crops are more or less at the mercy of the weather, particularly during certain critical periods in their growth. Variations in the weather during the growing season, such as delay in the outbreaks of rain, untimely or excessive rains, droughts, etc. would very seriously affect the development and the final yield of the crops.

Studies conducted in other countries such as India have given ample evidence for concluding that of all the 'controls', climate had the greatest effect on crop yields over a series of years (Acuna 1980). In the field of agroforestry, climatic information could be used as a basis for determining which species of plants and animals could better survive in an area; in the implementation of a cropping pattern in terms of proper combination of the crops; in the proper timing of cultural and development activities; and finally, as a factor that could be considered in planning and implementing a project to ensure effective and economic conduct of different activities. This should remind planners, agriculturists and foresters on the importance of climatic information and the need to take all efforts for its consideration in planning and implementing a project.

This paper presents the status and the extent of use and the need for climatic information for agroforestry systems in the Philippines.

Monitoring agrometeorological information in the Philippines

The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) is the government agency mandated to monitor atmospheric, geophysical and astronomic information for their useful utilization. The agency is best known to the public through its daily weather forecasts, advisories, bulletins and warnings through the broadcast and print media. It has the following functions (PAGASA 1977):

1. Observes, reports, and forecasts the state of the atmosphere, sea and rivers.
2. Issues warnings of severe weather systems, tropical cyclones, rough seas, floods (in specific areas) and related hazards.
3. Provides climatological, meteorological, geophysical and astronomical information and related environmental data.
4. Provides assistance on the interpretation of environmental data and weather forecasts and on related problems.
5. Maintains and disseminates precise Philippine Standard Time.
6. Collaborate with other agencies on disaster mitigation and community preparedness.
7. Pursues integrated research and training programs in areas within its distinctive competence.
8. Actively involves itself in interagency, international and regional endeavors and projects in the fields of atmospheric science, geophysics and astronomy.
9. To undertake these functions, the PAGASA maintains and operates several networks of observing stations country-wide supported by communication links. The following are the types and numbers of stations composing the networks:

Meteorological forecasting center	1
Main meteorological office	1
Synoptic	54
Upper-air synoptic	9
Radar	9
Climatological	450

Agrometeorological	28
Visual storm signal	36
Main flood forecast center	4
Hydrometeorological	66
Storm surge monitoring	4

PAGASA is divided into major offices or divisions; one is the Agrometeorological Division which manages the operations of the different agrometeorological stations. These stations were established to gather and provide, on a routine basis, simultaneous meteorological and biological information. A list of existing stations is given in the Appendix.

A typical agrometeorological station in the Philippines has the following recording instruments set up in a well-exposed area: raingauges (ordinary and automatic) for precipitation intensity; sunshine recorder for sunshine duration; pyrheliometer for solar radiation; evaporation pan for evaporation rate; soil thermometer to record soil temperature; hygrothermograph to record relative humidity and atmospheric temperature; and an anenometer for wind velocity.

At present, there are 28 agrometeorological stations of which about 75% are auxiliary stations stations owned by other government agencies, schools or private institutions. They receive assistance from PAGASA in the setting up of the instruments and for technical support. Many of these stations are located at agricultural and forestry schools (Acuna 1980) and most of them are in an experimental site to monitor the effects of weather elements on crops.

From the various meteorological stations, data are relayed to the Agrometeorological Division which is responsible for the processing and interpretation of data prior to dissemination. To complement its services to the public, it conducts lectures and advisories, offers technical assistance to other agencies and individuals, and disseminate information through the broadcast and print media. It also conducts weather-crop relation studies and their application to farm operations. The response of the crops to weather conditions at different times of the year are used in recommending crop-weather calendars for specific localities (Acuna 1980).

Extent of using climatic information in agroforestry systems

Most of the existing agroforestry systems in the Philippines do not have sustained productivity. Among the various reasons for the relatively unsuccessful implementation are:

1. Existing agroforestry farms are experimental, still trying to discover the proper combination of species and proper cultural activities to improve productivity;
2. Aside from the lack of manpower, the extension service has not really achieved a considerable degree of its objectives;
3. Negative attitudes of the upland farmers to the technology being introduced;
4. Lack of considerable government support for the program (e.g., insufficient funds for research and extension); and
5. Non-consideration of some physical and environmental factors in the planning and implementation of agroforestry projects.

Agencies involved in the implementation of agroforestry programmes are the Bureau of Forest Development (BFD); Forest Research Institute (FORI); University of the Philippines at Los Banos; College of Forestry (UPLBCF); Philippine Council for Agriculture and Resources Research and Development (PCARRD); logging companies; some upland farmers; and several schools offering agroforestry and forestry programmes such as the Don Mariano Marcos Memorial State University (DMMMSU).

FORI and the College of Forestry at UPLB conduct researches on agroforestry and other related fields. The results of these researches are transmitted to the implementing agency, the BFD, for execution. It is the responsibility of the BFD to establish extension services to transmit the improved technology to the farmers. But since agroforestry is still a relatively new concept and with the presence of tree components requiring a long period to maturity, there are still very few completed research projects. In the case of the UPLBCF, it has its own Social Forestry department to implement research findings in the field.

Nevertheless, the mode of implementing their programmes is the same. Because it is difficult to change the farming system of a certain upland community, the approach is to introduce improvements to the existing cropping schemes.* And because of the lack of provisions and acceptance by the upland farmers, existing agroforestry farms are located in selected pilot project areas and will serve as demonstration farms to adjacent communities.

Some improvements being introduced are the planting of forest crops (e.g., ipil-ipil, acacia, agoho, narra, mahogany); short-term crops (e.g., sweet potato, peanut, ginger, mongobean, corn); medium- term crops (e.g., pineapple, cassava); and long-term crops (e.g., papaya, cacao, coffee, black pepper); and the application of farming techniques (furrow contour, hedgerow and furrow contour, contour strip cropping, terracing and buffer contour) (FORI 1986).

Some logging industries such as the Paper Industries Corporation of the Philippines (PICOP) have also promoted the practice of agroforestry by inducing farmers to plant fast-growing tree species on their farm lots and then buying their wood products at reasonable prices.

Universities and other agencies conduct agroforestry researches with the financial assistance of PCARRD, the National Science and Technology Authority (NSTA), the International Foundation for Science (IFS), and other funding institutions. But most of the researches being conducted are cropping patterns, still discovering whether a certain tree crop is compatible with a set of agricultural crops already thriving in the locality.

Within some of the different research stations, meteorological instruments are set up to monitor the effect of climatic factors on crops. In short, climatic information is only being used in agroforestry research to assess the effects of weather elements on crop responses and performance. In most of the other agroforestry systems, farmers plant the combination of trees and agricultural crops that have been thriving in the locality and those that could provide their economic needs. With this practice, at least, climatic factors have been considered; but there may be more crop combinations that would perform better in the area if they were guided by meteorological information.

As of this time, most of the agrometeorological studies conducted on agroforestry have been on provenance trials, soil moisture, germination, soil erosion, shading by trees, environmental changes as a result of farming schemes, plant diseases, rehabilitation of forest areas, and time of planting (Gayanila 1984). With these, it seems that

Personal interviews with Nicanor Iscala, BFD; Marcelino Dalmacio, FORI; and Vicente Ato, UPLBCF.

many important researches have already been conducted but most of the results have not yet been transformed to marketable goods for the farmers. The extension services must do a lot of work in this regard.

Conclusions and recommendations

The response of many plants to the different weather elements is still the subject of continuing research. With only 28 agromet stations, it could be inferred that there are not enough stations to provide climatic information specifically for agroforestry. Almost 50% of these stations are located in schools and other agencies not directly involved in agroforestry. They are not really being used to provide direct information to the upland farmers but to satisfy the immediate needs of the agencies' projects. For schools, for example, the instruments are used for instruction and in supporting research projects.

Because of this situation, there is a dire need for agencies involved in gathering and monitoring climatic information to coordinate with agencies implementing agroforestry programmes, with the goal of producing better plans and implementation of programmes. This will maximize the use of the very few agromet stations.

There is an apparent need to increase the present number of agromet stations and the kind of instruments used to provide agrometeorological information. Likewise, a more comprehensive and effective extension programme should be formulated to disseminate more information in a manner acceptable to the upland farmers.

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FORI. 1986. *Information Brochure.*

Gayanilo, V.G. **1984.** *Abstract bibliography of agrometeorological researches.* Terminal Report.

PAGAS **A. 1977.** *Primer.*

Appendix: Existing agrometeorological stations

1. Mariano Marcos State University — Batac, Ilocos Norte
2. Isabela State University — Echague, Isabela
3. Benguet State University — La Trinidad, Benguet
4. PAGASA Office - Beguio City
5. Bureau of Plant Industry — Baguio City
6. Central Luzon State University — Munoz, Nueva Ecija
7. Hacienda Luisita — San Miguel, Tarlac
8. Central Agromet Observatory — PAGASA, Quezon City
9. Cuyambay — Tanay, Rizal
10. University of the Philippines at Los Banos, Laguna
11. Camarines Sur Agricultural College — Camarines Sur
12. Albay Provincial Nursery — Albay
13. University of Eastern Philippines — Catarman, Northern Samar
14. Mambusao Technical College — Mambusao, Capiz

15.Visayas State College of Agriculture — Baybay, Leyte
16.Sab-a-Basin — Tacloban City
17.La Granja, La Carlota — Negros Occidental
18.Calape - Bohol
19.Bayugan — Agusan del Sur
20.Trento — Agusan del Sur
21.Central Mindanao University — Musuan, Bukidnon
22.Dagat Kidavao — Valencia, Bukidnon
23.Kahaponan Auxilliary Station — Valencia, Bukidnon
24.Mindanao State University — Marawi City, Lanao del Sur
25.Twin Rivers — Tagum, Davao del Norte
26.Philippine Coconut Authority — Davao City
27.University of Southern Mindanao — Kabacan, North Cotabato
28.Palawan National Agricultural College — Aborlan, Palawan

SECTION

Measurement and analysis of agroforestry experiments

Inexpensive instrumentation for monitoring PAR in agroforestry

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Abstract

A review of methods for sensing and integrating the transmissivity of agroforestry canopies to photosynthetically active radiation with reference to sampling pattern, costs and ergonomics.

