

# The ecological effects of eucalyptus

FAO  
FORESTRY  
PAPER

59



FOOD  
AND  
AGRICULTURE  
ORGANIZATION  
OF THE  
UNITED NATIONS

# The ecological effects of eucalyptus

by  
**M.E.D. Poore**  
and  
**C. Fries**

First Printing 1985  
Second Printing 1986  
Third Printing 1988

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

M-32  
ISBN 92-5-102286-0

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying or otherwise, without the prior permission of the copyright owner. Applications for such permission, with a statement of the purpose and extent of the reproduction, should be addressed to the Director, Publications Division, Food and Agriculture Organization of the United Nations, Via delle Terme di Caracalla, 00100 Rome, Italy.

## FOREWORD

Currently, world forests are being cut at many times the rate at which they are being replaced. In tropical countries, as an average, only one hectare is planted when 10 hectares of natural forests are being cleared. There are high and increasing demands for wood for industrial use and fuel needs especially in developing countries of the tropics with their increasing populations. To cope with this situation, option is often taken to plant fast-growing, highly utilizable, exotic tree species. One such exotic group is found in the more than 600 species of the genus Eucalyptus, whose popularity as plantation species is attributable to their being generally very adaptable, fast growing and with a wide range of utility from sawn wood and processed wood products to high calorific value fuelwood as well as a variety of environmental and ornamental uses. Such popularity may be judged by the more than 80 countries that have shown an interest in eucalypts and have planted more than 4 million hectares world-wide outside the natural range of Australia, S.E. Asia and the Pacific.

Yet amongst this popularity there has been a growing body of opinion that claims that eucalypts cause a variety of short to long term ills, impoverishing the environment in respect of the soils, water availability and wildlife even where plantations have been planted on waste lands devoid of tree cover. Some countries have even banned the planting of eucalypts.

It was because of the mounting criticism on one side and the large potential benefits that eucalypts can confer on forestry programmes in developing countries on the other that FAO decided to accept the offer made to it by the Swedish International Development Agency (SIDA) to carry out this study. The aim of the study is to analyse as dispassionately and objectively as possible the available information on the ecological effects of eucalypts and present the results in a condensed form.

FAO is indebted to Professor D. Poore and Mr. C. Fries, the consultants who researched and wrote the study and to Messrs. Gutierrez de la Lama (Spain), W. de P. Lima (Brazil) and C. Malvos (France) who supplied much useful specialist advice; and for the bibliographic assistance of the Director, Librarian and Staff of the Commonwealth Forestry Institute (CFI, UK) and the Director and Staff of the Centre Technique Forestier Tropical (CTFT, France), which proved invaluable.

It is hoped that the study will be useful to foresters and other land use planners and managers to better understand the relations between eucalypts and their ecological environment and put in proportion those too definite statements either in favour or against eucalyptus.



J.P. Lanly  
Director  
Forest Resources Division  
Forestry Department

CONTENTS

INTRODUCTION	1
The problem	1
The approach	2
CHAPTER I	
INFLUENCE ON THE WATER CYCLE	4
Introduction	4
The water cycle	4
Ecological effects	9
Climate	9
Microclimate	9
Interception	9
Throughfall and stemflow	13
Recharge of soil water	13
Surface run-off	14
Stream flow	14
Ground water	15
Shelterbelts and agro-forestry mixtures	15
Experimental catchments	16
Harmful effects of removing eucalypt forests	17
Discussion and conclusions	18
General conclusions and guidelines	20
CHAPTER II	
EROSION	21
Water erosion	21
Shelterbelts and wind erosion	22
CHAPTER III	
NUTRIENTS	
Introduction	23
Possible effects of <u>Eucalyptus</u> on the nutrient balance	25
Effect on input	27
Effect on outputs	27
The effects of eucalypts on soil quality	
- without cropping	31
Eucalypts on previously treeless sites	36
Comparison with managed forests of sal ( <u>Shorea robusta</u> ) and of sal plantations	37
Comparisons with pine	37
Eucalypts on peat	38
Conclusion	38
The effects of eucalypts on soil quality	
- with cropping	38
Direct effects of removal of the biomass	39
Indirect effects of harvesting	39
Nature of the evidence	40
Nutrient cost and conclusions	42
Guidelines	42

CHAPTER IV	
COMPETITION AND REPLACEMENT	44
Introduction	44
Competition effects	44
Replacement effects	45
Eucalypts and undergrowth	45
Eucalypts and neighbouring agricultural crops	46
Allelopathic effects	46
Eucalypts and animals	48
Comparison of natural (non-eucalypt)	
forest with plantations of eucalypts	
and of <u>Araucaria</u>	48
Comparison of indigenous eucalypt	
forests with eucalypt plantations	49
Comparison of indigenous eucalypt	
forests with forests of <u>Pinus</u>	
<u>radiata</u>	49
Conclusions	50
CHAPTER V	
SOME SOCIAL CONSIDERATIONS	51
CHAPTER VI	
CONCLUSIONS	53
Ecological effects	53
The nature of the research	53
The nature of the ecological effects	54
Conclusion	55



## INTRODUCTION

### The problem

The question of Eucalyptus plantations is one that arouses strong feelings, both for and against; and the arguments used by both the opponents and the supporters of eucalypts have often been based more on prejudice than on a balanced consideration of the facts. The genus has been a popular choice for introduction, especially in the warmer parts of the world, because of its rapid growth and the wide range of conditions in which the various species can grow. On the other hand these plantations have been strongly criticised in some quarters because they are alleged to cause adverse effects on soil (impoverishment and encouraging erosion), on hydrology (by drying up aquifers) and because they provide a relatively poor habitat for wildlife.

These criticisms are very varied. Some of them would apply equally to any other plantation species; for example that monocultures are more prone than mixed forests to the depredations of pests and diseases. Some separate eucalypts from other tree crops and claim that they are more harmful. Yet others are criticisms that are common to all introduced or exotic species, that they are unpalatable to indigenous animals and introduce a discordant note in the landscape.

At this stage it is perhaps worth pointing out the double standard that seems to be used in passing judgement on forestry crops in comparison with many agricultural crops. No one is surprised that the latter are often introduced species; indeed most crops in many parts of the world are of foreign origin (wheat, maize, rice, potatoes, manioc, rubber, oil palm, coconut and many others). No one is surprised either that the soil under agricultural crops becomes depleted if these are continuously cropped without adding fertiliser. But both of these features are considered grounds for criticism in forestry. A little of the same prejudice is beginning now to appear in considering the replacement of indigenous grazing lands by pastures of introduced species of grasses and legumes, but it is not nearly so strong as it appears to be in the case of exotic tree crops grown for wood. It is also strange and illogical that trees grown as agricultural crops or as ornamentals seem to be immune from this kind of criticism.

It should be remembered, too, in evaluating the ecological effects of eucalypts, that this is a vast genus, containing some 600 species (the exact number depends upon whether one takes a broad or a narrow view of what constitutes a species) of which at least 40 have been widely grown outside their natural geographical range. When it is realised that these are grown from the equatorial tropics, through the sub-tropics to arid, Mediterranean and warm temperate climates, from sea level to about 4000 metres altitude in the Andes, and on a very wide range of sites and soils, it should be appreciated that the difficulties of making valid generalisations are very great.

Some of the criticisms, too, have been caused by disappointed expectations rather than by ecological effects. Eucalypts have often been heralded as wonder species that will bring immediate solutions to local wood and erosion problems. When this is followed by plantings which fail, because they have frequently been of the wrong species or on the wrong sites, local peoples may be left with vegetation which is little if at all better than what was there before. The blame then often falls on the eucalypts rather than on the real culprit, which is bad forestry practice.



One of the principal reasons for planting eucalypts is because they grow more rapidly than other species on the same site; this increased growth is necessarily associated with a greater consumption of water. The question then arises: which is the more important in the circumstances of the case, wood or water?

The aim of this study is to provide a dispassionate survey of the available information on the ecological effects of eucalypts. It is hoped that this will be of value to those who are concerned in evaluating alternatives for development and land use, to the managers of forest and agricultural land, and to the interested public. It is hoped, too, that by dispelling some of the misunderstanding surrounding this subject, it will lead to better decisions about land use and to decisions that are more widely acceptable.

An annotated bibliography is included with the study. Each reference is classified according to subject and an indication is given of the usefulness of the particular paper to the subject of this review. It should be appreciated that not all references dealing with the cultivation of eucalypts are included, but only those that have some relevance to ecological effects. Also, many of the studies were designed to tackle other problems and the 'relevance classification' does not necessarily reflect the quality of the paper.

It should, however, be remarked that only a very few studies have produced reliable and statistically valid data from which firm conclusions can be drawn. Many dealt with only a part of the system or were not sufficiently rigorous in conception. Even the few comprehensive catchment studies produced results which, by their very nature, could not be extrapolated to other catchments with different hydrological characteristics or under different climates. Generally speaking the most useful literature was that which illuminated the general processes in the systems under review. This has important implications for the planning of future research work in this field.

The study is naturally limited to those subjects and regions for which published information is available. In fact the majority of the work carried out has been in few countries, principally Australia, Brazil, some Mediterranean countries and India. Almost all of it refers to plantations in blocks; there is little about row plantings, shelter-belts or agroforestry. But, if one is to judge by the results of the present review, one would expect the general principles governing the ecological effects of shelter belts and trees grown as cover crops to apply to eucalypts, qualified by any known features of the physiology of the eucalypt species in question.

#### The approach

This report is concerned with the ecological effects of growing eucalypts. The ecological effects of any course of action (such as planting eucalypts) can only readily be judged by comparing the results of that action against some alternative (such as doing nothing or establishing a pine plantation). It is therefore very important to place any observation or experimental result in its full context.

The kind of effect that might be expected from replacing an area of climax rain forest with an eucalypt plantation (such as *Eucalyptus deglupta* in the rain forest of Mindanao in the Philippines) will be completely different from that of planting the same eucalypt on deforested and eroded land, such as the chalk hills of Cyprus or the eroded uplands of Peru. The former might be considered ecological degradation, the latter land restoration. But even this statement contains a judgement of relative values.

There are several different ecological situations in which eucalypts may be planted, among them the following: in place of existing closed forest; in place of other natural vegetation such as savanna, scrub or grassland; on degraded or waste land either as a potential crop or to assist in the control of erosion; within agricultural land, as

shelter belts, part of agroforestry systems, or as intensively managed crops for wood production. It is important to understand circumstances such as these if the effects are to be sensibly evaluated. For example, the degradation or improvement of soil under a plantation of eucalypt can only satisfactorily be judged with reference to the condition before planting took place.

This review concentrates on the effects on physical and biological features (on micro- and macroclimate, on soils, on water, on populations of wild animals and plants); it includes, too, substitution effects such as the reduction in area of other ecosystems that are replaced by eucalypts. It does not deal in detail with social and economic effects; though these are touched upon in Chapter V.

To a great extent, however, this distinction is artificial. Most ecological effects can only be evaluated with reference to what society wants; for example - is wood or water more important in a particular locality, or wood rather than grass fodder? High consumption of water is a characteristic to be valued if the purpose of planting is to dry out a swamp, but it is to be deprecated, and may rightly be criticised, if it draws down the water table in an area where water is in short supply or can be used for a highly profitable irrigated crop.

If it is admitted that the ultimate importance of ecological effects is because of their social consequences, it is a short step to accepting the argument that the planting of eucalypts can only be sensibly evaluated by taking all benefits and costs into account and including within these the ecological effects.

A distinction should, however, be made between ecological effects that are reversible and those that can only be reversed at great cost, if at all. If a crop depletes nutrients, these can be replaced by addition of fertiliser; this is a matter of economics. The loss of soil by sheet or gully erosion, in contrast, is irreversible and should be treated more seriously.

Many of the experiments described below were conducted with a specific or limited purpose; the greatest caution must be taken in extrapolating their results to other circumstances. Conclusions about the hydrological effects of an experiment in an arid region are most unlikely to have much validity in an area with high rainfall.

Similarly many of the results refer only to a particular part of a wider ecological process. For example they may cover the effect of the foliage of a tree in intercepting rainfall. This measure only has significance if it is viewed in the context of the whole water cycle.

In each of the main sections that follow, we shall therefore start with an explanation in simple language of the processes described in it so that these can be seen in context and the reader can make his own judgement of the significance of the results.

The main body of the report deals with ecological effects in four chapters: the first is concerned with eucalypts and water; the second with soil erosion; the third with soil fertility, and the fourth, how the planting of eucalypts interacts with other living organisms - the effects that eucalypts may have in competing with or displacing these. These chapters will be followed by a short discussion of some of the socio-economic implications of planting eucalypts. The review will end with a chapter summarising the main conclusions.

## CHAPTER I

### INFLUENCE ON THE WATER CYCLE

#### Introduction

The main criticisms that have been launched against Eucalyptus plantations in this respect are that they deplete water supplies and that, on sloping catchments, they do not regulate the flow of water as well as the natural vegetation which they sometimes replace. Some of these alleged effects would apply equally to belts of trees and to isolated or scattered trees.

The evidence for and against these views will be examined in this section. Before doing so, however, it is necessary to describe some of the main features of the circulation of water between the atmosphere, the forest (or tree) and the soil.

#### The water cycle

The relationships between plants, soil and water are complex; but some understanding of them is necessary to appreciate the possible effects of eucalypts (or any other trees) on local hydrology. They are shown in diagrammatic form in Fig. 1.

When an amount of rain (A) falls on an area covered with trees, some (B) reaches the soil directly or by dripping through the foliage, while some (C) is intercepted by the tree canopy. Of this latter amount, a proportion (D) evaporates and is lost to the site and the remainder (E) reaches the ground by flowing down the trunk (stem-flow).

The density of the trees, the nature of the leafy canopy and the character of the trunk and bark are important in determining these quantities. So, too, are climatic factors such as the intensity of rainfall, temperature, windiness (leading to more D) and mist (leading to more C and subsequently to drip and stemflow).

Once rainfall reaches the soil, some (F) may flow over the soil surface (surface run-off). This is the main cause of soil erosion by water. Some (G) may evaporate directly to the atmosphere, while the remainder sinks into the soil.

The amount of surface run-off (F) and the way this water behaves on the surface of the soil, depend upon a number of factors: the intensity of rainfall (the more concentrated the rainfall, the greater the run-off); the slope and evenness of the ground; the presence or absence of a protective layer, of leaves or gravel for example, that breaks the force of the raindrops or slows the movement of water down the slope; the nature of the soil surface, and particularly whether it allows water (H) to infiltrate readily and fast.

Under the best conditions all the water will infiltrate; there will be no run-off. Under less favourable conditions the water will run over the surface to streams, increasing their peak flows. This water may carry soil with it (sheet erosion) or, if it is canalised (for example by trees, grass tussocks or rocks) it may excavate gullies and cause even greater soil loss. Water which runs off in this way is lost to the plants on the slope and, because it does not infiltrate the soil, it does not contribute to the 'base flow' (the regular, stable flow) of streams draining the area.

On the other hand the movement of water once it has penetrated the soil is much affected by the climate. In dry climates or seasons (when the potential evapotranspiration is greater than the precipitation) there is a net movement of water upwards; in wet climates or seasons the movement is downwards.

There is very little upward movement of water in gravels or sands but in fine textured soils there is movement upwards through capillary action. This is why, in arid climates where the net movement of soil water is upwards, clay soils dry out more and are thus effectively drier than sands, whereas the opposite is the case in wet climates where the net movement of water is downwards.

When sufficient water penetrates the soil it can retain a certain amount (I) against the force of gravity. This is known as 'field-capacity'. Any surplus water (K) drains downwards to the water table (the level at which the soil is permanently saturated) and thence into streams, rivers or deep underground aquifers. The amount which is retained in the soil in this way is affected by the volume of soil, its texture and the organic matter in it. For example soil erosion reduces the amount of water available to plants by reducing the volume of soil; loamy soils hold more water than sands and gravels.

Plants rooting in this volume of soil can use most of the water to which their roots have access. They incorporate a small quantity of this in their living tissue and transpire the remainder (L) to the atmosphere. The total amount used depends upon the climate, upon the distribution of roots and upon the volume of soil occupied by them.

If there is plenty of water, the total evapotranspiration (evaporation from the ground plus the transpiration through the plant) depends largely on the radiation reaching the ground or the surface of the vegetation. In other words it is determined by the energy balance at the particular site rather than by the kind of vegetation. Thus it is roughly the same from any equal area, whether of lake, grassland or forest. This is a characteristic of the water cycle that is often not understood.

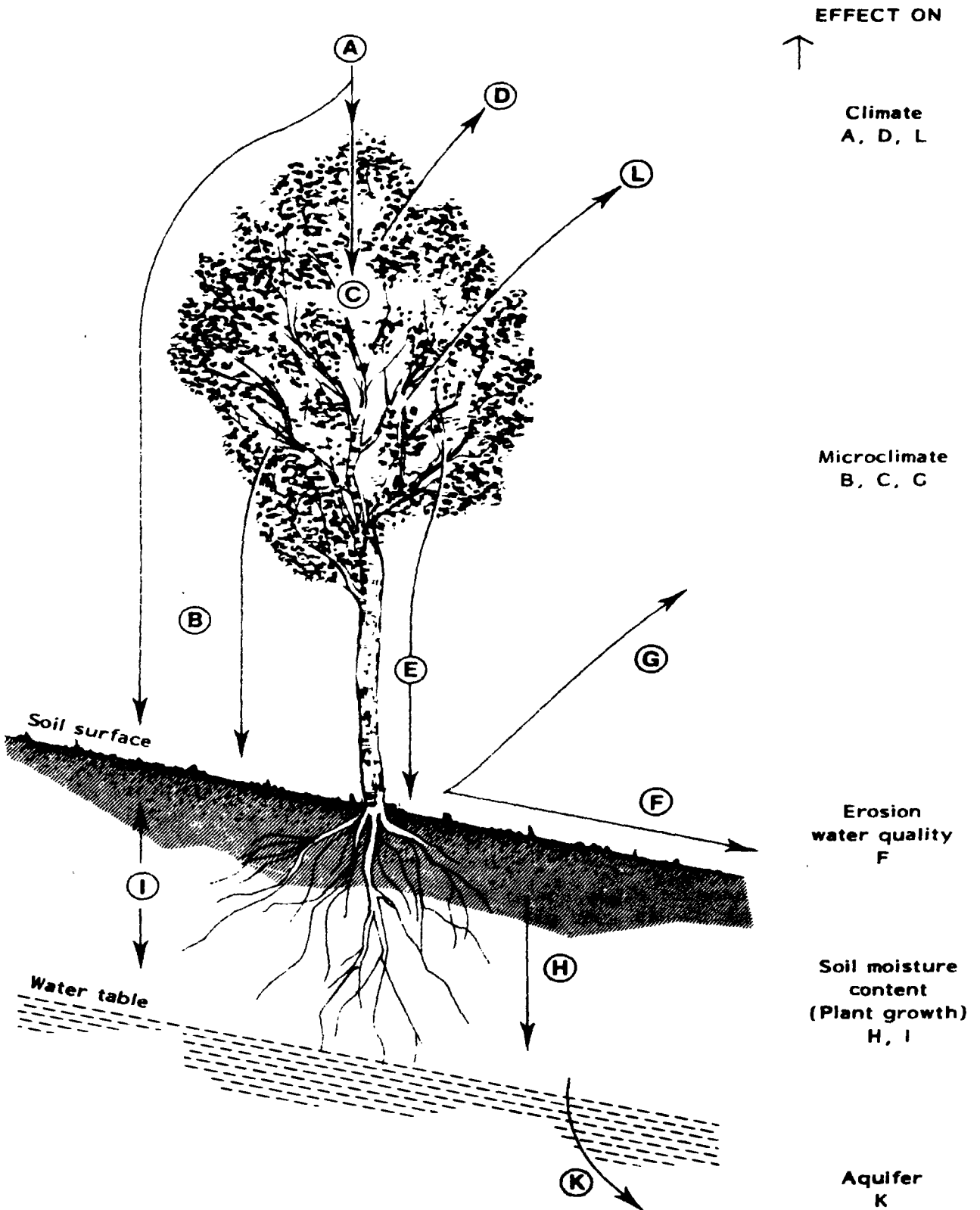
The position is different if water is in short supply; the plant may then put up barriers against loss (by losing its leaves, closing the stomata on its leaves etc.) There can also be barriers in the soil. A surface layer of dry leaves or of gravel may slow down or prevent the loss of water. In these circumstances the actual evapotranspiration can be much less than the potential (what would be lost if there were plenty of water).

The effect of trees on the hydrology of a catchment, and the performance of the trees themselves, is much influenced by whether they have access to perennial ground water or whether they depend on the bank of soil moisture which is only replenished by local precipitation. If tree roots have access to ground water the trees will not suffer from water shortage however dry the climate, and they will use as much water as they require - an amount which is broadly determined by the incoming radiation and by wind. If, on the other hand, they depend upon rainfall and the recharge of soil moisture by rainfall, the water available to them will be influenced by climate, and particularly by the seasonal fluctuations of the ratio between precipitation and potential evapotranspiration (P/E).

When trees lose their leaves or close their stomata, photosynthesis and growth stop. Water loss is a price that plants must pay for growth. The rate of growth of trees is broadly proportional to the amount of water that they use. If, therefore, the aim of growing trees is to produce a large volume of wood, it must be expected that they will consume large quantities of water. As eucalypts are often chosen precisely because they grow faster than other species, a greater consumption of water is only to be expected.

Once soil has dried to a certain degree, known as the 'wilting point', plants cannot extract any more water from it. But, if they have roots which reach the water table, they can transpire vigorously, even though the surface soil is far too dry to support plant growth. This accounts for the fact that trees and bushes are often seen growing in the gravel beds of dry streams in arid regions.

Fig. 1



When  $P > E$  there may be water left over after the trees have used what water they need. This can then penetrate deep into the soil and recharge streams or underground aquifers.

Where  $P < E$  trees and other vegetation will begin to suffer from water shortage and, according to their particular physiology, will restrict their use of water, slow down growth (and, if not drought-resistant, even die). The number of trees on any area of ground generally adjusts itself to the average amount of soil moisture available; trees with no access to ground water will therefore be more widely spaced in areas of low rainfall. If they are planted too densely, some will die. The amount of the water deficit in the soil will depend upon the distribution of plant roots, the degree to which the vegetation can control its own water loss, and the nature of the soil itself. The water deficit in the soil will persist until rainfall again exceeds evaporation and can recharge the soil.

Figure 2 illustrates four possible situations.

- (1) The vegetation is entirely rain-fed; the soil water content fluctuates according to the P/E ratio; no water drains to the water table; there may be surface run-off during heavy rain storms; if there is vegetation, it makes use of all the soil water, and its density and growth depend upon the soil water available to it.

The effects of vegetation in such a situation could be:

- (a) preventing water recharging the soil by intercepting it in the foliage.
- (b) in the special case of mist precipitation in rainless areas, increasing the moisture intercepted.
- (c) affecting storm run-off by the ways in which the plants themselves alter infiltration by their litter or change the way in which water flows over the soil.

Except in relation to (c), changing the kind of vegetation makes no difference to the regional hydrology (because none of the precipitation reaches the water table). The kind of vegetation can, however, have a considerable effect on the water available for its own growth. Eucalyptus, therefore, could have an influence on (a), (b), and in the competition between itself and other species for the limited amounts of soil water. The important question is this: is the influence of Eucalyptus different from that of other tree genera?

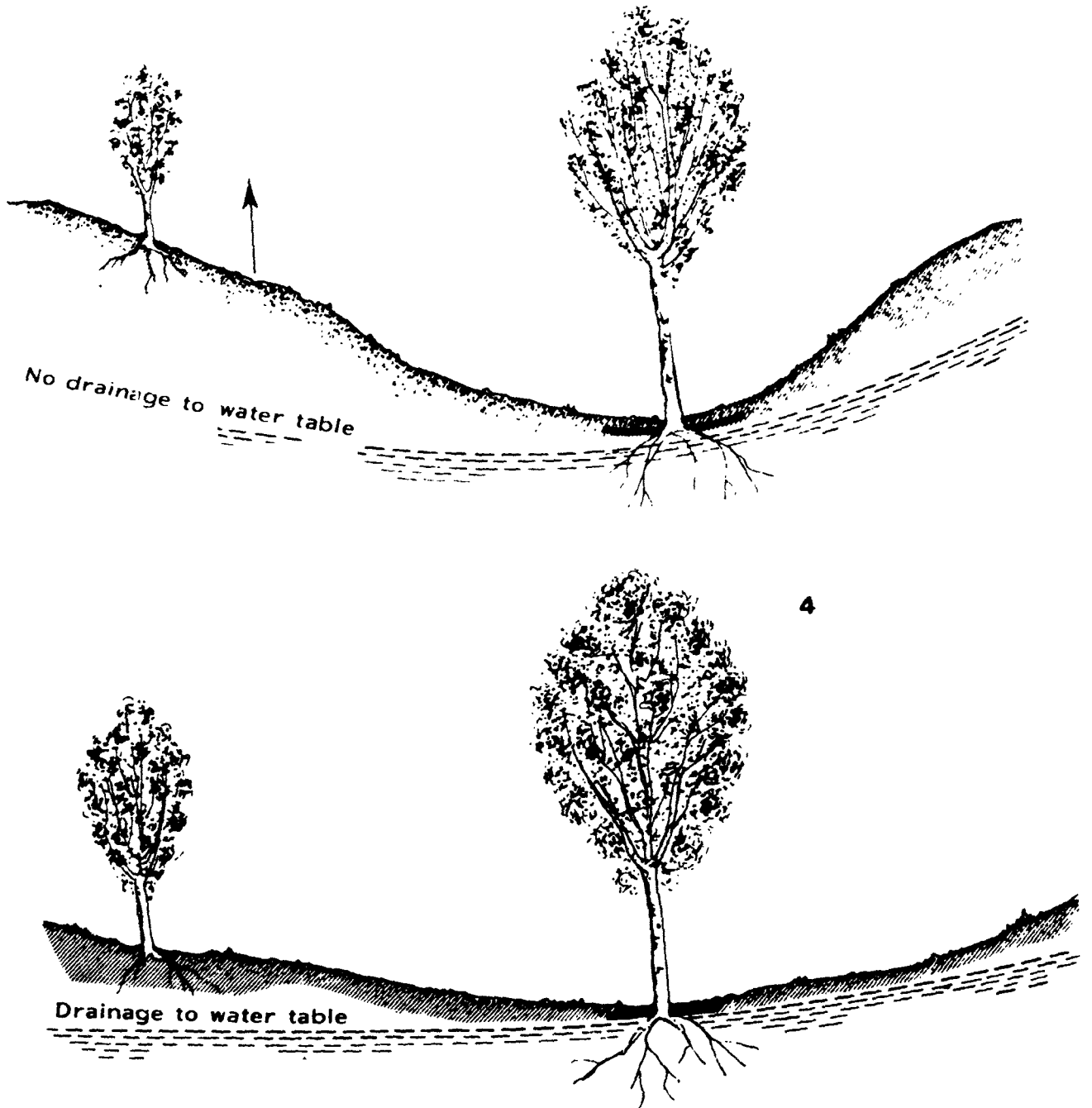
- (2) The climate is arid,  $P < E$ ; the water table is below the soil surface and there is little if any evaporation in the absence of vegetation; tree roots have access to ground water and the trees accordingly transpire vigorously and grow fast.

Under these circumstances all trees (indeed all kinds of vegetation) have a substantial effect on the aquifer, both on site and downstream. Do Eucalyptus species consume more water than others under similar circumstances?

- (3) The circumstances are the same as (1) except that  $P > E$  and excess water drains to the water table. Different kinds of vegetation may be more or less effective in making use of soil water and thus preventing it from reaching the water table. A gain in the growth of vegetation will carry the cost of a loss to the aquifer. How does Eucalyptus compare with other types of vegetation?

- (4) The circumstances are similar to (2) except that the water table fluctuates near, at or above the soil surface. Trees and other vegetation, by consuming water, have an effect on these levels. How does Eucalyptus compare with other vegetation?

Fig. 2



It will be seen that, in all these circumstances, eucalypts will have some effect on water relations either on site or downstream of the site. None of these effects are inherently good or bad, except perhaps erosion, but depend upon the relative importance of water supply, drainage, erosion control, wood supply etc. in the locality.

