SECOND EDITION

The Ecology of Tropical Food Crops

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Second Edition

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CAMBRIDGE
UNIVERSITY PRESS

Published by the Press Syndicate of the University of Cambridge
The Pitt Building, Trumpington Street, Cambridge CB2 1RP
40 West 20th Street, New York, NY 10011-4211, USA
10 Stamford Road, Oakleigh, Melbourne 3166, Australia

First published 1984
Second edition 1995

Printed in Great Britain at the University Press, Cambridge

A catalogue record for this book is available from the British Library

Library of Congress cataloguing in publication data

Norman, M. J. T. (Michael John Thornley)
The ecology of tropical food crops/M. J. T. Norman, C. J. Pearson, P. G. E. Searle. – 2nd ed.
p. cm.
Includes bibliographical references (p.) and index.
ISBN 0 521 41062 2 (hardback). – ISBN 0 521 42264 7 (paperback)
1. Food crops – Ecology – Tropics. 2. Tropical crops – Ecology.
I. Pearson, C. J. II. Searle, P. G. E. III. Title.
SB176.T76N67 1995
630′.2′5745264–dc20 94-31156 CIP

ISBN 0 521 41062 2 hardback
ISBN 0 521 42264 7 paperback

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PREFACE

The first edition of *The Ecology of Tropical Food Crops* was published at the end of a grand era of research on the physiology, ecology, agronomy, soil science and micrometeorology which underlie crop production. This research was driven by international concern about the need to increase food production to meet demands from increasing population, particularly in tropical countries, and by developments in scientific methodology and funding. As we began the preface of that edition: 'No-one in the 1980s needs to be reminded of the necessity to increase food production in tropical countries...the number of people in the tropics ...will rise by AD 2000 to over 3 billion.'

In the decade since, some things have changed markedly and others have remained unchanged. Agricultural science has changed: research in the disciplines which immediately underpin crop production has waned while more attention has been given to two complementary areas. More attention is now directed to farming systems and particularly to environmental research and resource management, and to more basic fields such as molecular biology. There is thus a broader attack on problems and opportunities of tropical food crops than ten years ago.

While predictions made in 1984 about population growth proved true, few people foresaw the consequences of that growth, the rural poverty which would persist and deepen in parts of the tropics, and the widespread degradation of soil and water which would result from poor management of tropical cropping systems. World population is now predicted to reach 8 billion by 2025 and most models suggest recurrent serious food shortages in tropical countries from 2000. Food shortages will be exacerbated in tropical countries by reduced yield potential in some areas due to global warming and to soil degradation resulting from widespread removal of tropical vegetation and over-cropping.

Further, in developed temperate countries, affluence, concern with 'quality of life' and the environment, and relatively poor economic rewards for farmers, all suggest that tropical countries are going to have to rely on their own crop production to meet their food shortages early in the twenty-first century.

The deepening need for increasing productivity of tropical crops will be met through creating opportunities based on better understanding of the crop environment. This approach remains unchanging. Also unchanging is our definition of the environment: its components are the atmosphere, the soil, the biotic environment, particularly pests and diseases (which we do not report), and the cropping systems of which the individual crop forms a part. Thus, after a decade it is timely to update this book while retaining its original format, as a source of information on the components of the ecology of tropical crops. As in the first edition, we have not reported on deliberate modifications to the environment through agronomic or other practices, nor on unplanned degradation or improvement of the environment as outcomes of cropping. Instead we have chosen to keep this volume of limited size and suggest complementary reading of crop management practices and regional resource assessments.

The book is in four parts. The first is a general account of the three environmental components which we cover, namely cropping systems, climate and soil. This is followed by parts devoted to the most important crops within each of the three broad groups of food crops: cereals, legumes and non-cereal food energy crops.