Introduction

I define agroforestry as an activity where woody plants (usually trees) are used in more or less intimate association with animals and/or crops in order to make use of ecological and economic interactions in the production of a wide range of materials including food, fuel, timber, fodder and chemicals.

Photosynthetically active radiation (PAR) is defined as that part of the electro-magnetic spectrum with wavelengths between 400-700 nm. It is that part of the sun's energy that is tapped by green plants and upon which all life ultimately depends. It is extremely useful to know how the canopy of the woody and non-woody components in an agroforestry system intercept this radiation. By knowing how much is intercepted one can calculate the photosynthetic efficiency of the system and match this against alternative canopy structures or theoretical models. By knowing about the trans-missivity of the tree canopy, that is how much light passes through it, one can gauge the potential for growing an understorey crop in close association with the trees. Know-ledge of the spatial and temporal variation of this available PAR is useful in the design and optimization of both overall and component crop yields. There are many general reviews on the measurement of PAR and the physiological effects of reduced PAR availability in plants (Anderson 1964; Coombs and Hall 1982; Monteith 1973; Sestak et al. 1971). In this paper I have attempted to concentrate on those aspects of special importance to the study of agroforestry.

Spatial aspects of agroforestry canopies

The spatial arrangement of systems includes horizontal and vertical planes. Horizon-tally one can consider the system to be an arrangement of holes in the ground of a particular geometry with crops allocated in different ways. The arrangement of holes can be regular, random or with systematic variation. Regular arrangements can be square, triangular or rectangular. Plants can be allocated to these holes as rows, e.g. as in alley cropping; in a random fashion, as in hand-broadcast mixtures in *Acacia* scrub; or in rectangular plantations, as in fruit and nut orchards).

Vertically the system can also be complex with what could crudely be described as canopy layers from different species with trees usually, but not always, occupying the top layer and herbaceous crops the bottom layer. In the more complex systems such as modified forest gardens, intermediate layers with shrubs and/or climbing vines complicate the vertical system further.

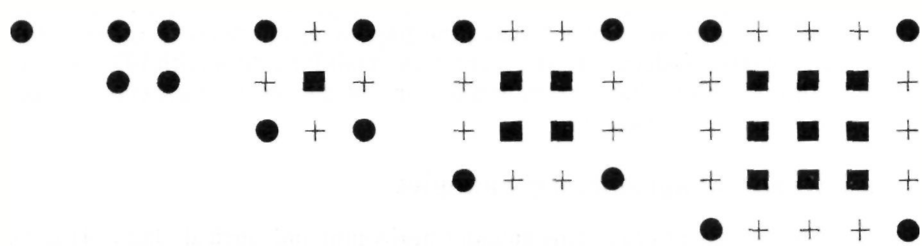
Spatially, then, the most important attribute of agroforestry systems is that they are very complex. They contain complexity in that they are discontinuous and that they contain mixtures of species with different leaf and whole-plant morphology and phenology.

Edge effects or how big is an agroforest?

I am not going to argue that a field crop with a single tree planted at its centre is an agroforestry system. Nevertheless, there are many cases where the tree component is so widely spaced that for all intents and purposes the system is a collection of individual trees. This occurs in tea and coffee where leguminous shade trees are widely spaced and during the establishment phase of plantation tree crops when they are intercropped. Edge effects are important in small agroforests and should be studied rather than ignored or designed around. Figure 1 shows the importance of edge effects for different sized plantation and represents a tree classification based on neighbours. Many agroforests are run by smallholders and are consequently small.

One can observe that if aspect is ignored then in most systems we have three broad categories of representative tree. If the trees are of different heights or species this will further complicate matters. It is a traditional and significant practice in Kerala to grow areca nut in a mixed age system with trees of 5-year age differences (Aiyer 1949). It is also evident from Figure 1 that for a repetitive rectangular array a sampling unit is a rectangle either with a tree at the centre or with a tree at each corner. For small agroforests tree height is of crucial importance in that it will directly affect the distribution of PAR available to the understorey. This is due to the important contribution made from radiation incident from the edges.

Figure 1 The size of the array of trees in a plantation and its impact on the number and form of representative trees assuming no major effects due to aspect.



Number of sensor points required

A single sensor is of no use as this will not be able to discriminate between changes due to the canopy or the atmosphere. Two sensors — one above the canopy and one below — will give a measure of canopy transmissivity; but where should the lower sensor be placed? In order to take into account the effect of aspect at least four sensors placed north, south, east and west will be required to adequately characterize an arrangement where the trees are not grown in continuous rows, i.e., the canopies do not touch within the row. I would suggest at least eight sensors to characterize an individual tree's #effect on the understorey replicated enough times so as to represent trees of a certain size or location. The understorey sensors should be placed at a few centimeters above the maximum height of the crop. Other layers of sensors will be needed to characterize PAR available to other species or other leaf layers if required. As the study will relate everything to the upper reference sensor, more than one should be used to insure continuity of the record in case of sensor failure. I would suggest therefore that a minimum of 15 sensors is required in most serious studies.

Active area of a sensor and costs

Obviously the larger the sensor the larger the area that PAR can be averaged over. The size of the sensor will be limited by cost and the resolution of the study. It is unlikely that any manufacturer will produce a sensor at a price lower than £ 100 that is guaranteed against some standard. There are several designs in the literature that can be built in a standard workshop. In order to choose the correct design it is important to define appropriate characteristics.

Ideally a PAR sensor should have the following characteristics: a suitable spectral response; a correct angular response; a rapid response time; a small surface area; a long life; and a negligible temperature response.

Two types of sensor have been used by plant scientists that differ in spectral response, i.e., the energy or PAR sensor and the photon or quantum sensor. The energy/PAR sensor has a more-or-less flat response between 400-700 nm and is calibrated in W m^{-2}. The photon or quantum sensor has a response based on Einstein's law of photochemical equivalence and is calibrated in E m" s" (McPherson 1969).

The quantum sensor is often preferred for measurements of photochemical efficiency in relation to absorbed PAR whilst the energy sensor is preferred for the measurement of PAR in relation to canopy transmissivities and where other meteorological and physiological measurements are available in energy units (Blackburn and Proctor 1983). The latter sensor can be calibrated against measurements taken by a Kipp solarimeter. Energy sensors have become increasingly popular since the publication of detailed crop response spectra (McCree 1976).

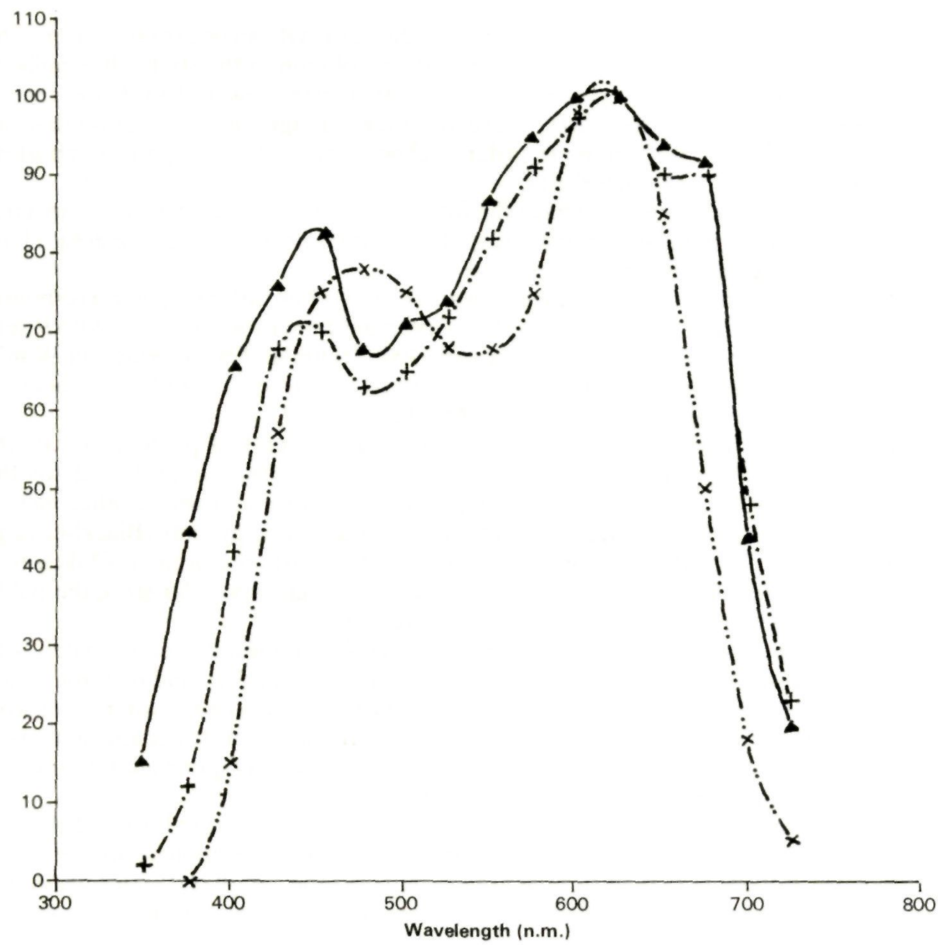
The standard angular response for sensors that is required is a close match with Lambert's cosine law (Anderson 1964). This is a physical standard and may not always be close to biological reality. This is the case in some terrestrial systems where the leaves are predominantly aligned away from the horizontal, and in most aquatic systems (-Williams and Jenkinson 1980). This is commonly observed in *Piper nigrum* trained on tree trunks in agroforestry systems of the humid tropics.