### Ecological effects

The possible ecological effects of eucalypt plantations (or plantations of any other tree species) on the water cycle are shown on the right hand side of Fig 1. These may be on: the local or regional climate; the microclimate within the forest; surface run-off of water (which may affect water quality and the amount of erosion); soil moisture content, and; the recharge of aquifers. Eucalypt plantations can, in principle, affect any of these by altering the quantities (A)-(K). Whether these changes are considered beneficial or not depends on the purpose of the plantations and a balance of the various costs and benefits in each instance.

### Climate

The effect of forest cover on climate is a controversial subject into which it is not possible to go in detail in this report. There is no evidence about eucalypt plantations in particular.

If forests are successfully established on hot, dry land which was previously devoid of vegetation (for example a denuded sandy area with a water table accessible to tree roots), they will alter the reflectivity of the ground (albedo), thus changing the energy balance; they will reduce the turbulence of the air near the ground and thus its dustiness. As a result they may increase local air humidity and reduce temperatures. Under these circumstances eucalypt plantations (like natural forest, or plantations of any other tree) may have some effect on local climate. But conclusive evidence is lacking.

### Microclimate

The climate within an eucalypt plantation will be moderated in comparison with a treeless area outside. This is well known from general microclimatic studies. The effect of eucalypt plantations will be similar to those in other plantations, though it may differ in detail. For example less shade is usually cast by eucalypts than by other broad leaved trees because of the way that eucalypt leaves often are held vertically on the twigs. These microclimatic effects consist of higher humidity, less sunlight, lower average temperatures and the moderation of extremes of temperature.

### Interception

Vegetation can have a significant effect on the amount of water that reaches the soil by intercepting some of the precipitation on its foliage. The amount intercepted and lost to the site is one of most important features differentiating various kinds of vegetation. The effect of this depends very much upon circumstances.

In conditions of drifting mist or cloud considerable amounts of water can be collected by the foliage and drip to the ground; this is water which would, in the absence of vegetation, drift over and be lost to the site. Lima and O'Loughlin (in press) review data from natural eucalypt forests in Australia. The highest values, the equivalent of



a rainfall of at least 25-50 mm a year, were found in the upper mountain sclerophyll forest (E. niphophila) on Mt Kosciusko, south-east Australia at an altitude of 1200-1500 m. In E. regnans forest near Melbourne (670 m altitude, rainfall 1200 mm) a 200 year old stand intercepted an average of 12.9 mm over a period of 4 years, and a stand of 80-90 year old trees intercepted 9.2 mm. Mist precipitation has a marked effect on local climates and particular forest types may be found only in areas where it occurs.

Lima and O'Loughlin go on to discuss the interception of rainfall.

" A more significant hydrologic effect of the presence of a forest cover in any particular site is the process of interception, through which rainfall is redistributed by the forest canopy, and part of it is lost through direct evaporation from the canopy. Considering the species diversity and the many different forest types of eucalypt, there isn't sufficient data on interception to give an overall picture of this important process on the hydrologic cycle in eucalypt forests. "The data that they have assembled are reproduced in Table 1.

There is some evidence about the proportion of rainfall intercepted by Eucalyptus spp. compared with that intercepted by other tree species, but it is hardly sufficient to make valid generalisations. The data are presented in Table 2.

Direct comparisons between eucalypts and other vegetation are made by Lima (1976), Smith (1974), George (1978), Dabral and Subba Rao, (1968 & 1969). These authors found a lower amount intercepted by Eucalyptus (11.65% compared with 27.0% in Pinus roxburghii, 20.8% in Tectona grandis, 38.2% in Shorea robusta and 28.5% in Acacia catechu). Smith (1974), comparing 35-year old Pinus radiata with a natural forest of E. rossii, E. maculata and E. dives found 18.7% in the pine compared with 10.9% in the eucalypts.

In contrast Lima finds a greater amount (12.2% compared with 6.6% in Pinus caribaea). This may perhaps be explained by the fact that Lima's pines were only 6 m high compared with 15.4 m in Eucalyptus saligna. On general grounds of leaf morphology and orientation one would expect interception to be higher in pine than in eucalyptus under similar conditions. Karschon (1971) found a sharp reduction in interception by E. camaldulensis to 5.3% two years after coppicing rising to 7.1% after 4 years.

In interpreting all these results it should be remembered that the proportion of rainfall intercepted varies greatly according to climate and the intensity of rainfall. Nevertheless it appears that, under a wide range of conditions, about a quarter of the precipitation is intercepted by eucalypt forests and re-evaporated to the atmosphere, thus becoming unavailable to recharge soil moisture or aquifers. Amounts tend generally to be higher for pines and perhaps lower for broad leaved trees that are not eucalypts. Lee (1980), in his book Forest Hydrology suggests that different kinds of vegetation fall into the following order in the amounts of water that they intercept: pines > eucalypts > other broad leaved trees > scrub > grassland. It should not be impossible to predict figures for interception by different species from a knowledge of their leaf morphology and the leaf area index of the particular stand (a measure of the area of leaf/area of ground).

Table 1

Interception loss (I), throughfall (T), Stemflow (Sf), Canopy storage (S), and regression equations relating interception, throughfall, and stemflow to gross precipitation (GR) in different eucalypt species.

Species	I(%)	T(%)	Sf(%)	S(mm)	Regression
<i>E. regnans</i>	22-26	-	2-3	-	-
<i>E. regnans</i> (mature)	23,2	72-76	4.3	-	I=0.176GR+1.51 T=0.775GR-1.36 Sf=0.05GR -0.15
<i>E. regnans</i> (40 yr-old)	18.7	72-76	5.3	-	I=0.150GR+1.09 T=0.790GR-0.88 Sf=0.06 GR-0.21
Mixed dry sclerophyll (A)	23.3	72-76	1.3	-	I=0.176GR+1.36 T=0.809GR-1.31 Sf=0.015GR-0.05
<u><i>E. melanophloia</i></u>	11	88	0.6	2	(T+Sf)=0.96GR-1.4
Mixed dry sclerophyll (B)	10.6	89	3	-	T=0.837GR-0.057 Sf=0.019GR+0.00
<u><i>E. signata</i></u>	22	65	13	-	-
<u><i>E. umbra</i></u>	22	75	3	-	-
<u><i>E. viminalis</i></u>	-	-	-	0.2	-
<u><i>E. dives</i></u>	-	-	-	0.3	-
<u><i>E. mannifera</i></u>	-	-	-	0.3	-
<u><i>E. cinerea</i></u>	-	-	-	0.4	-
<u><i>E. maculata</i></u>	-	-	-	0.5	-
<u><i>E. pauciflora</i></u>	-	-	-	0.8	-

(A) *E. obliqua*-*E. cypellocarpa*-*E. viminalis*-*E. baxteri*-*E. goniocalix*-*E. dives*

(B) *E. rossi*-*E. maculosa*-*E. dives*

Species	Climate		Height (m)	No. of trees per ha	Age (years)	Length of observa- tion (months)	Relia- bility	Intercep- tion (I) (%)	Stem flow (S) (%)	Through- fall (T) (%)	Reference
	Average Rain (mm)	Average Temp. (°C)									
Eucalyptus hybrid	1968	13.1	12.2	1658	6	12	low	11.65	7.6	80.75	George M. (1978)
Pinus roxburghii	"	"	ca.13	1156	26	3	low	27.0	3.3	69.7	Dabral & Subha Rao (1968)
Tectona grandis	"	"	ca.21	472	-	3	low	20.8	6.0	73.2	" "
Shorea robusta	"	"	23.77	668	37	3	low	38.2	7.2	54.6	" " (1969)
Acacia catechu	"	"	ca.18	574	27	3	low	28.5	4.2	67.3	" " (1969)
Eucalyptus saligna	1280	20	15.4	1667	6	24	good	12.2	4.2	83.6	Lima (1976,6)
Pinus caribaea	"	"	6	1667	6	24	good	6.6	3.0	90.4	" "
E. hybrid (tereticornis)	1000	(48)	12.1	1068	5	12	good	22.9	-	-	Banerjee (1972)
E. camaldulensis	600	9.2-30.0	11-14	1111	7-12	48	rel.high	14.63	4.53	80.84	Karshon (1967)
E. sp. (uneven, woodland)	-	-	-	-	-	-	-	4	-	-	Millett (1944) Karshon (1967)
E. niphophila	-	-	-	-	-	-	-	100.77	-	-	Costin and Wimbush (1961);Karshon(1967)
E. regnans (pole stands)	-	-	-	-	-	-	-	16.8-18.7	-	-	Brockes a. Turner (1963);Karshon(1967)
E. regnans (mature stand)	-	-	-	-	-	-	-	23.0-26.0	-	-	"
Shorea robusta	-	-	-	1678	-	-	-	25.3	-	-	Ray (1970)
Alstonia scholaris	-	-	-	1675	-	-	-	26.0	-	-	" "
E. camaldulensis (coppice)	600	9.2-30.0	6.1	870	2	12	rel.high	5.3	1.8	92.9	Karshon (1971)
" "	600	9.2-30.0	-	"	3	12	"	4.6	1.3	94.1	" "
" "	600	9.2-30.0	9.4	"	4	12	"	7.1	2.0	90.9	" "
E. sp. (natural forest)			12.5		nat	17	high	10.6		89.3	Smith (1974)
P. radiata (mature stand)			27		35	17	high	18.7		81.2	" "

### Throughfall and stemflow

The precipitation which falls on the tree canopy can be divided into three main fractions: water which is intercepted and evaporates (interception loss); that which flows down the trunk (stemflow); and throughfall. (Small amounts may also be stored in the canopy.) In any consideration of the water relations of plantations the interception loss, dealt with in the paragraph above, is the most significant. Throughfall and stemflow represent the balance of the precipitation which is not lost. Tables 1 and 2 give these amounts for different circumstances and species. Both throughfall and stemflow go to charge the moisture bank in the soil; because it enters close to the trunk, the stemflow will come into immediate contact with roots and may perhaps infiltrate more rapidly and effectively. Apart from this the relative proportions of throughfall and stemflow do not seem to be of much significance.

### Recharge of soil water

The sections which follow, on the recharge of soil water, surface run-off, stream flow, ground water and experimental catchments, are all closely related to one another, being all concerned with the fate of the water once it reaches the ground. Some attempt has been made to separate them in the discussion in order to make the argument easier to follow.

Studies in relation to the recharge of soils and aquifers have been made by Karschon and Heth (1967) in the central Coastal Plain of Israel. The experimental area in Israel has a semi-arid climate, with an average rainfall during the period of the study of c. 600 mm and a summer dry period of 3 to 5 months. The soil is a red sandy loam underlain at 120 cm by an illuvial clay horizon not penetrated by the roots. A comparison was made between a plantation of *E. camaldulensis* (11 m high) and open ground; both sites were level. The eucalyptus made use of all the water available to it. During the wet season evapotranspiration was proportional to evaporation from a pan of open water, but was sharply curtailed in the dry season. It is presumed that, if the trees had had access to ground water, they would have continued to transpire at a high rate. No surplus water was available from the plantation for run-off or drainage.

In contrast, the grass/herbaceous vegetation of the open plot used less water and approximately 20% went to drainage. No observations were recorded for erosion but, as the sites were flat, this was presumably negligible.

No comparison was made with other tree species, introduced or indigenous, but the authors comment that the annual rates of evapotranspiration from the eucalypts are comparable to those recorded by other workers for oak scrub and pine.

The authors conclude that the yield of eucalyptus timber (11.1 m<sup>3</sup> mean annual increment) 'by far offsets the value of that part of the water losses that would have been added to the ground water'. This is, however, a judgement of relative socio-economic benefits; others might assess them differently in different circumstances. It seems that, in this locality, the 'water yield' was reduced by about 20% compared with that from open ground, a figure which corresponds well with those given above for interception. It is probable that a somewhat similar loss would have occurred under any other tree crop, but such a comparison was not made in the course of these experiments.

It is evident that, under the circumstances, the contribution made by a tree-less plot to soil recharge + groundwater was significantly greater than from a plot covered by Eucalyptus.

'Surface run-off' -  
water flowing over the soil surface

Direct information on run-off in eucalypt plantations is slight, but some inferences may be made from measurements of stream flow, where the variations of peak flow and base flow may provide indirect evidence.

Chinnamani et al (1965) measured surface run-off as a percentage of rainfall at a site with an annual rainfall of 1340 mm in the Nilgiri hills, south India over a period of 7 years with 3 replications. They compared small plots (0.02 ha) in 5 types of vegetation: plantations of E. globulus and Acacia mollissima; shola (sub-montane evergreen forest); broom (Cytisus scoparius) and native grasses. The proportion of run-off from the eucalypts and acacia was similar to that from the shola, just over 1%; the broom was less and run-off from the grassland was negligible. These observations were continued by Samraj et al (1977) for another three years with similar results.

Stream flow

Mathur et al (1976) compared two small watersheds (0.87 and 1.87 ha) near Dehra Dun in north India, one covered with natural scrub and the other planted with a mixture of E. grandis and E. camaldulensis. The two catchments were calibrated for a period of 8 years, then one was planted, the other remaining as a control. Allowing for differences identified during the calibration period, (the slope of the forested catchment was 5.1% and of the other 9.5%) the afforested catchment showed a 28% reduction in run-off and a 73% reduction in peak rate. The eucalyptus was accompanied by dense scrub regrowth and about one fifth of the surface of the plot was cultivated at the time of planting. These may, at least in part, account for the results. In this context de la Lama (1982) comments on the importance of terracing in eucalypt plantations in reducing surface run-off and increasing infiltration.

A very detailed study is reported by Bailly et al (1974) from an area at an altitude of 1000 m on the east of Madagascar. They compared four catchment areas ranging in size from 7 to 100 ha; one in the natural mountain forest, two in secondary forest and one in a plantation of E. robusta which was 48 years old. The observations were continued for 8 years. They found that the total base flow was least from the eucalypt catchment and that the proportion of flood flow was, on average, 21.5% higher. The coefficient of flow (flow/precipitation) was also much less, indicating that less of the rainfall was contributing to the flow of the stream: 4-19% for the eucalyptus, compared with 16-44% for the forest and 28-56% for the brush.

They conclude: that the lower run-off from the forest, and particularly from the eucalyptus, in comparison with the scrub is accounted for by greater evapotranspiration; although the flood run-off is almost the same for the eucalyptus and the forest, the usable flow from the plantation is only about one third of that from the natural forest; that forest vegetation reduces greatly the peak flood flows and buffers the influence of flood flows. They comment that the much lower run-off from the eucalyptus could be attributed to increased evapotranspiration due to the uniform age and rapid growth of the stand compared with the climax natural forest, i.e. greater growth leads to greater use of water. It is also possible, however, that the catchments may not have been entirely water-tight.

### Ground water

Where tree roots are in continuous contact with the water table (situations 2 and 4 in Figure 2) any kind of vegetation transpires rapidly and consequently uses large quantities of water.

Two questions arise: (a) Is the use of large quantities of water beneficial or harmful in any particular circumstances; and (b) Do eucalypts use more than other trees under comparable conditions?

The answer to the first question is clearly that it depends upon circumstances. Eucalypts have been used from time to time to lower water tables in swampy areas, either to dry out the soils or to control mosquitos. Here the effects clearly accomplish their purpose and are beneficial. If, however, eucalypts lead to the reduction in volume of an aquifer which is used downstream for domestic water supply or for irrigation water, the effects are likely to be considered harmful. In all such cases it is important to consider the purpose of planting (building timber, poles, fuelwood, shade, shelter etc.), the various uses that might be made of the water and the total benefits and costs in the local socio-economic context.

Data are scarce on the water use of eucalyptus under conditions where supply is not limiting and it has not been possible to find any comparing eucalyptus with other trees. The most relevant information is included in Karschon and Heth (1967) and Karschon (1970). In the former paper the authors showed that during the wet season (October-April) the ratio of evapotranspiration to pan evaporation averaged 0.83-0.84 for a forest of *E. camaldulensis* while it occasionally exceeded it. The figures for evapo-transpiration, however, excluded the amounts of water intercepted in the canopy and presumably re-evaporated; so that the total evaporation may frequently have equalled or slightly exceeded pan evaporation. In the summer, water was limiting and the trees exercised control over transpiration, thus reducing water uptake.

In irrigation experiments Karschon (1970) found a strong increase in growth with additional water, but not in the summer. He attributed this to summer dormancy and decreased transpiration. He quotes Souleres (1964), however, as having obtained significant responses to irrigation water between April and October (summer months) in both *E. camaldulensis* and *E. gomphocephala*, indicating that transpiration was not reduced in this instance.

Little evidence has been found of the water consumption of eucalyptus under natural conditions of unlimited water during the summer months nor data comparing eucalyptus with other trees under such conditions. The observations on transpiration quoted below may, however, give some clues.

### Shelterbelts and agro-forestry mixtures

The effects of shelterbelts and agro-forestry mixtures are complex. They involve possible changes in the evapotranspiration and water use of the crop sheltered and the water use of the sheltering trees. The same considerations apply to agro-forestry mixtures.

The effects of shelterbelts are reviewed by Jensen (1983). They are different in dryland and irrigated areas and vary according to climatic conditions. Dryland wheat in southern Yugoslavia, for example, has been shown to use water more rapidly in a sheltered than in an open situation - perhaps because of increased growth. In contrast, in central Senegal, evaporation in a protected rice plantation was 40% lower than in one exposed to drying winds.

But Jensen has not found any measurements of the use of water by both the crop and the trees; nor is there any evidence to suggest that eucalypts differ in the effects they produce from any other kind of tree.

Simple measures of water consumption are not enough in such cases. Factors that should be taken into account are the benefits received from both the crops and the trees and the efficiency of water use in producing these benefits. Any alternative claims on the water would also be relevant.

### Experimental catchments

The only fully satisfactory study of experimental catchments involving a species of Eucalyptus is that reported by van Lill et al (1979). This was a catchment experiment carried out on the Eastern Transvaal Escarpment, South Africa. The mean annual rainfall during the experiment was 1140 mm during an early period of lower rainfall, which was followed by a period of higher rainfall (1,340 mm/yr). The original vegetation was a seasonally dry grassland (the dry season being from May to September), with evergreen broadleaved forest communities in a narrow belt along stream channels.

Gauging of the flow from the catchments under natural grass cover began in 1956. One of the catchments was planted to E. grandis in 1969 after 12 years of calibration, a second was planted to Pinus patula in 1971, and the third was maintained in the natural condition. Simple regression analysis procedures were used and showed that afforestation with E. grandis exerted an observable influence from the third year after planting, with a maximum apparent reduction in flow, expressed as rainfall equivalent, of between 300 and 380 mm/yr, and with maximum reductions in seasonal flow of about 200-260 mm/yr in summer and 100-130 mm/yr in winter.

From about the sixth year onward the winter soil moisture store was apparently not sufficient to meet evapotranspirative demand from the growing trees. The experiment, therefore, does not provide data on potential winter evapotranspiration in eucalypt stands.

At the time that the paper was published it was too early to draw definite conclusions about the influence of afforestation with Pinus patula, and therefore also the relative effects of the chosen species of eucalypt and pine. The authors suggest, tentatively, that the hydrological effects of the pine plantation are delayed by one year relative to the eucalypt, and that the reduction of flow is initially much smaller.

This paper also includes valuable observations on the relation between transpiration losses and the characteristics of a forest stand. In the early years of a stand transpiration (and interception loss) increase with age; but as the stand matures, such variables as leaf area index do not increase indefinitely, and physiological changes occur as the trees age. It is likely that E. grandis stands will behave like other forest stands, and that evapotranspiration is related to dimensional variables of the stand and inherent physiological characters rather than to absolute age. It is predicted therefore that the present trend in streamflow from the catchment afforested with E. grandis will not be maintained and that a reversal is in fact likely. The same pattern is likely in the case of the catchment planted to Pinus patula, but changes may be slower.

### Harmful effects of removing eucalypt forest

To emphasise the point that most ecological effects can only be reasonably evaluated in a defined socio-economic context, it is worth recounting the effect of removing eucalypt cover in Western Australia. The account is drawn from Pereira (1973).

" Where an evergreen forest uses water all the year round the clearing of the trees and planting of short-season annual crops can result in a big reduction in water use. In Western Australia this land-use change has been occurring on a large scale for several years and the hydrological results are already embarrassing. Some 120,000 km<sup>2</sup> of the native dry open woodland, under a winter rainfall regime of 400 to 600 mm annually, has been completely cleared of trees except for the borders of streambanks and drainage lines. The dominant woodland species were deep-rooted Eucalyptus. The land is now cropped in a rotation of wheat and short season annual grasses and clovers. There are no perennial grasses capable of sustaining grazing and the sheep survive in the dry season by eating the dead annual grasses and the seeds of the annual clover. With a hot dry summer giving an annual total for open-water evaporation of some 2000 mm or about four times the annual rainfall, it is indeed surprising that an excess of water should become apparent. Saline groundwater, however, lies beneath the woodland and where the trees are felled the excess winter rainfall raises the water level so that salt springs flow from the hillside and spread over the low lying areas. Dead and dying trees along several hundred miles of drainage lines offer striking indications of the continuing progress of a land-use change which ignores hydrology.

" Detailed surveys of the salted areas were carried out in 1955 and again in 1962. In the seven-year interval there was an increase of 720 km<sup>2</sup> in the salted land to give a current total of 1200 km<sup>2</sup> on a somewhat conservative basis of estimation. Even more important than the loss of land is the effect on the quality of the river water. Most of the streams were originally fresh, since under the woodland conditions the saline groundwater remained beneath a rather impervious layer of clay. There are unusually good records of the water quality since it was checked carefully by railway engineers from 1880 onwards. The Blackwood River, for example, was carefully checked for salinity in 1880 and was fresh enough for railway use. By 1910 there was heavy settlement and clearing for wheat production in the upper catchment areas of this river; by 1920 the water was already too salty for use in locomotives. Today it is too salty even for general irrigation and can be used only for salt-tolerant crops such as apple trees... The State Authorities have accepted the evidence as conclusive and have restricted clearing on some catchments in order to protect important sources of water".

It should, however, be emphasised once again that this effect is not peculiar to Eucalyptus, but could have been brought about, in these particular circumstances, by removing any kind of forest cover.



## Discussion and conclusions

### The questions and the evidence

The questions that we have tried to address in this survey of literature are the following:

Do eucalypts consume more water than the vegetation that they replace, or more than other alternative tree crops?

Do they have an adverse effect on the characteristics of water catchments compared with other vegetation such as natural forest or grassland?

The evidence reviewed has been of two kinds: scientific papers concerned specifically with research and observations on the effects of eucalypts on the water cycle; and general literature on the most recent knowledge about the principles of the hydrology of catchments.

The most valuable studies are those which attempt to deal with the whole system (the catchment studies of van Lill *et al*, 1980) and the general review of literature on the hydrology of eucalypt forests in Australia (Lima and O'Loughlin, in press). Most of the other papers deal only with small parts of the cycle; almost all are concerned with particular local conditions; and very few make rigorous comparisons between eucalypts and other alternative tree species or kinds of vegetation. Their findings must, therefore, be approached with caution, and interpreted in the light of the large body of general knowledge that has been accumulated recently on the working of the hydrological system and of catchment hydrology.

### Conclusions

Climate. The effects of planting a large area of eucalypts is likely to be the same as covering an area with other vegetation with a similar structure and albedo. It is likely to be beneficial if it replaces bare ground. Where there is drifting mist, eucalypts, like any other trees, will serve to collect additional precipitation. There is no conclusive evidence on the specific effects of eucalypts on climate.

Microclimate. There may be differences in the microclimate within eucalypt plantations compared with those of other tree species because they are evergreen and have a light foliage. There is no evidence on this subject.

Interception. In any forest interception represents the most important loss of water to the system. This is because most of it will re-evaporate without reaching the soil. It may, however, help to reduce the amount of water removed from the soil by tree roots and later transpired. There is a large body of data on interception. In general eucalypts appear to intercept between 11% and 20% of precipitation. This is less than pine, but much more than low vegetation. The evidence comparing eucalypts with other broad leaved species is conflicting.

Surface run-off. There is little comparative data. The amount of run-off depends upon the presence of litter and ground vegetation and this will certainly vary greatly according to the climate. The little evidence that exists suggests that run-off from eucalypt plantations is greater than from grassland or low shrub vegetation. The ground vegetation of eucalypt forests is sparse in dry climates due to root competition and, perhaps, allelopathic effects. Fires, to which eucalypts are particularly prone, will accentuate this by destroying both ground vegetation and litter.

The influence of eucalypts on run-off is also reflected in high peak flows and reduced base flows in catchments containing them. These adverse effects can, of course, be alleviated by terracing - a practice which is also beneficial for the establishment and growth of eucalypts on steep, dry sites.

Water consumption and the recharge of aquifers. The effects have been well summarised by Lima and O'Loughlin (in press) from which the following excerpts are quoted:

Lateral spreading and depth of penetration of the root systems of the eucalypts vary with species, and this has to do with the intensity of water uptake. Withdrawing of soil moisture also depends on stand density and soil and environmental conditions. In alpine dry sclerophyll conditions, soils water regime does not differ between eucalypt forests, grassland and herb-field.

In regions of deeper soils and higher rainfall regimes, soil water deficit created by eucalypt forests seems to be in the region of 250 mm/yr. In comparison with crop or pasture land, this means that eucalypt forested lands would yield approximately 70 mm/yr less streamflow or groundwater recharge. Comparative studies have shown that the overall soil water regime of eucalypt forests does not differ from that observed in pine plantations.

The effects on soil moisture reserves of eucalypt plantations apparently start to appear at the age of approximately 4-6 years, when the soil water deficit created by the plantations during the year is similar to the one observed in mature forest.

Transpiration rates differ among eucalypt species, varying apparently between 20 litres/tree/day to 40 litres. The evaporation rate from eucalypt forests in field conditions is more difficult to detect, but it appears to vary between 1.5 mm/day in winter to 6.0 mm/day in summer.

Some eucalypt species have not developed mechanisms for controlling higher rates of transpiration and are likely to suffer from drought stress, which limits their range of habitats. The majority of eucalypt species, however, do have some control of the rate of transpiration, which helps them to survive drought stress during part of every year, and which is apparently related to the rainfall regimes of their natural habitats.

Average catchment evapotranspiration of a well stocked eucalypt forest is probably around 1000 mm/yr for rainfall regimes above 1200 mm/yr. For drier regions, evapotranspiration also declines, perhaps reaching a value of 450 mm/yr when the rainfall regime is of the order of 500 mm/yr. For wetter regions evapotranspiration increases, eventually reaching a value of 1500 mm/yr for tropical eucalypt forests of lower latitudes. Comparative studies have shown average annual evapotranspiration in pine plantations to be in the same order of magnitude as that observed in eucalypt forests.

Young, vigorous, dense regrowth of *E. regnans* forest was found to yield less water than mature forest. At the age of 21 years, the difference of water yield was found to be around 200 mm/yr, but catchment yields tend to equalise as the regrowth matures.

Thinning and selective cutting in mature eucalypt forest can reduce water consumption and increase streamflow. Clearfelling mature, wet eucalypt forest increases streamflow by an average value of approximately 400 mm/yr. The effect of clearfelling on catchment yield is maximum during the second year after the cut.

In contrast the cutting of extensive eucalypt forests can increase the water yield of a catchment considerably and raise water tables in flat land downstream.

### General conclusions and guidelines

The plantation of extensive forests of eucalypt in any deforested catchment will substantially decrease water yield from that catchment; the felling of such forests will increase it. The effect of eucalypts in reducing water yield is probably less than that of pine and greater than that of other broad-leaved species; but all species of trees reduce water yield compared with scrub or grass.

If, therefore, the yield of water from the catchment or the state of the water table in the adjoining lowlands is important, very careful consideration should be given before conducting extensive afforestation or deforestation.

The effects of eucalypts on run-off, and therefore on erosion (see below), vary greatly according to local conditions of climate, slope, and use of the ground vegetation and litter by local peoples. It is a function of the protection afforded to the soil by ground vegetation and litter, and differences between eucalypts and other trees depend upon the effect of the various tree species on these. Planting conditions, thinning etc. on steep and erodible slopes should favour ground vegetation and the accumulation of litter and the forest floor should be protected from fire and from the collection of litter. Terracing can compensate for poor ground cover.