We are grateful to those who helped us with the first edition and whom we listed in that Preface. In addition, C.J. Asher, R.M. Bourke, E.T. Craswell, D.G. Edwards, M. Hutchinson, R.F. Isbell, A. Koppi, P. New and P.A. Sanchez have helped with this second edition. However, we are responsible for errors of fact, interpretation and judgement.

June 1994

M.J.T.N.
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In tropical developing countries farmers tend to grow a wide range of crops in a small area for subsistence or sale. To make full use of often limited resources a good understanding of how environmental conditions affect the characteristics and performance of these crops is essential. This book considers the response of tropical food crops to environmental factors such as climate, soil and farming system. Three types of crop are considered – cereals, legumes and non-cereal energy crops – with individual chapters on the four most important crops in each group. This material is set in context by introductory chapters on tropical farming systems, tropical climates and tropical soils.

This new, updated edition retains the successful formula of the first edition, and will serve the needs of advanced students of tropical agriculture, as well as professionals engaged in research and extension work in tropical crop production.

The ecology of tropical food crops

CONTENTS

I

GENERAL

1

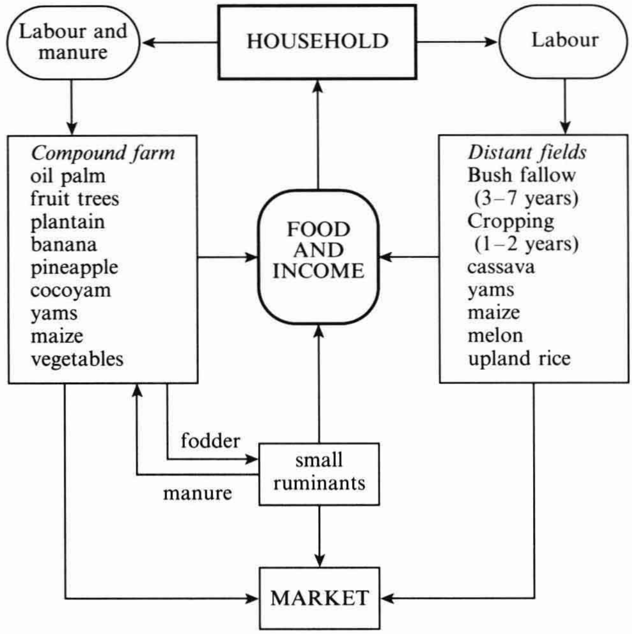
Tropical cropping systems

1.1 Introduction

Food crop systems are communities of plants which are managed to obtain food, profit, satisfaction or, most commonly, a combination of these goals. Conway (1987) encapsulated the goals in the term 'increased social value'. Such systems are purposeful in that farmers (who are part of the system) can set goals and change them even when their atmospheric, soil, technical, economic or social environment may not be changing (Bawden & Ison, 1992). Purposefulness also implies that farmers may pursue the same goals by following different behaviour patterns, either in the same or in different environments. Thus, although the market and physical environments are major constraints on the type of food crops grown, and cause farmers in a specific locality to grow similar mixes of crops, the management of any particular crop — its environment as modified by the farmer — will depend on the goals of that farmer. Figure 1.1 describes a root-crop-based farming system to illustrate the interrelationships between the purpose for which a system is managed and its human, market and physical components.

The individual crop is influenced by the system of which the crop is a component. Thus, the ecological conditions under which an individual crop is grown are determined not only by its atmospheric environment and soil, and the modifications made to this environment by the farmer — through ploughing, weeding, irrigating, applying fertiliser, cutting leaves for livestock, etc. — but also by the preceding crop, particularly if it was a legume. Farmers may elect to grow cassava during a low-fertility phase of their cropping sequence, not because such conditions are favourable to the crop, but because they know that it will yield moderately in the circumstances while other crops would fail. When the farmer plants two crops together in an intercropping pattern, the expectation is that neither will yield as well as it would if grown separately,

Fig. 1.1. A schema representing the components of a traditional mixed root-crop-based farming system in the wetter regions of sub-Saharan Africa. Source: Juo (1989).



but that the combined yield will exceed that from two single crops collectively occupying the same area, and the diversity of product will give greater security of income.