The response time of a sensor should be short in order to account for rapid changes in irradiance and photosynthesis, if instantaneous or short integration periods are used (Szeicz et al. 1964). A small surface area is required for complex systems where the spatial variation is important. Tube solarimeters are useful where spatial averaging is required as in row crop situations but tend to have deficiencies in angular response when filtered to measure PAR (Blackburn and Proctor 1983). Any sensor should have minimal interference from moisture and temperature and should not 'fatigue' with high light intensities, as has been the case with many of the filters in tube solarimeters.

The most popular sensor designs are based on silicon photocells with glass filters to remove the infra red response. These are stable and readily constructed (Williams and Austin 1977; Woodward and Yaqub 1979; Newman 1985). Selenium-cell-based sensors have the advantage of lower filter costs and are cheaper per unit active area in many instances (Newman 1984; Powell and Heath 1964; Jackson and Slater 1967).

All sensors are used with a load resistor in the short circuit mode in order to give a linear current-irradiance relationship and improve temperature stability. The spectral response of a PAR sensor built by the author from readily available components is given in Figure 2, along with the spectral response of crop species.

Figure 2 Spectral response of senor (x) and mean response of 20 field crop species (+) and 8 species grown in the field (A). (McCree 1976; Berman, Biran and Braunstein 1978).



Temporal aspects of PAR in agroforestry

Essentially this is no different from other systems in that the focus of the study will relate PAR to the period when the leaf area of the components is active. In order to compensate for changes in solar incidence angle, sampling should occur through the day either by instantaneous sampling over the sensor array or by integrating the value over the entire period. Changes in phenology throughout the year will be important in many studies.

Methods for integration or instantaneous logging

Electronic data loggers are now a reliable method for giving detailed information on the temporal variation in intensity of PAR. But at scan rates requiring five minutes (Anderson 1964; Newman 1984) or even two minutes (Salminen et al. 1983), analysis of the large quantities of data generated may require a main frame computer. The expense of the logging and analysis of data and the problems of security and signal loss due to damage to wires often precludes their use in remote sites.

In estimating canopy transmissivity, an integrated reading taken over the period of a day or more will often suffice. Several methods of integrating light measurements have been developed. These can be classified into electronic, electrochemical and photochemical methods. Commercial electronic integrators tend to be rather expensive, costing well over £ 100 (Appendix). Designs for the construction of inexpensive electronic integrators have been published (Woodward and Yaqub 1979; Saffel et al. 1979; Collocott 1980). The basic working principle is the conversion of the voltage output from a PAR sensor to a frequency which is fed to a counter. These devices can be difficult to construct in quantity and may require frequent changes of batteries if used for a long period (Woodward and Yaqub 1979). Recent advances in Complementary Metal Oxide Semiconductor (CMOS) chips with low power consumption should improve this (Collocott 1980). One design (Saffel et al. 1979) uses a calculator for the display counter and should reduce costs.

Electrochemical integrators that use the voltage output from a sensor have been used in the past. These involve some form of electrolysis or electroplating to integrate the output. Examples included the Siemans-Megatron direct-current meter which involved the measurement of gas volume from the electrolysis of dilute sulphuric acid (Trickett and Moulsley 1955), unfortunately no longer available. Another way is to measure the change in weight of copper deposited on copper or silver electrodes dipped in copper nitrate solution (Powell and Heath 1964; Jackson and Slater 1967; Fairbairn 1954). A further method involved the use of mercury coulometers where the position of a small volume of electrolyte is measured after the change in volume of mercury electrodes in a capillary tube. Weighing coulometers are difficult to read and will not stand any sudden shocks during transit or use.

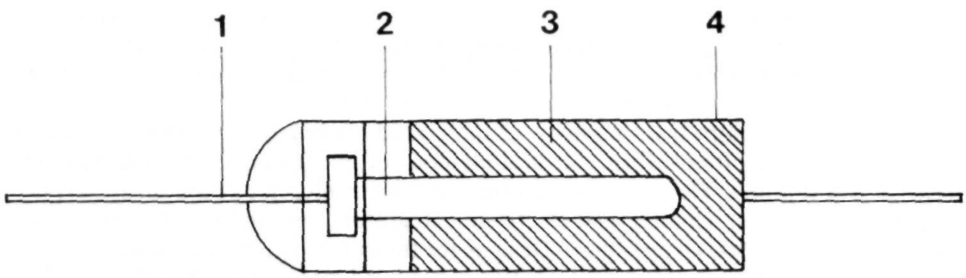
Photochemical sensor integrators in the form of photosensitive film/solutions have been used but suffer from sensitivity to infra red and ultra violet radiation and a poor angular response (Anderson 1964).

More recently, coulometers known as E cells have been used (Berman et al. 1978). These are inexpensive, accurate, can be read electronically and were used in the system outlined below.

E cells as integrators

E cells are small inexpensive components consisting of a silver can electrode housing a solution of silver ions and a gold electrode (Figure 3). They are distributed by G. E. Electronics in the UK (Appendix). The cells have an impedance of about 200 ohms at room temperature. They can be connected directly to a photocell sensor with an output of 50-100 u, A per **kW m^{-2}.**

Figure 3 Design of an E cell coulometer. Wire (1); gold electrode (2) insulated from silver can (4) by plastic plug; silver can contains silver ion electrolyte (3). (Monteith 1973; Berman, Biran and Braunstein 1978).



The electrochemical capacity of the integrator is about 2.2 x 10 silver atoms. The small self-contained component which looks like a small electrolytic capacitor can be readily mounted into a bnc plug. During operation, radiation reaching the sensor is converted into a current which is used to plate silver from the electrolyte onto the gold electrode. In order to 'read' the device, the E cell is removed from the circuit and a current passed in the opposite direction. The characteristics of the cell change drastically when all the silver is depleted from the gold electrode. As this point a potential difference exists that signals that the end point has been reached. The time taken for this end point to be reached is directly proportional to the total quantity of radiation falling on the sensor.

Using home made sensors the cost of a sensor integrator unit was below £ 10 (-Newman 1985). The total capacity of the E cell is 1000 u. A h. The output of the sensor is varied by changing the active area of the photocell. One determines the maximum amount of radiation to be recorded in kWh and attenuates the sensor to keep the integrator below full capacity during operation. This attenuation is achieved by optically masking the surface of the surface area or selecting components with appropriate surface area. It cannot be achieved by electrical means. Periods of one hour to one week can be integrated but radiation sensors should not be left unattended for more than one day due to errors produced by dirt and dust deposits.

Inexpensive interfaces for low cost microcomputers can readily be constructed (Newman 1985) to time deplating and convert this into the quantity of PAR per unit area. Calibration is carried out using a Kipp solarimeter. Other sensors could be used for measuring quanta or spectral quality. The instrument is stable at a wide range of temperatures (-15 °C to +60 °C) and can be used for over 10,000 times at low generating currents without loss of performance (Newman 1985). A certificated instrument will handle 40 channels and an RS232 interface is now available commercially (Didcot Instruments)

Conclusions and suggestions for further research

Due to the complex nature of agroforestry, any characterization of **PAR** will require the use of many sensors. The most popular sensing instrument used in complex discontinuous canopies is the filtered photocell in the form of a **PAR** or quantum sensor. Self-contained battery-powered integrators or E-cell integrators are recommended rather than data loggers for less-detailed agronomic studies due to lower cost, greater reliability and ease of data analysis. A list of UK manufacturers of equipment for PAR measurement is appended.

Further statistical research is required to optimize sampling pattern in a spatial and temporal sense. Recent developments in materials such as photochromic glass should allow the development of stable chemical methods for integrating **PAR.**

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Appendix: Instrument suppliers

Delta T. Devices Ltd., 128 Low Road, Burwell, Cambridge.
Didcot Instruements Ltd., Station Road, Abingdon, Oxon.
G.E. Electronics Ltd., Eardley House, Campden Hill Road, Kensington, London.
Skye Instruments Ltd., The Old Manse, Skeabost Gridge, Portree, Isle of Skye.

Appropriate instrumentation and the appropriateness of instrumentation for agroforestry and agricultural research in developing countries

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Abstract

Instruments for the measurement of crop and environmental parameters may be mechanical or electrical, simple or complex. The use of some instruments in developing countries can be problematical for various reasons.

General and specific problems of commercial instrumentation as well as the benefits and problems of alternative strategies, as they relate to developing countries, are discussed.

Introduction

Recent events in certain African countries have highlighted the critical nature of their food production and the catastrophic results which can occur when adverse natural forces impinge on fragile ecosystems. The need for agricultural research in such areas is self evident and represents an important facet of the total endevour aimed at solving or at least ameliorating the problem.

Increased food availability will depend on increased crop yields (McCarthy and Mwangi 1982); although pricing systems, extension services, storage technology, etc. will play an important part. Yield sustainability is important. The measurement of environmental variables (temperatures, rain, solar radiation, etc.) in crop space management and an understanding of crop response to these factors is important in assessing a crop's potential productivity for various agroclimatic situations and management practices.

Such physiological and agrometeorological research frequently requires electronic or mechanical instrumentation. The electronic instrument may be of the manual kind requiring the presence of the operator or the automatic kind which may be left to collect data, the data being later retrieved at some convenient time. Non-electronic instruments may range from the simple evaporimeter to the more complex actinograph.

Here we examine the problems of such instrument-based research in developing countries; propose some solutions, although perhaps partial; and discuss the spin-off benefits and problems arising from the suggested approach.