The costs and benefits of each proposal for eucalypt planting should be carefully assessed on its merits paying particular attention to the ecological characteristics of the site, on the importance of water yield in the catchment affected, and on the pattern of local need for forest produce and for water.

## CHAPTER II

### EROSION

#### Water erosion

There is almost no experimental evidence in the literature comparing soil erosion under eucalypts with that under other forms of vegetation. Chinnamani *et al* (1965), working in the Nilgiris, India (see section on 'run-off' above), found negligible soil loss under scrub, broom, grassland and plantations of Eucalyptus globulus and Acacia mollissima, except immediately after the preparation of sites for planting and after thinning. Mathur *et al* (1976) measured soil loss in the experiments described above in the section on 'stream flow'; the variability in the results obtained was, however, too great to draw any reliable conclusions.

Little, therefore, can be added to the discussion of Harcharik and Kunkle (1978) on this subject. The following is adapted from their summary.

Most eucalypts are not good trees for erosion control. When young, they are very susceptible to grass competition, and to obtain good growth clean weeding is necessary during the establishment period, which is undesirable on steep or eroding terrain. Even mature stands may be ineffective in halting surface run-off.

Stein (1952) for example observed that in steep dry areas where Eucalyptus globulus had been planted, understory development and litter build-up were insufficient to prevent surface run-off. E. globulus is a fast growing, heavy crowned tree which casts a dense shade but little litter. In closed plantations it has a great water demand and an exceptionally extensive and dense root system which enable it to compete successfully for available soil moisture, especially with smaller, shallow rooted plants. This would be of little importance in humid areas, such as parts of southern India where the undergrowth survived well under E. globulus, but where rainfall is less than 750mm the failure of an understory to develop, coupled with a weakly developed forest floor, leaves the soil exposed to run-off. Under such conditions, Stein (1952) recommended thinning dense stands, planting at wider spacings (187 -231 trees per hectare) or irrigation to stimulate understory development.

Dense plantations of eucalypts, therefore, are usually not recommended for erosion control, particularly in semi-arid climates, except where their litter production can compensate for a light understory or where planting is done in conjunction with engineering works or cover crops. [In many such places, however, the litter is collected by local people for fuel or is removed to reduce the hazard of fire. We have had verbal accounts of crowns of eucalypts raised many centimetres above the soil surface because of sheet erosion or wind erosion under these circumstances.]

Where water and soil retaining structures are built, however, eucalypts are sometimes planted on steep, erosion-prone terrain. For semi-arid regions, Goor and Barney (1976) suggested E. camaldulensis, E. hemiphloia and E. occidentalis. On the more humid Mambilla Plateau (1500 - 2000 m elevation) in Nigeria, Fox (1977) recommended E. grandis hybrid (with E. saligna) for rapid site coverage and for the production of large volumes of wood on steep, eroded areas when planted in conjunction with contour trenches.

Shelterbelts and wind erosion

As has been mentioned above, eucalypts are frequently planted as shelter belts and therefore provide some protection against wind erosion. Since, however, this is strictly a physical phenomenon, its effects depend solely upon the physical characteristics of the site and of the shelter belt. The species used has no influence on the result except, of course, is so far as different species have different physical characteristics. The effect of shelter belts in checking soil soil erosion has been reviewed by Jensen (1983), to which the reader is referred for further information.

## CHAPTER III

### NUTRIENTS

#### Introduction

It is impossible here to provide a full introduction to soils and the nutrient cycle, but, as in the case of water, it is necessary to explain some of the general features of the nutrient economy of an ecosystem before it is possible to understand the various possible effects of introducing a plantation of Eucalyptus into it. We shall, therefore, present a simple model of the economy of the main mineral elements (except nitrogen) that are important in plant nutrition (P, K, Mg, Ca, S and the trace elements); these all behave in essentially the same manner. We shall then explain how the nitrogen economy differs from this. For simplicity the model will be developed for an ecosystem which is in a state of dynamic equilibrium and which is not being cropped by Man. It then is relatively simple to use this to show the kinds of effect that are introduced by human activities.

The various inputs and outputs of mineral elements are portrayed in Figure 3. The biomass (the living plants and animals) and the soil can together be considered as a bank of minerals. (There is also an internal circulation within the bank to which we shall return later; but meanwhile we shall be concerned solely with the inputs to and outputs from the system.)

There are two main inputs:

- (1) from the atmosphere (A) as dissolved salts, aerosols or dust, which are either collected directly by incoming precipitation from the air or are washed off parts of plants on which they have previously been deposited. (Trees, because of the area and arrangement of their foliage, are particularly effective in collecting quantities of solids and aerosols which are blown into the canopy);
- (2) from the chemical and physical weathering of the rocks underlying the soil (B). In addition animals moving into the area may import nutrients either in the form of faeces or as dead bodies (C). (The import of phosphorus under bird roosts can amount to significant quantities.) Equally animals may export minerals (D) by moving away from the area.

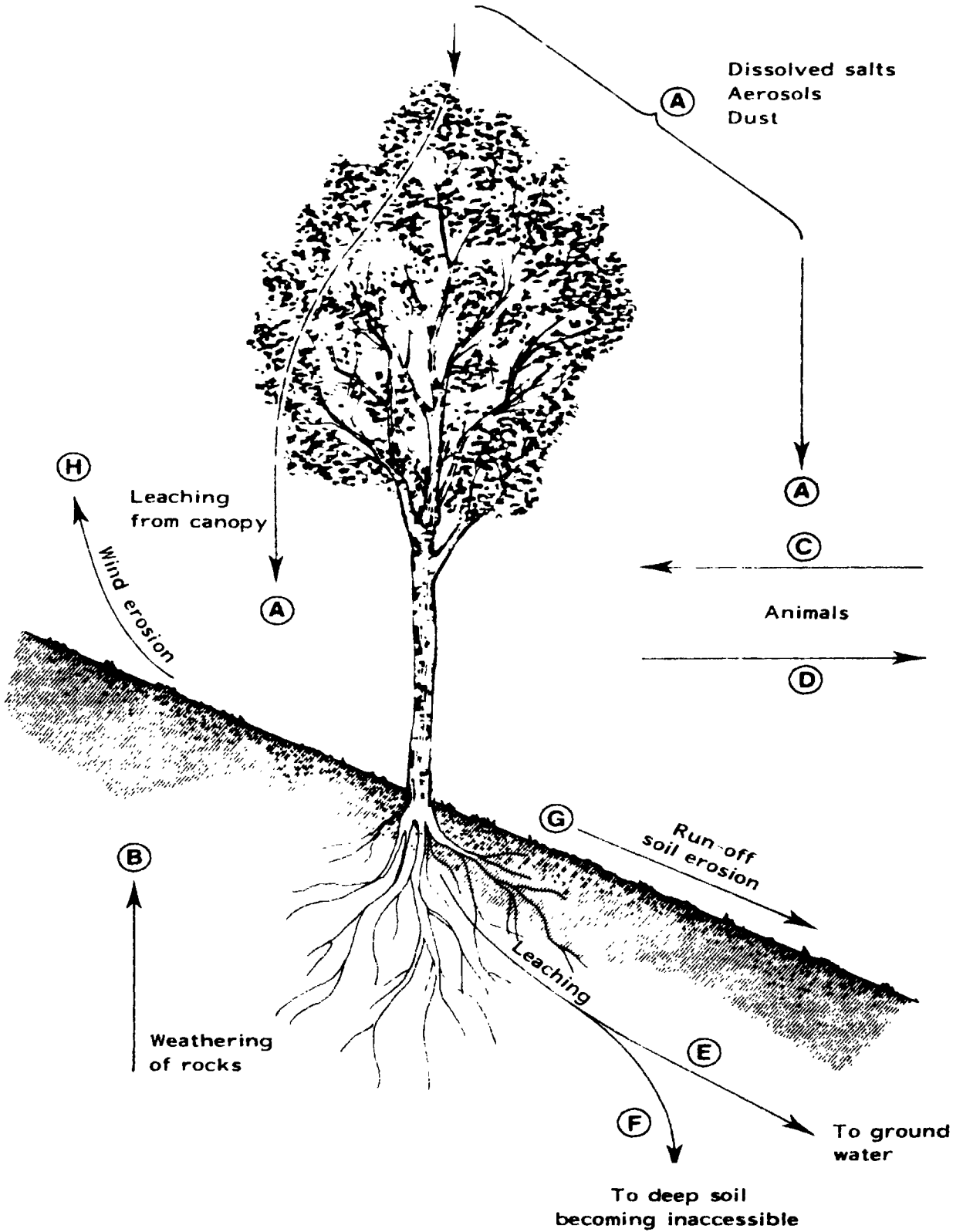
The main outputs are the following:

- (1) by being washed out (leached) from the soil by infiltrating rain water, in which case they leave the system either as ground water (E) or by descending to inaccessible levels in the soil (F).
- (2) by being removed by water flowing over the surface either dissolved in run-off or transported in eroded soil (G).
- (3) by being blown off the soil surface by wind erosion (H).

The nature of the vegetation cover has an effect on all these processes and their relative importance varies very much according to circumstances.

Fig. 3

MINERAL INPUTS AND OUTPUTS  
(not nitrogen)



Within the system there is also a circulation of nutrients. Minerals are taken up by roots from the soil. A small amount may also be absorbed by the leaves from rain water but this is generally more than outweighed by nutrients washed out of the leaves and reaching the soil dissolved in rain water. Leaves, twigs, flowers, fruits, faeces and dead animal bodies fall onto the ground and are there mineralised by the action of organisms that hasten decomposition (fungi, bacteria and the like) and the minerals thus made available are absorbed once more by plant roots. The effect of organic matter on soil structure is very important in determining the amounts of base elements that are available for plant growth.

These are the essential features of the bank of minerals within an ecosystem and of the circulation of minerals between the biomass and the body of the soil. An additional complication is introduced by the fact that some minerals (notably phosphorus and iron) may be immobilised in the soil and become unavailable for plant growth. For this reason, and also because it is very difficult to get any accurate measures of the rate at which minerals are released by the weathering of rocks, the exact amount of mineral elements available, or potentially available, at any time to contribute to plant growth is very difficult to assess. This introduces an element of uncertainty into all the estimates and forecasts that are put forward later in this section.

All these processes also occur in the case of nitrogen, but there are additional complications in this case, largely due to the fact that this element can enter or leave the system not only in ionic form (as nitrate, nitrite and ammonium ions) but as the gases nitrogen, nitrous oxide and ammonia (see Figure 4).

The principal additional inputs are:

- (1) nitrates can be synthesised from nitrogen gas in bacterial nodules on the roots of particular species of plants, notably members of the family Leguminosae and of the genera Alnus and Casuarina. Nitrates can also be produced by certain blue green algae.
- (2) nitrogen compounds are also said to be synthesised in electrical storms from elementary nitrogen and to reach the system in precipitation. Söderlund in Anon (1981) discusses the amount of nitrogen made available world wide by wet and dry deposition.

The main additional losses are:

- (1) from the oxidation of organic matter on the surface of the soil either from exposure to high temperatures and bright light (e.g. when forest is cleared) or by burning.
- (2) by the process of denitrification under unaerobic conditions in the soil, the nitrogen being released as nitrogen gas or as nitrous oxide.

The amount and condition of the organic matter in the soil is important in determining whether the nitrogen in it can be absorbed by plant roots.

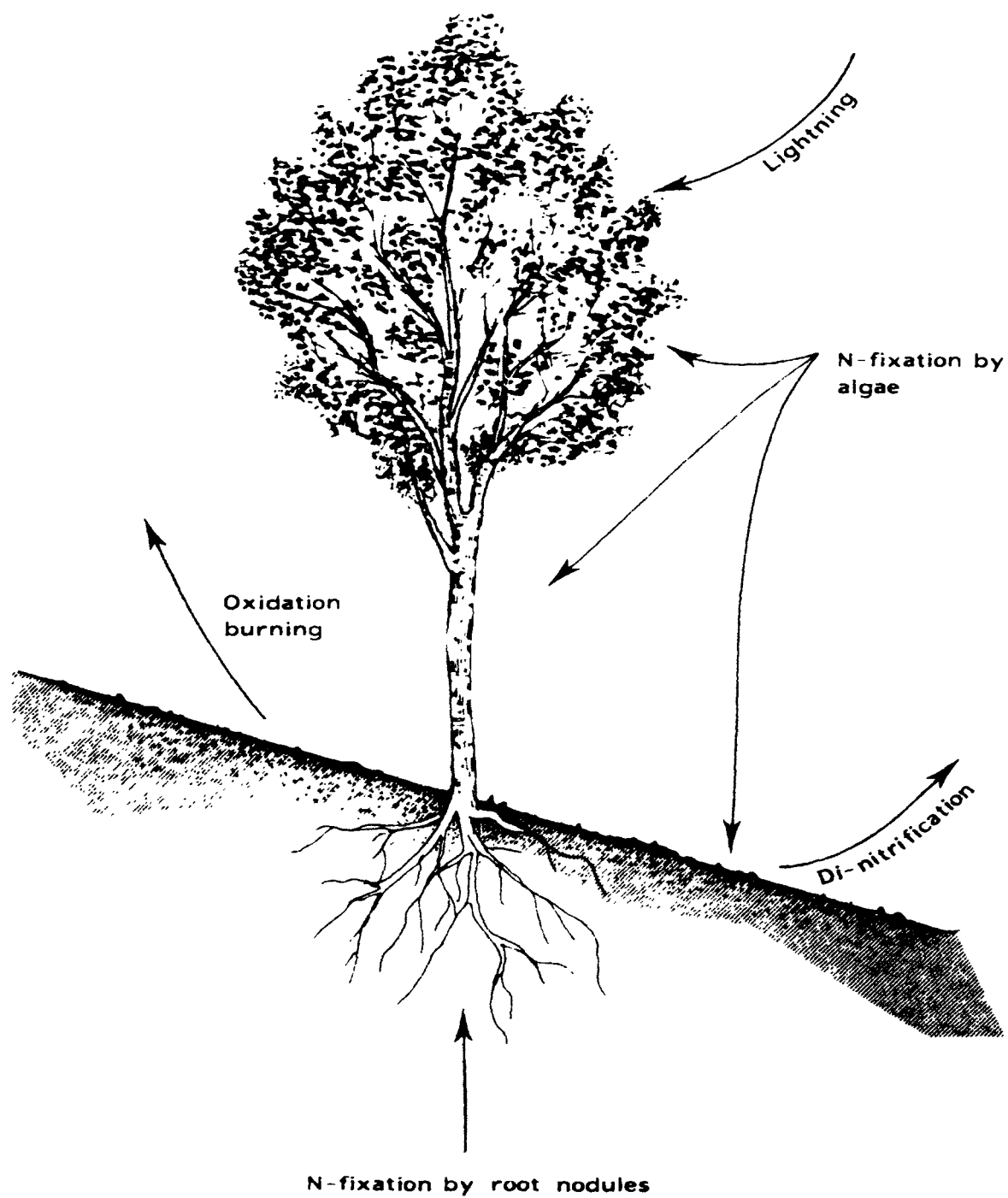
#### Possible effects of Eucalyptus on the nutrient balance

A number of possible effects of plantings of eucalypts on the nutrient balance have been suggested. One criticism of eucalypts is that they may deplete the nutrients on the site, particularly if they are grown and cropped for several rotations. This is, of course, a general point that can be made about all fast growing tree crops, Eucalyptus among them. How valid is it; and is there any evidence that eucalypts have any special demands in this respect? It has also been suggested that eucalypts may promote the loss of nutrients by encouraging increased run-off and loss of soil by water and wind erosion.



Fig. 4

ADDITIONAL OUTPUTS AND INPUTS FOR NITROGEN



On the other hand, it has been claimed that eucalypts may improve soil characteristics when planted on degraded or deforested sites by improving the structure of the surface soil, by penetrating relatively impermeable layers of sub-soil and by drawing up nutrients from depth. Is there any basis to these claims?

#### Effect on input

There is little conclusive evidence on the effect of input via precipitation. George (1979) has estimated the nutrients contained in the rainfall, stemflow and throughfall in a plantation of Eucalyptus hybrid at Dehra Dun, north India. The data on concentrations of nutrients are presented in Table 3 and total yields (in kg/ha/year) in Table 4. It will be seen that the concentration of salts in stemflow and, to a lesser extent, in throughfall are greater than in the rainwater; but it is unclear whether these additional amounts come from leaching of the foliage (i.e. internal circulation) or by washing aerosols and dust from the leaves (i.e. an input). Attiwill (1966), however, in a study made of mature E. obliqua forest in the Great Dividing Range, south-eastern Australia concludes that the principal contribution was made by leaching nutrients from the leaves.

Lima (1975) compared the influence of E. saligna and Pinus caribaea var caribaea on the quality of rain water measured by conductivity, colour and turbidity. He found these more altered by eucalyptus than by pine, and more in stemflow than in throughfall. Stemflow may have particular importance in bringing nutrients directly into the zone of feeding roots.

Table 5 gives examples of estimated inputs of elements in rainfall and of amounts of elements released by the weathering of granite; both are from Australia. These figures are illustrative of the orders of magnitude of possible inputs. Other figures are given in Table 6 where they are compared with losses in streamflow; these data are discussed below. No evidence is available about inputs by animals nor of comparisons between eucalypts and other trees.

Lima and O'Loughlin (in press) present interesting evidence of the interaction of rainfall with the forest canopy. Table 7 compares the nutrient content of rainwater, throughfall and stemflow in four different kinds of eucalypt forest. It can be seen that there is a consistent enrichment of rainfall water after it passes through the canopy, especially in sodium and potassium. The leached sodium represents about two times as much as is found in the litter fall, and potassium 1.3 times. This process is clearly important in the internal circulation of elements within the ecosystem; but, of course, only the precipitation and washed off particles lead to a net input of nutrients.

#### Effects on outputs

The only evidence available is from natural eucalypt forests; and there are evident dangers in extrapolating from these to plantations, especially as forestry operations (harvesting, road building etc.) may lead to accelerated loss of nutrients by erosion. Lima and O'Loughlin (in press) review the evidence on the quality of water draining from catchments containing natural eucalypt forests and conclude that quality is usually high. It depends strongly on geological and soil properties rather than on the type of vegetation. In catchments characterised by permeable soils water quality varies little with discharge; in catchments with less permeable soils quality varies with the discharge, reflecting the different proportions of base flow and surface run-off. There is, too a danger of sheet erosion in low grade, dry forests with areas of bare soil. The composition of the forest does, however, occasionally influence water quality. A forest of E. diversicolor, whose heavy litter is rich in total bases, produced water of a higher pH than forest of E. marginata and E. wandoo.

Table 3

Concentration of nutrients in stemflow, throughfall and rainwater

	Nutrients (ppm)				
	K	Ca	Mg	N	P
Stemflow	3.07	3.01	0.19	0.18	0.07
Throughfall	0.70	0.65	0.15	0.15	0.01
Rainwater	0.31	0.35	0.15	0.10	0.01

From: George (1979)

Table 4

Nutrient return through stemflow, throughfall and rainwater (kg/ha/year)

	Nutrients				
	K	Ca	Mg	N	P
Stemflow	3.9	3.8	0.2	0.2	0.1
Throughfall	9.4	8.8	2.0	2.0	0.1
Total	13.3	12.6	2.2	2.2	0.2
Rainwater	5.2	5.9	2.5	1.7	0.2
Grand Total	18.5	18.5	4.7	3.9	0.4

From: George (1979)

Table 5

Inputs of nutrients into forest ecosystems through  
rainfall and weathering of granite

Element	Ranges of values reported for accession of elements in rainfall in Australia (kg ha <sup>-1</sup> yr <sup>-1</sup> )	Elements released by weathering granite (kg ha <sup>-1</sup> yr <sup>-1</sup> )
Na	2 111	9
K	03 14	9
Mg	03 15	2
Ca	08 35	6
Cl	2 180	0.06
NH <sub>4</sub> N	07 2	
NO <sub>3</sub> N	03 1	
P	01 03	0.07
Mn		0.11

From: Hingston, F.J. (1977)

Table 6

Catchment nutrient input in precipitation (R)  
and output in streamflow (Q), in some eucalypt  
forests (Kg. ha<sup>-1</sup>.yr<sup>-1</sup> )

Species	Ca		Mg		K		P		Na	
	R	Q	R	Q	R	Q	R	Q	R	Q
<u>E. obliqua</u> (A)	2.6	0.2	5.4	3.6	2.0	2.0	0.01	0.02	-	-
Dry scler.	3.2	0.4	1.1	1.1	1.8	0.3	0.01	0.01	2.8	2.7
<u>E. obliqua</u>	1.3	0.2	1.4	3.6	4.2	2.1	-	-	17.9	19.8
Wet-dry sclerop. (B)	7.0	7.1	1.5	4.5	-	-	0.33	0.26	2.5	15.9
<u>E. regnans</u> (C)	6.6	10.3	2.6	4.9	2.9	7.5	0.15	0.12	12.4	20.4
<u>E. regnans</u> (D)	6.6	16.8	2.6	7.4	2.9	8.7	0.15	0.15	12.4	32.8

(A) E. radiata - E. viminalis - E. mannifera

(B) E. radiata - E. dives - E. delegatensis - E. pauciflora - E. dalrympleana

(C) 60% old growth, 16% regrowth

(D) old growth

From: Lima and O'Loughlin

Table 7

Leaching of nutrients from eucalypt forests canopy by rainfall  
(P = rainfall, T = throughfall, Sf = stemflow)

Species	Process	kg/ha/year					
		K	Ca	Mg	Na	SO <sub>4</sub>	P
<u>E. signata-E. umbra</u>	P	3.4	3.2	5.9	5.0	9.6	-
	T	8.5	14.0	7.2	44.0	17.0	-
	Sf	0.9	0.8	1.1	8.1	0.7	-
<u>E. melanophloia</u>	P	2.6	1.9	0.7	3.7	-	0.1
	T	22.1	9.3	8.1	6.4	-	0.5
	Sf	0.7	0.5	0.5	0.2	-	0.01
<u>E. obliqua</u>	P	4.2	1.3	1.4	17.9	-	-
	T	15.4	6.3	6.0	37.2	-	-
<u>E. obliqua</u>	P	2.0	2.7	5.4	16.8	-	-
	T	13.4	8.0	7.3	25.4	-	-

From: Lima and O'Loughlin

Table 6 gives some comparative figures of inputs to and outputs from catchments under different kinds of forest. There is little consistency in these figures. Considering comparative figures from other parts of the world, the authors comment: "In general, output of nutrients exceeds the input, but the balance varies from cation to cation. Variation in input is related to the geographical location of the catchment. Variation in the output will reflect catchment characteristics and vegetation cover. For one individual catchment, the balance of some nutrients will also vary from year to year. By comparison with world data the nutrient balance in eucalypt plantations shown in Table 6 shows a conservative balance, which reflects a stable condition being exerted by the undisturbed eucalypt ecosystem".

#### The effects of eucalypts on soil quality - without cropping

As explained in the introduction, one would expect the effect to vary greatly according to the kind of vegetation in which the plantations are established. Eucalypts may occasionally be used to replace primary climax forest (e.g. *E. deglupta* in place of dipterocarp forests in Mindanao in the Philippines); they may be planted as a potentially more productive crop in place of exploited indigenous forest (e.g. as a substitute for sal, *Shorea robusta*, in north India); they may be used to revegetate deforested or degraded land (as in the Peruvian Andes), or they may be introduced into agricultural land. All these circumstances are different. Add to these the range of climatic conditions, soils and species of eucalypt; and the number of answers become legion to the simple question: what effect do eucalypts have on soil fertility?

If the plantations are cropped, the situation is once again quite different. The effects of cropping will be discussed separately in a later section.

FAO, in collaboration with IUFRO, initiated a study in the 1950s and early 1960s, the conclusions of which are presented in Anon (1966) and in Giulimondi (1959). Karschon (1961) provides a review of the literature to that date. Research was carried out in Italy, Morocco and Spain, mostly on previously treeless sites, on the following aspects:

#### A. The extraction of minerals from the soil

Distribution of the principal mineral elements in the various parts of the tree.

Immobilisation and extraction by the eucalyptus stand in comparison to such actions by other cultivations under the same conditions.

#### B. Influence of the eucalyptus stand on the chemical and physical properties of the soil

Accumulation and evolution of litter.

Cycle of mineral elements.

Evolution of humus.

Influence on microflora.

Anon (1966) gives a list of all the publications originating from the study and drew the following conclusions:

"One may affirm that, even in soils that are relatively non-fertile, the mineral distribution from eucalypt trees is slight [sic].

The evolution of the litter leads to a 'mull' type of humus which, even on very permeable sandy soil, does not give rise to any evident phenomenon of drainage at the base or of acidification.

The microbiologic flora of the soil does not appear to be considerably influenced by the Eucalyptus stand.

Later work has been concerned with three fields:

the effects of eucalypts on previously treeless sites;

comparison with managed sal (Shorea robusta) forests and sal plantations;

comparison of eucalypts with pine plantations.

#### Eucalypts on previously treeless sites

Eucalypts are very widely used for the afforestation of previously treeless sites, because of their generally rapid growth and ability to grow on very poor soils, in particular those that are deficient in phosphorus. In addition to planting for wood, shelter and shade, they have been used for erosion control, as it has naturally been assumed that a cover of trees would provide better protection than the degraded vegetation that they replace. It has been an additional point in their favour that they are unpalatable to stock and therefore more likely to survive where the land has been degraded by overgrazing. Their ecological effects in such situations are thus of wide interest.

Yadav et al (1959) examined a 5-year old plantation of Eucalyptus sp. at Asorori, Uttar Pradesh, India. They reported a movement downwards of CaO and of the finer soil particles; a fall in pH, MgO, total K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub> and available phosphorus, and a rise in available potassium.

Liani (1959) examined a 25-year old stand of E. camaldulensis on sandy calcareous soil near Catania in Sicily. There was an accumulation of acid humus but there was no evidence of movement of iron in the profile. The accumulation of organic matter was high (20.33kg/m<sup>2</sup>), higher than that of other eucalyptus sites that he had previously studied (10.45); (pinewood gave 7.54 an agricultural land 2.92). Organic matter was highest where there was an understory of Acacia saligna, Robinia pseudacacia and Phragmites.

Bernhard-Reversat (1982) made a laboratory study of the decomposition of the litter of E. camaldulensis. He found that there was an abundant litter fall but that the proportion of fine material in the surface soil was small; the disappearance and mineralisation of the litter was relatively slow, but mineralisation of carbon continued in old litter; the litter contained a substantial proportion of hydrolysable substances which were only retained in the soil if there was sufficient clay in it, and there was a reduction of organic matter in the silty-clay fraction of the soil. Acacia seyal behaved differently, with much more humus remaining. Melaleuca was similar to Eucalyptus and Azidarachta was intermediate.



In this context Mullette et al (1974) reported that the growth of E. gummifera, a species of very impoverished soils on ridgetop habitats responded markedly to insoluble phosphates. They suggested an interaction between root exudates, micro-organisms, aluminium ions and root uptake mechanisms to account for its ability to make use of these substances.

#### Comparison with managed forests of sal (Shorea robusta) and of sal plantations

Singhal et al (1975) and Singhal (1984) report on a 5-year comparison between a coppice growth of natural sal and a plantation of Eucalyptus sp. near Dehra Dun. The amount of organic matter accumulated under sal was much greater than under eucalyptus; but humification was more rapid under the latter; its litter was more hydrolysable and the humic material moved more readily downwards in the soil. They concluded that eucalyptus had a beneficial effect on soil structure and thus on fertility.

Jha and Pande (1984) have compared a plantation of E. camaldulensis (made in 1967), a plantation of sal (made in 1926) and natural sal forest, again near Dehra Dun, on old alluvium.

They concluded that:

None of the monocultures could surpass the natural sal in organic matter accumulation, total N, P and available N, P and K

A 14-year old monoculture of eucalypt showed higher accumulation of organic matter than a monoculture of sal

The soil under eucalyptus had a tendency to retain more water than the sal monoculture.

