Improving Cash Crops in Africa

Factors Influencing the Productivity of Cotton, Coffee, and Tea Grown by Smallholders

Stephen J. Carr
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Improving Cash Crops in Africa

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Library of Congress Cataloging-in-Publication Data

Carr, Stephen.

Improving cash crops in Africa : factors influencing the productivity of cotton, coffee, and tea grown by smallholders / Stephen J. Carr.

p. cm. — (World Bank technical paper, ISSN 0253-7494 ; no. 216)

Includes bibliographical references.

ISBN 0-8213-2509-4


I. Title. II. Series.

HD9017.S82C37 1993

338.1'0967—dc20 93-5127
ABSTRACT

This study draws together information on the technology available to small-scale farmers in Africa for the production of cotton, coffee and tea. It records the wide variation in the national average yields of these crops, as well as the differences in productivity that exist between smallholders and commercial growers in the same country.

A recurring theme in the paper is that, unlike food crops, which have to be produced for survival irrespective of government interventions, yields of these cash crops are heavily dependent upon government policies and management capacity. These range from the restriction of the growing of cotton to the most favored areas in one country as compared to its encouragement in depressed marginal areas in another, to taxation, exchange rate, subsidy and input-supply policies. Technology suited to the needs of the small-scale farmer has been well developed for these crops and, although labor constraints account for the lack of adoption of some of the yield-enhancing practices, it is often inimical government strategies or failures in public-sector management that have removed the incentives for their uptake. One conclusion of the study is that any projects intended to encourage increased efficiency of production or greater yields per unit of land should first focus on whether there are policy changes that must precede the wider uptake of the available intensifying technology.

The paper has been produced as a "ready-reference" work for agriculturalists and economists responsible for planning, executing or supervising activities relating to these crops in Sub-Saharan Africa. It covers the influence of planting material, agronomic practices and purchased inputs on yields, and details some of the constraints that inhibit their use. It highlights the impact that research has had on providing the means for raising productivity but also points out that extension staff must be prepared to look at the entire family-farming operation, as well as its constraints and goals, if farmers are to receive appropriate and applicable advice on these specific crops, rather than exhortations to adopt theoretically sound but unachievable strategies.
ACKNOWLEDGMENTS

The author wishes to thank Jock Anderson for his role in suggesting the writing of this paper and for his detailed editorial work, which greatly benefited its presentation, and Corazon Solomon for sympathetic assistance and patient word processing. He also wishes to acknowledge his thanks to Robert Christiansen, Jacob Kampen, Gert Stern and Nicholas Wallis for their helpful remarks, without implicating them for any remaining shortcomings of the work.
FOREWORD

The problems of stagnation in many agricultural sectors of Sub-Saharan Africa, at least relative to those of much of the rest of the world, persist and the potential role of improved agricultural technology in ameliorating such problems remains imperative. Progress will not be easy, however, because of the multitude of economic and social constraints that impede technological progress in this part of the world. In seeking to forge new productivity gains in Africa, we need to be conscious of such constraints, and it is to this end that the present work is directed.

Following on the success of Steven Carr’s previous World Bank Technical Paper No. 109 (Technology for Small-Scale Farmers in Sub-Saharan Africa), we asked him to take some time out from his retirement in Malawi to bring his considerable experience and expertise to bear on three of the "cash" crops important in many countries of Sub-Saharan Africa. We were assisted in this process by the Special Program for Agricultural Research in Africa (SPAAR).

Due to the extensive and valuable personal experience of Mr. Carr in the area of plantation crops, we have decided to publish this material with the intention of providing a unique "best practice synthesis," recognizing that the reference section is somewhat slim, especially as regards the Francophone experience with robusta coffee and cotton. In making this work available, we are hopeful that it will be in a form that makes its use convenient for a variety of development professionals, including both agriculturalists, perhaps less experienced with these crops in Africa, and economists and planners, who may not have direct operational experience with them in an African context.

Many challenges remain for further technical progress in nearly all Africa’s crops and these are being urgently addressed through various contemporary activities, including a considerable portion of the efforts of the research institutes of the expanded CGIAR, and the important initiatives being coordinated under the umbrella of SPAAR.

Michel Petit
Director
Agriculture & Natural Resources Dept.
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INTRODUCTION

This paper is a sequel to an earlier publication that reviewed the availability of applicable technology for food crop production by small-scale farmers in Africa (World Bank Technical Paper Number 109). It is intended to provide a brief account of technology available for improving the productivity on farms producing cotton, coffee and tea. This is combined with analysis of the constraints that have limited farmer uptake of some of the available innovations. It is hoped that what is a synthesis of predominantly anglophone African experience will provide a useful guide to those who have to make decisions relating to the development of these crops but who do not have the benefit of field experience with their production by smallholders in Africa. Unlike the paper on food crops, this study does not specifically draw on the experience of recent World Bank projects. This is because the latest Bank investments in coffee and tea have been almost entirely confined to processing and marketing, and not to field production. In the case of cotton there has been some investment on the production side but it has been confined to a narrow geographical region and one particular approach (namely, specialized, vertically-integrated private-sector development), which does not provide a balanced picture of the broad spectrum of conditions under which cotton is produced by smallholders. The focus on the African farm in this paper is not to deny the profound importance of improved technologies beyond the farm in processing and marketing. These are matters for another occasion.

Coffee and cotton are Africa’s most important export crops, providing a cash income for millions of smallholder families. The scale and intensity of their production varies widely but, in most situations, there has been a long tradition of research that has provided appropriate technical recommendations. Tea is a minor crop in continental terms but has been important in helping groups of farmers in areas that are poorly suited to other crops. It also offers an example of how a combination of good research, good extension and good organization has provided a quite new source of income for tens of thousands of smallholders and the major export for a country (Kenya).

<table>
<thead>
<tr>
<th>Product</th>
<th>Area 1,000 ha</th>
<th>Value $ million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>3,636</td>
<td>1,104.4</td>
</tr>
<tr>
<td>Coffee</td>
<td>3,728</td>
<td>2,513.6</td>
</tr>
<tr>
<td>Tea</td>
<td>176</td>
<td>319.2</td>
</tr>
</tbody>
</table>

Source: FAO Trade and Production Yearbooks, 1988
There are two major differences between smallholder food-crop and export-crop production that need to be taken into account when considering crop development strategies. These both arise from the fact that smallholders in Africa have to grow food crops for survival, whilst they are not under the same pressure to grow export crops. The first consequence of this situation is that there are large areas in Africa where the constraint on increasing productivity of the staple foods is ecological. This can take the form of poor or acid soils, or scant or erratic rainfall. At present there is little truly applicable technology available to deal with the soil fertility problems of the wet tropics or with increasing the productivity of Africa's main grains (sorghum and millet) in semi-arid areas. The planting of the major tree crops for export and, to a lesser extent, of cotton is largely confined to areas well suited to their growth. This situation is quite easily achieved through the siting of marketing and processing facilities. Under these conditions the constraint on productivity is less likely to be ecological. Well developed technologies suited to smallholders are available, and many such farmers have achieved yields comparable to those of commercial estates. This leads into the second major difference between basic food crops and export commodities. Food production will continue almost regardless of government policies. The past 25 years have provided abundant examples of small-scale farmers continuing to feed their families under conditions of financial turmoil and wide fluctuations in government policy. The situation with major export crops is quite different. Total output and yield levels are heavily dependent on government policies and strategies. This is true not only in the actual sphere of agricultural production but in relation to policies on exchange rates, the management of the processing and transport industries and the retailing of consumer goods. Uganda in the 1970s provides a good example of this situation. During that decade food production was maintained and was reflected in lowered child mortality and increased life expectancy. Export crop production, on the other hand, suffered greatly. Tea sales stopped almost completely at a time of particularly attractive international prices and cotton production dropped to less than 10 percent of its level at the start of the decade. Uganda in a few years changed from being the largest exporter of medium staple cotton in Africa to a situation in which it was unable to satisfy the demand of local spinning mills. These changes were unrelated to technical factors of production or international terms of trade and were solely the outcome of a breakdown of the rule of law and the consequent collapse of the marketing system.

Uganda may seem an extreme and atypical case of the impact of government policy on export crop production but, in fact, there are plenty of examples from other, less traumatic situations. In Tanzania between 1975 and 1985 there was a steady erosion of the price differential between cotton and competing crops, and production of cotton declined dramatically. When this situation was reversed, cotton production reached its previous peak level, but national transport policies were such that the crop could not be moved quickly and so farmers had difficulty in selling their cotton, and production again fell sharply. Even in francophone West Africa, in which there has been a common strategy for intensifying and expanding cotton production and, in many cases, a single development agency (CFDT), there have still been wide disparities in policy with regard to input subsidies and price support. This is clearly reflected in the price paid to farmers for seed cotton in different countries, as illustrated for one indicative season in the following table.
Net price Paid to Farmers for Seed Cotton after Deduction of Input Costs in Various Francophone African Countries

(FCFA per kg 1985/86 season)

<table>
<thead>
<tr>
<th>Country</th>
<th>Benin</th>
<th>Burkina</th>
<th>Cameroon</th>
<th>Mali</th>
<th>R.C.A.</th>
<th>R.C.I.</th>
<th>Senegal</th>
<th>Chad</th>
<th>Togo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>203</td>
<td>188</td>
<td>321</td>
<td>147</td>
<td>166</td>
<td>198</td>
<td>256</td>
<td>158</td>
<td>194</td>
</tr>
</tbody>
</table>

Part of the variation stemmed from transport costs but most of it derived from subsidy policies that provided farmers with quite different levels of incentive and this led to diverse farm practices.