Appropriateness of instrumentation

It can be appreciated that some commercial equipment may not be suitable for use in developing countries (Coulson 1984). Besides some of the reasons that are outlined later, fundamental questions can be raised concerning the validity of measurements made by some instruments. Some of these questions can be asked regardless of the climate in which the instrument is operated, while some may result because of the extreme climate in which they are operated. Both these situations affect researchers in the Third World. In the case where the basic functioning of the equipment is suspect, the developing-country researcher may not have the back-up facilities to investigate the problem. The lack of scientific journals and technical books may be an added disadvantage. In developing countries where food production may be limited by the climate and working conditions, both of these are likely to be extreme. Such factors as the radiation load on equipment and sensors, the effects of dust, high humidity storage conditions, the rough roads that have to be travelled, etc., may render the instrument inappropriate for use in the conditions that prevail. The fact that an instrument may not perform well under them may not be fully apparent to the manufacturer or local researcher at the time when the equipment is ordered. At the more banal end of equipment problems is the fact that some equipment is not easy to physically use outdoors, though this may be as applicable in developed countries as in developing ones. However, what may be minor inconveniences in temperate climates can become major problems in extreme conditions.

Appropriate instrumentation

In the context of appropriate instrumentation we should initially consider innovation rather than invention. For our purposes, innovation can be regarded as the use of existing technology for appropriate local use. The early stages of appropriate instrument development or the assessment of alternative ones should initially involve the simplest but most useful ones, though complex commercial equipment can be tested, in some cases using relatively simple techniques. If the construction of an electronic instrument is being considered, two main problems should be assessed. The first is that the skill levels available will partially dictate the complexity of the instrument and the probability of its successful completion. Complex equipment can be expected to take longer to make and have a smaller chance of success than simpler equipment. An early and complete failure in an attempt to build or test an instrument does little to encourage further attempts. A second problem is that it is likely the components for a complex instrument may cost a lot more and may not be locally available. The cost of components in a developing country can be very high due to import duty and sales taxes and having to order them from overseas can involve long delays. It is quite possible that to make an instrument can cost more in parts than importing the ready made one, should one be available. In this respect projects with overseas 'back-stopping' have an advantage since urgently needed components or advice can easily be provided.

The equipment

Electronic

The advances in electronics over the recent years have led to increased sophistication and complexity in field instrument design. The miniaturization of circuits resulting from the advances in semiconductor device technology (Page 1985) is starting to revolutionize the instruments used in crop field research in the same way it revolutionized microcomputers. However, the restricted demand for electronic field equipment has not yet led to price reductions and, in some cases, more 'user friendliness', as has been the case with home-based consumer items.

The specialized knowledge required to design and produce commercial field equipment successfully separates the majority of users from understanding the principles of instrument sensors and signal conversion systems and thus often from information about its accuracy. The inclusion of internal calculation facilities obviating the tiresome manipulation of raw data or sensor outputs is now commonplace. The fact that some commercial equipment has the facility to interface with a microcomputer can further separate the user from understanding the equipment. Fault finding and maintenance can thus become a critical problem.

Non-electronic

Many pieces of non-electronic equipment may be used in agricultural research, particularly in agrometeorology, and some of these may be relatively simple. Simplicity and accuracy, resulting from an understanding of the principles of operation, leads to a more universal use and acceptance. For instance the Gunn-Bellani radiometer which is based on simple principles is routinely used in East Africa because of past work on its calibration. It is possible that other simple instruments could be used for research if the factors influencing their operation were better understood. Some examples are given later.

The developing country and equipment

It would seen axiomatic that countries or global regions that have a high risk potential for food production problems are the ones least able to support the research to ameliorate them. Bilateral and multilateral donors give assistance usually in the form of capital aid. By using such funds, equipment can be purchased, usually in the donor's country. In some cases they may provide local funds from which the recipient country can purchase equipment, again from the donor country, but overcoming the problems of the researcher obtaining foreign exchange. While such funds are of obvious benefit to the recipient country, unexpected problems can and do occur, e.g. mismatch between requirements and the eventually-supplied item, the arrival of non-functional or partly functional equipment and long time delays betwen purchase initiation and eventual receipt. We have experienced delays amounting to years, for equipment which was essentially 'off the shelf in the donor country.

The rapid advances in electronics coupled with delivery delays can mean that newer models of the equipment may have been released in the donor country prior to receipt of the older model by the developing country. This can lead to problems in obtaining spare parts and, coupled with problems of maintenance, this can lead to equipment being shelved.

Cost and complexity of some commercial equipment can discriminate against young local researchers in developing countries. Besides having to generate a project in which equipment funding can heavily outweigh other expenses the researcher may be faced with the problems of foreign exchange regulations and future unexpected expenses when spare parts or overseas maintenance are required. The lack of sustainable back-up facilities during a project can put the whole scheme at risk. The high cost of commercial equipment will naturally limit its distribution in a developing country which in turn limits both the amount of data taken and possibly where the data are taken.

Lack of technical skills is a problem which faces developing countries. Although there maybe the opportunity for both local and overseas training, 'hands on' experience in a local problem situation would seem to have many benefits. The involvement of local staff in, for example, small electronics projects or equipment function investigations raises skill levels and forms a basis for further training. The need for many measurements in agroforestry and agricultural research situations coupled with technical staff with low skill levels may necessitate the use of equipment that is both cheap and easily used. However the validity of using existing equipment may have to be researched. Such an endeavour may bring simpler cheaper equipment into use as well as train staff. Donor projects which provide training and technical 'back-stopping' in such situations can be invaluable in assuring that research and training efforts do not come to a premature end.

Endeavours to make appropriate instruments or in some cases assess the appropriateness of others can take place with reference to one or more specific requirements (Appendix). The requirements fall into three categories: (a) an actual need to make a specific measurement not provided by a piece of commercial equipment; (b) to overcome constraints such as the lack of money; (c) to produce a meaningful training exercise. It can readily be appreciated that each of these requirements will have its own set of individual problems. For instance with requirement (a) it could be that novel sensor applications may have to be investigated while in (b) cheap alternatives may be tried out. Being a training exercise, (c) is likely to invole a high time commitment. While requirements (a), (b) and (c) may be identified along with certain problems, interconnected 'spin-off benefits occur. For instance if a novel instrument is produced (e.g., (a) above) or production is attempted to save money (e.g., (b) above), valuable 'hands on' training (c) may result. If the instrument is relatively simple, its potential construction by other users may be possible and the original constructors may then become involved in 'user-friendliness' considerations.

In most developing countries training may become an important common factor in all projects, since without elevating the skill levels, the problems of long acquisition time or prospects of more data being obtained may not be solved. Similarly, without the elevation of skills, problems with equipment imported from developed countries will eventually occur.

In the case studies that follow, three main areas of endeavour may be identified. One is the production of pieces of equipment, another is the assessment of simpler alternative methods or instruments. The third is the assessment of the functioning of existing commercial equipment. The first two could be considered appropriate instrumentation; the third, the appropriateness of instrumentation. In all these, the authors have noted a strong training component, whether serendipitous or intended.

Solar radiation

Solar radiation data have many uses and various types of data exist. Such data may be, for instance, collected from meteorological stations or from within crops or at crop interfaces. Meteorological data in developed countries are increasingly being taken with automated electronic weather stations. Because of the level of technician training, shortage of money, etc., this approach may not be possible in developing countries.

In Tanzania non-electrical equipment (the actinograph and Gunn- Bellani) was used to collect data at various sites. The results were compared with more sophisticated equipment at the University of Dar es Salaam in cooperation with the National Directorate of Meteorology (Stigter and Waryoba 1981; Stigter, Jiwaji and Musabilha 1987; Stigter et al. in prep). This allowed the performance of non- electrical equipment to be assessed and simultaneously also allowed simple alternative electrical equipment to be assessed in terms of cost effectiveness. The skill levels of local staff were greatly increased by this project. Thus, in this case, while the central theme was to find appropriate instruments, a spin off was training.

Problems of maintenance, repair and power supply have been addressed at the University of Dar es Salaam for the integration of solar energy values (Stigter and Mabuba 1980; Stigter and Kainkwa 1983). Maintenance and repair problems were solved by local technical staff, previously trained through a Dutch University Co-operative Project, as they were able to identify malfunctioning electronic modules which could then be sent to The Netherlands or elsewhere (via the project) for repair or replacement. The problems of unreliable power supply were solved by the use of electrochemically integrating equipment. Rechargeable batteries which could be recharged using simple solar cells are an alternative and are presently used in the project.

Appropriate low-cost solar radiation intruments could be used in the large numbers required particularly in agroforestry or agricultural research. Such instruments have recently been described (Newman 1985). Large numbers of these could be conveniently 'read' using a microcomputer. The basic approach however uses existing technology in an ingenious way.

Requests for the loan of solar radiation equipment by graduate students of the University of Nairobi working at various research stations prompted an attempt to produce a cheap electrical instrument for PAR measurement. The problem such students faced was either the lack of any instrument for such measurements or the availability of non-functional commercial equipment which had proved difficult or impossible to get repaired. The construction of the initial instrument involved consideration of available sensors, linearization, cosine response, circuit design and construction, general construction techniques and calibration. During a three- month training scheme conducted by the University of Nairobi and the University of York, an Electronics Link technician (funded by The British Council) was able to 'update' this instrument from analogue to digital. This change has allowed new avenues of data storage to be investigated; for instance a circuit has been designed to allow many light readings to be put into memory and retrieved later. This would allow rapid spot measurements to be made in crops and at crop interfaces.

The appropriateness of some commercial solar radiation equipment has come into question during its use in our experiments. In circumstances common in the tropics, particularly in semi-arid and arid regions, it has been found that some of the materials used may deteriorate rapidly under the high solar loads experienced. The manufacturers are aware of the problem, though the field experimenter may not be initially aware of how quickly the deterioration occurs in some tropical conditions. One of us (CLC) found a filter in a solarimeter to break down after only 15 min exposure on the coast just south of Mombasa, Kenya.

Temperature measurement

Crop and soil temperatures have an impact on crop productivity through various physiological processes. Commercial equipment which measures temperature can have either or both of two main drawbacks. It can be expensive and it may not measure what it purports to (Coulson et al. 1986). Examples can be cited to illustrate both these situations.