Eucalyptus resulted in an increase of soil pH; but the sal monoculture led to a lowering of pH in comparison with natural sal.

Total nitrogen and phosphorus were found to be low in the sal monoculture compared to eucalyptus, but the total potassium was more.

Available nitrogen and phosphorus were low under the sal monoculture in comparison to eucalyptus, but available potassium was high.

Raising a monoculture of Eucalyptus in a natural sal area caused no damage to the soil fertility and proved superior to long standing sal monoculture in that locality

#### Comparisons with pine

Jamet (1975) made a comparison between pine and eucalypt plantations (E. camaldulensis, E. saligna, E. platyphylla and a unnamed species of pine) on sandy soils at Pointe Noire on the coastal plain of the Peoples' Republic of Congo. The eucalypt plantations dated back to 1953; the pines were a little more recent. The mean precipitation was 1283 mm but varied widely between 2047 mm and 295 mm during the 14 years of measurement. There is a pronounced dry season. The vegetation is a low savanna.

The soils are weakly acid with a low clay fraction and poor in organic matter. There was better humification under the eucalypt, a reduction of calcium and weak acidification under both, but especially under the pines where there was also a tendency to podsolisation.

#### Eucalypts on peat

Zohar (1976 and 1979) reported on the development of *E. tereticornis* and its effect on nitrate levels in the soil on recently reclaimed peat in the Hula valley, Israel. Because of the high water table growth was exceptionally fast, 12 m high and 18 cm DBH after 4 years. Soil nitrates were found to be significantly lower in the eucalyptus plantation than in a comparable treeless area. The intensive cultivation of eucalypts here is suggested as a means of reducing eutrophication in Lake Tiberias.

#### Conclusion

The studies carried out on the effect of uncropped eucalypts on soil quality are almost totally confined to the Mediterranean and to the sub-tropical zone of north India; and only in the latter case have comparisons been made between eucalyptus, natural forest and plantations of an indigenous species, sal (*Shorea robusta*). These studies, therefore, only cover a very small range of the conditions in which eucalypts are grown. These effects have only been examined over a relatively short time. In general one may conclude that the effects of eucalyptus cover on treeless sites improve soil fertility by developing a mull humus, although there are indications that on certain soils the humus may be slightly acid. Comparisons with sal and with pine plantations are also generally favourable. In comparison with *Brachystegia* woodland in Zambia there is a reduction of termite activity and a build up of undecomposed leaf litter (see Chapter IV, below). There is no evidence in these localities of any deterioration and the possibility of irreversible damage seems very remote. The suggestion that eucalyptus might be used to reduce eutrophication is interesting.

#### The effects of eucalypts on soil quality - with cropping

A very different situation arises if the forest is cropped. A loss of nutrients will then certainly occur in the harvested material and this is likely to be accentuated by the effects of harvesting operations. In the management of natural forest it is usually assumed, possibly wrongly in some cases, that the loss of nutrients during harvesting will be compensated by new natural inputs during the course of the rotation (from materials dissolved in rain water, weathering of rocks, nitrogen from legumes etc. See Figs 3 and 4). But as harvesting becomes more intensive, this is unlikely to remain so.

The position has been well stated by Raison and Crane (1981). The following paragraphs are based upon their paper.

The productivity of even-aged plantations which are clear felled before maturity can be considerably greater than that of the native forests which preceded them. The increased growth rates and removal of biomass will increase the demand on the soil for nutrients and more disturbance of the site may markedly increase the potential for associated losses of organic matter and nutrients from the forest ecosystem.

The consequences for tree nutrition of shortening rotations can broadly be divided into two categories:

- (a) direct effects on the rate of nutrient drain from the site, and
- (b) indirect effects associated with harvesting, site preparation and development of the new stand.

### Direct effects of removal of the biomass

The amount of nutrients and rate at which they are directly exported in biomass depends on: the species grown; the length of the rotation, and; the degree to which biomass is utilised.

Increasing demand for forest products and new technologies has stimulated higher levels of biomass utilisation and shortening of rotations. Sometimes both strategies are applied together, leading to what has been called 'fibre farming'. Increased utilisation of the biomass (e.g. whole tree harvesting in which all the above ground biomass is removed or complete tree harvesting in which the stumps and roots are also included) can increase up to 5-fold the amount of some nutrients removed from the forest. The percentage increase in nutrient removal with whole tree logging as compared with conventional logging is greatest when harvesting young stands where relatively more of the nutrients of the above ground biomass are stored in the components of the canopy. The shortening of rotations also increases the rate at which nutrients are removed in harvested biomass, because more material is removed in any particular period. Where the level of utilisation is increased and rotational length is decreased, the nutritional efficiency is reduced (and nutritional cost increased) compared with more traditional management such as harvesting of logs only and management on longer rotations.

### Indirect effects of harvesting

Shortened rotations increase the frequency of disturbance to the site from harvesting and site preparation. The proportion of the time when the site is not fully occupied by a closed canopy forest (which offers some protection to the soil) will also increase. Site disturbance will usually lead either to direct loss of nutrients or to increased potential for loss from the site. The relative magnitude of nutrient export from a site in biomass compared to that associated with site disturbance is highly variable, but the latter can sometimes be greater than the former. It can be caused by leaching, erosion, transfer to the atmosphere, undesirable redistribution of nutrients and soil compaction.

The rate of soil erosion on a forested site is difficult to measure as is any assessment of its consequences for future productivity. It is clear that accelerated erosion is undesirable because both the most nutrient rich and best structured soil is removed. Removal of 1 cm of nutrient rich surface soil can result in the export of about 24 kg P and 240 kg N per hectare. Even modest rates of erosion during a forest rotation may result in losses of nutrients of the same order of magnitude as occur in harvested biomass.

Disturbance of the soil and litter layer in harvesting often leads to increased leaching of nutrient ions. Factors such as the removal of vegetation, increased exposure and associated soil respiration rates are involved. Leaching losses after clear felling and site preparation are highly variable, but losses are usually greatest for N and cations. Commercial clearfelling can result in losses of Ca and N amounting to 30-50% or more of those removed in conventional harvesting of biomass. Normally however losses are less. The effects of shortened rotations on leaching rates have not been reported, but average long-term rates would be expected to increase because of more frequent disturbance of the site and an increase in the proportion of the time that the site is not fully occupied by actively growing vegetation. Increased leaching further aggravates the increased drain on site nutrients imposed by frequent harvesting of nutrient rich biomass under shorter rotation.

Burning of slash between rotations leads to some direct loss of nutrients and there can be additional losses during the fire, especially of volatile elements, from duff layers and organically enriched surface soil during the fire, as well as a later loss of fire-mobilised elements from the soil. Losses of elements, especially N, P and S

resulting from burning may be equal to or greater than that removed in harvested biomass. But, although more complete utilisation of biomass directly increases export of nutrients from a site, it may eliminate the need for slash reduction burning and hence prevent large losses of elements (especially N) from duff and surface soils.

Increased soil respiration, after exposure of the soil at the time of harvesting can also lead to the loss of soil organic matter. Serious reductions of up to 60% in the organic matter of soils following cropping with Pinus radiata plantations in Australia have been shown, together with a widening of the C/N ratios (Raison and Crane, 1981). Such a loss of organic matter is likely to have serious nutritional consequences because soil organic matter is so intrinsically associated with most physical, chemical and biological aspects of soil fertility.

Windrowing which is often used during site preparation can lead to removal of surface soil with detrimental effects on subsequent nutrient supply and tree growth. The degree and seriousness of the soil disturbance and compaction caused by traffic of machines during harvesting and site preparation is highly variable. It depends greatly on soil type but, on all types, shortened rotations will increase the potential for losses from these causes.

In examining the ecological effects of the growing and harvesting of eucalypt plantations, one must try to distinguish between those effects that would be associated with comparable harvesting of any other plantation species and those that are specific to eucalyptus. For example the indirect effects mentioned above would all be associated equally with other plantation species.

#### Nature of the evidence

The literature on this subject can be divided into three categories:

- (a) those papers that give data on the biomass and the nutrient content of various components of the forest crop (leaves, twigs, bark, roots etc.)
- (b) those that compare the nutrient content of the crop with the nutrient store in the soil; and
- (c) those that make estimates of the nutrient cost of harvesting and the consequences of using different species and systems of management.

Of these the most significant is the last category, especially when the authors discuss the relative use of nutrients by eucalypts and other alternative crops. The literature in the first category is listed in the bibliography but is not reviewed in the discussion that follows.

#### Comparison of the export of nutrients with soil reserves

Andrae and Krapfenbauer (1979) made a study in the Brazilian State of Rio Grande do Sul of the biomass and nutrients in a 4-year old stand of E. saligna. The climate in the locality is sub-tropical with hot wet summers and cool wet winters, the natural vegetation a grass pampa. The soil is poor with a horizon of clay accumulation. The study was made of 12 representative trees of 4-14cm DBH.

The total biomass of the stand was 56t/ha of which 38 t (69%) was tree biomass above ground, 10t (17%) biomass below ground and 8t (14%) the biomass of the litter and the vegetation of the forest floor. Annual biomass production was estimated as between 14.7 and 17.1 t/ha, the differing estimates depending upon assumptions about the life span of the evergreen leaves.

The amounts of nutrients in the various components of the system are given in Table 8. From this it can be seen that even the wood alone contains a large proportion of the phosphorus and potassium of the system. In the lower part of the Table figures are shown for the relation between the nutrients in the litter and soil compared with those in the biomass. Comparable figures are given for a 17 year old stand of Araucaria angustifolia, from which it will be seen that the situation in relation to all elements is even more critical in the case of the Araucaria than it is for E. saligna.

Wise and Pitman (1981) have also compared the amounts of nutrients likely to be removed in the harvesting of typical 10 year old plantations of various species of eucalypt (E. grandis, E. laevopinea, E. maculata, E. saligna, E. sieberi and E. viminalis) with the bank of nutrients in a number of typical soils in New South Wales and Queensland.

The main limiting nutrients are considered to be phosphorus, sulphur and possibly calcium. Comparisons of nutrient removals with the nutrient status of the soils gives some indication of "the magnitude of the nutrient removals in relation to the available nutrient reserve in the soil. When this is done it is apparent that calcium and potassium may be the first nutrients to become limiting on many sites under a series of short rotation plantations. . ." They give estimates of the amounts of nutrients which are likely to be added to the system by the weathering of granite and by inputs in rainfall. These are shown in Table 8. They comment that "natural inputs could on many coastal sites readily replace sodium and chlorine and perhaps magnesium. Potassium may be partially replaced but calcium, phosphorus and nitrogen will not be sufficiently supplied in natural inputs to replace removals and in addition will be further depleted by natural outputs".

They then make a comparison between the nutrient removals from short rotation plantations, from an average native forest with an annual wood removal of 2m<sup>3</sup>/ha (a very productive forest in New South Wales would yield about 5m<sup>3</sup>) and from a cereal crop. Their calculations lead to the conclusion that the nutrient removal under a natural sawlog regime would average less than 5% of that removed in total tree utilisation in short rotation plantations. This is due to retention of leaves, branches and bark, a larger proportion of heartwood and lower productivity. The comparison with cereals over a 10 year period (one fallow year in four) is even more striking. Nitrogen removals are 2-4 times higher than in the eucalypt plantations and those of phosphorus 10-20 times higher.

Raison and Crane (1982) make a most illuminating comparison between plantations of E. delegatensis and Pinus radiata. Their conclusions are quoted in full in the following paragraphs:

There can be a marked interaction between the type of tree species and the length of the rotation, which will affect the rate of nutrient export and nutritional efficiency. A study of the distribution of biomass and phosphorus in the boles (wood + bark) in two commercially significant species, Eucalyptus delegatensis and Pinus radiata in Australia led to the following conclusions:

- (a) a markedly higher concentration of P was found in sapwood than in heartwood for both species. This was shown especially in E. delegatensis where the ratio of P in the sapwood to that in the heartwood was 33:1, compared with a ratio of 9:1 found in P. radiata.
- (b) significantly more sapwood formation in P. radiata. Heartwood formation did not commence in P. radiata until aged 17, compared with E. delegatensis where heartwood commenced to form at age 7 years.
- (c) the combination of faster growth rate and higher average concentration of P in the boles (a consequence of (a) and (b) above) resulted in greater rates of P removal when harvesting P. radiata compared with E. delegatensis. These rates are shown in Table 9.

Table  
Nutrient content of various components and

		N	P	K	Ca	Mg
<i>E. saligna</i>	A Soil 0-25 cm	4508	13.5	225	195	279
	B Soil 0-75 cm	11522	29.9	635	3240	835
	C Litter	63	2.7	20	100	15
	D Return by leaf fall/yr	41-61	24-35	40-60	43-64	11-17
	E Tree and ground vegetation	230	30.4	221	251	52
	F Wood	20.84	12.21	41.89	16.59	6.10
	G Bark	13.18	2.35	25.95	56.60	12.99
	H Branches	29.60	3.39	44.95	69.36	7.33
	I Leaves	107.66	6.94	61.06	64.23	16.64
	K Tree (F+G+H+I)	171.28	24.89	173.15	206.78	43.06
<i>E. saligna</i>	Litter and soil (0-25 cm)/biomass A + C	19.87	0.53	1.11	3.96	5.65
<i>Araucaria angustifolia</i>	" " "	11.17	0.31	0.43	1.9	1.5

(d) independent of growth rate, the shortening of rotations increased the removal of P per unit of wood harvested. Table 9 shows that the amount of P removed per unit of wood harvested increased by 70% when the rotation age of E. delegatensis was reduced from 57 to 18 years. Removal of early thinnings (a form of shortened rotation management) results in a significant loss of nutrients from the P. radiata forest.

(e) theoretically, E. delegatensis will only become significantly more nutritionally efficient than P. radiata when grown on rotations of greater than 7 years. The comparative efficiency of E. delegatensis increased progressively with age.

This latter observation has led us to conclude that for rotations of about 7 years or less which are currently used with eucalyptus plantations in Brazil, there may be no nutritional advantage (in terms of reduced export of P in biomass) of eucalypts over other species . . . Eucalypts exhibiting high growth rates (40-80m<sup>3</sup>/ha/year) outside of Australia, and managed on short (<10 year) rotations will place heavy demands on soil reserves of nutrients (e.g. about 5kg/ha/year stored in wood) which are similar to those of annual agricultural crops (e.g. 7+ kg P/ha/year for corn). The harvesting of foliage in addition to wood will further increase the removal of nutrients, and it is very likely that regular fertilisation (at rates similar to those used for agricultural crops) will be required if fertility of the soil and productivity of the forest are to be sustained.

This would suggest that there is no demonstrated inherent advantage (or disadvantage) in using eucalypts rather than other genera, but that each situation should be examined on its merits.

#### Nutrient cost and conclusions

Madgewick et al (1981) make a comparison between two eucalypts (E. nitens and E. fastigiata) and P. radiata in North Island, New Zealand. Their comparison is between the eucalypts at 4 years and the pine when it reaches its maximum mean annual increment at 17 years. They calculate for each the nutrient cost - the amount of nutrient removed/unit of energy harvested. These nutrient costs are presented in Table 10. It will be seen that phosphorus costs were approximately the same in all cases but nitrogen costs from harvesting 4 year old E. fastigiata would have been almost four times those from the older P. radiata. Leaving foliage in the forest would decrease nutrient costs by about 10% for calcium and almost 50% for nitrogen.

They conclude: "Nutrient costs of energy from biomass are very sensitive to stand age in young stands where the relative proportions of foliage to wood and of young to old wood are changing quickly. Any comparison between Eucalyptus and Pinus radiata must be treated with caution until more is known about optimal silvicultural regimes for different species and their relative yields of liquid fuel".

#### Guidelines

Raison and Crane (1982) suggest two implications of this work that are important for our present study:

- (a) maintenance of organic matter is a critical factor on many Australian soils [this could well be generalised outside Australia], and;
- (b) nutrient removals should not be compared with total reserves of nutrients in the soil as a basis for assessing the significance of harvesting.

Table 9

Quantities and rates of phosphorus exported from the forest when harvesting E. delegatensis and P. radiata on short and long rotations

Parameter	Eucalypt ( <i>E. delegatensis</i> )		Pine ( <i>P. radiata</i> )	
	Tree rotation (yr)	18	57	18
Proportion of sapwood in stemwood (%)	52	28	100	90
P exported (kg P ha <sup>-1</sup> )				
in stemwood	9	17	28	56
in bark	4	8	18	24
in bole	13	25	46	80
Rates of P harvested in boles				
as per wood (q P t wood <sup>-1</sup> )	97	51	258	169
as per time (kg P ha <sup>-1</sup> yr <sup>-1</sup> )	0.73	0.44	2.53	1.97
Proportions compared to the longer rotation				
as per wood	1.7	1	1.5	1
as per time	1.6	1	1.3	1

includes 4 commercial thinnings at ages 16, 22, 28 and 34 prior to clearfelling at age 40

(after Crane and Raison 1981)



Table 10

Mean annual increment and nutrient cost of energy

	Pinus radiata		E. nitens		E. fastigata	
	Stem + Total branch		Stem + Total branch		Stem + Total branch	
Age (years)	17	17	4	4	4	4
Mean annual increment oven-dry (t/ha)	18	17	18	20	13	15
Energy ( $10^8$ J/ha/year)	202	305	326	377	238	268
Nutrient cost per $10^6$ J						
N (kg)	46	74	122	220	135	268
P (kg)	11	14	10	15	9	17
K (kg)	65	80	172	203	157	207
Ca(kg)	50	55	200	220	170	206
Mg(kg)	16	17	35	42	37	51

From: Madgwick et al (1981)

In general, inputs of nutrients should aim to maintain (or improve) the nutrient supplying capacity of the soil. Thus more nutrients generally need to be added than are removed in biomass because of the low efficiency of recovery of applied (fertiliser) nutrients by trees.

They propose the following strategies:

Leaving nutrient-rich biomass on the site; not harvesting root systems on most sites; removal of bark from tree trunks and its retention on the site wherever possible.

Use of conservative site preparation procedures which minimise disturbance and loss of nutrients and organic matter from slash, litter layers and surface soil.

Efficient use of fertilisers.

The possible use of legumes (either inter-cropped or during a fallow period between rotations) to assist in the maintenance of soil organic matter and nitrogen economy.

Use of tree stock selected for their low nutrient demand.

## CHAPTER IV

### COMPETITION AND REPLACEMENT

#### Introduction

This section deals with the effect on vegetation and fauna of inserting eucalyptus plantations into areas where they were not present before. These effects are broadly of two kinds which are called in this report competition and replacement.

#### Competition effects

When eucalypts are planted in any area of natural or semi-natural vegetation, this has an effect on the fauna and flora of that particular area. This may be due to shading, competition for nutrients or water, site disturbance, allelopathic effects (direct chemical influences of eucalypts on other plants) and the cumulative effects of any changes in the soil.

The fauna will also be affected. Plantations of eucalypts will afford a totally new habitat, by changing the ground flora, the structure of the vegetation, and, most important, substituting one species - an exotic - to occupy the dominant place in the community. Exotics generally support a poorer community of herbivorous animals than the species they replace - this is one of the reasons why they are successful; and they therefore make a smaller contribution to the lower end of the animal food-chain than do native species.

It is necessary to emphasise, however, that the effect of any plantation will depend upon the nature of the community it replaces, and on the ecological characteristics of the region. For example, in an arid area, eucalypts may well suppress ground vegetation by competing for water; but they are unlikely to do so in an area of high rainfall.

All plantations tend to have effects on flora and fauna. They create uniformity - one dominant tree, grown in large uniform stands which are also usually managed in blocks. (Some natural stands are of course composed of one species and of uniform age, but this is unusual.) There is an absence of overmature and dead trees (an important habitat for many animals). Plantations promote a flora that has less biomass and is poorer in species than that present in natural forest. But, of course, if they replace overgrazed pasture, the vegetation may well become more luxurious than it was before, at least in the earlier years of the plantations. The impoverishing effects of large uniform monocultures can also be offset by management - well planned clearings, leaving some overmature trees, small groups of native trees etc. Tree plantations, too, are seldom formed of a single clone as they often are in agricultural crops.

Generally speaking, however, plantations of exotics will be poorer in species and contain different species than the natural forest they replace. When they displace non-forest communities they will create a forest environment, which may be a good thing; but this is unlikely to favour the species characteristic of the previous open ground.

Such blanket replacement is, of course, common in relation to agricultural crops. The effect of tree monocultures (whether rubber, oil palm, teak, Gmelina, pines or eucalypts) are likely to be less severe than those of, say, cotton or maize, because those trees are planted in the natural vegetation and do not, therefore, replace it totally as does an annual crop. and because the rotations are longer.

In this matter of competition there are few facts relating to particular tree crops, but there are certain general ecological principles that are well known and which can be applied. Each case needs to be examined on its own merits.

### Replacement effects

The problem of competition grades into that of replacement.

When an eucalyptus plantation is established, it replaces one ecosystem by another that is substantially different. The location and extent of eucalypt plantations should therefore be considered against the sum of the benefits received from the ecosystems that they are intended to replace. As well as the local social, economic and environmental benefits of these ecosystems, attention should be paid to their place in any national policy for the conservation of wildlife and of the genetic resources of the native flora and fauna. If, for example, eucalypt plantations eliminate the last example of a forest type that is found nowhere else, the effect is quite different from that of replacing one tenth of a more widespread forest type. The environmental impact of eucalypt plantations in replacing natural ecosystems can only be assessed if the extent of each type of natural ecosystem is known. Decisions about whether or not such replacement is justified can only properly be taken against a background of a national policy for the conservation of nature and genetic resources.

### Eucalypts and undergrowth

Comparative studies available are from India (Mathur et al, 1980; Mathur and Soni, 1983; Rajvansi et al, 1983) and from Malawi (Jocque, 1977). The Indian studies are concerned with comparisons between Eucalyptus species (E. camaldulensis, E. grandis and E. hybrid) and sal (Shorea robusta) forest near Dehra Dun in north India, and the study from Malawi with a comparison between about 4 hectares of a 6-year old, 15 m-high plantation of E. grandis and an adjacent woodland, of comparable height, dominated by Brachystegia spiciformis. This is in the wettest part of Malawi with an annual rainfall between 1500 and over 2200 mm.

Mathur et al (1980) compared plantations (E. camaldulensis and E. grandis) with sal forest and secondary brushwood resulting 14 years after clearing of sal forest; (this forest frequently almost forms a monoculture). Both number of species and cover were greatest in the eucalypt plantations and least in the sal forest. There was the same ranking in amounts of litter, above ground phytomass and below ground phytomass - the two last excluding trees. The proportion of the line transects used which lay under crown canopy (a measure of shading) were recorded as: eucalypt 74.7%; brushwood 53.79% and sal 36.29%; of ground vegetation it was 3.98%. Although these results suggest better and richer vegetation under the eucalypts, the results are vitiated by the fact that the eucalypt and brushwood area were protected from grazing, the sal was not.

Further comparisons (Mathur and Soni, 1983, Rajvasti, 1983) between sal and eucalypts come to similar conclusions. The sal, however, contains higher proportions of shrubs and fewer annuals; Ageratum conyzoides, a widespread annual weed is the commonest species under eucalypt.

The stand of eucalypt in Malawi has a very open canopy. Undergrowth is patchy consisting either of a dense shrub layer of young native trees and some true shrubs or of a grassy herb layer dominated by Panicum spp. There is still a great influence of the flora of the natural woodland in the plantation, 45% of the species of the Brachystegia woodland occurring there. The shade-loving herbs of the original woodland are less well represented (30%) than shrubs and vines (47%) and trees (57%). Mosses and epiphytes, common in the natural stand, are completely absent, and mushrooms have almost disappeared. The most specialised plants are replaced by tolerant weeds. The litter is thicker and mainly composed of intact eucalypt leaves.

All these observations are in areas which would support tropical moist forest. No published information has been located for semi-arid or arid regions.

[The author has seen Eucalyptus deglupta plantations replacing mixed Dipterocarp forest in the Philippines (Mindanao Island). The tree and shrub flora of the natural forest had been totally replaced; so too had the ground flora, which in this case consists mainly of regeneration of the many tree species characteristic of the forest. In contrast old eucalypt plantings in the temperate rainforest near Sintra, Portugal contains a dense ground vegetation of the indigenous flora.]

#### Eucalypts and neighbouring agricultural crops

Some effects of shelterbelts have already been discussed above in Chapter I and II and reference has been made to the review by Jensen (1983). The inter-relations of shelterbelts with crops are very complex and are not peculiar to eucalypts; they are shared by other tree species that are used for this purpose. They may include shelter from damage by blown sand, shelter from drying winds, increased temperatures, and reduced transpiration; but equally competition for water and nutrients. The exact effects depend greatly on circumstances; and not all of them are fully understood. There is, however, no convincing evidence that the effects of eucalypts are different from those of any other tree species; but, it must be admitted, that no experimental work has been designed to demonstrate such differences. The following examples demonstrate the kind of effects that have been reported.

Giulimondi (1960, 1961) and Giulimondi and Giovannini (1960) examined the effect of shelter belts of E. x trabutii (25 years old) near Rome and E. camaldulensis (30 year old) near Catania in Sicily, the former on a silty-clay loam and the latter on sand. The rainfall at Catania is low, about 500 mm a year. They found marked drying of soil in the summer months up to 10-15 m from the shelter belts in the heavier soil and up to 20-25 m in the sand. Yields of lucerne were reduced accordingly. On the other hand establishment and growth of lucerne were higher in a 5-8 m strip close to the trees after a particularly rainy winter.

Shelterbelts 60m wide of Eucalyptus microtheca proved effective in protecting irrigated areas in the Gezira, Sudan from encroachment by desert sand; similar results were achieved with Prosopis chilensis and Acacia mellifera. Yields of oranges were substantially raised in California, for distances up to five times the height of protecting belts of E. globulus. But yields of non-irrigated Vigna unguiculata sheltered by 10m high E. camaldulensis north of Kano in Nigeria were only 35% of those grown in the open. (Data quoted by Jensen, 1983).

#### Allelopathic effects

There have been suggestions that certain species of Eucalyptus may produce chemicals from their leaves or litter that inhibit the germination or growth of other species of plant. This phenomenon is known as allelopathy. It is an effect which is quite different from direct competition for water, minerals or light.

In the Hunter Valley, New South Wales, Australia Story (1967) detected, under several different species of tree, circular patches which were more sparsely covered with grass than their surroundings. The trees involved were Acacia pendula, Callitris calcarata, Casuarina luehmannii, Eucalyptus crebra, E. dawsonii, E. mellicodora, E. moluccana and Notelaea microcarpa. After careful investigation he established that competition for water was not the cause and that competition for nutrients seemed unlikely. He concluded that chemical exudates were probably responsible.

Table 11

Comparisons for animals between indigenous forests and plantations

Author	Country	Group	Indigenous veg.		Plantation		
			Euc	Non-Euc	Pine	Euc	Maucaria
Dirtz <u>et al</u> (1975)	Brazil	Small mammals		x		x	x
Frirnd (1982)	Australia	Mammals	x		x		
Neumann (1979)	Australia	Beetles	x		x		
Stryn (1977)	S. Africa	Birds		x		x	
Woviarski (1979)	Australia	Birds	x			x	
Jocoué (1977)	Malawi	Spiders/ Termites		x		x	

Since that date there has been some experimental work which shows that some species of eucalypt do have an inhibitory effect on the associated vegetation. This has been reviewed by MacLaren (1983) from which the following account is adapted.

Del Moral and Muller (1970) noted that E. camaldulensis inhibited improved grassland species including Bromus mollis and Lolium multiflorum. There was more vegetation under oak, in 45% sunlight, than under the eucalypt, in 64% sunlight; soil moisture in the litter zone was greater than in open areas nearby. Al-Mousawi and Al-Naib (1975) found a scarcity of herbaceous plants in plantations of E. microtheca in Central Iraq, which was not due to moisture, nutrients or shading; but leaf extracts, decaying leaves and soil inhibited germination and growth of associated species. The volatile inhibitors found were the same as those identified for E. globulus by Del Moral and Muller (1969). They found that the absence of vegetation beneath E. globulus could not be attributed to competition for essential resources, but phytotoxins in fog-drip appeared to be capable of causing this. A number of annual grasses were tested with the solution coming through the canopy. Two, Bromus mollis and Lolium multiflorum, were highly sensitive and others less so.