Yield levels of the three crops under review are heavily dependent on the use of purchased inputs, and government policies and interventions have a major impact on their uptake. Long-delayed payments to coffee farmers in Kenya have resulted in reduced input use and a marked decline in average yields. High cotton yields are only possible with effective insect control. In Zimbabwe, government policy has stabilized the ratio between seed cotton prices and insecticide costs for a number of years so that a Zimbabwean smallholder has had to produce about 100 kg of seed cotton to pay for a tail boom spray pack for 0.5 ha. In Tanzania, on the other hand, high marketing costs and inefficient procurement procedures have led to a situation in which farmers in the 1988/89 season had to produce 207 kg of seed cotton to purchase a 0.5 ha spray pack as compared to 87 kg ten years earlier. Not surprisingly, there is much greater use of insecticides on cotton in Zimbabwe.

Whilst the main purpose in this paper is to focus on the technical aspects of increasing farm productivity of cotton, coffee and tea, these must be viewed in the context of government policies and performance to a far greater degree than is the case with staple food crops. There are technical matters requiring further research but, in many cases, production increases will be most readily achieved through changes in the policies and strategies of governments aimed at removing the constraints that prevent smallholders from making use of the technology already available.

**SUMMARY OF MAIN FINDINGS BY COMMODITY**

The paper consists of three main sections covering the crops under review and a final brief chapter on some priorities for research and extension.
Cotton

This crop differs considerably from the other two covered in this paper because it is an annual and because it can be grown in areas of comparatively low rainfall. The area under the crop can, therefore, fluctuate greatly between seasons in response to government policies. The crop's ability to produce some harvest under marginal conditions can lead to a conflict of interest between the welfare of resource-poor families and a marketing authority that focuses on efficiency. High cotton yields are dependent on the effective use of insecticides to control insect pests. A cotton authority may choose to focus its efforts on selected ecological areas and comparatively resource-rich families so as to ensure a good return to investments in inputs and guarantee high overall average yields. Such a strategy penalizes families situated in areas in which cotton is the only possible cash crop but in which the use of high-cost inputs is too risky. It also militates against resource-poor families, whose labor constraints result in a crop that cannot justify high input use. Any comparison of overall yields between different countries needs to take into account whether the crop is confined to the most efficient producers to serve the policies of an authority or whether it is perceived as a means of also providing a low-input and low-output cash crop for disadvantaged families and communities. Other strategies may also merit consideration, such as an authority providing some services (such as seed distribution and seed cotton purchase) in less-favored areas.

Cotton is mostly grown in areas with a short monomodal rainy season and, in consequence, there are often crucial clashes in labor demand at planting and weeding between it and the staple food crops. The priority given to different crops will depend upon a family's perception of the trustworthiness of the marketing systems for both cotton and staple food. Where there is little trust, food crops will be given priority and cotton yields will suffer. Where there is strong trust (e.g., Zimbabwe), farmers may give priority to cotton because of its greater tolerance of erratic rainfall.

Coffee

The two main commercial coffee crops grown in Africa are Robusta and Arabica. The technology for producing high yields of both is well developed, but smallholder yields often fall well below the farm-level potential for a given area. The actual reasons for this differ between the two crops, but the causes can be traced to government policies.

In the case of Robusta, which grows in humid tropical areas, high yields can be achieved by growing the crop in pure stand without shade but with regular weed control and heavy mulching. Many farmers have lost trust in the marketing system, have faced delayed payments or have had to compete for labor with a more profitable crop (e.g., cocoa). In consequence they have adopted a technology of growing the crop interplanted with bananas or in forest shade. This reduces the burden of weeding and mulching and, in the case of interplanting, guarantees an alternative crop if the marketing system for coffee falters. It also results in comparatively low yields. The adoption of available technology to increase yields
will depend on fostering long-term confidence in the pricing and marketing system to induce farmers to adopt an equally long-term strategy involving greatly increased labor input.

Arabica coffee is grown in the highland areas of Africa and the achievement of high yields is much more dependent than Robusta on the use of purchased inputs for the effective control of pests and diseases to which the crop is prone. The use of such inputs can only be justified on a well-maintained garden, and so farmers need the incentive to invest both labor and cash into the crop. When government policies have provided such incentives, smallholder yields have compared favorably with those of commercial farmers under similar conditions. All too often, however, delayed crop payments, high levels of taxation and inefficient input distribution have limited the incentives and, in consequence, the yields.

Tea

Tea is an unusual crop for three reasons. First, it can grow on acid soils in cool moist areas that are poorly suited to most other crops. It has, therefore, been used to bring development to previously poor and neglected areas. Second, it has a productive life of over a hundred years and the level of productivity can be greatly influenced by early management. Sound technical advice at the time of establishment is of much greater importance for tea than for most other crops. Patchy establishment, poor soil conservation and improper early shaping of tea bushes are faults that are extremely difficult to rectify after the establishment of the crop, and yet influence yields for a century. Third, tea requires harvesting many times per year and the main labour requirement is for the actual plucking of the crop. Once the crop is well established, a tea authority's most effective role in stimulating high yields is to provide a collection system that maximizes plucking opportunity for farmers and a payment system that provides the incentive to persist with the almost daily harvesting of the crop. Government policies can affect plucking efficiency to the degree to which they favor the free movement of labor from one area to another.

Tea yields have increased dramatically in recent years and many smallholders today achieve yields unthought of on commercial estates 30 years ago. There are still technical problems with weed control on smallholder plots but, in general, the constraints on production are more dependent on the quality of services and incentives provided to farmers than on the availability of suitable technology.

SUMMARY OF PRIORITIES FOR EXTENSION AND RESEARCH

This section highlights the urgent need for an extension service that responds to farmers' actual constraints rather than providing exhortations to adopt ideal practices. A number of the constraints on the three crops under review can only be overcome by adjustments in other parts of the cropping system, and extension staff need to be trained to look beyond the confines of a single enterprise. Examples of specific constraints are given, together with possible lines of action. Research for these crops has produced much valuable
work but there are unsolved problems, in particular, the challenge of offering farmers less expensive and less hazardous methods of controlling pests and diseases. The section briefly outlines several of these research priorities.
Chapter I

COTTON

Cotton is grown across a wide range of ecological zones from the edges of Lake Victoria to the borders of the Sahara desert. This is one reason for the wide disparity in average yields between countries. It is the most drought-tolerant of the major export crops grown by smallholders in Africa and for this reason is frequently the cash crop of last resort for farmers in difficult agricultural areas. This wide level of adaptation has frequently led to clashes of interest between productivity and social-welfare objectives. Cotton growing in marginal areas provides farmers with increased security because total failure of the cotton crop is rarer than that of companion food crops. At the same time the low yields obtained under such circumstances may be unacceptable to a cotton authority aiming at increasing the efficiency of a vertically integrated industry. These are much greater than in the case of the major food crops, as shown in Table 1.

Table 3. Comparison Between National Average Yields of Cotton and Associated Food Crops in Selected Major Producing Countries for the 1987/88 Season (yields in kg/ha)

<table>
<thead>
<tr>
<th></th>
<th>Cotton (Lint)</th>
<th>Maize</th>
<th>Sorghum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burkina Faso</td>
<td>398</td>
<td>819</td>
<td>779</td>
</tr>
<tr>
<td>Tanzania</td>
<td>191</td>
<td>1,360</td>
<td>817</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>445</td>
<td>1,733</td>
<td>800</td>
</tr>
<tr>
<td>Uganda</td>
<td>114</td>
<td>1,082</td>
<td>1,452</td>
</tr>
<tr>
<td>Nigeria</td>
<td>60</td>
<td>2,143</td>
<td>1,098</td>
</tr>
<tr>
<td>Cameroon</td>
<td>476</td>
<td>844</td>
<td>-</td>
</tr>
<tr>
<td>Côte D’Ivoire</td>
<td>631</td>
<td>701</td>
<td>632</td>
</tr>
<tr>
<td>Mali</td>
<td>503</td>
<td>1,851</td>
<td>-</td>
</tr>
</tbody>
</table>

Sources: Bell and Gillham (1989) and FAO (1988).