Measurements on beans indicated that the leaf temperatures obtained depended on the instrument used (Coulson 1985; Coulson et al. 1988). The use of a small thermistor in a simple circuit for measuring leaf temperatures provided encouragement for the production of a simple leaf-temperature measuring device. This was constructed (Coulson and Musyoki 1986) with a view to simplicity and cheapness and to obviate one fault inherent in our commercial instrument. Considerations involved the analysis of problems inherent in contact leaf temperature measurements and calibration methods. Although an appropriate instrument was the initial consideration, cheapness and training were important 'spin-offs'.

Problems of non-contact temperature measurements using infra-red thermometers (IRT) have been addressed at the University of Dar es Salaam (Stigter, Jiwaji and Makonda 1982; Stigter, Makonda and Jiwaji 1982, 1983; Stigter Mwampaja and Kainkwa 1984). Besides the drawback of high cost, IRTs may suffer from other faults, calibration not being the least important. Using 'commonly available' equipment and locally developed techniques it was possible to improve the performance of a non-commercial Dutch IRT. Initially the thermocouples necessary for testing the IRT were made in Holland, though during the project it was possible to fabricate them at Dar es Salaam as well as to develop the methodology for the construction of the calibration surface.

Problems in making temperature measurements in the tropics may occur because of the high solar radiation levels. Problems may also occur in temperate regions with some types of equipment but they may be potentially more serious in the tropics. Uncontrolled radiation falling on the inlet tubing of an expensive imported piece of equipment was found to be a main cause of erroneous results in an experiment to examine leaf/air temperature differences (Coulson et al. 1988).

In field experiments there is a frequent need to take environmental readings over long periods of time, perhaps at frequent intervals. Data loggers are of use in such situations, especially at distant experimental sites. Although commercial data loggers are available, though at high cost, maintenance problems can limit their applicability in developing countries, except where there is adequate back-up.

This view depends on the situation of the individual researcher. The breadth of skills at a university can be expected to be greater than in many other situations; and as such may lend itself to the use of more complex instrumentation. For example, because of a previous successful attempt to use a simple technique and a cycling millivolt recorder to record temperatures (Coulson and Taylor 1984) and the wide skill base at the University of Nairobi, the development of a prototype temperature data logger was undertaken. It attempted to solve two problems. In the first case, further investigations on crop flower abscission (Kamweti and Coulson 1984) required the frequent measurement of air temperatures within a crop over a period of weeks; and secondly, a graduate student in the Physics Department of the University of Nairobi required an electronics project for his thesis research. The prototype logger (Namuye 1986) incorporated an existing microprocessor board which simplified the task.

In this endeavour it was necessary for people of different disciplines to appreciate problems outside their own. Besides the production of a piece of potentially useful equipment, the enterprise served as an excellent training opportunity in the application of electronics, as well as inducing a great amount of local confidence. As a result of this experience, a field data logger is being developed for use in a Ph.D research on alley cropping in Machakos District.

Wind and air movement observations

Information on air movement parameters in and around crops is important. However, the two main problems are that commercial instruments may not measure the wind components that occur in and around crops; and in multi-point simultaneous sampling situations the necessary duplication of commercial equipment may be too expensive. In Dar-es-Salaam and Wad-Medani (Sudan) an investigation of simple appropriate techniques for measuring air movements was undertaken. Work was carried out to elucidate the factors affecting the evaporation of water from shaded Piche evaporimeters, since data from this instrument had been used to replace the aerodynamic term in the Penman evaporation equation (Stigter and Uiso 1981; Stigter, Uiso and Rashidi 1984). The instruments being simple and cheap could possibly be used as multi- point air movement sensors, via mass exchange observations. This work continues.

The use of naptha or moth balls as air movement indicators is currently being studied at Wageningen in relation to two ongoing agroforestry projects in the tropics involving air flow in low-density tree plantations. The Pich6 will also be tried out in these projects.

Soil water and crop water use

Information on water availability and use is of obvious importance in many developing countries. Unfortunately their measurement is not easy, particularly if it is necessary to make readings over long periods of time at distant sites.

We have been unable to successfully measure soil moisture in Nairobi using commercial psychrometric equipment. The initial interest by the overseas manufacturer in the problem seems to have waned leaving us with expensive but non-functional equipment. The equipment is now over three years old and is well out of its guarantee period. Its complexity, coupled with lack of circuit diagrams means that local repair is probably impossible. Special batteries are not available locally. A similar situation has arisen with a neutron probe. Following return from the manufacturer the probe functioned for about an hour and the new fault was diagnosed as an IC which the manufacturer says is no longer available.

Both of these problems illustrate the shortcomings of using complex electronic equipment in developing countries. Both might have been solved had an overseas-linked project been operative to cover the cost of equipment shipment back to the manufacturer and with an overseas contact to explain the fault to the manufacturer and keep track of the instrument during its repair and subsequent shipment back.

The use of resistance blocks may offer a cheaper alternative allowing many points to be sampled, an important point considering the possible inhomogeneity of soils and highly variable microclimatic gradients arising in agroforestry situations. The use of an AC bridge eliminates problems of the capacitance effect found with DC techniques, though the electronics of the meter maybe sensitive to the high temperatures commonly found in the tropics. However, resistance blocks are not without their problems and some of these are presently being investigated at Wageningen through the TTMI project prior to their use in the field in Kenya, this being an example of the use of a linked project.

Lysimeters are large and expensive pieces of equipment. Parts of these could be fabricated in developing countries and it is possible that with the purchase of some parts from overseas a commercial equivalent could be produced. Comparison with simple 'oil drum' lysimeters could then take place locally.

Discussion

The consideration of instrumentation has been divided into the appropriateness of instrumentation and appropriate instrumentation. The former covers the functioning of commercial equipment under optimum conditions and extreme conditions. Appropriate instrumentation refers to the construction anduse of simple equipment whose maintenance and use is within the general skill levels locally available and whose accuracy is acceptable.

The cost of locally built appropriate instruments can be assessed. If the development is the first one attempted, the cost will be relatively high and the major part of this will be the development costs. These will include initial equipment such as soldering irons, multimeters, oscilloscopes, trial components; and the time spent by personnel. While hardware can be easily costed, time estimation is more difficult except in an industrial situation where the criterion is profit versus loss. One of the important initial considerations concerning the building of appropriate equipment is the cost advantage of doing so. High customs duties can increase costs so much that it could be cheaper to import a commercial equivalent. If this is the case little encouragement is given to local developments unless duty is waived and even if this is done the time taken to clear such items can be very dispiriting.

From the point of view of training, established courses can be costed; but frequently such courses, necessary as they are, lack relevant 'hands on' experience. Such experience is best gained in trying to solve real problems in the country in which they occur. In institutes of learning, training and research or development are the basis of the job and the training of one person helps others. In such a situation costing of time is more difficult. What is more important is the question of which endeavour is most profitably started with reference to perhaps numerous aims (Appendix).

Some of the difficulties that occur in the transfer of methodology and technology involve language. The developmental state of a language has important implications in this, since some languages have been able to embrace the abstract concepts associated with modern technology while others have not. Whether we are involved in the testing of commercial equipment or the building of appropriate equipment, this problem will exist. The development *of a lingua franca* is necessary and will naturally occur with the people involved in the various endeavours. (English has shown itself to be a convenient scientific language).

Unless we continue to find ways of dealing with the problems outlined, developing countries will be increasingly and adversely affected.

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Appendix:
Considerations for appropriate instrumentation (AI)

Scientific and educational requirements	**AI considerations**
Type of measurement required	Develops awareness of sensor applicability and specific measurement needs
Level of sophistication and accuracy	Develops awareness of minimum requirements and performance limits
Usability and durability	Develops awareness of practical aspects of equipment
Performance	Analysis of performance and possibility of improvement and tropicalization
Distribution and availability	More data required or more students using equipment simultaneously

Overcoming constraints	**AI Considerations**
Lack of funds	Possible cheapness of AI
Lack of foreign exchange	Possible purchase of components locally
Long acquisition time	Can be longer or shorter depending on complexity of AI
Lack of trained personnel to operate or maintain sophisticated commercial equipment	Simplification and dedication of equipment for local operation
Maintenance problems	Locally built, therefore locally maintained
Restricted distribution or access	Local production, maintenance and possible cheapness will increase distribution

Training of local staff	**AI** Considerations
Design and development skills Fabrication skills Maintenance skills Improvement of local confidence	Result from local investigations of commercial equipment and local production of equipment

The design and analysis of experiments to monitor agroforestry systems

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Abstract

The experimental designs available for monitoring agroforestry systems both on a large scale and for measurement of microclimate will be reviewed. These will include designs for investigating the treelcrop interface as well as conventional field plot trials. Analyses appropriate to the designs will be suggested.

Why design experiments?

A glance through the literature relating to the measurement of microclimate and other environmental variables will reveal large amounts of data which are the results of isolated observations rather than designed experiments. The usefulness of this work could be greatly improved by the use of properly designed experiments incorporating the principles of randomization and replication. Without replication it is impossible to judge whether an observation is an isolated freak result or is typical of the system being studied, and without randomization there is always a risk of bias.

Designs for agroforestry

It must be remembered that the same basic experimental designs are just as appropriate for agroforestry experiments as for other field experiments, and the same analyses are, in general, equally valid whether the variable being measured is yield or is an environmental variable. Thus the need for blocking and other devices to control the residual variation or 'error' still applies in agroforestry experiments, and the advantages of using a factorial design are just as great. Further details on these subjects may be found in any textbook on experimental design (e.g., Cox (1958), which is very readable). In addition the literature on the design of intercropping experiments is of considerable relevance to agroforestry and has been reviewed by Mead and Riley (1981).