This phenomenon, which is not confined to eucalypts, could be a significant deterrent in choosing species for erosion control or in circumstances when grazing under tree cover was important.

#### Eucalypts and animals

There are several published studies on aspects of this subject from Australia, Brazil, Malawi and South America. Two different kinds of comparison are involved: between indigenous and exotic, and between natural forests and plantations. Table 11 shows the distribution of the different studies in this respect.

#### Comparison of natural (non-eucalypt) forest with plantations of eucalypts and of Araucaria

Three papers cover this. Dietz et al (1975) compare two areas of mixed natural forest with a 10-year old plantation of E. saligna and a 31-year old plantation of Araucaria angustifolia, a species native to Brazil. The two areas had once been indigenous evergreen tropical rain forest and were recovering from complete devastation, one 15 years ago and the other 52. Populations of small mammals were sampled by trapping in all four forests. Five species of mammal were involved (Orzomys nigripes, Monodelphis americana, Marmosa sp., Akodon arviculoides and Blarinomys breviceps). The highest relative densities of small mammals were found in the Araucaria plantation, the lowest in the eucalypt plantation. Densities in the two natural forests were statistically the same and lay between the two plantations. The diversity of captured species was highest in the natural forests and least in the homogeneous plantations.

Jacques (1977), in the account of Malawi forests discussed above in the section on 'ground vegetation', compares the density of webs and the weight of the individuals of the large spider Nephila sp. in eleven plots each of 7 x 7 m in eucalypt plantation and in Brachystegia woodland. The density of webs, and average weight of spiders, was significantly higher in the latter, 950:200 webs per hectare and 958:770 mg weight. He draws the conclusion that this is due to insufficient food in the plantation and surmises that the spider would disappear in large pure eucalypt plantations. The activity of termites was also significantly lower in the plantation.

Steyn (1977) made a qualitative comparison of the bird populations between eucalypt plantations (mainly of *E. grandis*) which cover over 25,000 ha in north eastern Transvaal and the natural lowveld ('Lowveld Sour Bushveld') containing strips of trees and shrubs along watercourses. He showed how the numbers and behaviour of certain species had been modified in the areas of plantations.

He discussed:

those birds that use the eucalypt trees and which feed in the plantations;

those that use the understory of the older plantations for breeding and hunting for food;

those that breed in the plantations and feed elsewhere; and

those that use eucalypt plantations for feeding only.

Some lowveld birds also made irregular invasions into the plantations, particularly during a winter drought in 1969/70.

Steyn also identified some niches which were filled by specialised birds in Australia but which were not yet filled by indigenous species in South Africa.

He concluded that eucalypt plantations were not as sterile and unsuitable for bird life as they were often accused of being. Some less adaptable species had been driven out; and plantations were unsuited to the way of life of some species - for example the purple crested louries (*Gallirex porphyreolophus*), which is a fruit-eater, and widow birds, bishop birds and some larks and pipits which prefer open country.

#### Comparison of indigenous eucalypt forests with eucalypt plantations

Woinarski (1979) compared the birds of a 25-year old plantation of *E. botryoides* with those of an adjacent natural forest of mixed age *E. dives* with an open, moderately tall canopy and a varied shrub and grass understory. The site was close to Melbourne, Australia. He found that six species were significantly more common in the plantation and nine species in the natural forest. The diversity of bird species was slightly higher in natural forest. There were more hawking species, fewer species that gleaned food from bark and branches, and fewer that ate seeds, fruit and nectar. Some species were more common in the interior of the plantations than at the edges.

#### Comparison of indigenous eucalypt forests with forests of *Pinus radiata*

Two comparisons of this kind have been made. One, Friend (1982), was in Gippsland, Victoria and compared mammals; the other, in north-east Victoria, compared beetles (Neumann (1979)).

For the mammals, the richness in species was lower and the proportion of introduced species was higher in plantations, particularly in the younger stands where no over-story vegetation existed. Certain small ground-dwelling species were favoured in plantations of particular ages, depending on their requirements for food and refuge. Larger ground-dwelling herbivores and carnivores were common in the pine plantations, although feeding areas for herbivores were restricted in middle-aged plantations to the edges of compartments or to tracks. Most arboreal herbivores, nectivores and users of



tree hollows were uncommon in plantations, where they were restricted to remnants of native forest. Their long-term survival in plantations was considered questionable. Some arboreal species with relatively broad requirements for food and refuge were able to exist within older plantation compartments which supported some understory shrubs.

In pine plantations the number of mammal species was greatest near edges adjacent to native forest, and where there was a mosaic of remnants of native forest and pine stands of various ages. Windrows may be important refuges for some of the smaller native mammals in first rotation plantations, for such species were absent from young second rotation plantations which lacked windrows.

The findings of Neumann (1979) on beetles were similar. The diversity of communities of beetles was found to be significantly higher in mature eucalypt than in the older stands of pine because, in the eucalypt, there was a more even distribution of individuals among species and a greater richness of species. In both, the range of species was greater during the spring and summer than during the autumn and winter.

Neginhal (1980) described the effects of progressive reforestation since 1958 of secondary grassland in the Ranibennur Blackbuck Sanctuary of 119 sq km in Karnataka, India. This resulted in the recovery of populations of the blackbuck (Antelope cervicapra), Indian bustard (Chloriotis nigriceps) and wolf (Canis lupus) that were nearly extinct. He considered it doubtful whether this trend would be maintained if the remaining open areas were planted.

#### Conclusions

Some relatively clear and simple generalizations can be drawn from this work:

that plantations have a less diverse flora and fauna than indigenous forests;

that plantations of exotics have a less diverse flora and fauna than plantations of indigenous species;

that plantations can be made into more favourable habitats for animals and plants by appropriate management which provides suitable habitats for the species one wishes to attract. Leaving patches or corridors of indigenous vegetation helps greatly in this;

limited plantings in treeless areas and the shelter that these provide can be beneficial to populations of wildlife.

## CHAPTER V

### SOME SOCIAL CONSIDERATIONS

We have already emphasised in the introduction that any distinction between ecological effects and the wider social and economic consequences of planting eucalypts is largely artificial, because it is mainly in their influence on people that the importance of ecological effects resides. This Chapter considers, in very general terms, the ways in which eucalypts may affect people, so that the earlier chapters may be seen in a wider context.

The planting of eucalypts can have a number of different kinds of effect.

These may be purely site-specific, such as possible changes of soil fertility affecting only the area of plantation or the effects of shade and root competition on pasture grasses underneath the trees.

Alternatively they may be non-local, affecting conditions away from the site such as the regional hydrology.

A third category includes activities that might be described as disruptive. Under this category would be included the displacement caused by eucalypt plantations: of other forms of land use, of products or of employment.

Most of the ecological effects described in the chapter on water are non-local in their influence; those on soil fertility and allelopathy are site specific; those on plant competition are also site specific, but the replacement of one kind of plant community by another would be classified as disruptive. All of these have social implications: some purely local that can be provided for by local consultation; others of wider significance, requiring evaluation in the regional or even the national context.

Much too will depend upon the scale of proposed planting. Eucalypts have become controversial largely because they are so widely planted and in such large quantities. The effects are therefore very evident. Also, as has been mentioned above, they have often been planted with a flourish of trumpets as the tree to solve all problems, and some of the criticism that they have received is because of disappointed expectations.

In addition to the purely ecological questions which have been addressed in earlier chapters the following are features of eucalypts, and of their growing, that are considered to be of significance in a social context. They are categorised below as advantages and disadvantages, listed in no particular order of importance.

#### Advantages

A multi-purpose tree, providing wood, shade, shelter, honey, oils and, from some species (e.g. E. microtheca) seeds.

Highly productive and, when grown in suitable conditions, can be coppiced readily.

Litter can be collected and used as fuel.

Provides shade from the side and the shade is light, so that there are good possibilities for intercropping; [there is some difference of opinion about its suitability for inter-cropping].

Disadvantages

Unsuitable for browse and as fodder.

Unsuitable for harvesting by machete when large.

Difficulties in raising seedlings, weeding and protection from stock; [some of these are common to other plantation species].

The collection of litter for fuel makes the site prone to erosion.

Can displace agriculture from land suitable for food production.

Land seizure for planting and displacement of labour.

Can lead to fuelwood becoming a market commodity where previously it was a free good.

These are considerations, which, together with the ecological effects, need to be taken into account in making decisions whether to plant or not to plant. They are likely to vary from case to case; but any adverse effects could certainly be mitigated by careful planning and local consultation.

## CHAPTER VI

### CONCLUSIONS

Each of the preceding chapters has included an evaluation of the available evidence and any specific conclusions that it was possible to draw. Some guidelines have also been suggested. It is not proposed to repeat these in detail here but rather to draw some more general conclusions.

The questions that will face those who have to decide whether or not to plant Eucalyptus are these:

Does the planting of Eucalyptus in particular circumstances carry costs, in the broadest sense of the word, that would not be associated with the planting of some other species?

If there are costs, will these be offset by the advantages (in rapid growth or adaptability to adverse conditions) that would be gained by planting Eucalyptus?

An additional question which will have to be faced by those who plan research is this:

Is there enough evidence, as judged by this review and from what is known of the social implications of planting eucalypts, to reach valid decisions on these matters?

If there is not, what kind of information or research programmes are necessary to correct the deficiency?

How important is the problem in general rather than local terms; and what investment in research does it therefore warrant?

#### Ecological effects:

##### The nature of the research

We have already commented in the introduction and the text on two difficulties: that of producing any valid generalizations on a subject which covers so many different species and local circumstances; and the artificiality of the distinction between costs associated with 'ecological' effects and costs which may, more strictly, be considered 'social'.

The second of these difficulties can only be overcome by a more critical study than has been possible here of the social attitudes to the growing of eucalypts and the social costs and benefits associated with it. It is strongly recommended that such a study should be made to complement the present work.

The first is not so easy to solve. If sufficiently critical experiments were to be set up comparing eucalypts with alternative plantation trees and with natural vegetation in all the possible sites and circumstances where the problem is likely to arise, the labour and cost would be out of all proportion to the importance of the problem. On the other hand, limited unreplicated trials, such as many that we have reviewed, are not even valid for local use.

The most useful research for the purposes of this review has been of two kinds: fundamental research that has been concerned with elucidating the general processes (of the water cycle and catchment hydrology; of nutrient cycling; and of the physics of

shelter belts) and that which has dealt in a comprehensive and critical manner with a whole system (notably the total catchment studies). But even the latter can only be extrapolated to comparable conditions elsewhere; and it is unreasonable to suppose that such studies can be carried out for all the numerous circumstances in which a comparison between eucalypts and other species is needed.

The most profitable way forward would seem to be to use the 'systems' already developed for catchment studies and for the nutrient cycle; to refine these if necessary to apply as precisely as possible to the case of eucalypts; and identify the critical measurements that would be required, in each particular case, to assess the likely effects of any interference with the system (in this instance planting eucalypts). If some relatively simple measurements could be devised, this would give early warning of any serious consequences and would enable prescriptions to be made in advance (for example for fertilizer treatment). It is recommended that FAO should encourage research along these lines.

#### The nature of the ecological effects

The following is a brief summary of the main findings of the review:

Water. Catchments under forest have a lower water yield than those under scrub or grassland; but they may regulate flow better, depending upon the nature of the ground cover. There is evidence however from the humid tropics, that young, rapidly growing eucalypt plantations consume more water, and regulate flow less well, than natural forests.

There are indications from Australian work that eucalypt plantations may reduce the yield of catchments more than pine, but the evidence is not conclusive.

Eucalypts are often planted where there have been no trees before. Under these circumstances the water yield of catchments is reduced and water tables are drawn down. The effect is greatest when trees are young and growing rapidly. Other tree genera would probably produce comparable effects.

The strong surface roots of some eucalypts mean that they compete vigorously with ground vegetation and with neighbouring crops in situations where water is in short supply.

Critical evidence is lacking on two important questions: do eucalypts use more water or have a greater effect on the water regime than other species of tree; and are eucalypts more efficient in their use of water (produce more wood per unit of water used) than other species? Possibly, however, there is no general answer to either of these questions.

Erosion. Eucalypts are not good trees for erosion control. Under dry conditions ground vegetation is suppressed by root competition. This effect is accentuated by collection or burning of the litter, but reduced by terracing. Their performance as shelter belts, is similar to other trees of the same size and shape.

Nutrients. Natural eucalypt forest appears to control the leaching and run-off of nutrients as well as, even perhaps slightly better than, other natural forests.

The effects of uncropped eucalypts on soil depends upon the state of the soil in which they are planted; beneficial in degraded sites, probably not so when replacing indigenous forest. There is evidence that eucalypt litter decomposes less well (because of reduced activity of termites) than the litter of indigenous Brachystegia woodland, in Malawi.

Where eucalypts are planted in bare sites, there is an accumulation and incorporation of organic matter. This is mull in most circumstances, but mor has been reported. There is no evidence of podsolization or irreversible deterioration of soil.

Eucalypts planted on nitrogen-rich peat have been shown to take up large quantities of nitrogen and could be used for reducing eutrophication.

The cropping of eucalypts on short rotation, especially if the whole biomass is taken, leads to rapid depletion of the reserve of nutrients in the soil. This is a direct consequence of their rapid growth; it would apply in much the same way to any other highly productive crop, and is also closely associated with length of rotation. There is some evidence that the removal of nutrients in comparable crops of pine are greater. Calculations of 'nutrient cost' should be made in each instance and fertilizer treatment decided accordingly.

Competition. The effects of eucalyptus on ground vegetation depend very much upon climate; most of these are because of competition for water; the effects of reduced light are probably less than those caused by some other broad leaved trees or pines, because of the light shade cast by eucalypt foliage. Ground vegetation is less affected in wet conditions than in dry, when it may be greatly reduced, leaving the soil bare and prone to erosion.

There is evidence that some eucalypt species produce toxins that inhibit the growth of some annual herbs.

Numbers and diversity of animals (evidenced by mammals, birds and insects) are less in exotic eucalypt plantations than in natural forest. The usual relation seems to apply: natural forest > plantations of indigenous species > plantations of exotics. This effect can be reduced but not eliminated by managing to produce suitable habitats.

Displacement. Eucalypt plantations largely displace the ecosystems that were there before. The relative importance, both ecological and social, of these original ecosystems should be carefully balanced against the advantages to be gained from the new plantations.

### Conclusion

In conclusion, having reviewed the evidence very thoroughly, we must stress that there can be no universal answer, either favourable or unfavourable, to the planting of eucalypts. Nor should there be any universal answer: each case should be examined on its individual merits. We cannot see how further general research, however detailed, can alter this conclusion.

We stress that eucalypts should not be planted, especially on a large scale, without a careful and intelligent assessment of the social and economic consequences, and an attempt to balance advantages against disadvantages. This can probably best be done by a sympathetic examination of the ecological circumstances and of the needs of local people. In the case of the ecology, this will be assisted by an understanding of the results of the fundamental research on water, nutrients etc. to which we have referred.

Short-term ad hoc research on particular sites may be of some help in making local decisions; but the results of such research must not be extrapolated to other different circumstances nor must unwarranted generalizations be made from it.

## ANNOTATED BIBLIOGRAPHY

This bibliography comprises all the published literature that could be traced dealing with the ecological effects of Eucalyptus. References on other topics, such as growth, silviculture or socio-economic matters, are only included if they have relevance to environmental issues.

Apart from the reference, each entry contains three other items: a subject classification; a classification of usefulness and relevance; and a short summary of the contents of the publication. As far as possible, all the literature on the main topics of the study has been collected and read; in a few cases only the abstract has been obtained, and this is noted in the entry.

### The subject classification

Each reference has been classified with one or more indices, as follows:

- W Use of water, hydrology, etc.
- N Use of nutrients, fertilisation, nutrient content in soil and biomass, etc.
- E Other ecological effects than N and W.
- G General literature (often books) used for preparing the report.
- R Reviews of other articles. Seldom cited (the original is cited).
- M Miscellaneous. Debate, personal opinions, applications, etc.

### Usefulness classification

Each reference has been classified, as follows:

- xxx Very useful for this study (strong evidence), cited. Key-reference.
- xx Useful. Often cited. Reliability satisfactory.
- x Not very useful for the study. Useful as orientation or as examples of ecological effects. May also be of low reliability. Most reviews are also placed here.

Al-Mousawi, A.H. and Al-Naib, F.A.G. Allelopathic effects of Eucalyptus microtheca F. Muell. Journal of the University of Kuwait (Sci.) 2 59-66  
1975

E xx Experimental study confirmed that scarcity of herbaceous species under E. microtheca in Iraq was probably due to phenolic and volatile contents in the leaves rather than to competition.

Andrae, F. von and A. Krapfenbauer. Untersuchungen über Biomassen- und Nährstoffverhältnisse in einer vierjährigen Aufforstung mit Eucalyptus saligna Smith in Santa Maria, R.S., Brasilien. Centralblatt für das gesamte Forstwesen 96 (1) 1-29.  
1979

N xxx Complete biomass and nutrient study and comprehensive analysis for tree and soil. Low content of P and K in soil compared with the tree, leading to the conclusion that sustained yield is endangered for the stand in question.

Anon. Research on relationship between Eucalyptus and soil. FAO, Joint  
1960 Sub-Commission on Mediterranean Forestry Problems, Working Party on Eucalyptus, 4th session, April-May 1960, Lisbon. Secretariat Note. 2pp.

NW x Although the IUFRO/FAO-sponsored studies during the late 50s are reliable, information on water and nutrient requirements is still missing.

Anon. Research on the Relationship between Eucalyptus Stands and the Soil.  
1966 Report from IUFRO-meeting in Munich 1966. p 13-24.

N xx Presents the state of the IUFRO/FAO sponsored eucalypt studies beginning in the late 50s (10 references). Data on the uptake of nutrient and influence of soil under mediterranean conditions are presented. The conclusions ("eucalypts have slight or no negative influence on soil") are based on incomplete data.

Anon. Map of the world distribution of arid regions. Explanatory note. Unesco,  
1977 MAB Technical Notes 7. 55 pp, 1 map.

G xx Contains a fairly detailed map dividing the world into hyper-arid, arid, semi-arid, sub-humid and humid zones, based on precipitation and potential evapotranspiration.

Anon. Eucalyptus for wood production. CSIRO, Adelaide, Australia. 434 pp.  
1978

G xx Gives a full review of the subject.

Anon. Relatório referente ao período de Julho de 1977 a Junho de 1978 do  
1978 projecto "Estudos do ecossistema eucaliptal". Centro de Estudos Florestais das Universidades de Lisboa. 37 pp.

N xx Presents the state of eucalypt studies in Portugal and some results from them. Data on nutrient content in bark and stem wood of E. globulus are presented. Few replications (5 trees). Gives also figures for nutrient content in cereals. No conclusions drawn. Plans are presented for further research on a broad field.



- Anon.  
1978 Tropical forest ecosystems. A state of knowledge report. Unesco/UNEP/FAO, Natural resources research XIV. 683 pp.
- G xx Contains two very useful chapters for this study: "Water balance and soils" (256-269) and "Decomposition and biochemical cycles" (270-285).
- Anon.  
1979 Eucalyptus for planting. FAO, Forestry Series No. 11. Rome.
- G xx Comprehensive, but contains nothing about the ecological effects of extensive eucalypt planting.
- Anon  
1981 Terrestrial Nitrogen Cycles. Processes, Ecosystem Strategies and Management Impacts. Proceedings of an International Workshop arranged by the SCOPE/UNEP International Nitrogen Unit of the Royal Swedish Academy of Sciences and the Commission for Research on Natural Resources of the Swedish Council for Planning and Coordination of Research, Gysinge Vårdshus, Osterfärnebo, Sweden. Ecological Bulletin No. 33. 717 pp.
- Anon.
- Programme de Recherche d'Accompagnement du PARFOB (bilan 83 de recherches). Institut Sénégalais de Recherches Agricoles, Centre National de Recherches Forestières, Dakar, Sénégal. 16 pp.
- W x Soil moisture in upper 3 meters under 0.5-1.5-year-old plantation of E. camaldulensis has decreased under semi-arid conditions 1.5 years after measurements started. Soil moisture under natural forest (Acacia seyal) decreases less and increases under bare soil. No conclusions drawn since the experiment has just started. Many replications. A potentially valuable study.
- Ashton, D.H.  
1975 The Root and Shoot Development of Eucalyptus regnans F. Muell. Australian Journal of Botany 23 867-887.
- G xx Describes the root system of E. regnans in Victoria, Australia from seedling to mature tree. Examples from different sites are given (slopes, dry sites, swamps, etc.). Illustrative figures.
- Attiwill, P.M.  
1966 The chemical composition of rainwater in relation to cycling of nutrients in mature Eucalyptus forest. Plant and Soil 24 (3) 390-406.
- N xxx The ionic concentration (ions containing P, K, Ca, Mg and Na) in rainwater collected beneath the forest canopy was greater than the concentration in rainwater collected in an open area. The conclusion that this is caused by foliar leaching seems reasonable.
- Attiwill, P.M.  
1972 Phosphorus adsorption isotherms and growth responses for a highly weathered Eucalyptus forest soil. Paper for section 3 in "Australian forest-tree nutrition conference", 1971, Canberra, Forestry and Timber Bureau.
- N x The phosphorus uptake and dry matter production for E. delegatensis, Pinus radiata and wheat were greater on a soil with high phosphorus content than in one with a low content in Victoria, Australia.

Awe, J.O.; Shepherd, K.R. and R.G. Florence. Root Development in Provenances of  
1976 Eucalyptus camaldulensis Dehn. Australian Forestry 39 (3) 201-209.

G xx Root development for six provenances of E. camaldulensis and one each for E. saligna and E. pilularis was examined under simulated natural conditions in the dry interior of Australia. The results suggest that E. camaldulensis establishes successfully in a rapidly drying soil since it can produce a massive root system rapidly. The six provenances are ranged.

Babalola, O. and A.G. Samie. The Use of a Neutron Technique in Studying Soil Moisture  
1972 Profiles under Forest Vegetation in the Northern Guinea Zone of Nigeria. Tropical Science 14 (2) 159-168.

W xx The soil moisture profile (0-100 cm) of a sandy loam was determined over a 12 months period at a natural woodland (mainly Isoberlinia doka) and a 10-year-old E. citriodora plantation under semi-arid conditions. The water storage was higher under natural woodland, but eucalypts were more able to obtain moisture from greater depths.

Bailly, C.; Benoit de Coignac, G.; Malvos, C.; Ningre, J.M. and J.M. Sarrailh. Etude  
1974 de l'influence du couvert naturel et de ses modifications à Madagascar. E xpérimentations en bassins versants élémentaires. C.T.F.T. (Centre Technique Forestier Tropical), Cahiers Scientifiques No. 4. 114 pp.

W xxx Run-off studies etc. were conducted for 8 years on four different sites. E. robusta prevented erosion to very large extent compared with various crops. The conclusion that reduced run-off peaks lead to less erosion seems well-founded.

Bailly, C.R. and P.N. Sall. Adaptation de l'Eucalyptus à la sécheresse. Institut  
1983 or 84 Sénégalais de Recherches Agricoles, Centre National de Recherches Forestières, Dakar, Sénégal. 6 pp.

W ? Soil moisture changes under planted E. camaldulensis, 30-40 year old natural Acacia seyal and bare soil measured for 2 years under semi-arid conditions. NO conclusions were drawn because of the short time of the experiment. The wilting point for E. camaldulensis was found to be at pF 4.8.

Baker, T.G. Dry matter, nitrogen, and phosphorus content of litterfall and branchfall  
1983 in Pinus radiata and Eucalyptus forests. New Zealand Journal of Forestry Science 13 (2) 205-221.

N xx Concentration of N was similar in litter in one c. 20-year-old E. regnans stand and five 18-22 year old Pinus radiata stands in central Gippsland, Victoria, Australia. Concentration of P was higher in the litter in the pine stands. The litter fall was approximately twice as high in the eucalypt stand than in the pine stands. Litter from natural E. obliqua and E. sieberi also analysed.

Balagopalan, M. and A.I. Jose. Distribution of organic carbon and different forms of  
1984 nitrogen in a natural forest and adjacent eucalypt plantation at Agrippa, Kerala. Abstract of Paper for National Seminar on Eucalyptus, January 30-31 1984, Kerala, India.

N ? Abstract. pH and the oxidation in the soil under natural forest (not specified) was lower than under the eucalypt plantation. Organic carbon content, cation exchange capacity, total N and different forms of N was higher under natural forest. No figures or description are given in the abstract.

Baldy, C.; Poupon, H. and A. Schoenenberger. Etude des variations de la teneur en eau du sol en fonction du couvert végétal en Tunisie du Nord. Annales de l'Institut National de Recherches Forestières de Tunisie 4 (3). 40 pp.

W xx Soil moisture pattern under E. camaldulensis, E. maideni, E. saligna, Pinus radiata, P. pinea and a clearing (grass) at Zerniza was described. The eucalypts were found to dry out the soil faster than the pines during the three months dry period and the drying pattern is different at different depths. The height as well as the diameter growth for the eucalypts were "negative" during the dry period.

Banerjee, A.K. Evapo-transpiration from a young Eucalyptus hybrid plantation of West Bengal. Proceeding at Symposium on Man Made Forests in India, June 8-10 1972, Dehra Dun, India. p III D 17-23.

W xxx Precipitation, stemflow and throughfall were measured during 1 year in a 5-year-old E. hybrid plantation under humid conditions. Evapotranspiration and soil moisture storage were calculated. The conclusion (soil moisture did not decrease) is only indicative.

Banerjee, S.P. and K. Singh. Characteristics of the soils of some Eucalyptus plantations of Madhya Pradesh. Proceeding at Symposium on Man Made Forests in India, June 8-10 1972, Dehra Dun, India. p III D 35-48.

G xx The soil of 13 E. hybrid plantations is described. Analysing the large amount of data led the authors to suggest that, for this species, (1) shallow soils are not good sites (water supply and rooting) (2) a "band" of  $\text{CaCO}_3$  stops root growth and (3) high organic matter and nitrogen content is congenial, but (4) not water-logged conditions.

Bara T., S. 1970 Estudio sobre Eucalyptus globulus. I. Composición mineral de las hojas en relación con suposición en el árbol, la composición del suelo y la edad. Evolución del suelo por el cultivo de los eucaliptos en el Monte Muíño del Ayuntamiento de Zas (La Coruña). Instituto Florestal de Investigaciones y Experiencias, Madrid. Comunicacion No. 67.

N xx Abstract. Content of elements was analysed in leaves of, and the sandy soils under 5, 7, 8, 10, 11 and 12 year old plantations of E. globulus. N, P, Mg, Cu and Zn increased in the leaves, while B and Al decreased, as the stands became older. Also the cation exchange capacity decreased. No figures given.

Bara T., S. 1971 Avance de los resultados de los efectos de eucalypto sobre la composición granulométrica y química del suelo en Lourizán (Pontevedra). Departamento Forestal de Zonas Húmedas, Pontevedra, Spain. 11 pp.

N xx Soil characteristics under an approx. 100 year old E. globulus plantation were analogous to those under a stand of Quercus robur (age unknown) and a 30 year old Pinus pinaster stand in humid NW Spain. It is not possible to evaluate the onclusion that Eucalyptus silviculture had not led to soil degradation or depletion of nutrient reserves in the area, since the different species were planted on different soils.

Bara T., S. 1982 Efectos ecologicos del Eucalyptus globulus en Galicia. Paper presented at the 1st Asamblea Nacional de Investigación Forestal, May 1982, Madrid, Spain.

N x Report on the same work as above

Bara T., S. Efectos del Eucalyptus globulus sobre la composición de los suelos de 1983 Galicia. I. Índice estimativo de la degradación. Paper presented at Seminario de Estudios Gallegos, Area de Ciencias Agrarias. II. Jornadas de Estudio Sobre el Tema "Os usos do Monte en Galicia", October 1983, Lourizan, Pontevedra, Spain.

N x Report on the same work as above.

Bell, F.C. and M.T. Gatenby. Effects of exotic softwood afforestation on water yield. 1969 Water Research Foundation of Australia, Kingsford, N.S.W. Bulletin No. 15. 99 pp.