Two factors need to be taken into consideration when comparing national yield averages. The first concerns policy. In some countries cotton production is encouraged in marginal areas as a means of providing added income and security. Elsewhere such areas are excluded by the denial of marketing facilities. In one country resource-poor families are excluded from cotton growing by the refusal of access to seeds and production inputs. In
another the policy may be to encourage as wide a participation in cotton growing as possible by the issue of free seed to all applicants. Overall yields will naturally be different in a community in which only the 30 percent of population who have the necessary resources become cotton growers by comparison with one in which 90 percent grow the crop. At the same time, one country may have access to resources, which allows for the adjustment of prices to make high-input use attractive at the cost of heavy losses to the government. Another may expose its growers to the full impact of changes in terms of trade that, in turn, may make input use unattractive. The second factor is ecological. Yields of cotton can vary greatly between seasons and between ecological zones. Interseasonal differences in smallholder yields of up to 400 kg/ha seed cotton can occur in areas of erratic rainfall. Differences between ecological zones are illustrated from Burkina Faso in Table 2.

Table 2. Geographical Distribution of Yields in Burkina Faso
1985/86 Season (kg/ha seed cotton)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hauts Bassins</td>
<td>1,414</td>
</tr>
<tr>
<td>Mouhoun</td>
<td>1,287</td>
</tr>
<tr>
<td>AVV</td>
<td>1,048</td>
</tr>
<tr>
<td>Comoe</td>
<td>929</td>
</tr>
<tr>
<td>Centre</td>
<td>341</td>
</tr>
</tbody>
</table>

Source: World Bank Sahelian Department files

Simple comparisons between national averages, which do not take these factors into account, can lead to mistaken conclusions.

At the same time, there are also great differences in yield between farmers in comparable ecological zones. Again these tend to be wider than those of the dominant staples in many major producing areas. One reason for this is that insect pests are a major hazard in cotton growing and yields are largely determined by the adequacy of chemical control. Cowpeas offer the only comparable situation amongst the major African food crops and there are equally large differences between yields of effectively sprayed and unsprayed fields. There are consequently quite clearly defined groups of cotton farmers using high, medium and low levels of purchased inputs. These, in turn, have to be linked with comparable levels of labor use, which result in smallholder yields of seed cotton that vary between 200 and 1600 kg/ha. The balance between the number of farmers in each of these three categories in a given country determines the national yield per unit of land. This balance is in part related to national policies and institutional efficiency but may also result from deliberate farmer decision making in situations in which low yields per unit of land represent the best use of resources, so that low yields may be the result of good farm management. In the following sections, the major factors
influencing cotton yields are reviewed and the technical reasons as to why farmers achieve such widely differing output per unit of land planted to cotton are discussed.

NATURAL FACTORS

Climate

Cotton is a crop that thrives under quite high temperatures. The optimum for germination and early seedling growth is 34°C. As growth proceeds, the plant is most productive with a daytime temperature of 33°C and a night temperature of 28°C. Low night temperatures foster fungal diseases whilst long periods of cloudiness lead to increased boll shedding. As a result of these factors, a farmer in the hot, sunny Luangwa Valley of Zambia will obtain substantially higher yields than a farmer in the cooler, cloudier areas of Uganda when both use the same level of management.

Cotton is tolerant of drought and produces a crop under conditions of poor and erratic rainfall. To achieve good yields, however, requires well-distributed rain over a period of five months with a peak requirement from the 10th to 20th week after planting. The total requirement obviously depends upon levels of evapotranspiration and soil type but, as a general rule of thumb, the total effective rainfall over the growing period should not be less than 650 mm. Care needs to be taken in comparing cotton yields between regions to ensure that due weight is given to the impact of variations in moisture availability on yields. In the Kadoma area of Zimbabwe, experienced smallholder cotton growers averaged 900 kg/ha in the 1988/89 season but only an estimated 500 kg/ha in the 1989/90 season, because of differences in rainfall between the two years. Similarly, the considerable difference between the national averages of Burkina Faso and Côte d'Ivoire needs to be reviewed in the light of variations in rainfall reliability as not only in terms of farm-level technology and institutional management.

Soils

Cotton is tolerant of a wide range of soil types but soil quality can have a major impact on yields in two important and quite distinctive ways. The first concerns soil acidity. Soils that are sandy and continuously cultivated in areas where there is an excess of precipitation over evaporation for some period of the year will become increasingly acid. This in turn will inhibit the growth of cotton irrespective of management or fertilizer use. A good example of this is provided in the densely populated area of granitic sands of the Mwanza area of Tanzania. This used to be farmed on the basis of three years fallow and three years cropping. Population pressure has eliminated the fallow and, under continuous cultivation since the 1940s, the soil has become increasingly acid and cotton yields have fallen sharply. Table 3 gives data from Ukuriguru Research Station situated in this area, which demonstrate the decline in the yields of seed cotton on continuously cultivated plots even though treated with fertilizers and sprays. Yields were rapidly restored by liming,
which offsets the soil acidity, but this is not a practicable strategy for smallholders because of the large quantities required and the absence of significant deposits in the region.

Table 3. Five-Year Average Yields of Seed Cotton from Continuously Cultivated Plots on Ukiriguru Research Station (kg/ha)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>787</td>
<td>392</td>
<td>288</td>
<td>397</td>
<td>188</td>
</tr>
</tbody>
</table>

Source: Annual Reports of the Station.

The application of some nitrogenous fertilizers tends to increase the acidity slightly and further depress yields. Under these circumstances, the use of insecticides becomes uneconomic. In consequence, cotton growing has declined in this area and has moved to soils with a higher inherent pH. At present there are no viable technical alternatives that would enable farmers to achieve high yields of cotton on these leached acid sands. Although this is not a common situation in Africa, it is one that could be repeated elsewhere on comparable soils as population pressure leads to continuous cultivation over long periods.

The second soil condition that can have a major influence on yields is quite different. This involves heavy cracking clays that can only be worked for a short period after being wetted. Before the rains begin they are too hard to plough with oxen. After heavy rain they are too sticky. With an extremely narrow planting "window," farmers in land-plentiful areas aim to plant as large an area as possible in a short period. On the plains of Shinyanga in Tanzania they do this by broadcasting seed onto the bare ground and then assembling as many ox teams as the family can muster and ploughing in the seed. In this way, they are able to establish large areas of poorly spaced plants in the two or three planting days available. Using the recommended method of careful hand planting in lines would result in greatly reduced areas under the crop. Because the plants are scattered they cannot be mechanically weeded and there is a minimum of hand weeding. Yields per unit area of land (which is not in short supply) are low but yields per unit of labor are high. This is a classical case of poor husbandry being good farming. Extension services have concentrated on trying to convince farmers to adopt much more intensive methods that result in greatly reduced returns to labor, rather than on improving on the existing extensive system. As population pressure increases in a number of areas in Africa, there will be a growing interest in these more difficult heavy clay soils. The development of ox-drawn drills for direct seeding into uncultivated soil (along the lines already available for tractors) combined with appropriate ox-drawn weeding equipment would enable farmers to make fuller use of these areas of high yield potential.
AGRONOMIC PRACTICES

As with any annual crop, farmers can take a number of managerial decisions that can have a profound impact on crop yields. With most crops, this includes the choice of planting material, but cotton farmers are usually issued with seed and have no control over this aspect of production. This section will, therefore, focus on the farming practices that are the main determinants of yield and over which the farmer has some control.

FARMING PRACTICES WITH THE GREATEST IMPACT ON YIELDS

Time of Planting

In cotton-growing areas with monomodal patterns of rainfall and a five-month wet season, the optimum planting time for cotton is as early as possible after the rains have broken. The penalty for delaying planting under such conditions is heavy, as is shown by the following examples from Northern Nigeria and Zimbabwe.

Table 4. Yields of Cotton Expressed as Percentages of the Yield from Sowing at the Optimum Time for Northern Nigeria and Zimbabwe

<table>
<thead>
<tr>
<th>Delay in weeks after optimum date</th>
<th>Northern Nigeria</th>
<th>Northern Nigeria</th>
<th>Zimbabwe Gatooma</th>
<th>Zimbabwe Sinoia</th>
<th>Zimbabwe Glendale</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>92</td>
<td>95</td>
<td>89</td>
<td>82</td>
<td>91</td>
</tr>
<tr>
<td>4</td>
<td>67</td>
<td>56</td>
<td>69</td>
<td>58</td>
<td>77</td>
</tr>
<tr>
<td>6</td>
<td>54</td>
<td>8</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* a/ Average for three years.
* b/ Example from a single year.

Source: Northern Nigeria Empire Cotton Growing Corporation *Progress Reports*
Zimbabwe *Annual Report* of the Cotton Research Institute, 1980/81.

Under these circumstances a month to six weeks delay in planting reduces the yield potential on a farmer’s field to the point where a full program of insect control is not financially attractive so that yield losses from late planting are compounded by increased insect damage.
The overall yield differences between early and late planted cotton are, in fact, greater than those reflected in the research results recorded above, in which all the cotton was sprayed.