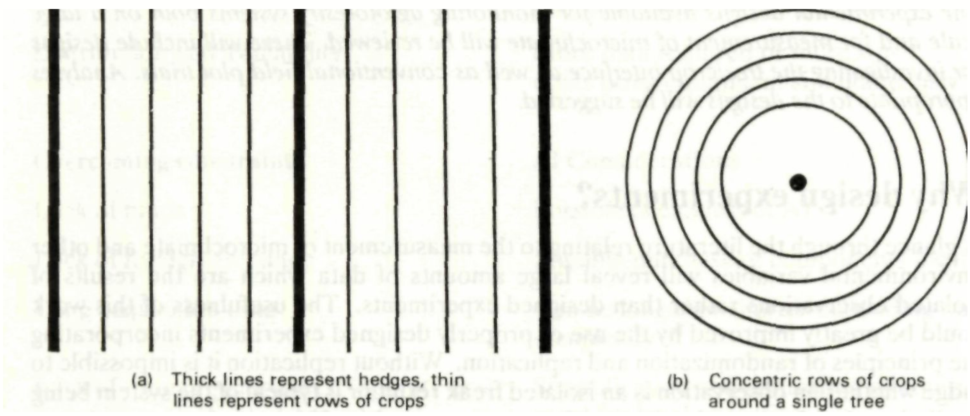
It is not, of course, possible to list the best design for every conceivable experiment. Instead I will discuss those designs which seem to have the most potential for use in agroforestry, using the following headings:

- simple designs for investigating the tree/crop (or tree/tree) interface;
- systematic designs for spacing experiments; and
- general designs for agroforestry systems.

Simple designs for investigating the tree-crop interface

Figure 1 shows two designs given in Chetty (1986) which could be used to investigate the interface. The designs should be replicated unless they are purely observational and in the case of Figure la the orientation should be randomized (perhaps with just two possible orientations). In both cases the analysis will involve fitting response curves describing the change in the variable measured with increasing distance from the interface. In Figure la, the effect of orientation could be considered and in Figure lb, aspect (north, south, east or west).

Figure 1 Two designs for investigating the tree-crop interface:
(a) parallel rows of trees and crops;
(b) concentric rows of crops around a single tree.
Thick lines represent hedges; thin lines, rows of crops.

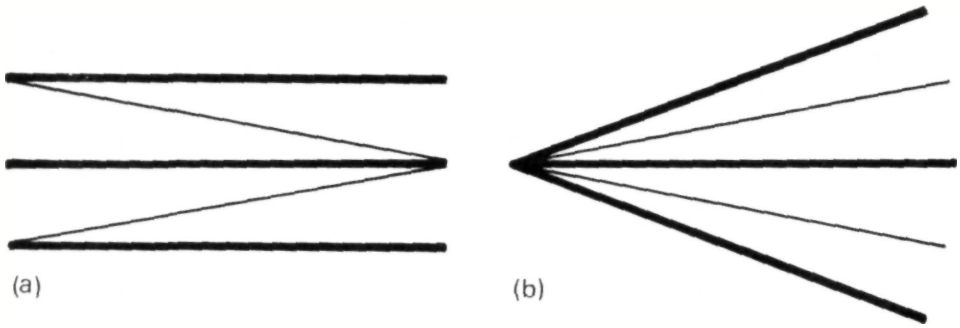


Systematic designs

Many agroforestry experiments are designed to investigate the optimal plant spacing for a particular system and in this type of experiment traditional, fully-randomized designs have a number of shortcomings. Even where the spacing of only one component of the system is to be investigated, the number of'treatments' (i.e., different spacings) is liable to be comparatively high and, combined with the need for adequate guard areas to separate the different spacings, this results in an unacceptably large block size for a randomized complete block design. Even when an incomplete block design is used a considerable proportion of the experimental area will be taken up with the guard areas. Secondly the size of the plots needed will depend on the spacing used: closely spaced plants requiring a smaller area. This may create problems in arranging the plots in the field, unless all plots are made the same size as the largest, which again results in a waste of the experimental area.

The solution to these problems is to use a systematic design in which spacing varies in a regular fashion, thus removing much of the need for growth areas. Figure 2 shows two very simple systematic designs for a hedge-crop intercropping situation. Suitably replicated, the effect of spacing could be investigated by examining the change in yield, or any other variable, along the length of the plot by fitting an appropriate response curve. One of the five systematic designs proposed by Nelder (1962) for use in mono-cropping situations is shown in Figure 3. The shape of the area available to each plant is constant, but its size increases radically; another of Nelder's designs varies the shape but keeps the area constant. These four designs suffer from the disadvantage that the crops are not rectangularly arranged, but lie on the arcs of circles. Bleasdale's (1967) parallel row design (Figure 4) avoids this, although at the cost of confounding the effects of area and shape.

Figure 2 Two simple designs in which spacing varies systematically. Thick lines represent hedges; thin lines, rows of crops.

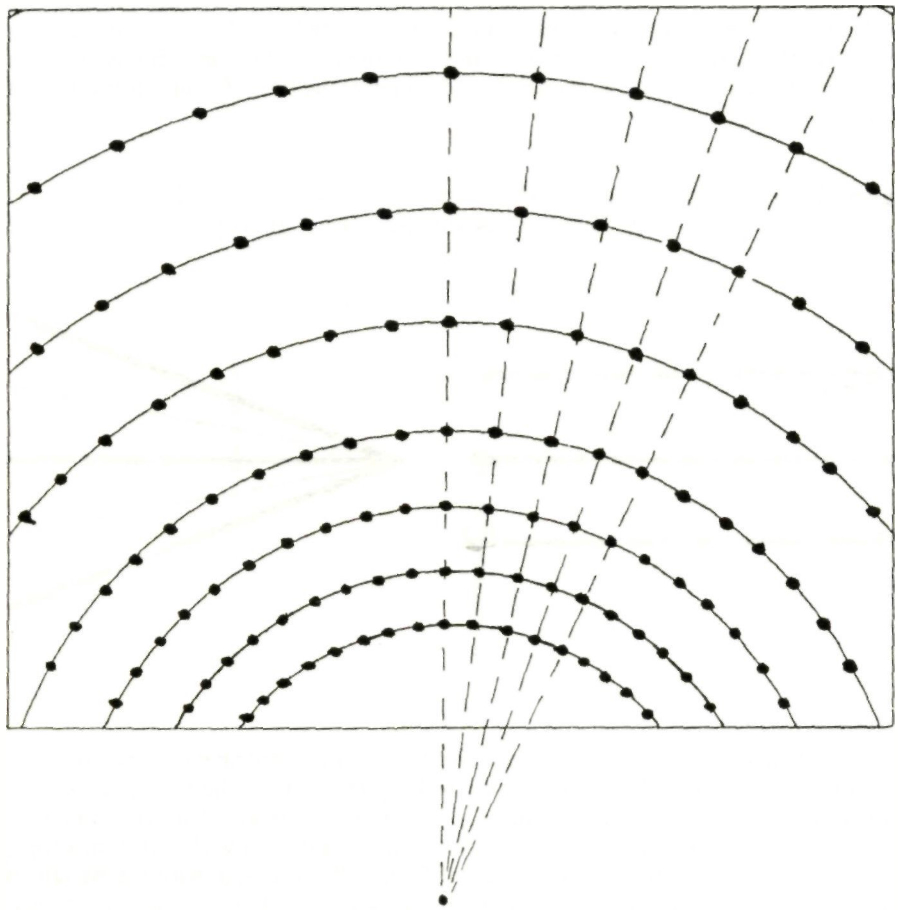


These designs can be adapted to deal with a system involving more than one species in a number of ways. Where it is desired to keep the ratio of the two species constant but vary the overall density a certain proportion of the 'spokes' (radii) can be planted with each species. Planting alternate spokes in a fan design with different crops, for example, will produce the simple design of Figure 2b (although with the within spoke density varying as well as the distance between spokes). Where the density of only one of the species is to be varied it is planted in the positions indicated by the fan design while the other species is planted on the same land at its usual spacing.

Figure 5 provides a design which allows the effect of independent variation of the densities of two crops to be examined. It consists of two parallel row designs arranged at right angles; the scale of the two designs can, of course, be different to allow for differences in size and desired density between the two crops. Analysis is again by examining response curves, but since both densities are varied, the response surface in two dimensions is now of interest. A nearest-neighbour type of analysis, which will be discussed later in this paper, may also be of use in this experiment.

Before leaving the subject of systematic designs a word of caution should be added. These designs were developed by Nelder, Bleasdale and others for use at experimental stations in Britain where the land was known to be fairly homogeneous. They should not be used on land with a trend across it, or on land that has not been studied previously, since any such trend could seriously distort the results. Even where no trends are believed to exist, the experiments should be replicated, with the replications at different orientations; this will in any case help to eliminate factors such as wind funnelling, the

Figure 3 A fan design (Nelder 1962).



effect of which depends on orientation. As long as the design is properly replicated small scale heterogeneity is less important, but will result in differences in the response curves between the replications.

Another disadvantage of the designs is that the death of one tree has an effect on the effective spacing of the neighbouring trees. It is therefore important to grow some non-experimental plants of a similar species and age nearby to act as replacements in the event of this occurring. For similar reasons systematic designs are not generally useful when thinning must be carried out during the course of an experiment. Finally it should be noted that while guard rows are not necessary within each replication, they are still needed at the edges and between the treatments where the experiment involves factors other than spacing.

Figure 4 A parallel-row design (Bleasdale 1967).
Individual plants are shown only in the central section.

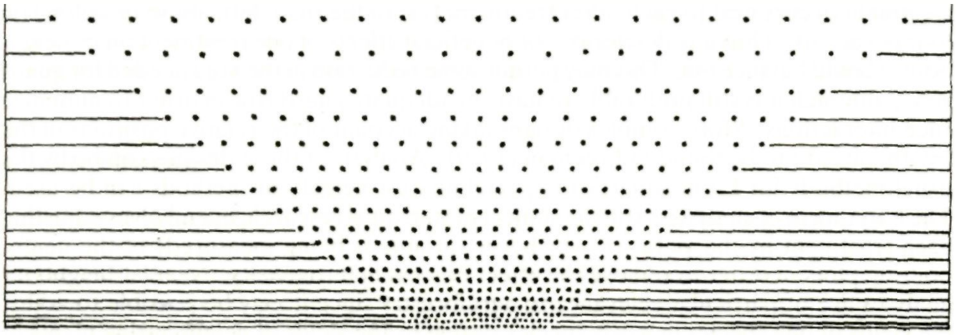


Figure 5 Two superimposed parallel-row designs. Vertical lines indicate rows of trees; horizontal lines indicate rows of crops.