This interdependence of crops within a cropping pattern provides the rationale for those sections in the chapters on individual crops that are concerned with that crop's place in tropical cropping systems. It is appropriate to precede these with a general account of the character of cropping systems in the tropics. Since the food crops covered in the book are all grown as annuals, with the exception of bananas and some cassava, this introductory chapter will be restricted to annual crop systems and to mixed annual/perennial systems in which annuals are a major component.

1.2 Classification of cropping systems

Each of the general texts concerned with tropical farming systems (Grigg, 1974; Manshard, 1974; Norman, 1979; Ruthenberg, 1980) uses different methods of classification and different nomenclature. The difficulties in arriving at a general-purpose farming systems typology which is at the same time rational and useful are discussed by Norman (1979). However, the restriction of this chapter to a particular group — tropical cropping systems of which annual crops (excluding vegetables) are a dominant or important component — makes the task of classification somewhat easier. The main categories here adopted, and given below, are based on those of Norman (1979):

1. Shifting cultivation systems.
2. Semi-intensive rainfed systems.
3. Intensive rainfed systems.
4. Irrigated and flooded systems.
5. Mixed annual/perennial systems.

The first two classes are rainfed cropping systems characterised by a fallow period during which no crop is grown and native or adventive species recolonise the cropped area. These and the third class form a series based on increasing *cultivation frequency*; that is, the duration of the cropping phase as a percentage of the total duration of the cultivation cycle (crop plus fallow). Thus if in a shifting cultivation system the land is on average cropped for 1 year and fallowed for 9 years, cultivation frequency is 10%. The boundary between shifting and semi-intensive cultivation is arbitrarily set at a cultivation frequency of 30%, and that between semi-intensive and intensive cultivation at 70%.

The fourth category has two subclasses: irrigated upland (i.e., non-flooded) systems and flooded or 'wet' rice systems. It is important to recognise that rice is grown under three sets of conditions: as a rainfed upland crop and as a flooded crop (wet rice) that may or may not be irrigated. The global area of non-irrigated wet rice substantially exceeds that of irrigated wet rice.

The fifth category, mixed annual/perennial systems, includes the following three subclasses: systems of annual crops in association with herbaceous perennials or semi-perennials, 'mixed garden' systems, and systems of annual crops in association with perennial tree crops.

1.3 Shifting cultivation systems

The term 'shifting cultivation' describes systems of rainfed cropping with annuals, biennials or short-lived perennials in which a cropping period alternates with a longer rest or fallow period, during which the abandoned crop area is recolonised by native herbaceous, shrub or tree species or by adventive species that find the ecological conditions favourable (Norman, 1979). The limit of cultivation frequency beyond which such cropping patterns are no longer termed 'shifting' is quite arbitrary: 30% (Ruthenberg, 1980) is the figure used here, while the limit for Sanchez (1976) is 50% and for Allan (1965) 10%.

One consistent feature of areas in which shifting cultivation is practised, and when cultivation frequency has become too high for the full re-establishment of forest before the next cropping break, is the development of savanna or scrub vegetation in place of forest. The term 'bush fallow' (Boserup, 1965; Morgan, 1969) is often applied to this type of fallow vegetation and to the cropping systems associated with it, as distinct from 'forest fallow' systems where the fallow break is long enough for trees to re-establish. Allan (1965) and Spencer (1966) carry the categorisation of shifting cultivation systems further. Regional accounts of shifting cultivation systems are given by Allan (1965), Vine (1968), Morgan (1969) and FAO (1974) for Africa; by Spencer (1966) and Kunstadter, Chapman & Sanga Sabhasri (1978) for southeast Asia and by Watters (1971) for Latin America. At this point it is worth noting that shifting cultivators, particularly in wet tropical forests, often gather a significant proportion of their total food supply from wild plants. Powell (1976) lists for New Guinea 251 species used for food: about 20% cultivated, 20% both cultivated and harvested wild, and 60% harvested wild.