In areas with bimodal patterns of rainfall, which are found in the main cotton-growing areas of Uganda, Kenya and Tanzania, the situation is not as clearcut and there have been fluctuations in advice over time as to the best planting date. A good example of this comes from N.E. Uganda, which, until the early 1970s, was the most important rainfed cotton-growing area in Sub-Saharan Africa. For 30 years, the recommended planting date for cotton was mid-June. In the 1950s, experiments were initiated with much earlier planting dates, which apparently indicated that late April to early May was the best time to plant, and extension advice was modified accordingly. Unfortunately, the experiments did not copy the conditions on farmers’ fields and the late-planted plots suffered from leaching and a build-up of pests that were not typical of actual farming conditions. In 1970 the weaknesses of the experimental design were appreciated and corrected with a striking impact on yields. This is detailed in Table 5 and this gives some indication of the problems of identifying the optimal planting date in a bimodal rainfall area, whilst providing a salutary lesson regarding experimental design.

Table 5. Yields of Cotton from Different Dates of Planting at Ngetta, Uganda, 1966-70
(Yields in lbs of seed cotton per acre)

<table>
<thead>
<tr>
<th></th>
<th>March</th>
<th>April</th>
<th>Early May</th>
<th>Late May</th>
<th>Early June</th>
<th>Late June</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>-</td>
<td>720</td>
<td>1,000</td>
<td>300</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>1967</td>
<td>-</td>
<td>600</td>
<td>300</td>
<td>80</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>1968</td>
<td>-</td>
<td>1,300</td>
<td>1,600</td>
<td>1,300</td>
<td>1,200</td>
<td>400</td>
</tr>
<tr>
<td>1969</td>
<td>1,000</td>
<td>750</td>
<td>650</td>
<td>200</td>
<td>170</td>
<td>100</td>
</tr>
<tr>
<td>1970</td>
<td>-</td>
<td>1,000</td>
<td>1,200</td>
<td>1,200</td>
<td>1,600</td>
<td>1,800</td>
</tr>
</tbody>
</table>
(modified trial)

Source: CGC (1975).

Despite these well-known losses, many smallholders plant their cotton well after the optimal time and suffer severe yield losses as a result. The reasons for this can be divided into two broad categories, managerial and institutional.

The managerial constraint arises from two causes. The first is that, in areas where soils are too hard to cultivate prior to the rains and land preparation is by hand or by hired ox teams, there are inevitable delays in the planting of all crops. The length of the delay is directly related to the resources of the family so that the richest can plant earliest. The fact
that some families achieve early planting and high yields in a particular community does not mean that all others can emulate them, and the wide variations in yield between families in a homogeneous area will be a reflection of access to labor and draft power as well as to skill and initiative. The second arises when the early weeding of a staple food crop clashes with the best planting time for cotton. Again, resource-rich farmers can overcome the bottleneck whilst resource-poor households have to delay cotton planting.

The institutional constraint concerns the degree of trust that farmers have in the cotton marketing arrangements and in the reliability of the food market. Examples of this can be drawn from Zimbabwe and Tanzania. In both these countries at least part of the cotton crop is grown in areas in which it is more dependable than maize under conditions of erratic rainfall. In Zimbabwe, farmers believe that they will be paid promptly for their cotton and that, with the money they receive, they will always be able to purchase food. In consequence cotton is given priority over maize and is planted with the first rains. In Tanzania, farmers have lost confidence in the efficiency of the cotton and maize marketing arrangements and can often only buy food at inflated prices. In consequence, food crops are given priority and this is one reason for the striking difference in yield between the two countries.

Timely planting is a critical factor in raising smallholder cotton yields. The actions that need to be taken to improve on the performance of the late planters may lie outside the immediate realm of cotton growing. They could include quicker maturing varieties of the staple food crops, credit for ox cultivators and planters for grain crops, guaranteed timely payment for the cotton crop and the encouragement of a trustworthy food supply market. Millions of hours have been spent by extension staff in Africa exhorting farmers to plant their cotton on time. This effort would have been much more fruitfully used in analyzing the details of farmers’ constraints and devising strategies by which they could be overcome.

There are situations in which late planting and low yields can represent good farming practice. When Uganda was Africa’s major cotton producer, large areas of cotton were planted some three months after the optimum date and gave seed cotton yields of about 150 kg/ha. This was strongly criticized by extension staff. In fact, farmers had to carry out an “autumn” ploughing of fallow land to bring it back into a suitable seedbed for the finger millet crop that was to be planted in the following “spring.” By dropping cotton seeds into the furrow during this operation, farmers obtained a gratuitous benefit of a small cotton crop to which no other labor was allocated until the children picked it during their holidays and thereby paid for their next year’s school fees. Tens of thousands of hectares were planted in this way. Another case of bad agronomy being good farming, but one that had an adverse impact on overall national cotton yields whilst constituting good risk management.

Weeding

Cotton is a slow starter and offers little competition to weeds in the early stages of development. For the same reason, it is susceptible to weed competition in its first two months and requires protection from that competition if yields are not to be seriously reduced. For farmers aiming at high yields with the use of purchased inputs, weeding requires more labor than any other task. Where this has to be carried out by hand, it is often
the main constraint on expanding the size of the family cotton plot. Various schemes in Africa for mechanized land preparation failed to achieve their goal of increasing the size of cotton plots because they did not address the major labor bottleneck of weeding. Survey data from Uganda and Zimbabwe provide estimates of between 34 and 48 percent of total labor being allocated to weeding for a crop in which land preparation was carried out with oxen. This demand for labor coincides with the weeding of food crops when cotton is planted on time, and can produce serious clashes in labor demand for resource-poor families. Farmers then face a choice of delaying cotton planting so as to stagger the work load of weeding or of delaying the weeding of cotton while they tend their food crops. Both strategies lead to yield losses. Herbicides offer one obvious technical solution to this challenge but foreign exchange shortages, poor delivery systems, unattractive benefit-cost ratios and weak extension have severely limited their use. Ox drawn weeders are another alternative and can lead to an 80 percent reduction in labor requirement (Okai 1963). Inter-row cultivation is only possible where there has been accurate row spacing and in a number of areas the desire to speed up planting leads to stands unsuitable for inter-row mechanical weeding. Farmers need help to devise methods of planting quickly in well-spaced rows, combined with demonstrations of the more exacting skill of inter-row cultivation. Good work has been done in this respect in francophone Africa but the cost of the equipment developed is becoming increasingly unattractive with the long-term decline in real cotton prices and simpler methods using cheaper tools are called for.

The loss of crop resulting from sub-optimal weeding depends upon the level of weed challenge and the availability of moisture to supply both weeds and cotton with adequate water for normal growth. Generalized figures are, therefore, of little use. An illustrative example in Table 6 from an early Nigerian experiment indicates the order of magnitude of the losses that can occur when weeding is delayed or omitted.

Table 6. A Nigerian Example of Yields of Seed Cotton Under Different Weeding Regimens

<table>
<thead>
<tr>
<th>Number of weedings</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield (kg/ha)</td>
<td>73</td>
<td>249</td>
<td>401</td>
<td>549</td>
<td>559</td>
</tr>
</tbody>
</table>

Source: Prentice (1972, p. 171).

Yield losses of 50 percent as a result of inadequate weed control are not uncommon. It is the combined impact of late planting and inadequate weeding that make it unattractive for resource-poor households to invest in purchased inputs for the cotton crop, and consequently lead to the extremes of yield found in areas where a cotton authority does not exclude such families from cotton production.
Strategies to assist farmers to overcome the weeding problem may be unrelated to the cotton crop itself, but may be focused on changes in labor demand in other parts of the farm. In Uganda a switch from finger millet to maize led to a large reduction in labor demand for the weeding of the staple grain crop and a consequent freeing of labor for other tasks. In Northern Nigeria, much of the low-input cotton is grown in mixed stands with food crops so that both can be weeded simultaneously. A switch to a quicker maturing grain could enable farmers to stagger their planting and, therefore, take the extreme pressure off the weeding labor peak. Because such strategies have frequently not been developed, resource-poor farmers have been unable to break out of a low-input, low-output pattern of cotton production.

Insect Pest Control

Cotton is subject to a wide range of pest attacks and in the absence of control measures, yields of seed cotton are unlikely to exceed 650 kg/ha. This was a typical figure for the American cotton industry in the 1930s and it was doubled with the introduction of effective chemical insecticides. One of the major contributing factors in the large difference that exists between national yields in Tanzania and Cameroon is that in the former only 10 percent of the crop is sprayed whilst the figure for the latter is over 90 percent. This paper will not provide a detailed review of cotton pests, a field long-since well covered by Pearson (1958), but will focus on those factors that influence both the uptake and the efficiency of insecticide use by smallholders.