General designs

As was stated above, agroforestry experiments can use the same designs that are used in single-species agronomic or forestry experiments. However, I want in this section to look at one or two more unusual designs which are particularly useful for agroforestry.

Figure 6 shows an example of a nearest-neighbour design; it can be seen that each treatment occurs next to each other treatment (i.e. to the right, left, above or below) on four occasions. Thus any deleterious or beneficial effects of one treatment on its neighbours should balance out. This may permit some reduction in the area needed for guard rows, although it is still preferable to have an adequate guard row in order to minimize such interactions. More complex designs taking account of the relative positions of the treatments are to be found in Freeman (1979). Analysis of these designs can be by the usual methods for Latin squares or special nearest-neighbour methods can be used. The latter form of analysis is still the subject of statistical research, but involves adjusting each treatment by the yield (or whichever variable is being measured) of the neighbouring plots in order to remove the effect of local heterogeneity. Nearest-neighbour analyses are of particular relevance to agroforestry since it may be possible to adjust the yields of one species in a two-species system by the yields of neighbouring plants of the other species.

Designs balanced for neighbours have also been worked out for the situation where plots are arranged in a long strip, so that only two neighbours need to be considered. These designs and their analysis are considered by Dyke and Shelley (1976).

Figure 6 A nearest-neighbour design based on a 5 x 5 Latin square.The numbers represent five different treatments.

```
1 2 3 4 5
4 5 1 2 2
2 3 4 5 1
5 1 2 3 4
3 4 5 1 2
```