W ? Abstract. 11 catchments in New South Wales, Australia, are described. Conclusions: No differences in water yields associated with mature Pinus radiata vs. mature eucalypt woodland. The species had also about the same water use. The conclusions cannot be evaluated from the abstract, but the method of comparing water use is not sufficiently critical.

Bellote, A.F.J.; Sarruge, J.R.; Haag, H.P. and G.D. de Oliveira. Absorção de macronutrientes e micronutrientes pelo Eucalyptus grandis (Hill, ex-Maiden) em função da idade. Silvicultura 8 (32) 633-643.

N x Content of elements in different parts of 1, 2, 3, 4, 5, 6 and 7 year old E. grandis plantations in São Paulo, Brazil, was analysed. The figures are wrongly calculated and no conclusions can be drawn.

Bernhard-Reversat, F. Décomposition et incorporation à la matière organique du sol de la litière d' Eucalyptus camaldulensis et de quelques autres essences. II. Evolution des substances solubles de la litière dans le sol. III. Fractionnement granulométrique de la matière organique du sol superficiel. ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer), Centre de Dakar-Hann. 33 pp.

N xx The mineralisation of the litter from E. camaldulensis and Acacia seyal was compared on 2 sites in Senegal under semi-arid conditions. After 8 days 50% of the acacia litter had mineralised in both sandy and clay soil, while the figures of eucalypt litter were 34% and 25% respectively. Four replications and further analysis of the litter content (more polyphenols in eucalypt litter) indicate the reliability of the results.

Bernhard-Reversat, F. Les cycles biochimiques des éléments minéraux en plantations d' Eucalyptus camaldulensis et en forêt naturelle à Acacia seyal au Sénégal (1ère année de mesures: 1980-81). ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer), Centre de Dakar. 17 pp.

N xxx Nutrient content in soil, undergrowth, litter and throughfall in E. camaldulensis and Acacia seyal stands have been measured during one year. The author concludes that the content of K in the soil is limited and P is not assimilated as it should (might be caused by lack of mycorrhiza). Many replications.

Bhatia, C.L. Eucalyptus in India - its status and research needs. Indian Forester 110 (2) 91-96.

R x A brief history of Eucalyptus in India is given and the most successful species are listed. The author states, without supporting evidence, that eucalypts are more favourable tree species than sal (Shorea robusta) for retaining both soil moisture and soil fertility but stresses the need for further research.

Biro, Y. and J. Galabert. Economie de l'eau et travail du sol dans les plantations forestières de zone sèche. Application à la zone Sahélo-Soudanaise. Bois et Forêts des Tropiques No. 127 29-44, 128 23-37.

G x The authors discuss real and potential evapotranspiration and conclude, mainly from C.T.F.T. research in Upper Volta, that trees (here E. crebra) diminish their transpiration rate when the soil dries out (No. 127).

G x The authors state that different tree species use water at different levels and show examples of root systems and of the fluctuation of moisture content in the soil during one year (experiences and results from C.T.F.T. research in Upper Volta). (No. 128).

Biro, Y. and J. Galabert. Economie de l'eau et travail du sol dans les plantations forestières de zone sèche. Application à la zone Sahélo-Soudanaise. Bois et Forêts des Tropiques No. 129 3-20, 130 12-22.

G x Planting trials in Upper Volta. Soil preparation for better water holding capacity and root penetration is described (No. 129).

G x About soil preparation for water economy (Upper Volta). (No. 130).

Biro, Y. and J. Galabert. Bioclimatologie et dynamique de l'eau dans une plantation d'Eucalyptus. C.T.F.T. (Centre Technique Forestier Tropical), Cahiers Scientifiques No. 1. 51 pp.

W xx Growth and water dynamics in a plantation of E. crebra in Upper Volta is described from the second to the fourth year after planting. The water reserve in the soil was decreasing, leading to the conclusion that some trees in the plantation would probably die as they grew older. This is, however, no evidence for the view that eucalypts in general dry out the soil too much for their own growth. It could be an example of planting eucalypts on the wrong site (too dry or badly prepared).

Bolotin, M. Growth of eucalypts on dune sand as related to soil profile. Contributions on Eucalyptus in Israel II, Ilanot and Kiriat Hayim, Israel, 13-17.

W x From two failed plantations with E. gomphocephala and E. camaldulensis in two locations (both sand dunes in Israel), the author drew the conclusion that the failure was caused by a hardpan 1-2 meters under the soil surface. It prevented water supply for young trees during dry periods.

Callister, P. Native shelterbelts protecting our trees while protecting our soil. Soil & Water, Issue No. 1 1983, 33-34.

M x The author suggests that shelterbelts should be planted with a row of fast growing species and one or more rows of slow growing indigenous species. Eucalypts could be used as the fast growing species. The suggestion comes from experience in New Zealand. A number of useful indigenous species are listed.

Chaturvedi, A.N. Eucalyptus in India. Indian Forester 102 (1) 57-63.  
1976

R x The paper describes the introduction of eucalypts in India, trials and experiments, planting technique, etc. Yield tables for E. hybrid are presented.

Chijioke, E.O. Impact on soils of fast-growing species in lowland humid tropics. FAO, Forestry Paper 21. 111 pp.  
1980

G xx The report deals with Gmelina arborea and Pinus caribea in exotic plantations. The author stresses the risk of soil nutrient depletion in short-rotation plantations and recommends regular analysis of soil fertility.

Chilvers, G.A. The root pattern in a mixed eucalypt forest. Australian Journal of Botany 20 229-234.  
1972

G x Studies of the root pattern in a mixed E. fastigata/E. dalrympleana forest in SE Australia shows that the roots of the two competing species intermingle and penetrate close to the opposing trunk.

Chinnamani, S.; Gupte, S.C.; Rege, N.D. and P.K. Thomas. Run-off studies under different forest covers in the Nilgiris. Indian Forester 91 (8) 676-679.  
1965

W xxx The stream run-off was presented as percentage of rainfall at a site with 16 % slope in the Nilgiris Hills in southern India, during 7 years. The annual rainfall is 1340 mm and the experiment contained 3 replications. Run-off from sites with E. globulus, Acacia mollissima and shola (sub-montane evergreen forest) was all just over 1%. Run-off from broom (Cytisus scoparius) was less and from the grassland negligible. The run-off showed correspondance with the intensity of rainfall.

Claudot, M. Influence de l'eucalyptus sur l'évolution des sols au Maroc. FAO, Sous-Commission de Coordination des Questions Forestières Méditerranéennes, Groupe de travail des Eucalyptus, deuxième session, 25 et 26 mai 1956, Nice, France. 2 pp.  
1956

N x The soil under a stand with E. camaldulensis in Morocco (semi-arid conditions) was analysed. The organic matter in the poor soil recovered slowly.

Cozzo, D. and M.H.C.K. de Riveros. Registro de la caída de materia orgánica y elementos minerales en una plantación de ocho años de Eucalyptus camaldulensis. Paper for Primer Congreso Forestal Argentino, October 6-11 1969, 590-598.  
1969

N x Soil characteristics under a 8-year-old and 17 meters high plantation of E. camaldulensis and a pasture with grasses were compared. The content of organic matter was approx. twice as high under the eucalypt stand as in the pasture soil. The capillarity was higher in the pasture soil, while the content of Ca, Mg and P did not differ much on the two sites. Few replications.

Crane, W.J.B. and R.J. Raison. Removal of phosphorus in logs when harvesting  
1980 Eucalyptus delegatensis and Pinus radiata forests on short and long  
rotations. Australian Forestry 43 (4) 253-260.

N xxx Removal of P from E. delegatensis and Pinus radiata was compared  
at different rotation ages. Shortening the rotation will increase the  
amount of P removed per unit of wood harvested for both species. The  
heartwood/sapwood relation and the concentration of nutrient in the two  
kinds of wood are discussed.

Crane, W.J.B. and R.J. Raison. The nutritional effect of short rotational  
1983 silviculture. Silvicultura 8 (32) 670-672.

N xxx The same presentation and discussion as in Crane & Raison (1980).  
The authors also conclude that E. delegatensis is more economical in its  
use of phosphorus than Pinus radiata, at least after 7 years of age when  
heartwood begins to form in the eucalypt.

Crane, W.J.B.; Raison, R.J.; Nicholls, G.H. and Godkin, C.M. The effect of rotational  
1981 age on the phosphorus requirements of forest plantations. Proceedings of  
Australian Forest Nutrition Workshop "Productivity in Perpetuity", 1981  
Canberra.

N xxx The same results are presented as in Crane & Raison (1980, 1983).

Cromer, R.N. and E.R. Williams. Biomass and nutrient accumulation in a planted E.  
1981 globulus (Labill) fertilizer trial. Proceedings of Australian Forest  
Nutrition Workshop "Productivity in Perpetuity", 1981, Canberra.

N x' Abstract. A plantation of E. globulus in Victoria, Australia,  
was treated with four levels of fertilisers containing nitrogen and  
phosphorus soon after planting. The positive effect on growth induced by  
the fertilisation was obvious.

Cromer, R.N.; Williams, E. and D. Tompkins. Biomass and nutrient uptake in fertilized  
1983 E. globulus. Silvicultura 8 (32) 672-674.

N x The same experiment as in Cromer & Williams (1981). The stem wood  
production, both in per cent of the total biomass production, and uptake  
of N and P in the stem increased after fertilisation.

Dabral, B.G. Preliminary observations on potential water requirement in Pinus  
1970 roxburghii, Eucalyptus citriodora, Populus casale (488) and Dalbergia  
latifolia. Indian Forester 96 (10) 775-780.

W xx Evapotranspiration was measured on Pinus roxburghii (2  
seedlings), Populus casale (3), E. citriodora (3) and Dalbergia latifolia  
(4) with an evapotranspirometer. The age of the seedlings ranged from 6  
to 22. The results are inconclusive because of the few replications and of  
doubtful applicability to adult trees in the field.

Dabral, B.C. and B.K. Subba Rao. Interception studies in chir and teak plantations -  
1968 New Forest. Indian Forester 94 (7) 541-551.

W xx Stemflow and throughfall were measured during 3 years in stands  
of Pinus roxburghii and Tectona grandis in northern India. Interception  
was calculated to be 27.0 % and 20.8 %, respectively, of the  
precipitation. Since few samples of stemflow were taken the results are  
only indicative.

Dabral, B.G. and B.K. Subba Rao. Interception studies in sal (Shorea robusta) and khair (Acacia catechu) plantations - New Forest. Indian Forester 95 (5) 314-323.

W xx Stemflow and throughfall were measured during 3 years in stands of sal and khair in northern India. Interception was calculated to be 38.2 % and 20.8 %, respectively, of precipitation. Since few samples of stemflow were taken the results are only indicative.

Dietz, J.M.; Couto, E.A.; Alfenas C., A.; Faccini, A. and G.F. da Silva. Efeitos de duas plantações de florestas homogêneas sobre populações de mamíferos pequenos. Brasil Florestal No. 23 54-57.

E xxx The number of individuals and species of small mammals were determined in 4 different forests in Minas Gerais, Brazil. In a 31 year old Araucaria angustifolia plantation there were significantly more individuals than in a 10 year old E. saligna plantation and 15 and 52 year old natural forests. The number of species varied between 2 and 3 in the different stands.

Evans, J. 1982 Plantation Forestry in the Tropics. Clarendon Press, Oxford. 472 pp.

G xx Gives a comprehensive review of the subject.

Feller, M.C. 1978 Nutrient movement into soils beneath eucalypt and exotic conifer forests in southern central Victoria. Australian Journal of Ecology 3 (4) 357-372.

N x Abstract. The volume of forest floor leachate of nutrients was greater in two eucalypt forests (E. obliqua and E. regnans) than in two nearby plantations of Pinus radiata and Pseudotsuga menziesii, in southern central Victoria, Australia. The author's conclusion that this is attributed to greater interception losses of water by the conifers seems reasonable.

Feller, M.C. 1981 Water balance in Eucalyptus regnans, E. obliqua, and Pinus radiata forests in Victoria. Australian Forestry 44 (3) 153-161.

N x Abstract. The movement of precipitation in a forest, as throughfall, stemflow, canopy and forest floor interception and forest floor leachate was estimated from measurements in two eucalypt forests (E. regnans and E. obliqua) and a Pinus radiata plantation, ca 60 km NE of Melbourne, Australia. Interception was greater in the pine forest than in the eucalypt forest. No figures are given in the abstract.

Florence, R.G. and R.L. Crocker. 1962 Analysis of blackbutt (Eucalyptus pilularis Sm.) seedling growth in a blackbutt forest soil. Ecology 43 (4) 670-679.

E xx Soil containing E. pilularis seedlings in a natural E. pilularis stand were irradiated; root hair development, shoot growth, etc. were induced. This could be caused by direct antagonism by micro-organisms.

Florenzano, G. 1956 Ricerche sui terreni coltivati ad eucalitti (II: Ricerche microbiologiche e biochimiche). Publicazioni del Centro di Sperimentazione Agricola e Forestale 1 133-152.

E xx The microbiological activity in soils under E. botryoides, E. gomphocephala, E. maidenii (Latina, Italy) and E. canaldulensis (Sardinia, Italy) was described and compared with a control of uncultivated soil. Bacteria, especially nitrifying ones, were scarce under the eucalypts, while the content of fungi was higher in the eucalyptus soil.



Florenzano, G. Ulteriori indagini sui terreni coltivati ad eucalitti (II: Ricerche microbiologiche). Pubblicazioni del Centro di Sperimentazione Agricola e Forestale 2 243-258.

E xx The results from a similar investigation to that in Florenzano (1956), carried out under a E. camaldulensis stand on sandy soil in Sicily, Italy, shows a different result. The microbiological activity was higher in the eucalyptus soil than in the soil of the control plot. The difference is not analysed.

Fox, A.V. 1977 Afforestation on difficult sites, eroded areas and steep slopes: with special emphasis on the Mambilla plateau. FAO, Paper for Symposium on Savanna Afforestation in Africa, 1976, Kaduna, Nigeria. 9 pp.

M x One chapter (p. 187) gives an example of the problems that may occur by using E. grandis as fuel wood in Nigeria. The species coppice best during the height of the rainy season when the forest products are normally not needed in any quantity. During the dry period stump mortality is approx. 25 %.

Friend, G.R. 1982 Mammal populations in exotic pine plantations and indigenous eucalypt forests in Gippsland, Victoria. Australian Forestry 45 (1) 3-18.

E xx Abstract. Comparisons of Pinus radiata plantations of different ages and adjacent natural eucalyptus forests in Australia showed that species richness in mammal populations was lower and the proportion of introduced species higher in the pine plantations.

George, M. 1978 Interception, stemflow and throughfall in a Eucalyptus hybrid plantation. Indian Forester 104 (11) 719-726.

W xx Stemflow and throughfall were measured during 12 months in a 6-year-old E. hybrid plantation in northern India. The interception was estimated to be 11.65 % of the precipitation of 1671.7 mm. There was no comparison with other species in the same experiment.

George, M. 1979 Nutrient return by stemflow, throughfall and rainwater in a Eucalyptus hybrid plantation. Indian Forester 105 (7) 493-499.

N x The concentration of nutrients was measured in stemflow, throughfall and rainfall in an E. hybrid plantation. The concentration decreased in the order: stemflow, throughfall and rain water. The total nutrient return (kg/ha/year) was calculated; also in the litter fall. No comparisons with other species.

George, M. 1982 Litter production and nutrient return in Eucalyptus hybrid plantations. Indian Forester 108 (4) 253-260.

N x In three E. hybrid plantations (5, 7 and 10 year old) in northern India the nutrient concentration in the litter and total litterfall were measured. A comparison of the return of different elements in stemflow, throughfall plus precipitation was made. Fairly comprehensive study.

George, M. 1984 Research needs in Eucalyptus plantations. Abstract of Paper for National Seminar on Eucalyptus, January 30-31 1984, Kerala, India.

R xx The author recommends that the bark should be left when harvesting a E. hybrid plantation, since it contains a proportionally large part of the nutrients stored in the biomass.

Ghosh, R.C.; Kaul, O.N. and B.K. Subba Rao. Some aspects of water relations and nutrition in Eucalyptus plantations. Indian Forester 104 (7) 517-524. 1978

R x The authors cite 14 references about interception, run-off, etc., in eucalypt plantations. Their conclusion is that the complaints about the adverse effects of eucalypt plantations in India are rather exaggerated.

Ghosh, R.C.; Kaul, O.N. and B.K. Subba Rao. Eucalyptus plantations (Water Relation and Nutrition). Forest Research Institute & Colleges, Dehra Dun, India. Extension Series 5. 12 pp. 1980

R x The same article as Ghosh et al (1978).

Giordano, E. Osservazioni sull'apparato radicale dell'Eucalyptus globulus Labill. Pubblicazioni del Centro di Sperimentazione Agricola e Forestale 10 135-147. 1969

G x The root systems of two individual E. globulus on a sandy soil in Italy are described. They were 7 years old and planted at 2 x 2 meters spacing. Most of the roots were within 1-2 meters from the tree and 1 meter deep. Taproots were formed, 4 and 2 meters long, respectively.

Giulimondi, G. Observations on cultivated soils adjacent to eucalypt windbreaks. FAO, Joint Sub-Commission on Mediterranean Forestry Problems, Working Party on Eucalyptus, fourth session, April-May 1960, Lisbon. 3 pp. 1960

E xx Presents the results from the study later reported in Giulimondi & Giovanni (1963).

Giulimondi, G. Windbreaks, Shelterbelts, Influence on Crops (Italy). Second World Eucalyptus Conference, São Paulo, August 13-28 1961. Reports and Documents Vol. II 1004-1007. 1961

E xx Presents the results from the study reported in Giulimondi & Giovanni (1963).

Giulimondi, G., Funicello, M. and G.M. Arru. Ricerche sui terreni coltivati ad eucalitti (I: Ricerche chimico fisiche). Pubblicazioni del Centro di Sperimentazione Agricola e Forestale 1 111-130. 1956

E x Chemical and physical characteristics were examined in 11 soil profiles under stands of E. camaldulensis, E. maidenii and E. botroyides at two locations in Italy (Latium and Arborea, Sicily). 10 control profiles were also investigated. Since the result is based on one-time measurement, the conclusion that the eucalypts caused chemical deterioration in the soil is not well grounded.

Giulimondi, G. and E. Giovanni. Ricerche sull'umidità del terreno in prossimità dei frangiventi di eucalitto. Pubblicazioni del Centro di Sperimentazione Agricola e Forestale 7 55-80. 1963

E xxx The effects of two eucalypt windbreaks on soil moisture and vegetation were examined during 3 years in Italy. The windbreaks consisted of belts 5 meters wide of 52 year old E. x trabutii in Catania and 30 year old E. camaldulensis in Latina. The soils were, respectively, silty clayish loam and sand, respectively. Soil moisture depletion was noticeable 10 and 20 meters from the different windbreaks. In Latina the yield of alfalfa decreased up to 20 meters from the windbreak.

Gonzales E., E. Efecto de la localización de los fertilizantes fosfatados en el crecimiento del eucalipto. Paper for FAO/IUFRO International Symposium on Forest Fertilization, December 3-7 1973, Paris.

N x NPK, NP, PK and P were used in a fertilisation trial on E. globulus in the humid parts of NE Spain. The fertilisers were (1) placed in the bottom of a planting hole or (2) mixed with the soil. N was always placed superficially. Positive (n.s.) response for P, only. Mixing the fertiliser with the soil (2) proved to be best.

Gonzales E. E. Contenido mineral de Eucalyptus globulus, Pinus pinea e Quercus suber e a biociclagem de alumínio destas espécies nos mesmos tipos de solo e clima mediterrâneo. Silvicultura 8 (32) 675-678.

N x Nutrient content in wood and bark was measured in E. globulus, Pinus pinea and Quercus suber in Spain (400-800 mm rainfall and 5 dry months per year). The author concludes that all nutrients, except for N and P, taken away at harvest of E. globulus at this location will be replaced by nature (by weathering and atmospheric deposition; reference for the latter).

Goor A. Y. and Barney C. W. Forest Tree Planting in Arid Zones. 2nd ed. New York. 1976 The Ronald Press Co. 504 pp.

G xx A general text.

Greenwood, E.A.N. and J.D. Beresford. Evaporation from vegetation in landscapes developing secondary salinity using the ventilated-chamber technique. I. Comparative transpiration from juvenile Eucalyptus above saline groundwater seeps. Journal of Hydrology 42 (3/4) 369-382.

W xx Transpiration studies were conducted on several Eucalyptus species near Perth, Australia. On one site the transpiration rate rose to three times the initial level during summer, suggesting that the roots had reached a zone of higher water content.

Gupta, A.C. and D.P. Raturi. Distribution of organic matter and nutrient content in a Eucalyptus hybrid plantation on lateritic soil in West Bengal. Indian Forester 110 (2) 122-128.

N x Nutrient content and biomass were determined for the above ground parts of a 10-year-old E. hybrid plantation in West Bengal, India. The main conclusion, based on only 6 sample trees, was that the relatively low phosphorus uptake in this study was a result of inherently poor soil.

Gupta, A.C.; Ullah, W. and V.C. Issac. A note on some soil moisture changes under permanent vegetative cover. Indian Forester 101 (9) 523-526.

W x A soil moisture study was conducted during two months under "Eucalyptus forest, fallow land, Acacia forest and grassland" in a semi-arid part of Jodhpur, India. The description of the study and the results are not complete, so it is impossible to evaluate the conclusions drawn.

- Gupta, R.K. 1984,a Role of Eucalyptus in soil and water conservation vis-a-vis social/agroforestry. Abstract of Paper for National Seminar on Eucalyptus, January 30-31 1984, Kerala, India.
- R xx A comprehensive and balanced review of research results on the use of water and nutrients by eucalypts. No conclusions are drawn, nor could they be drawn, on the ecological impact of eucalypts from the 50 cited references (of which 49 were Indian).
- Gupta, R.K. 1984,b Role of Eucalyptus in soil and water conservation vis a vis social and agro-forestry. Workshop on Eucalyptus plantation, June 29 1984, Bangalore, India. Papers and Proceedings 113-134.
- R xx Same as Gupta (1984,a).
- Haag, H.P.; Rocha Filho, J.V. de C.; de Oliveira, G.D. and J.R. Sarruge. 1983 Influencia de florestas implantadas de Eucalyptus e Pinus sobre las propiedades químicas do solo. Silvicultura 8 (32) 643-645.
- N x Chemical content in litterfall and soil (0-20 cm) under plantations of 20-year-old E. citriodora and 24-year-old Pinus taeda in São Paulo, Brazil, was determined. The organic matter in the soil, content of  $K^+$ ,  $Mg^{2+}$  and  $Al^{3+}$  was higher under the eucalypt. No details about the size of the experiment.
- Haag, H.P.; Sarruge, J.R.; de Oliveira, G.D.; Poggiani, F. and C.A. Ferreira. 1976 Análise foliar em cinco espécies de eucaliptos. IPEF No. 13 99-116.
- N x Foliar analysis and increment measurements on 8-year-old E. grandis, E. microcory, E. resinifera, E. robusta and E. saligna in São Paulo, Brazil, showed a correlation between high nutrient concentration in the leaves and increment.
- Henrici, M. 1947 Transpiration of South African plant associations (Part II: Indigenous and exotic trees under semi-arid conditions). Union of South Africa, Department of Agriculture, Botany and Plant Pathology, Series No. 9, Science Bulletin No. 248. 19 pp.
- W x Transpiration rate was measured with a balance of indigenous and introduced tree species in South Africa. No clear trends could be seen from the results. Water regulating mechanisms in plants are discussed comprehensively.
- Herbert, M.A. 1983 The response of Eucalyptus grandis to fertilizing with nitrogen, phosphorus, potassium and dolomitic lime on a Mispah soil series. South African Forestry Journal No. 124 4-12.
- N x Abstract. Stem form had improved and yield increased 8 years after fertilising E. grandis seedlings with NPK and dolomitic lime in South Africa, compared with unfertilised seedlings.
- Heth, D. and R. Karschon. 1963 Interception of rainfall by Eucalyptus camaldulensis Dehn. Contributions on Eucalyptus in Israel II, Ilanot and Kiriat Hayim, Israel, 7-12.
- W x Stemflow and throughfall were measured during 2 years in two E. camaldulensis plantations, 7 and 8 year old, on the Central Coastal Plain in Israel (annual rainfall 600 mm). Interception was calculated to be 14.3 % of precipitation the first year and 14.9 % the second year. Stemflow was measured on 6 trees.

- Hingston, F.J. Sources of, and sinks for, nutrients in forest ecosystems. 1977  
Proceedings Nutrient Cycling in Indigenous Forest Ecosystems Symposium. CSIRO Division of Range Management. Perth, Western Australia.
- N x A useful review.
- Hogmans, P., Flinn, D.W. and P.W. Farrell. Nitrogen mineralisation in a sandy soil under native eucalypt forest and exotic pine plantations in relation to moisture content. Communications in Soil Science and Plant Analysis 11 (1) 71-79. 1980
- N x Abstract. Ammonification was found to be strongly dependent upon soil moisture, and slightly higher in the soil under a native eucalypt forest than under a Pinus radiata plantation in Australia.
- Hurditch, W.J., Charley, J.L. and B.N. Richards. Sulphur cycling in forests of Fraser Islands and coastal New South Wales. Sulphur in Australia. Paper delivered at workshop convened by the Australian National Committee for SCOPE "Sulphur Cycling in Australian Ecosystems", April 3-4 1978, Canberra. 1980
- N x Sulphur concentration and circulation described in two natural eucalypt (E. pilularis and E. microcorys) stands.
- Irion, G. Holzplantage im Urwald? Naturwissenschaften 68 (3) 133-138. 1981
- M x Abstract. It is suggested that the soil in a pulpwood project in the Amazonas region in Brazil will be completely exhausted after the second generation of E. deglupta and other fast growing species.
- Iyengar, N.S. and N.S.S. Narayana. Eucalyptus: To grow or not to grow. Workshop on Eucalyptus Plantation, June 29 1984, Bangalore, India. Papers and Proceedings 223-227. 1984
- M x The author present an economic model in which private and social costs and benefits from growing Eucalyptus are included. India.
- Jackson, J.K. Use of fertilizers in savanna plantations. Voluntary paper prepared for the FAO/DANIDA Training course on Forest Nursery and Establishment Techniques for African Savannas which was cancelled. Lecture notes 152-159. 1977
- N x General about fertilising Eucalyptus on the savanna, Africa. Boron deficiency is described. 3 tables with results from fertiliser trials are presented.
- Jacobs, M.R. Growth habit of Eucalyptus. Forest and Timber Bureau, Canberra, Australia. 262 pp. 1955
- G xx Gives a full review of the subject.
- Janet, R. Evolution des principales caractéristiques des sols des reboisements de Loudima (Congo). Cahier ORSTOM, série Pédologie No. 8 (3/4) 235-253. 1975
- N xx Some chemical characteristics of the soil were measured under some 5-15 year old eucalypt stands, 6-11 year old pine stands and savanna vegetation in southern Congo. The organic matter was less under the eucalypt stands and much less under the pine stands than in the savanna soil. C/N was similar in all soils and the older the plantations were the more acid was the top soil.