Cost and Returns

There are wide inter-country differences in the relative producer price of seed cotton and the cost of insecticides. These depend on the level of input and output subsidies, the efficiency of the procurement and marketing systems, and the degree and type of pest challenge, amongst other factors. In Zimbabwe for both the 1987/88 and 1988/89 seasons, a farmer had to produce 234 kg of seed cotton to pay for sufficient insecticide to spray 1 ha. In Tanzania the respective figures were 304 and 414 kg. With few exceptions, the stagnation of cotton prices over the past decade has led to a situation in which farmers have to produce more cotton to cover the cost of a recommended package of insecticide than they did in the 1970s. This means that there are increasing numbers of farmers who find that they can no longer afford the full recommended spray regimen and who then either use less than the recommended application or cease spraying altogether. A rough guide to the impact of spraying can be given by dividing farmers into three groups according to physical and managerial constraints as outlined in Table 7.
Table 7. Conditions of Three Groups of Cotton Farmers and the Impact of Insecticidal Spraying on their Yields

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Specialist Growers</th>
<th>Middle-Level Growers</th>
<th>Marginal Growers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adequate rainfall</td>
<td>Adequate rainfall</td>
<td>Unreliable rainfall</td>
<td></td>
</tr>
<tr>
<td>No serious soil problems</td>
<td>No serious soil problems</td>
<td>Difficult soil conditions</td>
<td></td>
</tr>
<tr>
<td>Use fertilizer</td>
<td>No fertilizer</td>
<td>No fertilizer</td>
<td></td>
</tr>
<tr>
<td>Able to plant on time</td>
<td>Moderate delay in planting</td>
<td>Major delays in planting</td>
<td></td>
</tr>
<tr>
<td>Able to weed adequately</td>
<td>Moderate weed control</td>
<td>Major delays in weeding</td>
<td></td>
</tr>
</tbody>
</table>

| Yield with spraying kg/ha       | 1,400              | 800                  | 450              |
| Yield without spraying kg/ha    | 600                | 400                  | 350              |

The first group should have no problem with covering the cost of a full spray regimen, and development initiatives should be concentrated on the efficiency and timeliness of input delivery and on the technical content of the advice provided on pest control. Such farmers exist in virtually every African cotton-producing country. It is the group on which attention has been focused with such success in a number of francophone West African countries and which has resulted in high national average yields.

The second group, which includes a considerable number of growers in both anglophone and francophone countries, will require increasing help to overcome their labor constraints if they are to justify the cost of a full insecticidal control program under conditions of declining protection of input and output prices.

To the third group belong large numbers of farmers for whom cotton constitutes their only viable cash crop under conditions that are sub-optimal physically or institutionally. Any attempt to improve on yields of such farmers has to focus on overcoming constraints on labor for the timely operation of critical tasks or of physical or institutional weaknesses, before one tries to encourage the widespread use of insecticides. The failure of major programs to encourage insecticidal use in Uganda and Tanzania, programs that overlooked the low inherent yields of farmers resulting from other factors, provides a salutary lesson in the need for an accurate analysis of the actual constraints faced by farmers.
Effectiveness of Spraying

The introduction of chemical insecticides in the 1950s provided the hope that it would become a simple task to control the pests that had always been a major constraint on cotton yields. In the 1950s a regimen of four sprays of DDT at fortnightly intervals on cotton in East Africa led to appreciable increases in yield. Unfortunately, the impact did not last for long. The elimination of natural predators led to changing patterns of insect attack and the need for much more frequent sprays with a range of pesticides. The chemical industry has continued to develop more effective packages of chemicals, and farmers who have well-established cotton, good advice and timely supplies can achieve a high degree of control over pests with currently available materials. Unfortunately, many farmers lack one or more of those conditions. The effectiveness and long-term sustainability of the control of insects is affected in three major factors:

(a) farmers whose yields are constrained by natural or managerial factors can only afford to spray once or twice. This may simply wipe out the predators and have little impact on yields. Alternatively they may over-dilute chemicals to spread them out and so foster the build-up of resistant strains of insects. Extension staff seldom know how to advise farmers under these circumstances and there is a major gap in both research and extension as to how to advise farmers who can only afford part of a recommended package;

(b) the effectiveness of a modern spray program depends upon applying the product on a particular insect at the correct time. Delays of days or even in some cases of hours in the application of a specific chemical can undermine most of its effectiveness. Farmers who are dependent on public-sector credit and supply systems are all too often faced with late deliveries, which can greatly reduce the returns on their outlay on insecticides. Research and extension, while valuable in identifying thresholds (perhaps through use of pheromone intervention traps, etc.) and advising on effective intervention, in fact, are of little use if delivery systems cannot be improved; and

(c) efficient delivery is often linked with private-sector participation, but requires strong supervision and control from a truly disinterested party. Chemical companies have found it to their advantage to press home the use of one or two of their products over the whole of a cotton growing area where a more appropriate strategy to achieve the best economic and most sustainable solution would involve a wider spectrum of chemicals and a rotation of some of those around different parts of the country to counteract the build-up of resistance to a single product. In the effort to encourage the private sector to provide efficient services to farmers, it is also important to strengthen the hand of the extension service to ensure that farmers really do receive the advice that is most advantageous to them rather than to the supplier.

The most effective control of insects is achieved when a spray regimen is tailored to the actual occurrence of insect eggs or larva in the field. This demands the scouting of fields on a regular basis to identify and count insect pests. Great efforts have been put into training farmers in these techniques but not always thus far with lasting success. In a survey of 200
smallholders in the cotton-growing areas of Zimbabwe (where a lot of training has been done), it was found (Jowah 1987) that:

(a) a high proportion were able to recognize the larva of the major pests;

(b) 99 percent stated that they believed that scouting was the best basis for deciding on when and what to spray; and

(c) 90 percent of them sprayed on a fixed weekly basis unconnected to scouting.

More recent experience in Zimbabwe is, fortunately (at least according to Bank missions in 1992), rather more encouraging in modifying spray regimens.

In the francophone countries, experiments are in hand to combine "calendar" and scouting spray regimens. The proposal (IRCT 1990) is to switch farmers to a fortnightly "calendar" program, instead of the weekly one now followed. In the intervening period, they would do any other spraying on the basis of scouting.

Research and extension staff and the chemical companies have a considerable task ahead of them to assist farmers in making effective use of insecticides to minimize waste and maximize impact.

Methods of Application

There are two major ways of applying liquid insecticides with hand-operated equipment. The first is with high volumes of water and a knapsack sprayer. The second is with low volumes of insecticide and a battery-operated device. The introduction of the second group of applicators (ULV and Electrodyn) was considered a major technical breakthrough, which reduced labor requirement greatly and speeded up the spraying process. Unfortunately, the depressed state of a number of African countries' economies in the 1980s has resulted in periodic shortages and consequently greatly inflated prices for the electric batteries required to operate the low-volume sprayers. As a result, farmers in a number of countries still use the slower, more labor-demanding knapsack sprayers. There are also conditions (particularly in areas of high night temperatures) where cotton growth is so rank that low-volume electrically operated sprayers do not provide adequate cover. In deciding on a spraying system, there is a need to assess:

(a) the availability of water;

(b) the effectiveness of various systems in achieving penetration and coverage by the insecticide; and

(c) the reliability of supply and costs of batteries in remote rural areas.
**Human Safety**

There is an increasing awareness of the need to include an assessment of potential health hazards in selecting an insect control program. Despite this, there are times when the actual conditions under which sprays are applied are not fully taken into account. In assessing the safety of a given recommendation for African smallholders, the following factors need to be considered:

(a) the bulk of users are illiterate;

(b) the overwhelming majority will use no protective devices when handling chemicals;

(c) most users will work barefoot;

(d) with oil-based chemicals, many users will remove part of their clothing to avoid staining or spoiling;

(e) it is a common practice to eat in the fields and water is seldom available for adequate washing of hands between the time of using chemicals and eating food with the fingers; and

(f) spraying may often be carried out by young children.

Fortunately, the introduction of synthetic pyrethroids has resulted in some reduction in health hazard but the need remains for a strong impartial 'watchdog,' which is thoroughly conversant with the actual conditions under which chemicals are going to be used.

**The Use of Fertilizers**

The impact of fertilizer on cotton is broadly governed by the following factors:

(a) availability of moisture;

(b) soil type; and

(c) levels of husbandry and insect control.

These three factors will be considered in the following sections.

Because cotton is often used as a cash crop of last resort in areas of unreliable rainfall, it can be difficult to offer farmers advice on fertilizer use that will be consistently profitable. Typical of this situation is work carried out in farmers' fields by the Cotton Research Institute of Zimbabwe. In the 1983/84 annual report, it is recorded that there were no significant yield differences between fertilized and unfertilized cotton because of dry
weather. The 1985/86 report, which followed a good rainy season, records a mean yield increase of 300 kg/ha of seed cotton from the same fertilizer dressing. Where government policy confines cotton growing to dependable rainfall areas this factor does not pose too much of a problem. Where cotton is viewed more broadly as a crop that can add to the welfare of people in marginal rainfall areas, then the use of fertilizer at undistorted input/output prices is unlikely to provide a dependable extension message to farmers because the number of years in which there will be a response will be too few to offset those in which there is none.

The response of cotton to fertilizer under adequate rainfall conditions is also determined by soil type. Cotton production is adversely affected by calcium deficiency at pH levels below 5.4 and, under such conditions, fertilizers that are themselves acidifying (e.g., sulphate of ammonia) can actually depress yields. Even when there is no actual depression, the returns to fertilizer will often be financially unattractive. This situation was well-documented by a series of experiments carried out by the Ukuriguku Research Station in Tanzania in the 1960s and early 1970s. This work was followed by a program of trials carried out in Sengerema district by FAO, the overall results of which are given in Table 8.