Figure 7 A beehive design. The symbols o and x represent two different species. The full design consists of two hexagons, with the positions of the two species interchanged in the second one.

```
    X X X X X
   X X 0 O X X
  X O O X O O X
 X O X O O X O X
X X O O O O O X X
 X O X O O X O X
  X O O X O O X
   X X 0 0 X X
    X X X X X
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In most experiments plants are arranged in rows but, if the interactions between individual plants are of interest, a hexagonal grid can be useful and such arrangements have been used in competition experiments. These designs are termed beehive designs and further information about them may be found in Veevers and Boffey (1975) and Martin (1973). An example is shown in Figure 7 in which o and x represent two different species. It can be seen that different plants have different numbers of neighbours of the other species, thus allowing the measurement of competitive effects. Hexagonal designs can be easily adapted to the situation where more than two species are involved and provide a greater number of inter-specific interfaces than in a row layout.

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Sampling procedures

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Abstract

Where large plantations are being studied it is necessary to use some form of sampling. The various methods available (eg.simple random sampling, stratified random sampling and systematic sampling) will be discussed. Particular attention will be paid to the situation where climatic variables can be used as a basis for stratification.

Why sample?

In any scientific investigation there will be situations where it is advantageous to use some form of sampling. There are three basic reasons why this may be the case:

1. Complete enumeration might take too long or be too expensive due to the large number of measurements needed; e.g., we might wish to find the average height of the trees in a 10,000 ha forest;
2. Destructive measurements: for example, the true germination rate of a batch of seeds could be found by growing them in a laboratory, but this would leave none to sow in the field;
3. In some circumstances sampling may actually give more reliable results than complete enumeration. This may arise if the smaller number of measurements allows more care to be taken over each or permits the use of more sophisticated equipment, leading to more accurate measurements.

Definitions

In everyday speech the words 'accuracy' and 'precision' are nearly synonymous, but in the context of sampling they have different meanings. **Accuracy** refers to the success in estimating the true value, whereas **precision** describes how closely clustered the values of successive estimates are. To make this clearer, consider the measurement of wind speed. If we asked four people to guess the speed and took an average of their guesses, the result might, by chance, be very accurate (i.e. close to the true speed), but would probably be imprecise (the four estimates are likely to be very different). On the other hand, if we took four readings using an anemometer which always under-recorded the speed by 20 per cent, the results might be precise, but not very accurate. The latter result could also be described as **biased;** that is, it contains a systematic error. Whether precision or accuracy is more important depends on the situation being investigated, although both properties are obviously desirable.

In a sampling procedure the objects or sites, on which individual measurements are made, are termed **sampling units** and the **population** consists of all such sampling units. A sample refers to a group of sampling units selected from the population, on which measurements are made.

Simple random sampling

In simple random sampling not only does each sampling unit in the population have the same chance of inclusion in the sample, but each combination of n units (where n is the sample size) is equally likely to be included. This is achieved by randomly selecting each unit in the sample from amongst the whole population.

The method is best considered by taking an example. Suppose there are forty shade trees in a section of a coffee plantation and we wish to make a variety of measurements at the tree-crop interfaces of a sample of these trees. (Thus in this case the sampling units are the trees or, more specifically, the forty interfaces.) The stages in taking a simple random sample are:

1. Decide on the population. This might be all forty trees, or we might wish to exclude trees on the edge of the plantation, for example.
2. Decide on the sample size. This will depend on the equipment available and the precision required for the final estimates.
3. Select the sample by a random method (usually by using tables of random numbers). Beware of semi-random methods, such as throwing quadrats; these lead to bias.
4. Take the measurements and calculate means and standard errors.

Systematic sampling

One problem with simple random sampling is that coverage can be very uneven. Thus in the example of the last section all the trees selected to form the sample might come from the same corner of the plantation. An obvious way to avoid this is to select a regular pattern of sampling units (e.g., every fifth tree); this is systematic sampling. To give another example, in a soil survey of an area of land a grid of squares would be drawn on the map and a soil sample taken from the same position within each square. The particular systematic sample chosen must be selected at random and the simplest way of doing this, in order to avoid all risk of this, is to choose one sampling unit at random from amongst the whole population, and then to select the other units in the sample relative to it.

The advantages of systematic sampling are as follows:

1. Its even coverage will frequently lead to greater precision than a simple random sample;
2. Once the random starting point has been chosen the process is very simple to operate;
3. The information obtained can easily be used to construct a map, if desired;
4. The population size need not be exactly known at the start.

The chief disadvantage of systematic sampling is that the precision cannot be calculated and so no reliable standard error can be quoted for the mean. Approximate formulae, which give some idea of the precision subject to certain conditions, are to be found in Yates (1981) and Cochran (1977). How important knowledge of precision is will depend on the purpose of the experiment and the nature of the variable being measured; the experimenter must weigh this against the likely advantages before deciding to adopt systematic sampling.

One situation where systematic sampling should be used with care is when there is some form of periodicity or regular variation amongst the sampling units. For example, it is obviously unwise when sampling soil on terracing 10 m wide to adopt a systematic sample at 10 m intervals (or 20 m or 30 m, etc.), since all samples will be at the same position relative to the terraces. Even when the sampling interval is not particularly close to the scale of periodicity (or a multiple of it) there is some risk of bias, especially in small samples. Unaligned systematic sampling may help in this situation (see Cochran 1977).

Stratified random sampling

Both the methods discussed so far have not exploited the structure of the population; stratified random sampling divides the units into two or more strata, grouping similar units into the same stratum. Separate estimates are then obtained for each stratum, usually using simple random sampling, and these are finally combined to give an overall estimate. Provided the sampling units in a stratum really are less variable than units in different strata, this method provides a more precise estimate than does simple random sampling. In addition the method is very useful where separate estimates are in any case needed for different sections of the population, or where it is desirable to divide the population for administrative reasons. One slight disadvantage is that it is necessary to know the sizes of the strata.

Many different factors can be used to stratify the population; for a large survey (e.g., over a whole region) it might be possible to use climatic data, where these exist. Otherwise factors such as geographic area, soil type, height above sea level, or land ownership can be used. Satellite photographs have formed the basis for stratification in some studies. On a smaller scale, any past or present knowledge of the site can be used. Where the edge of a plantation or plot is different from the centre, this can possibly be treated as a separate stratum.

Formulae for the estimates and their standard errors can be found in any of the books recommended below. These books also contain advice and formulae relating to the number of units that should be sampled from each stratum.

Discussion

In conclusion, the relative merits of the methods discussed can be summarized as follows: Simple random sampling is adequate for populations that are fairly homogeneous, particularly where the total number of units is small. Stratified random sampling, on the other hand, should be used when the population is heterogeneous, but can be divided into more homogeneous sub-populations. Systematic sampling is a good procedure to adopt when even coverage is important, but is not appropriate if exact knowledge of the precision is required, and should be used with care when there is any regular variation amongst the sampling units.

This review of sampling procedures is by no means exhaustive and the following topics would repay some study for those doing a lot of sampling; multistage sampling, cluster sampling, and ratio and regression estimators (including double sampling as a means of updating surveys, which is described in Freese (1961)).

Acknowledgement

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References and further reading

The following books are readable, and do not demand a high level of mathematical knowledge:

Freese, F. **1962.** *Elementary forest sampling.* U.S. Department of Agriculture Handbook No. 232.

Freese, F. 1984. *Statistics for land managers; an introduction to sampling methods and statistical analysis for foresters, farmers and environmental biologists).* Paeony Press. (This is the same as the 1962 Freese book.)

Sampford, M.R. 1962. *An introduction to sampling theory.* Edinburgh and London: Oliver & Boyd. (This book was written for agriculturists, and is highly recommended).

Webster, R. **1977.** *Quantitative and numerical methods in soil classification.* Oxford: Clarendon Press. (Chapters 4-6 cover sampling, with particular reference to soil sampling).

When further details are required the books below should be consulted. However, they are not nearly as easy to read as the above and are therefore of much less use to the beginner.

Cochran, W.G. 1977. *Sampling techniques.* New York and London: John Wiley and Sons.

Yates, F. 1981. *Sampling methods for censuses and surveys.* London: Griffin.

Finally, the following guide, which is not yet published, should be a very useful source of advice on the practical details of sampling in a forest:

Adiard, P.G. (in preparation). *Guide to the establishment, measurement and analysis of permanent sample plots.* Oxford: Forestry Institute.

The analysis of data from several sites and years

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Abstract

The collection of data from different sites and/or years gives rise to a data set subject to both spatial and temporal variability caused by climatic and other variables. Any statistical analysis of the data must take into account these different types of variation; a review of the available methods with reference to agroforestry experiments is presented.

Introduction

It is common practice to extend the results of a simple experiment by repeating the trial at a number of different sites or over a number of years. Such extensive experimentation will provide information about the treatments or genotypes under a range of environmental conditions. Although sites may be chosen according to similarities of soil-type, climatic or other factors maybe present that will give rise to possible differences in the results obtained. Experiments repeated over years will be subject to fluctuations in weather patterns. The analysis of data from such a range of environments permits the experimenter to determine the sensitivity of his treatments or varieties to a range of conditions and to provide recommendations about their use for a wider geographical area.

The data collected from such an experimental scheme, however, present substantial problems of analysis. Statistical analysis depends heavily upon the idea of randomness; data collected from a number of locations or from several years cannot be considered random: sites are chosen for their particular characters; and years, in terms of climate, can be considered to be correlated to some degree. Particular techniques thus need to be adopted when analysing data from treatments or varieties collected from a number of environments. Where the environments are represented by different points in time it is sometimes possible to examine the behaviour of the varieties by response curves over time with possible adjustments for seasonal effects. This is discussed in greater detail in the following paper (this Section) by S. Langton. Concentration here is on the more general data set classified according to treatments (or genotypes) and environments.

Analyses available

Much statistical research has been done on the examination of genotype x environment data sets and, since no single technique has been found for analysis, research is continuing. A summary of suitable approaches to the analysis of such data sets is given in Freeman (1973). More recent work was presented by Silvey (1982) and by Goodchild (1982) at the Xlth International Biometric Conference.

Although each data set requires analysis tailored to its structure, a common approach to the analysis of data collected from different environments is as follows:

1. Analysis of variance of the complete data set to determine whether genotype x environment interactions exist; if they do not exist, there is little problem but if they do exist, then interactions need examination.
2. Joint regression analysis of genotype yield on environment as described by Finlay and Wilkinson (1963) to detect genotype sensitivity to changes of environment.
3. Multivariate analysis of the genotype x environment table, possibly by one or more of the following methods:

   — principal components analysis;
   — canonical variate analysis;
   — cluster analysis;
   — principal coordinate analysis; or
   — significant rank ordering.

Analysis of variance

A most important part of any statistical analysis is to determine the questions that are to be answered. When data are collected at a number of sites, are recommendations required for each site, for groups of sites or for the one area incorporating them all? Only with this information can a relevant analysis be produced. If data are to be combined from different environments then an analysis of variance accounting for the main effects of genotype and of environment and for their interaction will determine whether any substantial interaction exists. Subdivision of the main effects and interaction into components of interest are described by Cochran and Cox (1957) together with appropriate significance tests.

Joint regression analysis

If genotype x environment interactions exist these can be examined in more detail by regressing the genotype means upon a variate of environmental indices. The sum of squares for the interaction can thus be subdivided into a component for the heterogeneity of these regressions and a remainder component. Each of these components can be subdivided correspondingly into comparisons of interest. Environmental indices can be determined in different ways. Wood (1976) examines a number of them. The usual choice of index is the mean yield of all genotypes at each environment, but others are the yield of control genotypes; climatic variables such as rainfall, altitude, temperature; environmental variables such as N% in the plant or the P content of soil; or even a combination or function of several of these external variables. The method of joint regression analysis provides useful indications of the behaviour of each genotype as external conditions vary. Response to environmental change cannot always be expected to be linear and an extreme index value for one site may well distort results. In practice it would be wise to perform such regressions for several different forms of index to avoid the use of spurious results.

Multivariate analysis

The data in the two-way genotype x environment table can be considered as a multivariate set in order to investigate the variation within it more fully. Principal component analysis can be used to identify those environments that are most influential in the production of interactions. Similarly, the technique can be used to identify groups of genotypes contributing largely to the interaction. The method is described clearly in Holland (1969); a brief outline is given here.

Principal component analysis involves the transformation of the original variates into a new set, usually of fewer variates, which are independent and which successively account for maximum proportions of the total variation. The independence property means the new variates are more easily examined by standard statistical methods; the fact that fewer variates are involved means that calculations are less cumbersome. Although principal components do not necessarily correspond to biological interpretations, Holland (1969) shows that by geometrical manipulation linear functions of the original variates can be found, having biological meaning, thus aiding more fully in the interpretation of the data. Canonical variate analysis has been used by Paterson (1974) to test whether the environments differ in their response to the treatments (-genotypes). Although the treatments are not random effects, Paterson was able to produce a satisfactory analysis, although the method appears to be of most use with large data sets.

Other methods used are cluster analysis and principal co-ordinate analysis. In cluster analysis, attempts are made to find similarities between clusters of environments using the yields from the treatments or genotypes. Various methods for calculating similarities exist and these may give rise to different clusters. Principal coordinate analysis has also been used by Shukla (1972) to demonstrate groups of genotypes making similar contributions.

A recent approach to the examination of genotype x environment interaction data is presented in Beale and Goodchild (1980). They used analysis of variance followed by a ranking process and called this significant rank order. It should be noted that this approach was suitable for the data in question, analysis of variance alone and ranking procedures alone not being used because of the nature of the variation in the data and the small number of replicates. Analysis of variance was used for the data from each environment (site) separately to provide least significant differences (LSDs). The means for the genotypes within each site were then ranked and grouped together if their difference was less than the appropriate LSD. The groupings obtained were compared from site to site. Interactions could be clearly seen through such examination. Care, however, is needed when using the LSD since its use over many pairs of means gives low precision.

Discussion

If data from many sites are required to be combined then no single method of analysis exists. Exploration of the data is necessary by several approaches: joint regression analysis to determine the response of the genotypes to site fluctuations and multivariate approaches to determine clusters within sites (environments) or within treatments (genotypes). The nature of the experiment and the form of the data will need close scrutiny to indicate which analyses are suitable and whether any further modification of the analyses is necessary; no routine form of analysis is possible, the analyses chosen depending upon the information required from the data.

Acknowledgement

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The analysis of data collected over time

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Abstract

Experiments are frequently carried out on the same experimental plots over a number of years. This poses a number of problems which will be described, together with the proposed solutions. In particular, the use of response curves for describing changes in yield over time will be considered.

Introduction

One difference between experiments involving trees and those involving field crops only is that the former generally continue for a period of years, whereas the latter often only last for one year or season. Thus in agroforestry experiments the data frequently consist of sets of successive measurements of the variables of interest, one set for each year or season, with the same treatments being maintained at each plot through the experiment (this situation should not be confused with a cross-over type of experiment, where different treatments are applied successively to the same experimental units). Such data are referred to in the statistical literature as 'repeated measurements', and the best way of analysing them has been a subject of considerable controversy.

Methods of analysis

The simplest method of dealing with repeated measurements of this sort is to sum or average them over time, and then carry out an analysis of variance on these sums or means. This analysis is perfectly correct from a statistical point of view, but provides no information regarding changes in the data with time.

One procedure that has been used to produce such information is simply to produce a separate analysis of variance for each time or season. Each of these analyses, with its associated tests of significance, is completely valid but, because results in successive seasons will almost certainly be correlated, the analyses are not independent of each other. In practice this means that, for example, significant treatment effects in five successive years in the experiment do not provide such good evidence for real differences between treatments as would significant treatment effects in five totally separate experiments. This type of analysis is not as attractive as it appears at first sight.

One common, but erroneous, method of analysis is to treat time as a factor, usually a sub-plot factor in a split-plot analysis. The first objection to such an analysis is that time can never be properly randomized; each treatment is in its second year of growth in the same calendar year, for example. Randomization is, of course, essential for a valid analysis of variance. A further problem with the split-plot analysis is that the sub-plot error is unlikely to be homogeneous, because observations closer in time are likely to be more closely correlated than those further apart (Rowell and Walters 1976). Similar objections apply to the 'split-block' or 'criss- cross' type of analysis which is sometimes recommended.

Multivariate methods have sometimes been used for the analysis of repeated measurements (Cole and Grizzle 1966) and this approach is unquestionably valid. Unfortunately these methods are conceptually more difficult and the results are not always easy to interpret. Hence there is a strong case for avoiding a multivariate approach where there is an alternative that is statistically sound.

The fifth method provides such an alternative; it was first used by Wishart (1938) and was described in detail by Rowell and Walters (1976). It involves the analysis of contrasts over time, and is discussed below.

The analysis of contrasts over time

The hypothetical example that I will use to describe this method consists of an experiment arranged as three randomized blocks of three treatments each (Table 1). The treatments are actually three different agroforestry systems and the objective of the experiment is to compare the changes in soil moisture content between the systems. Measurements were taken every 30 days over a period of 90 days following rain; during this time there was no rain or irrigation so the soil moisture content shows a continuous decline.

Table 1 Hypothetical data for analysis

	Day:		30	60	90
System	Block		Moisturecontent, %		
	1	19.83	14.83	12.17	8.67
	2	20.58	14.58	11.92	9.42
	3	21.08	17.08	12.42	7.92
	1	20.58	19.25	17.58	9.08
	2	19.33	20.00	19.33	12.83
	3	20.58	19.25	17.58	13.08
	1	19.67	17.50	14.00	12.33
	2	19.67	17.50	15.00	11.33
	3	19.17	18.00	16.50	11.83

NB: Variables measured on a percentage scale should normally be transformed before analysis.

The first stage in the analysis is to plot the mean soil moisture content for each system against time (Figure 1). This graph clearly shows that the moisture content is decreasing