The essential principles of shifting cultivation are that, during the fallow phase, nutrients are taken up by the recolonising vegetation and are returned to the surface soil as litter. Nutrients accumulated in the above-ground vegetation are made available to subsequent crops when the vegetation is cut down and burned. Cropping continues until available soil nutrients in the crop root zone decline, through crop uptake and perhaps immobilisation or leaching, to a level that gives an unacceptably low yield. 'Unacceptable' signifies the point at which the cultivator decides that the expected increment in crop yield from abandoning the current site and preparing a new one will repay the additional input of fresh clearing. The decision to abandon a crop area and clear elsewhere may also be influenced by the increased ingress of arable weeds as the cropping phase is extended.

Nutrient cycling in shifting cultivation systems is a complex of processes; major contributions to our understanding have been made by Nye & Greenland (1960) in relation to African conditions and by Sanchez (1976) in relation to Latin America.

During the fallow phase, nutrients are returned to the soil from the vegetation through litter fall, rainwash, timber fall and root decomposition. Litter fall is the most important. Below are given the average annual rates of nutrient return in litter from three African forest sites (Nye & Greenland, 1960):

Dry matter	12.5 t ha^{-1}	K	73 kg ha^{-1}
N	184 kg ha^{-1}	Ca	142 kg ha^{-1}
P	6 kg ha^{-1}	Mg	47 kg ha^{-1}

Under tropical forest, litter decomposition is rapid: 50–500% per year, according to McGinnis & Golley (1967), quoted by Sanchez (1976). Much of the resulting available nutrient store is, of course, subsequently taken up again and recycled through the forest vegetation; the net gain to the cropping system when the land is cleared is largely those nutrients taken up by trees from subsoil layers that would otherwise be unavailable to shallow-rooted annual crops.

When the fallow vegetation is cut down and burned, much of the nitrogen and sulphur is lost to the atmosphere, but other nutrients remain in readily available form in the ash. The figures given below for nutrient addition to the topsoil after burning 17-year-old secondary forest in Peru are from Sanchez (1976):

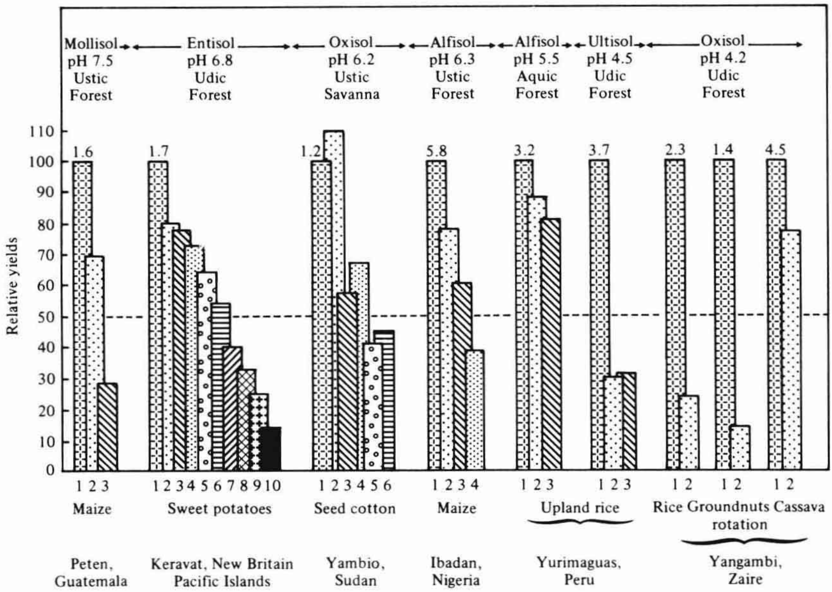
N	67 kg ha^{-1}	Ca	75 kg ha^{-1}
P	6 kg ha^{-1}	Mg	16 kg ha^{-1}
K	38 kg ha^{-1}		

The magnitude of the available nutrient increment depends not only on the amount of nutrients accumulated in the vegetation before burning, which is broadly related to biomass and hence to the duration of the fallow, but also on the efficiency of the burn.