Table 8. Results of FAO Fertilizer Trials in Sengerema District, Tanzania in 1979
(Yields in kg/ha seed cotton)

<table>
<thead>
<tr>
<th>No. of trials</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average yield fertilized with 30N-35P</td>
<td>525</td>
</tr>
<tr>
<td>Average yield unfertilized</td>
<td>458</td>
</tr>
<tr>
<td>Increment from fertilizer</td>
<td>67</td>
</tr>
<tr>
<td>Incremental yield required to give a 2:1 benefit/cost ratio</td>
<td>540</td>
</tr>
<tr>
<td>Number of trials giving a 2:1 benefit/cost ratio</td>
<td>1</td>
</tr>
<tr>
<td>Number of trials covering the cost of fertilizer</td>
<td>4</td>
</tr>
</tbody>
</table>

Source: FAO Tanzania Office, Fertilizer Trial Reports.

This situation has not changed and in the latest published results from Ukiriguru Research Station it was recorded that the current recommendation of 30N and 15P used on the Hill Sands gave a mean increase of 1 kg/ha seed cotton. Out of the 21 sites at which trials were carried out, there were only 6 at which the incremental yield would have covered the cost of fertilizer. It is not surprising that, in the 1988/89 season, the cooperative union recorded no sales of fertilizer for cotton in that area.

Parts of Teso in Uganda were facing similar problems in the late 1960s after many years of continuous cultivation. In francophone West Africa, cotton is a much more recently introduced crop but similar problems could be expected under comparable soil conditions in the future.
At the opposite extreme are the rich black clay soils of parts of Mwanza and Shinyanga in Tanzania and the Luangwa Valley in Zambia on which added fertilizer has little impact at present because of an adequacy of available soil nutrients for the levels of yields being achieved under existing management practices.

The third factor influencing the response of cotton to fertilizer is the general level of management of the crop. This is true of any crop but in cotton the importance of insect control is particularly significant. If farmers cannot gain good control over insect pests for any reason, there is little hope that fertilizer use will be worthwhile. There is widespread experience from a number of countries that, if farmers have limited resources to allocate to the purchase of inputs for cotton, they will allocate them to insecticides rather than fertilizer. This is the opposite to the situation for most other major crops.

There are, of course, large areas of cotton where moisture, soil pH and the availability of insecticides are not constraints. In such areas there will be considerable differences in the response of cotton to fertilizer but experience in a number of countries would indicate that a typical recommendation for smallholders of 35N and 25P per ha will give between 120 and 250 kg/ha of extra seed cotton. The financial attractiveness of such responses will obviously depend on the wide range of factors that determine input and output prices. An example of the incremental yields that are needed to make fertilizer use attractive can be taken from Zimbabwe in which services to cotton growers are efficient, and input and output prices are weighted in the farmer’s favor. The use of the current recommended fertilizer application requires the production of 212 kg/ha of extra seed cotton to give a benefit/cost ratio of two on the cost of fertilizer only, without any consideration of incremental labor. Given that this figure is close to the incremental yields achieved on experimental plots, it does mean that only the more efficient farmers are likely to find fertilizer use on cotton attractive in many areas unless prices are considerably distorted. The high percentage of farmers using fertilizer in francophone West Africa in the mid-1980s reflects both the protection of prices and large subsidies on inputs that farmers enjoyed and the concentration of the program on areas and farm families best able to respond to a strategy of intensification.

OTHER FARMING PRACTICES

Four other agricultural practices can influence yields, but have much less impact than those discussed above. They are plant populations, thinning, depth of planting and moisture conservation.

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Because of the unpredictability of the climate, the incremental labor involved and high opportunity cost of cash in rural households, it is widely considered that a benefit/cost ratio of 2 is the minimum required to make a purchased input attractive to smallholders in Africa.
Plant Populations

Unlike many other annual crops, cotton yields show little difference with respect to wide variations in plant spacing. A study by King (1963) of spacing experiments in six African countries revealed "little difference over a wide variation of spacings." In Zimbabwe over several seasons, there was no significant difference in yield between populations of 17,000 to 67,000 plants per ha and this is typical of experience elsewhere. What closer spacing does is increase the farmer's tasks of planting and thinning, which take place at times of labor shortage. It also increases the work of harvesting and sorting, which are labor-intensive tasks. Closer spacing leads to the production of larger numbers of smaller bolls. Experimental work in Uganda gave a 20 percent increase in the number of bolls to be picked from a change in plant population from 24,000 to 104,000 plants per ha with no significant increase in yield (CGC 1970). Wider spacing appears to provide some limitation on insect damage and for unsprayed cotton there may be advantages in reducing populations to 20,000 per ha (Walton 1962). A common spacing used by smallholders in Africa is 37,000 plants per ha and there would have to be exceptional circumstances that would result in any significant change in yields as a result of radically altering this figure. Such an exception might be a move from sprayed to unsprayed cotton production resulting from financial or institutional factors that could make a reduction in plant numbers advantageous.

Thinning

Most smallholder cotton in Africa is planted by hand. Untreated cotton seed is fuzzy and it is difficult to separate the seeds quickly when they are being planted. In consequence, too many seeds are often dropped into one hole. This not only results in substantial losses of seed, but in excessive competition by young seedlings in their early stage of development. Farmers find it easier to plant more accurately if seed is delinted. If it is done with acid the process has the advantage of controlling seed-borne diseases and, if properly carried out, of leading to quicker and more uniform germination and a lowering of seed requirement. Its potential disadvantages include that of having to move seed over considerable distances for treatment unless each ginnery has its own facility. There can also be an actual reduction in seed quality if the process is not accurately controlled. A cotton strategy in a given area will need to consider the comparative costs and benefits of delinting in relation to the efficiency of the organizing authority, the value of seed and the level of other husbandry practices that have a more significant impact on yield. In a situation in which delinting might delay the supply of seeds to farmers and have an unfavorable impact on planting dates, there is no question that it would be better to deliver fuzzy seed on time.

Delayed thinning of plants results in some reduction of yields, albeit not of the same order as delayed planting. Hand thinning is usually a part of the first weeding round. Initiatives that help farmers to overcome labor bottlenecks on their farms at first weeding will contribute to more timely thinning, which could make a 10 to 15 percent difference to yields.
Depth of Planting

Cotton should be sown at a depth of 2 to 4 cm. If the seed is at a greater depth, it will have an impact on the uniformity of germination and the vigor of the crop. For most smallholders this is not a problem but, for farmers with a narrow planting "window" who broadcast their seed or drop it into the furrow behind the plough, the seed may be buried too deeply with a consequent impact on both germination and early growth. Direct drilling into bare, uncultivated ground with a specially designed ox-drawn implement would overcome this problem and provide straight, even rows to facilitate ox-powered weeding. Tractor-drawn drills of this type are widely available but, as is so often the case, the profits to be made from ox-drawn equipment are too small to encourage private-sector research and development. The public sector carries out research on mechanization but seldom moves on to an effective development and production phase. In consequence, farmers who have to hurry to plant cotton on difficult soils have little chance of achieving even and optimal planting depth.

Moisture Conservation

In areas where cotton suffers from time to time from severe water stress resulting from low or erratic rainfall, there has been considerable research effort focused on methods of water conservation. In both East and West Africa, the principal focus of attention has been on tied ridges. This involves the construction of ridges with a small dam across the furrow every three or four yards to hold water in place following a storm. Although this technology has been advocated by extension staff for many years, there has been little adoption by farmers. One of the main reasons for this is that, in wet years, the system can lead to serious waterlogging because water cannot drain from the field. Farmers are recommended to break down the "ties" to allow the water to escape under such circumstances, and then rebuild them again. This has proved unattractively labor-intensive.

The alternative to tied ridges, which has been researched in Zimbabwe, is the digging of "potholes" at intervals between rows of cotton planted on the flat. These capture water in pools and reduce runoff from the field. Although this approach does not involve the risk of waterlogging, it inevitably carries with it the risk of having no impact on yields in a year of favorable rainfall. In Zimbabwe, yield increases of 28 percent have been recorded in a dry year, with no benefits obtained in a wet one (CRI 1988).