- Jamet, R. 1975 Evolution des principales caractéristiques des sols des reboisements de Pointe-Noire. ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer), Centre de Brazzaville. 38 pp.
- N xx Chemical characteristics of the soil were measured under pine and eucalypt plantations dating back to 1953 on poor sandy soils unsuitable for agriculture on the coastal plain near Pointe Noire, Congo. There was better humification of organic matter under eucalyptus, some acidification, podsolisation and lowering of calcium under pine, and an increase of potassium under eucalyptus.
- Jensen, A. Martin 1983 Shelterbelt effects in tropical and temperate zones. International Development Research Centre Manuscript Reports IDRC-MR80e 6lpp
- R xxx A valuable general review of shelterbelts
- Jha, M.N. and P. Pande. 1984 Impact on growing Eucalyptus and sal monocultures on soil in natural sal area of Doon Valley. Indian Forester 110 (1) 16-22.
- N xx In a study in northern India the soil characteristics under plantations of Shorea robusta, E. camaldulensis and natural S. robusta were compared. Though the study was limited, the authors drew the conclusion that eucalypt monocultures did not damage natural sal soil and also proved superior to sal monoculture in this respect.
- Jha, M.N. and R.K. Rathore. 1981 A study of soil moisture patterns in Eucalyptus and pine stands. Indian Forester 107 (7) 420-425.
- W x The soil moisture depletion under a Eucalyptus and a Pinus stand was followed during non-monsoon in an experiment without replications, in northern India. The results can not be generalised.
- Jocque, C.A. 1984 Malawi. A terrestrial baselines study of the Vipha Pulpmill Project Area. FAO Internal Report.
- E xx Contains an useful comparison of the spider Nephila and of the activity of termites in Brachystegia woodland and an eucalypt plantation.
- Kadeba, O. and E.A. Aduayi. 1984 Soil properties under Pinus caribaea stands and natural tropical savanna vegetation. Submitted for publication by Elsevier (in press) (Amsterdam).
- N Not seen.
- Kaplan, J. 1961 Water Relations in Eucalypts. Second World Eucalyptus Conference, São Paulo, August 13-28 1961. Reports and Documents Vol. II 1008-1014.
- R x The author reviews research on effects on soil water from growing eucalypts, and concludes that the need for research is great.
- Kaplan, J. 1974 The ecology of Eucalyptus camaldulensis Dehn. in Israel. La-Yaaran 24 (1-2) 7-2, 31-30.
- W xx English summary. In an investigation on water relations in two provenances of E. camaldulensis in Israel, the author found that soil moisture content controlled transpiration.

Karschon, R. Soil Evolution Affected by Eucalypts. Second World Eucalyptus Conference, São Paulo August 13-28 1961. Reports and Documents Vol. II 897-910.

R x The author reviews research on the influence of eucalypts on soil evolution and the effect of fertilisers on the species (2 parts). He also gives his opinion on research that is needed.

Karschon, R. The effect of irrigation upon growth of Eucalyptus camaldulensis Dehn. FAO, Committee on the Coordination of Mediterranean Forestry Research, fourth session, September 29-30 1970, Ankara, Turkey. 5 pp.

W xx In a 5-year-old plantation of E. camaldulensis at Ilanot, Israel, the growing stock was more than doubled by irrigation over a four year period. The annual rainfall is about 600 mm and the annual irrigation was about 525 mm.

Karschon, R. The effect of coppice cutting on the water balance of Eucalyptus camaldulensis Dehn. Israel Journal of Agricultural Research 21 (3) 115-126.

W xx Soil moisture recharge and depletion was measured for 4 years in a 4-year-old coppice of E. camaldulensis (0-4 years after cutting) and in a nearby clearing. The 4-year-old eucalypts transpired as much as the previous plantation. The calculated evapotranspiration was very low in the first year of the coppice.

Karschon, R. and D. Heth. The water balance of a plantation of Eucalyptus camaldulensis Dehn. Contributions on Eucalyptus in Israel III, Ilanot and Kiriath Hayim, Israel, 7-34, and La-Yaaran 17 (1).

W xxx Stemflow, throughfall, precipitation and soil moisture recharge were measured in a 9-12 year old E. camaldulensis stand and a nearby clearing in the central Coast Plain of Israel. It was evident that the plantation used more water than the clearing (from evapotranspiration), but no comparison with other tree species was made.

Khan, M.A.R. A comparative account of the avifauna of the sholas and the neighbouring plantations in the Nilgiris. Paper in Symposium on Ecology and Conservation of Birds and Mammals in India. Journal of the Bombay Natural History Society 75 1028-1035.

E xx Abstract. The bird fauna was compared in shola (evergreen sub-montane forest) and neighbouring Eucalyptus and Acacia plantations in the Nilgiris, India. It was found to be relatively poorer in the plantations than in the shola.

Krishnamurthy, B.V. Ecological destruction through Government's policies. Workshop on Eucalyptus Plantation, June 29 1984, Bangalore, India. Papers and Proceedings 9-16.

M x Without citing any scientific report or any other publication, the author states that the plantation of eucalypts "permanently destroys the land". Karnataka, India.

Krishnamurthy, R. and V. Clement. Response of Eucalyptus "hybrid" (Mysore gum) to major nutrient elements. Abstract of Paper for National Seminar on Eucalyptus, January 30-31 1984, Kerala, India.

N x In a fertilisation experiment with E. hybrid in southern India the mortality during an unusual drought from March to June 1983 was 11.25 % in fertilised plantations, while it was 80 % in the adjoining unfertilised plantations.

Kushalappa, K.A. Nutrient status in Eucalyptus "hybrid" monoculture. Abstract of Paper for National Seminar on Eucalyptus, January 30-31 1984, Kerala, India.

N xx Abstract. Nutrient content in the soil was measured one year before and 5 years after planting E. hybrid in Karnataka, southern India. It is not possible from the abstract to evaluate the conclusion that Eucalyptus monocultures are not harmful to soils in dry zones. The study seems to have been well planned.

de la Lama, G. G. Atlas del eucalipto. Ministerio de Agricultura, Instituto Nacional de Investigaciones Agrarias e Instituto Nacional para la Conservacion de la Naturaleza Vol. 5 (appendix) Madrid 82 pp.

Lamb, D. A suspected phosphorus and potassium deficiency in the tropical eucalypt E. deglupta. Paper for FAO/IUFRO International Symposium on Forest Fertilization, December 3-7 1973, Paris.

N x The conclusions from a fertilisation trial with E. deglupta in Papua, New Guinea were: the deficiency symptoms observed are not good diagnostic tools, since there could be multiple deficiency.

Lee, R. Forest Hydrology Columbia University Press, New York.

W x A good general text.

Lepoutre, B. and T. Mandouri. Résultats des essais préliminaires de fumure minérale sur Pinus pinaster et Eucalyptus camaldulensis en Mamora. Annales de la Recherche Forestière au Maroc 16 65-89.

N Results are presented from a fertilisation trial in Morocco.

Liani, A. Ulteriori indagini sui terreni coltivati ad eucalitti (I: Recherche chimico-fisiche). Pubblicazioni del Centro di Sperimentazione Agricola e Forestale 2 193-201.

E xx The organic matter, etc., in soils under 27 year old E. camaldulensis (with and without understory), Pinus pinea and agricultural land were examined in an experiment in Sicily, Italy. The average organic matter in the A horizon was 20.33, 10.45, 7.54 and 2.92 kg/m<sup>2</sup>, respectively. Before the planting the soils were similar.

Lima, W. P. Interceptação da chuva em povoamentos de eucalipto e de pinheiro. IPEF No. 13 75-90.

W xxx Stemflow and throughfall were measured during the summer 1974-75 in 6-year-old plantations of E. saligna (15.4 m) and Pinus caribea var caribea (6 m) in São Paulo, Brazil. The interception was calculated to be 12.2% and 6.6 % of the precipitation, respectively.



Lima, W. P. 1983 Soil Moisture Regime in Tropical Pine Plantations and in "Cerrado" Vegetation in the State of São Paulo, Brazil. IPEF No. 23 5-10.

W x The soil moisture content was measured during 24 months under Pinus occarpa, P. caribea var hondurensis and open land on the Brazilian "cerrado". The only statistical difference found, was a higher moisture content in the top layer of the cerrado soil than in the top layer of the soil under the pine stand.

Lima, W. P. and D. Barbin. 1975 Efeito de plantações de Eucalyptus e Pinus sobre a qualidade da água da chuva. IPEF No. 11 23-35.

N xx Chemical and physical properties of rain water were determined under 5-year-old E. saligna and Pinus caribea var caribea in São Paulo, Brazil. The conductivity, colour and turbidity were generally more altered under the eucalypt stand than under the pine stand, and more in stemflow than in throughfall.

Lima, W. P. and O. Freire. 1976 Evapotranspiração em plantações de eucalipto e de pinheiro, e em vegetação herbácea natural. IPEF No. 12 103-107.

W xx The evapotranspiration from stands of E. saligna, Pinus caribea var caribea and open land (grass) in São Paulo, Brazil was estimated to be 206, 211 and 196 mm, respectively. The authors conclude that there is no adverse effect of reforestation with eucalypts or pine on that site.

Lima, W. P. 1983 Consumo de água em florestas de eucalipto. Paper for the symposium "Solos-nutrição em Florestas de Eucalipto", October 1-2 1983, Piracicaba, Brazil. 15 pp.

W xxx A critical review of the water relations and water consumption of a number of species of eucalypt in natural forest in Australia.

Lima, W. P. 1984 Hidrologia de florestas implantadas. Paper for XI Seminario sobre Actualidades e Perspectivas Florestais: A Influencia das Florestas no Manejo de Bacias Hidrográficas, February 7-8 1984, Curitiba, Brazil. 11 pp.

W xx Discusses the hydrology of plantations and attributes the difference in the apparent consumption largely to differences in interception. Mentions Eucalyptus, Pseudotsuga and Pinus. Also Gaultheria and Pteridium.

Lima, W. P. and O'Loughlin, E. M. The hydrology of eucalypt forests in Australia - a (in press) review. Submitted for publication in IPEF (Piracicaba, Brazil).

W xxx A comprehensive and valuable review.

Loumeto, J.J. 1983 Note succincte sur l'exportation minérale dans un peuplement d'Eucalyptus 3ges de 7 ans 2 mois. C.T.F.T. (Centre Technique Forestier Tropical), Centre du Congo. 11 pp.

N x Nutrient content was measured in different parts of two E. hybrid trees which grew on a sandy soil in Congo. The sample is too small generalise the result.

Lozano, J.M. and F. Velasco. Evolución del humus y de la microflora telúrica por la implantación de Eucalyptus camaldulensis Dehn. en bosques autóctonos de Extremadura. Anales de Edafología y Agrobiología 40 (5/6) 711-720.

N xx Abstract. The soil under a E. camaldulensis stand was compared with that under a mixed Quercus ssp stand in Spain. The soil was more acid, had lower exchange cation content, etc., under the eucalypts. It was also becoming converted from mull to moder humus, while it was not under the mixed Quercus stand.

Lubrano, L. Researches on the nutrient-demand of some species of Eucalyptus. FAO World Symposium on Man-Made Forests and their Industrial Importance, April 14-25 1967, Canberra. Voluntary Paper 1801-1826.

N x The nutrient content was measured in different parts of E. globulus, E. viminalis and E. ovata in Italy. The return of nutrients from the trees via residues is also presented. Main results: Content of K is higher in E. globulus and in E. viminalis than in E. ovata. For the first two species approx. 60 % of N, P, K and Ca is stored in above the ground biomass exported at cutting.

Maclaren, P. Chemical welfare in the forest. A Review of Allelopathy with regard to New Zealand. New Zealand Journal of Forestry 28 (1) 73-92.

E xxx The author cites 5 articles dealing with allelopathic effects by E. camaldulensis, E. pilularis, E. microtheca and E. globulus on grasses. No figures are given.

Madgewick, H.A.I.; Beets, P. and S. Gallagher. Dry matter accumulation, nutrient and energy content of the above ground portion of 4-year-old stands of Eucalyptus nitens and E. fastigata. New Zealand Journal of Forestry Science 11 (1) 53-59.

N xxx The amount of nutrients removed per unit of wood energy harvested was calculated for 4-year-old E. fastigata and E. nitens and 17 year old Pinus radiata, on North Island, New Zealand. Nitrogen cost was estimated to be approx. 4 times higher for E. fastigata than for the pine, while it was almost the same for phosphorus.

Mathew, C.; Hameed, A. and R.S. Aiyer. Effect on Eucalyptus monoculture on the physico-chemical properties and erodibility of some forest soils. Abstract of Paper for National Seminar on Eucalyptus, January 30-31, 1984 Kerala, India.

E x Abstract. Physical and chemical characteristics were examined in the soil under 15, 10 and 5 year old Eucalyptus plantations and under an adjoining natural forest. Also the erosion ratio was measured. No figures are given in the abstract.

Mathur, H.N.; Babu, R.; Joshie, P. and B. Singh. Effect of clearfelling and reforestation on runoff and peak rates in small watersheds. Indian Forester 102 (4) 219-226.

W xxx The stream run-off was compared over 5 years from a watershed in northern India with natural shrub and one with a mixture of planted E. grandis and E. camaldulensis. These were calibrated for 8 years previously. The afforested catchment showed a 28 % reduction in stream run-off and a 73% reduction in peak rate.

Mathur, H.N.; Jain, N. and S.S. Sajwan. Ground cover and undergrowth in 1980 Eucalyptus, brushwood and sal forest - an ecological assessment. Van Vigyan 18 (3/4) 56-61.

E x Undergrowth characteristics are described in a natural Shorea robusta stand, secondary brushwood and a mixed E. grandis and E. camaldulensis plantation in humid northern India. No firm conclusions can be drawn since two of the sites were unprotected from grazing.

Mathur, H.N. and S.F.H. Raj. Groundwater regime under blue-gum at Osemund Nilgiris - 1980 initial observations. Indian Forester 106 (8) 547-554.

W x The authors measured the level of the water table in 5 wells in a catchment in the Nilgiris, India. No conclusion, except from that the levels differ, could be drawn from the result.

Mathur, H.N.; Raj, S.F.H. and S. Naithani. Ground water quality (pH) under different 1984 vegetative covers at Osemund (Nilgiri Hills). Indian Forester 110 (2) 110-116.

W xx pH was measured in the groundwater, every fortnight during 2 years under a 14-year-old E. globulus plantation, shola (evergreen sub-montane forest) and grassland. No significant differences were found under the different vegetation covers. The pH fluctuated over the year: approx. pH 5.6 in the rainy season and pH 6.5 during the dry season.

Mathur, H.N. and P. Soni. Comparative account on undergrowth under Eucalyptus and Sal 1983 in three different localities of Doon Valley. Indian Forester 109 (12) 882-890.

E x In an inventory the undergrowth in 6 stands (Shorea robusta and E. hybrid), was compared in pairs. No firm conclusions can be drawn since the sites were either unprotected from grazing or from fuel wood collection. Northern India.

Mathur, N.K. and A.K. Sharma. Eucalyptus in reclamation of saline and alkaline soils 1984 in India. Indian Forester 110 (1) 9-15.

M x The authors argue in favour of the use of Eucalyptus in India on sites with high alkalinity or salinity, since some of the species have salt resistant provenances. Some species are listed.

Mathur, R.S.; Sharma, K.K. and M.Y. Ansari. Economics of Eucalyptus plantations under 1984 Agro-forestry. Indian Forester 110 (2) 171-201.

M x The authors present economic results from different combinations of crops, including eucalypts, in agro-forestry in Uttar Pradesh, India.

Mello do A., H. Contribuição ao estudo do consumo de água por Eucalyptus alba Reinw., 1961 Piptadenia rigida Benth. e Astronium urundeuva (Fr. Allen.) Engl. Second World Eucalyptus Conference, São Paulo, August 13-28 1961. Reports and Documents Vol. II 1015-1029.

W xx The transpiration rate of 8-year-old E. alba was measured under laboratory conditions during one year in São Paulo, Brazil. The rate was highest during summer (the rainy season) and lowest during winter (the dry season).

- Metro, A. and G. de Beaucorps. L'influence de peuplement d'Eucalyptus sur l'évolution des sols sablonneux du Rharb. FAO, Sous-Commission de Coordination des Questions Forestières Méditerranéennes, Voyage d'étude des Eucalyptus au Maroc, Octobre 22-30 1954. 11 pp.
- N xx Nutrient content in above ground biomass and in a poor soil under stands of E. camaldulensis and E. gomphocephala in the semi-arid parts of Morocco (500 mm annual rain fall). K was exported to such an extent that it had to be replaced by fertilisation.
- Molina, F.; Bara, S. and P. Ruiz-Zorilla. El Monte Gallego aspectos relacionados con su fertilidad. Hoja Técnica. Ministerio de Agricultura, Instituto Nacional de Investigaciones Agrarias, Madrid. 14 pp.
- N x The authors review results from measurements of nutrient content in the biomass of E. globulus, E. camaldulensis, E. gomphocephala and in the soil underneath. Galicia, Spain. They conclude that the soil is not depleted in nutrients by the eucalypts.
- del Moral, R. and C.H. Muller. Fog drip: a mechanism of toxin transport from Eucalyptus globulus. Bulletin of the Torrey Botanical Club 96 (4) 467-475.
- E xxx Fog drip from a stand of E. globulus growing in California was collected and applied on different herbaceous species. Growth inhibition in some cases could only have been caused by allelopathic effects.
- del Moral, R and Muller, C.H. The allelopathic effects of Eucalyptus camaldulensis. American Midland Naturalist 83 254-282.
- E xxx The absence of annual vegetation near naturalized stands of E. camaldulensis could not be explained by differences in soil, grazing, lightetc. Extracted terpenes and water soluble toxins proved toxic to germinating seeds of annuals on heavier soils but not on sands. 10 phenolic toxins were isolated; 5 identified.
- Morani, V. Observations effectuées en Italie sur l'évolution du sol produit par les Eucalyptus. FAO, Sous-Commission de Coordination des Questions Forestières Méditerranéennes, Groupe de travail des Eucalyptus, deuxième session, 25 et 26 mai 1956, Nice, France. 4 pp.
- R x The author reviews publications from soil studies under stands of Eucalyptus in the Mediterranean region. No conclusions.
- Muller, C.H. The role of chemical inhibition (allelopathy) in vegetational composition. Bulletin of the Torrey Botanical Club 93 (5) 332-351.
- E x The author suggests that highly volatile metabolites from, for example, eucalypts are produced by the plant itself. Extracted in large quantities they can have allelopathic effects. No figures or evidence.
- Mullette, K.J., Hannon, N.J. and A.G.L. Elliott. Insoluble phosphorus usage by Eucalyptus. Plant and Soil 41 199-205.
- N xx In a well designed experiment seedlings of E. gummifera showed a remarkable growth response to insoluble phosphates. The author suggests that it could apply to other eucalypt species as well.

Muthana, K.D. and G.D. Arora. Performance of Eucalyptus camaldulensis on shallow and deep sandy loam of Pali (W. Rajasthan). Annals of Arid Zone 15 (4) 297-300.

M x E. camaldulensis was planted in a shallow soil (15 cm to a hard pan) and a deep soil (70-180 cm to a hard pan) in Rajasthan, India. After ten years the trees in the shallow soil were 5 meters high and in the deep soil 15 meters high. The difference in height growth was already evident in the first year after planting.

Nakhdjvani, F. Recherches sur les effets des brise-vent dans la région du Khouzistan. 1972 Revue Forestière Française 24 (3) 203-207.

M x Windbreaks with E. camaldulensis, Tamarix stricta and Acacia arabia were planted in 1959 in Khouzistan, Iran. Results from experiments with artificial windbreaks are presented.

Neginhal, S.G. Ecological impact of afforestation at the Ranibennur Blackbuck Sanctuary. Journal of the Bombay National History Society 75 (Suppl.) 1254-1258. 1980

E xx Progressive afforestation in Karnataka, India, with E. tereticornis since 1958 has resulted in the recovery of virtually extinct populations of blackbuck (Antelope cervicapra), great Indian bustard (Choriotis nigriceps) and wolf (Canis lupus). It is suggested that some open land must remain to maintain the populations. No figures are given in the abstract.

Neumann, F.G. Beetle communities in eucalyptus and pine forests in north-eastern Victoria. Australian Forest Research 9 (4) 277-293. 1979

E x Beetle communities were studied during two years in eucalypt forests and Pinus radiata plantations in Australia. The community diversity was significantly higher in the eucalypt forest than in the older stand of pine.

Nshubemuki, L. and F.G.R. Somi. Water use by Eucalyptus - observations and probable exaggerations. Tanzania Silvicultur Technical Note (New Series) No. 44. 13 pp. 1979

R x The authors give a well balanced review of the water use by eucalypts. They draw the conclusion that more research has to be done on the subject, and comparisons with other species are necessary.

Nzindukiyimana, A. and I.Sabasajya. Lutte anti-érosive à Gikongoro: le boisement de la colline Mujyejuru. Bulletin Agricole du Rwanda 10 (1) 36-38. 1977

W x Abstract. Afforestation of the hills in Rwanda to control erosion involves planting Eucalyptus at intermediate altitudes. Nothing in the abstract is said about the result.

Osara, N.A. and P. Mikola. O impacto das plantações de eucaliptos no equilíbrio das águas. Paper in booklet (O Eucalipto a Ecologia) prepared for the Aracruz Pulp and Paper Co, Brazil. 35-36. 1975

M x The authors reply to criticisms concerning the high water demand of eucalypt plantations in Brazil. No evidence is given.

Pacifico H., V. A cultura do eucalipto no melhoramento do solo. Second World  
1961 Eucalyptus Conference, São Paulo, August 13-28 1961. Vol. Reports and  
Documents II 911-918.

N x After cutting a 37-year-old stand of E. tereticornis in Araras,  
Brazil, rich harvests of coffee were obtained. Results of soil analysis  
are given. The author's conclusion that the eucalypt had improved the  
soil cannot possibly be drawn from the data.

Pan, C.S. Rainfall interception in (1) a Eucalyptus robusta plantation; (2)  
1974 Cunninghamia lanceolata plantations with different degrees of thinning;  
(3) Calocedrus (Libocedrus) formosana plantations with different  
spacings. Taiwan Forestry Research Institute, Bulletin No. 253; 255; 256.  
8+12+11 pp.

W x Abstract. Interception was estimated for 14-20 year old E.  
robusta and some other species, planted with different spacing, during  
the rainy season of 1972 in Taiwan. The interception was found to be less  
at 1.5 x 2 meters spacing than at 1.5 x 1.5 or 2 x 2 meters spacing. No  
quantifications in the abstract.

Pereira, H.C. Land use and water resources. Cambridge University Press, London. 246 pp.  
1973

G xx A comprehensive book about water resources and watershed  
management. Many references.

Piccolo, A.L.G.; da Silva, E.M.P.; Lelis, G.J.; Ramos, M.R. and M.S. Kachan. Plants  
1972,a invading plantations of Eucalyptus robusta. Revista de Agricultura,  
Piracicaba, Brazil 47 (2) 81-85.

E x The invading species were recorded for a 52 year old E. robusta  
plantation in Brazil. The most abundant of the species reproduce by  
vegetative means. No comparisons with other tree species.

Piccolo, A.L.G.; Vidal, R.; Cattai, I.A.; Lordello, M.H.; Hebling, R.M.D.; Baldoni, M.  
1972,b de L. and S.A. Bonini. Plants tolerant of shading by Eucalyptus alba.  
Revista de Agricultura, Piracicaba, Brazil 47 (2) 87-90.

E x Further observations compared with Piccolo et al (1972,a). A  
comparison between the undergrowth in E. alba, E. microcorys and E.  
robusta stands gave no significant differences.

Pochon, J. and H. de Barjac et Faivre-Amiot. L'influence de plantations d'Eucalyptus  
1959 au Maroc sur la microflore et l'humus du sol. Annales de l'Institut  
Pasteur No. 3 403-406.

N x The authors suggest that the fast mineralisation, without forming  
humus, under a 10-year-old E. camaldulensis stand is due to lack of  
balance in the soil microflora. The text contains contradictions and  
nothing is said about the method of the study.

Poggiani, F. Ciclo de Nutrientes e Productividade de Floresta Implantada. Silvicultura  
1976 1 (3) 45-48.

N x A general discussion of the cycle of nutrients and forest  
productivity.

- Poggiani, F.; do Couto, H.T.Z.; Corradini, L. and E.C.M. Fazzio. Exportação de biomassa e nutrientes através da exportação dos troncos e das copas de um povoamento de Eucalyptus saligna. IPEF No. 25 37-39.
- N xxx Nutrient content was measured in different parts of the trees (50 trees were analysed) in an 8 year old E. saligna plantation, in São Paulo, Brazil. The upper 1 meter of the soil was also analysed. About 30 % of the macro nutrients were in the branches and leaves. The soil was very poor, and the lack of P and K could be presumed, since the content of these elements in the biomass was twice as high as in the soil.
- Poggiani, F.; do Couto, H.T.Z. and W. Suiter Filho. Biomass and Nutrient Estimates in Short Rotation Intensively Cultured Plantation of Eucalyptus grandis. IPEF No. 23 37-42.
- N xxx Nutrient content was measured in the biomass of a 2.5-year-old E. grandis plantation in Minas Gerais, Brazil. 24 trees were analysed. The analyses of the nutrient content in the upper 1.2 meters of the soil, when compared with the content in the biomass, shows that the soil has a big shortage of P and K.
- Poggiani, F.; do Couto, H.T.Z. and W. Suiter Filho. Biomass and Nutrient Estimates in Short Rotation Intensively Cultured Plantation of Eucalyptus grandis. Silvicultura 8 (32) 648-651
- N xxx The same article as Poggiani et al (1983,b).
- Poupon, H. Description des appareils aérien et souterrain d'Eucalyptus camaldulensis Dehn. introduit en Tunisie du nord. Cahier ORSTOM, série Biologie No. 17 47-59.
- G x The above- and underground parts of a population of E. camaldulensis in Zerniza, Tunisia, were described. A 2.20 meter tap root with a diameter of 55 cm at 0.8 meters depth was formed. Most of the roots less than 1 cm in diameter were found in the upper 25 cm of the soil.
- Prasad, U. Trial of Eucalyptus hybrids FRI-4 and FRI-5 on different doses of manure. Abstract of Paper for National Seminar on Eucalyptus, January 30-31 1984, Kerala, India.
- N x Abstract. A fertilisation trial was done with 2 provenances of E. hybrid in the state of Bihar, India. As well as an increase in growth, mortality decreased on the fertilised plots. No figures are given in the abstract.
- Puri, D.N.; Vishwanatham, M.K. and S.K. Dhyani. Eucalyptus - a boon for social/agro-forestry. Workshop on Eucalyptus plantation, June 29 1984, Bangalore, India. Papers and Proceedings 99-105.
- M x A biased contribution to the Eucalyptus discussion in India. Pro-eucalypt.
- Raison, R.J. and W.J.B. Crane. Nutritional costs of shortened rotations in plantation forestry. 17th IUFRO World Congress, 1981, Kyoto. Proceedings Div. I, 63-72.
- N xxx Removal of P from E. delegatensis and Pinus radiata was compared at different rotation ages. Shortening rotation will increase the amount of P removed per unit of wood harvested for both species. The heartwood/sapwood relation and the concentration of nutrients in the two kinds of wood re discussed. E. delegatensis is, in theory, more nutrient efficient (nutrient use per produced unit dry wood) than the pine, and the comparative efficiency increases progressively with age.

Raison, R.J.; Khanna, P.K. and W.J.B. Crane. Effects on intensified harvesting on rates of nitrogen and phosphorus removal from Pinus radiata and Eucalyptus forests in Australia and New Zealand. New Zealand Journal of Forestry Science 12 (2) 394-403.

N xxx Nutrient content was measured in the different parts of the trees in two 9.5 year old E. globulus plantations and two Pinus radiata plantations, 8 and 29 year old, was measured. The result leads to the conclusion that full tree harvesting increases nutrient exportation by about 100 %.

Raj, F.H.; Rajan, N.C.M. and K. Rajagopal. Some hydrological investigations on Blue gum at Osamund (Nilgiris). Abstract of Paper for National Seminar on Eucalyptus, January 30-31 1984, Kerala, India.

W ? Abstract. Investigations have been carried out since 1977 on various aspects of the hydrological cycle under E. globulus in the Nilgiris Hills, India. No results are given in the abstract.

Rajamannar, A.; Ramaswami, P.P. and Krishnamoorthy. Certain soil characteristics of plantation soils of different altitude. Indian Journal of Forestry 1 (3) 185-188.

N x Soil characteristics (pH, organic carbon etc.) are given for 51 samples in E. tereticornis and E. globulus plantations in India. No analyses or comparisons with other genera are made.

Rajvanshi, A; Soni, S.; Kukreti, U.D. and M.M. Srivastava. A comparative study of undergrowth of sal forest and eucalyptus plantation at Golatappar-Dehra Dun during rainy season. Indian Journal of Forestry 6 (2) 117-119.