The rate of decline in crop yield as the cropping phase progresses is dependent upon the natural fertility of the soil, on the amount of nutrients available in the ash, and on the nutrient requirements of the crops grown in the sequence. Figure 1.2 summarises some of the more reliable data. The data from Peru illustrate the effect of soil type and those from Zaïre the effect of crop type.

Various cropping tactics have evolved to mitigate the effects on crop production of declining fertility, the recovery of woody vegetation from cut stumps, and the increased incidence of arable weeds as the cropping phase proceeds. It is usual for the most valued crops — cash crops or primary subsistence energy crops — to be grown in the early phases of

Fig. 1.2. Yield decline with continued cropping in shifting cultivation systems. Figures below columns represent years of cropping; figures above columns are yields in t ha^{-1}. Source: Sanchez (1976).



the cropping period, and for legumes to become more prominent in the later phases as available soil nitrogen declines. In the final year before the site is abandoned, it is common to plant crops with one or more of the following characteristics:

1. Tall robust crops able to compete with weeds.
2. Crops capable of yielding moderately well under low fertility.
3. Crops with an extended growing period, including biennials and perennials, that will continue to yield, with little or no attention from the cultivator, during the early part of the fallow phase.
4. Crops planted as a subsistence energy reserve in the case of failure of the primary crop (such crops may never be harvested).

Cassava, for example, has all these characteristics: in a survey of shifting cultivation systems in Zaïre, Miracle (1967) recorded cassava 5 times more frequently as the last crop than as the first crop in forest fallow systems and 11 times more frequently in bush fallow systems.

It is a common generalisation that cropping patterns in shifting cultivation are characterised by a very complex and irregular array of crop species grown in a single cleared area. This is only true of cropping in lowland forest in areas of favourable soil water regime. With increasing limitation to the environment, e.g., a shorter growing season, lower fertility, or lower temperature determined by altitude, diversity is reduced.

Where mixed cropping is practised, the exploitation of micro-environments within the cleared area by crops with specific requirements or tolerances is ingenious. Thus shade-tolerant species are planted on the shady margin of the plot, moisture-demanding species at the bottom of sloping sites, fertility-demanding species on localised ash concentrations or on hoed-up mounds of topsoil, and climbing species against unfelled tree trunks or beside rigid upright crops.

1.4 Semi-intensive and intensive rainfed systems

In Section 1.3, reference was made to the complex and irregular time and space pattern of crops in a single clearing that is characteristic of shifting cultivation in favourable environments. Such patterns may be described by the general phrase 'mixed cropping', signifying any situation where more than one crop is grown on a given land area at any one time. As will be seen in Section 1.4.2, the transition from shifting cultivation to more intensive cropping is associated with the emergence of more regular cropping patterns. In order to be able to discuss these, some definitions are given below; for a more complete list of terms relating to cropping systems, see IRRI (1984).

Intercropping. More than one crop on a given area at one time arranged in a geometric pattern. A typical pattern in India might be two rows of sorghum alternating with one row of pigeon pea.

Relay cropping. A form of intercropping where not all the crops are planted at the same time. A typical Indonesian example is rice and maize planted together and cassava interplanted a month or so later.

Sequential cropping. More than one crop (or intercrop) on a given area in the same year, the second crop being planted after the first is harvested.

Cropping index. The number of successive crops grown on the same land each year.

Land Equivalent Ratio (LER). The ratio of the area needed under sole cropping to the one under intercropping to give equal amounts of yield at the same management level.

Useful regional accounts of semi-intensive and intensive rainfed cropping systems are given by Harwood & Price (1976) for Asia, Okigbo &