In assessing the role of labor-demanding moisture conservation techniques for African smallholders, it is important that research should be able to advise extension staff as to the proportion of seasons the technology will produce a significant positive impact on yields. This increase will need to provide an attractive return to labor calculated over several seasons, and not just in those years when moisture is a constraint on growth.
PLANTING MATERIAL

Smallholder cotton producers in Africa normally have no choice as to the seed that they will plant. It is selected and issued or sold by the authority responsible for purchasing and/or ginning the crop. At the same time, the seed used by the farmer can have an impact on final returns. This paper will not provide a detailed review of the methods and results of cotton breeding in a range of countries but rather will outline a few of the achievements and issues relating to the genetic quality of seed provided to farmers. There are four main areas in which breeders have assisted smallholders in maintaining or increasing their cotton production in recent decades. These are:

(a) the development of resistance to jassid, a major pest of cotton. Modern cotton varieties are bred to have built-in resistance to the attacks of this insect, which used to be responsible for considerable crop losses;

(b) the development of resistance to bacterial blight and *Alternaria* boll rot and tolerance of *Verticillium* wilt. All of these are diseases that have a potential to considerably reduce yields;

(c) the production of a quality of fibre that is acceptable to the spinners and that can, therefore, maintain both demand and favorable prices for the crop; and

(d) the improvement in the ratio between seed and lint (the ginning-out percentage). For many years, it was considered normal for 100 kg of seed cotton to produce about 33 kg of lint. Today it is possible to achieve 40 kg. The ginning-out percentage is actually determined by a number of factors including:

(i) the genetic make-up of the variety;
(ii) the method of ginning. Roller gins give 1 to 2 percent more lint than sawgins;
(iii) the use of mechanical delinting; and
(iv) the climatic conditions under which the crop is grown, which can account for up to 2 percent difference in ginning-out percentage.

It is progress in the first of these factors that has contributed most to the improvement in lint out-run in recent years.

The role of breeding has influenced fibre quality and ginning percentage more than yield for many years. Average cotton yields on smallholder fields are between 20 and 50 percent of those achieved on research plots so that few of them are making use of more than a fraction of the genetic potential of the material available to them. The broad objectives of future breeding programs are likely to continue to be focused on increased pest and disease resistance and on improving the quality of fibre in line with the changing needs of the
spinners while also increasing ginning-out percentage. Some of the scope for the last-mentioned is suggested in Table 9 by the variations that exist between different countries.

At the same time, the future pattern of any breeding program should take into account the longer term objectives of a given country's cotton production strategy. There are bound to be differences in the development of a suitable plant for marginal farmers using few or no inputs and possibly growing the crop in a mixed stand, and for specialist cotton growers with resources to provide optimal management practices and high levels of inputs. A number of national breeding programs in the past have been geared to the needs of the latter group whilst the majority of local producers have belonged to the former. As with all effective research, the objectives of the program need to be closely related to the actual constraints of the intended beneficiaries.

Table 9. Ginning Out Percentages for Selected Countries
5-Year Average 1982-86

<table>
<thead>
<tr>
<th>Country</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Côte d'Ivoire</td>
<td>41.4</td>
</tr>
<tr>
<td>Senegal</td>
<td>38.8</td>
</tr>
<tr>
<td>Mali</td>
<td>38.5</td>
</tr>
<tr>
<td>Chad</td>
<td>37.8</td>
</tr>
<tr>
<td>Benin</td>
<td>37.7</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>36.5</td>
</tr>
<tr>
<td>CAR</td>
<td>36.4</td>
</tr>
</tbody>
</table>


**SUMMARY OF THE FACTORS INFLUENCING COTTON PRODUCTIVITY**

Although the focus of this section has been on the technical factors influencing cotton yields, these are in their turn shaped by institutional and policy factors. Any plans aimed at stimulating improvements in cotton production at the farmer level need to be formulated in the light of all three of these factors, briefly summarized below:

(a) **Policy.** There are two basic policy issues that affect smallholders:

(i) the first concerns the role that a government allocates to cotton growing. This can either be that of a specialized production system concentrating on technical efficiency, or as a method of assisting a broad spectrum of households. At the national level, this will determine whether cotton growing will be confined to the most favorable ecological areas or will be fostered also in marginal areas in which farmers have no alternative cash crop. At the local, level it will determine whether production will be concentrated on those
families with resources to ensure high yields or will be open also to resource-poor families, with inevitably much lower yields. The whole strategy of a cotton-production system including research, extension and input supply will be affected by this policy, as will national yield levels;

(ii) the second concerns the allocation of responsibility for the supply of inputs, and the marketing and processing of the crop. All of these can have a major impact on the yields that farmers achieve and the prices they receive. The purchasing, transporting and ginning of seed cotton all call for high levels of management and long and unsocial hours of work if the task is to be carried out efficiently, farmers paid promptly and high quality and ginning-out percentages achieved. The transfer of these activities to the public sector in several African countries resulted in declines in services and real returns to farmers and a consequent sharp fall in cotton production. Policies on the allocation of responsibility for the industry are, therefore, linked to institutional performance;

(b) Institutions. The willingness of farmers to grow cotton and the degree to which they give it priority over other crops on their farms hinges to a large degree on the following factors:

(i) the ease of marketing. Cotton is far bulkier than the harvest of most other crops. It, therefore, occupies a lot of storage space in the home if it cannot be marketed quickly. It also involves a considerable cost in time, money or both if it has to be transported a long way to a buying point. This becomes even more serious when buyers fail to take the produce when it is first presented and the farmer has to make repeated trips to dispose of the crop;

(ii) the promptness of payment. If food-insecure families are to give priority to cotton growing in areas of erratic rainfall, they must have confidence that they will be paid promptly for the cotton, so that they can purchase food. In areas where food security is not a problem, it is likely that other crops will offer more competition to cotton for the allocation of resources. Delayed payment for cotton can tip the balance in favor of alternative crops that offer immediate payment, even if cotton gives supposedly higher returns to labor;

(iii) the efficiency and dependability of the local food market. Farmers will only give primacy to cotton over food crops if they are confident that the cash they earn from cotton can be used to purchase food readily and at acceptable prices. Zimbabwe is an example of a country that offers such security. Farmers give primacy to cotton in the allocation of resources and Zimbabwe achieves high yields of cotton in relation to the ecological conditions under which it is grown; and
(iv) the efficiency and cost-effectiveness of the input-supply agencies. The quality and timing of seed supply, the quality of advice and the timeliness and cost of insecticides can have a profound impact both on the uptake and yield of cotton. Wide variations in price and advice exist between countries and these provide indications as to possible scope for institutional improvement;

(c) Technical factors. This paper has highlighted the role that climate, soil fertility, time of planting, weed and insect control have on yields of seed cotton. A number of projects have focused attention on the supply of inputs to improve soil fertility and insect control. Where these have been concentrated largely on those farmers with resources to achieve timely planting and weed control, they have resulted in some striking successes in raising average yields (e.g., Burkina Faso). Where they have not been selective and have not provided resource-poor farmers with a means of overcoming major labor bottlenecks, they have failed (e.g., Tanzania). Because of the dominant role that insect control plays in determining potential yields, it has been a major focus of attention. At the same time, its impact and financial viability are almost totally dependent on the quality of other agronomic practices and, more than for most crops, the improvement of only one technique will have but a marginal influence on productivity.

The extreme variations in average cotton yields between major African producing countries can give rise to expectations of readily available possibilities for the transfer of technology and replicability of yield increases. This chapter has sought to highlight the powerful influence of national policies on the role of cotton in a society as well as the complex interaction of institutional, ecological and technical factors that actually determine yield levels. All of these need to be considered in any strategy for assisting farmers to improve the efficiency of their cotton production.
Chapter 2

COFFEE

The main commercial coffee crop of Africa is derived from two species of coffee, C. canephora or Robusta and C. arabica or Arabica. The former is more suited to hot humid areas where temperatures seldom fall below 18°C; the average is around 26°C and with a well-distributed annual rainfall of not less than 1500 mm. Arabica coffee requires cooler conditions and flourishes best where the average annual temperature is about 20°C and there are not too large variations. It does best with an annual rainfall of not less than 1200 mm with a clear-cut dry season of 6 to 12 weeks. Several major producing countries have Robusta coffee in their lowlands and Arabica in their highlands (e.g., Uganda, Tanzania, Cameroon) whilst others concentrate on just one (e.g., Côte d'Ivoire, Kenya, Ethiopia). In terms of value of sales, coffee is Africa’s major cash crop with a total area of some 3.763 million ha. The major producers are listed in Table 10. Before referring to this table, a word on terminology is in order. Coffee is harvested from the bush as either wet or dry cherry. Wet cherry can be processed by direct drying; alternatively, it can be pulped, fermented and dried to produce parchment. Dry cherry and parchment are hulled (and may be polished) and sorted to produce clean (or green) coffee. Typical conversion factors are:

(a) 1000 kg dry cherry gives 500 kg clean coffee.
(b) 1000 kg cherry gives 200 kg parchment, gives 160 kg clean coffee.

Table 10. Major Coffee-Growing Countries of Africa and Aspects of their Production, 1989/90

<table>
<thead>
<tr>
<th>Country</th>
<th>Type of Coffee Grown</th>
<th>Production of (green) coffee</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Robusta</td>
<td>Arabica</td>
</tr>
<tr>
<td>Côte d'Ivoire</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>Uganda</td>
<td>87</td>
<td>13</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Kenya</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Zaire</td>
<td>85</td>
<td>15</td>
</tr>
<tr>
<td>Cameroon</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>Madagascar</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>Tanzania</td>
<td>25</td>
<td>75</td>
</tr>
</tbody>
</table>

Source: USDA Commodity Reports.
This chapter will deal with the two main coffee species in separate sections because of the considerable differences in production techniques of the two forms.