E xx The undergrowth was compared in a 13-year-old Eucalyptus plantation and in a natural sal (Shorea robusta) forest in humid northern India, during the rainy season. The number of species was higher in the plantation than in the sal forest, 65 compared with 37. There were most annuals in the former and perennials in the latter. 10 samples per stand.

Rakhmanov, V.V. (The hydrological role of eucalypts.) Lesnoe Khozyai'stvo No. 5 24-28 1980 (Ru).

R x Abstract. The article reviews Russian, Indian and Australian literature about the water use of eucalypts.

Rambelli, A. Qualche indagine sulla microbiologia dei terreni coltivati ad eucalitto. Pubblicazioni del Centro di Sperimentazione Agricola e Forestale 3 217-234.

E xx The microflora in the soil under Eucalyptus and agricultural crops was compared. The microbial population was found to be higher under eucalypts. The eucalypt soil had, however, become more acid compared with 4 years earlier. The author concludes that the eucalypt cultivation tends to cause deterioration of the biochemical and chemical characteristics of the soil. Italy.

Rambelli, A. Contributo allo studio dei micromiceti nei terreni coltivati ad eucalitto. Pubblicazioni del Centro di Sperimentazione Agricola e Forestale 3 235-253.

E x The fungus microflora under some Eucalyptus stands in Italy is described in detail.



- Ramballi, A. 1960 Research into microfungi in soils planted with Eucalyptus. FAO, Joint Sub-Commission on Mediterranean Forestry Problems, Working Party on Eucalyptus, Fourth session, April- May 1960, Lisbon. 5 pp.
- E xx Microfungi were identified under different Eucalyptus stands outside Rome. There was no significant variation in microbial populations although there was a noticeable difference in type of undergrowth.
- Rao, A.L. 1984 Eucalyptus in Andhra Pradesh. Indian Forester 110 (1) 1-8.
- M x The author describes the historical background and research on eucalypts in Andhra Pradesh, India. Nothing about ecological effects of growing eucalypts.
- Rao, P.R. 1984 The Eucalyptus controversy. Workshop on Eucalyptus plantation, June 29 1984, Bangalore, India. Papers and Proceedings 1-8.
- M x The author describes both ecologically and socially controversial factors, connected with growing eucalypts in India.
- Ray, M.P. 1970 Preliminary observations on stem-flow, etc., in Alstonia scholaris and Shorea robusta plantations at Arabari, West Bengal. Indian Forester 96 (7) 482-493.
- W x Interception varied between 22% and 36 % of precipitation in a stand of 16-17 year old and 8 meters high Alstonia scholaris in West Bengal, India. For a Shorea robusta stand of the same age and height the interception varied from 17% to 35%.
- Ray, R.M. 1984 Eucalyptus - a perspective. Indian Forester 110 (1) 86-89.
- M x The author points out advantages and disadvantages to extensive eucalyptus planting in India. No quantifications.
- Rocha Filho, J.V. de C.; Haag, H.P.; Oliveira, G.D. de and R.A. Pitelli. 1978 Ciclagem de nutrientes em florestas implantadas de Eucalyptus e Pinus. I. Distribuição no solo e na manta. Anais da Escola de Agricultura "Luiz de Queiroz" 35 113-123.
- N xx Abstract. Changes in nutrient content in the soils under E. citriodora and Pinus taeda in Brazil were measured. Organic carbon increased under both species. The eucalypt increased the soil K and Mg contents, while the pine increased the exchangeable Al in the 10-20 cm soil layer.
- Rudrappa, T. 1984 Allelopathic effects of Eucalyptus plantation. Workshop on Eucalyptus plantation, June 29 1984, Bangalore, India. Papers and Proceedings 109-111.
- ER xx The author cites 5 references about allelopathic effects of eucalypts.
- Samraj, P; Chinnamani, S. and B. Haldorai. 1977 Natural versus man-made forest in Nilgiris with special reference to run-off, soil loss and productivity. Indian Forester 103 (7) 460-465.
- W xx A continuation of the stream run-off study in the Nilgiris Hills in southern India reported by Chinnamani et al (1965). The results were similar to the ones in the previous study (small differences between run-off from E. globulus, Acacia mollissima, shola (sub-montane evergreen forest), broom (Cytisus scoparius) and native grasses).

- Sarlin, P. 1963,a L'eau et le sol. L'eau en forêt, en savane et dans les reboisements. Bois et Forêts des Tropiques No. 89 11-29.
- W x The author discusses the relation between water and soil for Eucalyptus plantations in Congo.
- Sarlin, P. 1963,b Programme spécial FAO d'éducation et de formation en Afrique. FAO, Centre de Perfectionnement sur les Techniques de Boisement en Savanne. Soudan, 9 Novembre - 19 Decembre 1963. Pédologie, Exposé No.3: L'eau du sol.
- N xx A relation without high correlation between soil water content and increment was found in eucalypt plantations in dry parts of Congo.
- Schoenenberger, A. 1970 Les données dendrographiques de la station expérimentale de Zerniza. Annales de l'Institut National de Recherches Forestières de Tunisie 4 (4). 28 pp.
- W x The variation in diameter growth of 2 E. maideni, 2 E. camaldulensis, 1 Pinus radiata and 1 P. pinaster was measured, sometimes daily, during two years in Tunisia. The growth was found to be related to water supply.
- Schönau, A.P.G. 1981 The effects of fertilizing on the foliar nutrient concentrations in Eucalyptus grandis. Fertilizer Research 2 73-82.
- N x Many significant changes in foliar nutrient concentrations were obtained as a result of fertilising a E. grandis stand in South Africa.
- Schönau, A.P.G. 1982 Additional effects of fertilizing on several foliar nutrient concentrations and ratios in Eucalyptus grandis. Fertilizer Research 3 385-397.
- N x In a fertilisation trial with E. grandis in South Africa a balanced P and N supply was found to be of great importance. Zn was found to be the most important micro nutrient.
- Schönau, A.P.G. 1983 Seasonal changes in foliar nutrient content of E. grandis. Silvicultura 8 (32) 683-685.
- N x Height growth of 1-3 year old E. grandis plantations was found to be closely related to foliar nutrient content (except for Fe) and rain fall in a study in South Africa. The author suggests that foliar nutrient content tests for fertiliser application should be carried out during the growing season.
- Schönau, A.P.G. and M.A. Herbert. 1982 Relationship between Growth Rate and Foliar Concentrations of Nitrogen, Phosphorus and Potassium for Eucalyptus grandis. Suid-Afrikaanse Bosbou tydskrif Nr. 120 19-23.
- N x In a fertilisation trial in South Africa it was found that the foliar content of N, P, and K for good growth of E. grandis should be 2.0, 0.17 and 0.70 %, respectively.
- Sharma, S.K.; Prasad, K.G. and G.N. Gupta. 1984 Growth of Eucalyptus grandis with fertiliser treatments on a severely truncated soil. Abstract of Paper for National Seminar on Eucalyptus, January 30-31 1984, Kerala, India.
- N x Abstract. The results from a fertilisation trial with E. grandis in southern India are presented. Material and method are well described.

Shiva, V. and J. Bandyopadhyay. Eucalyptus - a disastrous tree for India. The Ecologist 13 No. 5 184-187.

R x A biased review and analysis of the ecological effects of eucalypt planting in India. Anti-eucalypt.

Shiva, V. and Bandyopadhyay, J. Ecological audit of eucalyptus cultivation. 1984

R x A biased review and analysis of the ecological effects of eucalypt planting in India.

Shiva, V.; Somasekhara, R.S.T. and J. Bandyopadhyay. The ecology of eucalyptus and farm forestry policy in rainfed areas. Workshop on Eucalyptus plantation, June 29 1984, Bangalore, India. Papers and Proceedings 191-222.

R x A biased review containing 35 references on water and nutrient use by eucalypts. The authors draw the conclusion that the genus is a disaster for India.

Shyam, S.S. Forest development and Eucalyptus controversy in Karnataka. Workshop on Eucalyptus plantation, June 29 1984, Bangalore, India. Papers and Proceedings 45-72.

M x The author describes the controversy about planting eucalypts in Karnataka. A good review on the problem is given on p. 63-67.

Singh, K. and S.P. Banerjee. State of Soil Aggregation Under Plantation Forests and Agriculture in Alluvial Soil of Doon Valley. Van Vigyan 18 (3 & 4) 31-38.

E x Macro aggregates were studied in soils under different planted tree species in India. The percentage of aggregates bigger than 2 mm was highest for the soil under Shorea robusta. Then followed Tectona grandis, Eucalyptus sp., Acacia catechu and Pinus roxburghii. The aggregation was much better in the forest soils than in a neighbouring agricultural field. The sampling method is not described.

Singh, R.P. Net primary productivity and productive structure of Eucalyptus tereticornis Smith plantations grown in Gangetic plain. Indian Forester 108 (4) 261-269.

N x Litter fall was measured in 5, 6, 7, 8 and 9 year old plantations of E. tereticornis on the Gangetic plain in India. The annual production varied from 2.33 ton/ha at the age of 5 to 5.42 at the age of 9. The stand studied produced nearly the same as 40 year old Tectona grandis in another study, and nearly 50 % more than a 40 year old Shorea robusta stand, also in another study.

Singh, R.P. Nutrient cycle in Eucalyptus tereticornis Smith plantations. Indian Forester 110 (1) 76-85.

N xx Nitrogen, phosphorus and calcium content was determined in different parts of trees in 5, 6, 7, 8 and 9 year old plantations of E. tereticornis on the Gangetic plain in India. No consistent differences in concentration of any of the elements was found at the different ages.

Singhal, R.M. Effect of growing Eucalyptus on the status of soil organic matter on Dehra Dun forests. Abstract of Paper for National Seminar on Eucalyptus, January 1984 30-31 1984, Kerala, India.

E x Abstract. The same as Singhal et al (1975).

Singhal, R.M.; Banerjee, S.P. and T.C. Pathak. Effect of Eucalyptus monoculture on the status of soil organic matter in natural sal (Shorea robusta) zone in Doon Valley. Indian Forester 101 (12) 730-737.

E xx The organic matter was measured at different depths in a Eucalyptus and a sal (Shorea robusta) plantation 5 and 10 years after establishing. The conclusions (faster and easier nutrient cycling under the eucalypts than under sal, and therefore, a risk of loss of organic matter under sal) is not possible to evaluate, since the number of samples taken is not given.

Smith, M.K. Throughfall Stemflow and Interception in Pine and Eucalypt Forest. 1974 Australian Forestry 36 (3) 190-197.

W xx In a limited study (few samples) interception was calculated to be 18.7 % of the precipitation in a ca 35-year-old, mature, Pinus radiata stand and 10.6 % in a mature natural eucalypt forest. New South Wales, Australia.

Soulères, G. Elements concernant la sylviculture des boisements d'eucalyptus (Maroc). 1961 Second World Eucalyptus Conference, São Paulo, August 13-28 1961. Reports and Documents Vol. I 715-736.

W x Quoted by Karschon (1970). Not seen.

Stein, A.H. Nota sobre los resultados obtenidos en otros Países en las experiencias acerca de la influencia del Eucalyptus sobre la cubierta forestal de las hoyas hidrográficas y sobre el mejoramiento del suelo con su aplicación a la misma materia en Chile. Paper from "Misión Forestal de la FAO", No. 9. 1952 Santiago de Chile.

W x The author reviews research on eucalypts in high altitudes with high rainfall. Experiences from Chile are that if eucalypts (here E. globulus) is used to prevent erosion they should be planted with wide spacing (approx. 200 trees/ha), or be irrigated to stimulate the understorey.

Steyn, D.J. Occupation and Use of the Eucalyptus Plantations in the Tzaneen Area by 1977 Indigenous Birds. South Africa Forestry Journal No. 100 56-60.

E xxx The avifauna (birds) is described in some, less than 25-year-old, E. grandis plantations in NE Transvaal. The plantations were not considered sterile and unsuitable for birds, but some species have been "driven out" from the plantations. No figures are given.

Stibbe, E. Soil moisture depletion in summer by an eucalyptus grove in a desert area. 1975 Agro-Ecosystems (2) 117-126.

W ? Soil moisture was measured during the dry season in the principal root zone of a grove of E. occidentalis in a desert area in Israel (annual rainfall is 200 mm). The roots extracted soil moisture mainly during the season with rainfall.

- Story, R. 1967 Pasture patterns and associated soil water in partially cleared woodland. Australian Journal of Botany 15 175-187.
- E xx Circles with no vegetation around Acacia, Casuarina and Eucalyptus trees in western Australia, were not caused by root competition from the trees. At least no such evidence could be found in the thorough analysis made. It is thought that chemical exudates may be responsible.
- Subba Rao, B.K. Impact on Eucalyptus plantations on locality factors. Workshop on 1984 Eucalyptus plantation, June 29 1984, Bangalore, India. Papers and Proceedings 171-190.
- R x The author cites 32 references and makes a well balanced analysis of the water and nutrient demand of eucalypts. He points out the need for further research. Pro-eucalypt.
- Thomas, P.K.; Chandrasekhar, K. and B. Haldorai. 1972 An estimate of transpiration by Eucalyptus globulus from Nilgiris watershed. Indian Forester 98 (2) 168-172.
- W x The model used for estimating the transpiration from E. globulus in the Nilgiris, India, can not be used with any high claim to reliability. The results and conclusions are therefore uninteresting.
- Tiwari, K.M. 1983 Soil and water conservation - need for better management in the country. Indian Forester 109 (11) 775-780.
- M x The author states that reforestation partly solves the problem of unnecessary water losses in India. Different eucalypts are mentioned as useful species for this purpose, since they are not grazed.
- Tiwari, K.M. and R.S. Mathur. 1983 Water consumption and nutrient uptake by eucalypts. Indian Forester 109 (12) 851-860.
- R x The authors summarize some of the literature on water and nutrient use by eucalypts. From the references chosen they conclude that the soil fertility is improved under a eucalypt plantation but that there is no scientific evidence that plantations lower the water table.
- Turner, J. 1980 Nitrogen and phosphorus distributions in naturally regenerated Eucalyptus spp. and planted Douglas-fir. Australian Forest Research 10 (3) 289-294.
- N x Abstract. Nitrogen and phosphorus content in above-ground parts and the soil under naturally regenerated Eucalyptus spp. and planted Douglas-fir in New South Wales, Australia.
- Turner, J. and Kelly, J. 1977 Soil chemical properties under naturally regenerated Eucalyptus spp. and planted Douglas-fir. Australian Forest Research 7 (3) 163-172.
- N x Abstract. The chemical soil properties were compared under a 50-year-old Pseudotsuga menziesii plantation and a naturally regenerated Eucalyptus spp. forest in New South Wales, Australia. The result led the authors to the conclusion that the P. menziesii, on that site, had not had a detrimental effect on the chemical properties of the soil. The conclusion is not possible to evaluate from the abstract.

Turner, J. and M.J. Lambert. Nutrient cycling within a 27-year-old Eucalyptus grandis plantation in New South Wales. Forest Ecology and Management 6 (2) 155-168.

N X Abstract. the distribution of organic matter and nutrients was measured in a 27 year old plantation of E. grandis in humid parts of New South Wales, Australia. A management system was proposed on the basis of the results.

Van Lill, W.S.; Kruger, F.J. and Van Wyk, D.B. The effect of afforestation with Eucalyptus grandis Hill ex Maiden and Pinus patula Schlecht. et Cham. on streamflow from experimental catchments at Mokobulaan, Transvaal. Journal of Hydrology 48 107-118.

W xxx A critical catchment study in Transvaal, South Africa comparing E. grandis, Pinus patula and natural scrub after 12 years of calibration. Afforestation with Eucalyptus exerted an effect on flow after 3 years of 300-380 mm/yr. Too early for conclusive results from the pine.

Velasco de P., F. and Lozano C., J.M. Cambios sincológicos de la microflora telurica asociados a las repoblaciones forestales con especies exóticas. Anales de Edafologia y Agrobiologia 38 (5/6) 871-879.

E xx Abstract. Soil properties were studied under Castanea sativa woodland (climax forest), planted E. globulus and Pinus radiata in the humid parts of northern Spain. There was acidification under the plantations and the total microflora was diminishing. Data on method is not given in the abstract.

Walter, H. Harnickell, E. and D. Mueller-Dombois. Climate-diagram Maps of the Individual Continents and the Ecological Climatic Regions of the Earth. Supplement to the Vegetation Monographs. Springer-Verlag, Berlin, Heidelberg, New York. 36 pp (with 14 figures), 9 maps.

G xx Gives a detailed picture of climate all over the world.

Wise, P.K. and M.G. Pitman. Nutrient removal and replacement associated with short rotation eucalypt plantations. Australian Forestry 44 (3) 142-152.

N xxx The actual cost is calculated for replacing nutrients removed from typical 10 year old plantations with different eucalypt species in New South Wales, Australia. Under a native forest sawlog regime 6 % of the amount of nutrients is removed per unit of dry wood, compared with that associated with a total tree utilisation in short rotation plantations.

Woinarski, J.K.Z. Birds of Eucalyptus plantation and adjacent natural forest. Australian Forestry 42 (4) 243-247.

E xx The abundance of birds, observed during one year, was compared in a E. botryoides plantation near Melbourne, Australia, with the abundance in an adjacent mixed aged E. dives forest. Of the 48 listed species, 6 were significantly more common in the plantation and 9 were significantly more common in the natural forest.

Yadav, J.S.P.; Banerjee, S.P.; Badola, K.C. and K. Singh. Changes in soil properties consequent upon growing Eucalyptus in a natural sal (Shorea robusta) area. Indian Journal of Agricultural Chemistry 6 (2) 109-115.

N x Abstract. Five years of Eucalyptus monoculture in humid parts of northern India produced a downward movement of finer material, a slight decrease in pH and available phosphorus, while available potassium decreased. No figures in the abstract.

Zohar, Y. 1976 Growth of eucalypt on peat and its effect on soil nitrates. Agricultural Research Organization, Division of Forestry, Israel. Leaflet No. 57. 11 pp.

N xx Soil nitrates were found to be significantly lower in the peat under a eucalypt plantation, compared with outside the plantation. Hula Valley, Israel. Proposed for reducing eutrophication.

Zohar, Y. 1979 Plantation of eucalypt on Drained Lake Peat in the Hula Valley. La-Yaaran 29 (3-4) 43-48.

N xx Same as Zohar (1976).

## FAO TECHNICAL PAPERS

### FAO FORESTRY PAPERS:

1. Forest utilization contracts on public land, 1977 (E' F' S')
2. Planning of forest roads and harvesting systems, 1977 (E' F' S')
3. World list of forestry schools, 1977 (E/F/S')
- 3 Rev. 1 — World list of forestry schools, 1981 (E/F/S')
- 3 Rev. 2 — World list of forestry schools, 1986 (E/F/S')
4. World pulp and paper demand, supply and trade — Vol. 1, 1977 (E' F' S')  
Vol. 2, 1978 (E' F' S')
5. The marketing of tropical wood in South America, 1978 (E' S')
6. National parks planning, 1978 (E' F' S'')
7. Forestry for local community development, 1978 (E' F' S')
8. Establishment techniques for forest plantations, 1978 (Ar' C' E' F' S')
9. Wood chips, 1978 (C' E' S')
10. Assessment of logging costs from forest inventories in the tropics, 1978
  1. Principles and methodology (E' F' S')
  2. Data collection and calculations (E' F' S')
11. Savanna afforestation in Africa, 1978 (E' F')
12. China: forestry support for agriculture, 1978 (E')
13. Forest products prices, 1979 (E/F/S')
14. Mountain forest roads and harvesting, 1979 (E')
- 14 Rev. 1 — Logging and transport in steep terrain, 1985 (E')
15. AGRIS forestry wood catalogue of information and documentation services, 1979 (E/F/S')
16. China: integrated wood processing industries, 1979 (E' F' S'')
17. Economic analysis of forestry projects, 1979 (E' F' S')
- 17 Sup. 1 — Economic analysis of forestry projects: case studies, 1979 (E' S')
- 17 Sup. 2 — Economic analysis of forestry projects: readings, 1980 (E')
18. Forest products prices 1960-1978, 1980 (E/F/S')
19. Pulping and paper-making properties of fast-growing plantation wood species — Vol. 1, 1980 (E')  
Pulping and paper-making properties of fast-growing plantation wood species — Vol. 2, 1980 (E')
- 20/1. Forest tree improvement, 1985 (E' F' S')
- 20/2. A guide to forest seed handling, 1985 (E')
21. Impact on soils of fast-growing species in lowland humid tropics, 1980 (E' F')
- 22/1. Forest volume estimation and yield prediction, 1980  
Vol. 1 — Volume estimation (E' F' S')
- 22/2. Forest volume estimation and yield prediction, 1980  
Vol. 2 — Yield prediction (E' F' S')
23. Forest products prices 1961-1980, 1981 (E/F/S')
24. Cable logging systems, 1981 (E')
25. Public forestry administration in Latin America, 1981 (E')
26. Forestry and rural development, 1981 (E' F' S')
27. Manual of forest inventory, 1981 (E' F')
28. Small and medium sawmills in developing countries, 1981 (E' S')
29. World forest products, demand and supply 1990 and 2000, 1982 (E' F' S')
30. Tropical forest resources, 1982 (E/F/S')
31. Appropriate technology in forestry, 1982 (E')
32. Classification and definitions of forest products, 1982 (Ar/E/F/S')
33. Logging of mountain forests, 1982 (E' F' S')
34. Fruit-bearing forest trees, 1982 (E' F' S')
35. Forestry in China, 1982 (E')
36. Basic technology in forest operations, 1982 (E' F' S')
37. Conservation and development of tropical forest resources, 1982 (E' F' S')
38. Forest products prices 1962-1981, 1982 (E/F/S')
39. Frame saw manual, 1982 (E')
40. Circular saw manual, 1983 (E')
41. Simple technologies for charcoal making, 1983 (E' F' S')
42. Fuelwood supplies in the developing countries, 1983 (Ar' E' F' S')
43. Forest revenue systems in developing countries, 1983 (E' F' S')
- 44/1. Food and fruit-bearing forest species, 1983 (E' F' S')
- 44/2. Food and fruit-bearing forest species, 1984 (E' F' S')
- 44/3. Food and fruit-bearing forest species, 1986 (E' S')
45. Establishing pulp and paper mills, 1983 (E')
46. Forest products prices 1963-1982, 1983 (E/F/S')
47. Technical forestry education — design and implementation, 1984 (E')
48. Land evaluation for forestry, 1984 (E' S')
49. Wood extraction with oxen and agricultural tractors, 1986 (E' F' S')
50. Changes in shifting cultivation in Africa, 1984 (E' F')
- 50/1. Changes in shifting cultivation in Africa — seven case-studies, 1985 (E')
- 51/1. Etudes sur les volumes et la productivité des peuplements forestiers tropicaux  
1: Formations forestières sèches, 1984 (F')
- 52/1. Cost estimating in sawmilling industries: guidelines, 1984 (E')
- 52/2. Field manual on cost estimation in sawmilling industries, 1985 (E')
53. Intensive multiple-use forest management in Kerala (India), 1984 (E' F')
54. Planificación del desarrollo forestal, 1985 (S')
55. Intensive multiple-use forest management in the tropics, 1985 (E' F' S')



**FAO TECHNICAL PAPERS**

**FAO FORESTRY PAPERS:**

1. Forest utilization contracts on public land, 1977 (E\* F\* S')
2. Planning forest roads and harvesting systems, 1977 (E\* F\* S')
3. World list of forestry schools, 1977 (E/F/S')
- 3 Rev. 1 — World list of forestry schools, 1981 (E/F/S')
4. World pulp and paper demand, supply and trade — Vol. 1, 1977 (E\* F\* S')
- Vol. 2, 1978 (E\* F\* S')
5. The marketing of tropical wood in South America, 1978 (E\* S')
6. National parks planning, 1978 (E\* F\* S'\*)
7. Forestry for local community development, 1978 (E\* F\* S')
8. Establishment techniques for forest plantations, 1978 (Ar\*\* C\* E\*\* F\* S')
9. Wood chips, 1978 (C\* E\* S')
10. Assessment of logging costs from forest inventories in the tropics, 1978
  1. Principles and methodology (E\* F\* S')
  2. Data collection and calculations (E\* F\* S')
11. Savanna afforestation in Africa, 1978 (E\* F')
12. China: forestry support for agriculture, 1978 (E')
13. Forest products prices, 1979 (E/F/S')
14. Mountain forest roads and harvesting, 1979 (E')
- 14 Rev. 1 — Logging and transport in steep terrain, 1985 (E')
15. AGRIS forestry wood catalogue of information and documentation services, 1979 (E/F/S')
16. China: integrated wood processing industries, 1979 (E\* F\* S'\*)
17. Economic analysis of forestry projects, 1979 (E\* F\* S')
- 17 Sup. 1 — Economic analysis of forestry projects: case studies, 1979 (E\* S')
- 17 Sup. 2 — Economic analysis of forestry projects: readings, 1980 (E')
18. Forest products prices 1960-1978, 1980 (E/F/S')
19. Pulping and paper-making properties of fast-growing plantation wood species — Vol. 1, 1980 (E')
- Vol. 2, 1980 (E')
20. Forest tree improvement, 1985 (E\* S')
21. Impact on soils of fast-growing species in lowland humid tropics, 1980 (E\* F')
- 22/1. Forest volume estimation and yield prediction, 1980
  - Vol. 1 — Volume estimation (E\* F\* S')
- 22/2. Forest volume estimation and yield prediction, 1980
  - Vol. 2 — Yield prediction (E\* F\* S')
23. Forest products prices 1961-1980, 1981 (E/F/S')
24. Cable logging systems, 1981 (E')
25. Public forestry administration in Latin America, 1981 (E')
26. Forestry and rural development, 1981 (E\* F\* S')
27. Manual of forest inventory, 1981 (E\* F')
28. Small and medium sawmills in developing countries, 1981 (E\* S')
29. World forest products, demand and supply 1990 and 2000, 1982 (E\* F\* S')
30. Tropical forest resources, 1982 (E/F/S')
31. Appropriate technology in forestry, 1982 (E')
32. Classification and definitions of forest products, 1982 (Ar/E/F/S')
33. Logging of mountain forests, 1982 (E')
34. Fruit-bearing forest trees, 1982 (E\* F\* S')
35. Forestry in China, 1982 (E')
36. Basic technology in forest operations, 1982 (E\* F\* S')
37. Conservation and development of tropical forest resources, 1982 (E\* F\* S')
38. Forest products prices 1962-1981, 1982 (E/F/S')
39. Frame saw manual, 1982 (E')
40. Circular saw manual, 1983 (E')
41. Simple technologies for charcoal making, 1983 (E\* F\* S')
42. Fuelwood supplies in the developing countries, 1983 (Ar\* E\* F\* S')
43. Forest revenue systems in developing countries, 1983 (E')
- 44/1. Food and fruit-bearing forest species, 1983 (E\* F')
- 44/2. Food and fruit-bearing forest species, 1984 (E')
45. Establishing pulp and paper mills, 1983 (E')
46. Forest products prices 1963-1982, 1983 (E/F/S')
47. Technical forestry education — design and implementation, 1984 (E')
48. Land evaluation for forestry, 1984 (E')
49. Extracción de trozas mediante bueyes y tractores agrícolas, 1984 (S')
50. Changes in shifting cultivation in Africa, 1984 (E\* F')
- 51/1. Etudes sur les volumes et la productivité des peuplements forestiers tropicaux
  - 1: Formations forestières sèches, 1984 (F')
- 52/1. Cost estimating in sawmilling industries: guidelines, 1984 (E')
53. Intensive multiple-use forest management in Kerala (India), 1984 (E')
54. Planificación del desarrollo forestal, 1985 (S')
55. Intensive multiple-use forest management in the tropics, 1985 (E')
56. Breeding poplars for disease resistance, 1985 (E')
57. Coconut wood, 1985 (E')
58. Sawdoctoring manual, 1985 (E')
59. The ecological effects of eucalyptus, 1985 (E')

Availability: October 1985

Ar	—	Arabic	*	Available
C	—	Chinese	**	Out of print
E	—	English	***	In preparation
F	—	French		
S	—	Spanish		

*The FAO Technical Papers can be purchased locally through FAO sales agents or directly from Distribution and Sales Section, FAO, Via delle Terme di Caracalla, 00100 Rome, Italy.*