ROBUSTA COFFEE

Robusta coffee, in a favorable environment, lives up to its name and grows into a large bush that suffers from few pests and diseases. Its natural habitat is at the forest edge and, under suitable ecological conditions, it can survive with little management. These factors are reflected in the methods of production adopted by many African farmers. These include:

(a) semi-tended coffee in a thinned forest;
(b) coffee interplanted with cooking bananas; and
(c) coffee in pure stand.

The applicability of the major factors that influence coffee yields to these differing production methods will be considered in the following sections. These will consider the impact of planting material, agronomic practices and the use of inputs on the productivity of the crop.

PLANTING MATERIAL

From an early stage in the development of Robusta coffee as a commercial crop, it had been noted that, in any given population, a small percentage of exceptionally high-yielding trees make a disproportionate contribution to total yield. Therefore, selections were made of outstanding mother plants. Seed from these trees was then used for subsequent commercial planting. Robusta coffee is largely self-sterile so that all the seed produced was the result of cross-pollination. Because of the long period that it takes to evaluate accurately the real performance of a coffee bush, it was many years before it was realized that there was virtually no correlation between mother tree and progeny yields. This is well illustrated by work from Kawanda Research Station in Uganda, detailed in Table 11.

It can be seen that there was no reflection of the high yield of the mother trees in the mean yields of their progeny. It was also shown that the variability of yield between progeny was as great as in an unselected population. In consequence, the use of centralized seed gardens of superior mother trees to provide "improved" seed for smallholders has had little or no impact on yields or coffee quality.
Table 11. Progeny Performance from Selected Mother Trees  
(Yields in kg/ha of clean coffee)

<table>
<thead>
<tr>
<th>Mother Tree Yield (14-year mean)</th>
<th>Progeny Yield (6-year mean)</th>
<th>Best Individual Progeny Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Erecta Types</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,810</td>
<td>1,053</td>
<td>1,835</td>
</tr>
<tr>
<td>2,062</td>
<td>894</td>
<td>1,735</td>
</tr>
<tr>
<td>3,092</td>
<td>871</td>
<td>1,559</td>
</tr>
<tr>
<td>2,967</td>
<td>865</td>
<td>1,559</td>
</tr>
<tr>
<td>2,162</td>
<td>764</td>
<td>1,798</td>
</tr>
<tr>
<td><strong>Nganda Types</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,879</td>
<td>699</td>
<td>n.a.</td>
</tr>
<tr>
<td>2,112</td>
<td>595</td>
<td>n.a.</td>
</tr>
<tr>
<td>1,798</td>
<td>591</td>
<td>n.a.</td>
</tr>
<tr>
<td>2,401</td>
<td>586</td>
<td>n.a.</td>
</tr>
<tr>
<td>3,118</td>
<td>564</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Note: n.a. - not available

Source: Adapted from Leakey (1982).

Because of this, there was a return to the use of vegetative cuttings for plant propagation, which had been the basis of local planting before the 20th century. Cuttings were, however, selected from outstanding mother trees and a clonal system of propagation was developed, particularly in West Africa and Madagascar. Such material, which exactly replicates the parental genetic make-up, gives rise to plants with a performance similar to that of the mother tree. In the main Robusta coffee growing areas in East Africa, this development took place at a time of limited coffee export quotas that, combined with political factors, resulted in this technology not being developed beyond the research station. In West Africa, it has had a greater influence and, in the Côte d'Ivoire, some 42 cutting centers produced 21 million clonal plants in 1989/90, enough to plant some 16,000 ha. The impact of this development on smallholder yields is particularly difficult to judge. Average yields are only a small fraction of the genetic potential of even seedling material. The fact that farmers with clonal material obtain higher yields could be simply a reflection of the fact that
growers who take the trouble to obtain such plants are likely to use better management practices. Clonal selection and development for such factors as berry size, resistance to pests and diseases, heat and drought tolerance could all make a positive contribution to smallholder productivity. At the same time, as long as management practices are the dominant constraint on yields, differences in the performance of improved planting material may not make a major contribution to the productivity of low-input systems. Table 12 gives an overview of national yields in the major African producing countries.

Table 12. Yield of Green Coffee in Some Major Robusta Producing Countries, 1987

<table>
<thead>
<tr>
<th>Country</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uganda</td>
<td>872</td>
</tr>
<tr>
<td>Zaire</td>
<td>356</td>
</tr>
<tr>
<td>Cameroon</td>
<td>291</td>
</tr>
<tr>
<td>Tanzania</td>
<td>250</td>
</tr>
<tr>
<td>Côte d’Ivoire</td>
<td>224</td>
</tr>
</tbody>
</table>


The best Robusta coffee estates in the major producing countries achieve yields of up to 2000 kg/ha and research plots 3000 kg/ha. The reasons for these disparities lie with the agronomic practices used by farmers, rather than with the genetic composition and potential of the planting material.

AGRONOMIC PRACTICES

The dominant controlling factors determining smallholder Robusta coffee yields in Africa are the method of planting, plant populations and the degree of intercropping, weed control and the use of mulching and pruning. These will be considered in the following sections.

Method of Planting

Robusta coffee is grown in areas of high rainfall where the leaching of nutrients can lead to a rapid increase in acidity below the surface layer, over a number of geological formations. Coffee roots thrive best at a pH of 5.8 to 6.0 and there is little root development in soils with a pH of below 5.2.

Under conditions in which there is an acid subsoil underlying a shallow layer of more neutral topsoil, the early growth of coffee plants can be greatly enhanced by a planting
procedure of digging out holes of at least 60 cm x 60 cm x 60 cm and refilling them with topsoil from the surrounding area. This provides the young rooting system with a much more favorable environment for growth. Where these soil conditions exist, the difference in the overall development of the trees as between direct planting and planting into a hole filled with topsoil can be seen for some years. The method leads to earlier fruiting and higher yields. Where soils are rich, deep and have a favorable pH for some considerable depth, the impact of hole digging will be much less.

Plant Populations and Intercropping

The optimal number of plants per ha for Robusta coffee depends upon the type of coffee being planted and the system of production being used. Robusta coffee is a popular term covering a range of different cultivars or forms. Some like the "Nganda" type in Uganda have a naturally spreading habit and, even in pure stand, the recommended plant population based on research results is 500 trees per ha. "Erecta" types in pure stand of traditional material used to be planted at 900 per ha, but the recommendations for recent clonal releases is from 1400 to 1900 per ha.

In fact, few farmers actually plant a pure stand of coffee. A lot of Robusta coffee in West Africa is planted in forest that has been thinned out. The presence of forest trees, stumps and logs lead to scattered initial planting and, even when the garden has been fully cleared over several years and the number of forest trees reduced, the initial low plant population is maintained, often with other crops planted in the gaps. In the main Robusta coffee-producing areas of Uganda and Tanzania, the coffee is planted between stands of cooking bananas, which are the staple food of the area. Under this system, the plant population of the coffee is likely to be 300 to 500 per ha. An example of the yields under this system is given in Table 13.

This clearly shows the suppressive effect of the bananas on the early development of the coffee trees but, as the coffee grows more competitive, the farmer is able to obtain a full crop of bananas and get 40 percent of the coffee yield that would have been provided by a pure stand.

Increased population of coffee in pure stand with good management practices would undoubtedly lead to higher yields than those now being obtained by most smallholders. At the same time, the fluctuating price for Robusta coffee over time has led many farmers to adopt a low-input system of production with intercrops that can assure food supplies and help to offset low returns to coffee in years when yields or prices are particularly low. Any recommendation regarding optimal plant populations needs to be made in the light of the objectives of the farmer, with higher plant populations for "specialist" growers and lower ones for those who grow the crop on a low labor-input basis to provide a comparatively small part of their total net farm income, and who wish to intercrop to increase food security or to save land and labor.
Table 13. Yield of Robusta Coffee with Bananas Interplanted
(clean coffee kg/ha)

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>250</th>
<th>500</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>154</td>
<td>59</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>1961</td>
<td>148</td>
<td>114</td>
<td>46</td>
<td>48</td>
</tr>
<tr>
<td>1962</td>
<td>569</td>
<td>324</td>
<td>162</td>
<td>222</td>
</tr>
<tr>
<td>1963 (Year 4)</td>
<td>500</td>
<td>369</td>
<td>272</td>
<td>203</td>
</tr>
<tr>
<td>Mean</td>
<td>343</td>
<td>217</td>
<td>122</td>
<td>119</td>
</tr>
<tr>
<td>Mean as % of pure stand coffee</td>
<td>100</td>
<td>63</td>
<td>36</td>
<td>35</td>
</tr>
<tr>
<td>Year 4 yield as % of pure stand coffee</td>
<td>100</td>
<td>74</td>
<td>54</td>
<td>40</td>
</tr>
</tbody>
</table>

Source: Mitchell (1965).

**Weed Control and the Use of Mulching**

Robusta coffee has a shallow rooting system and, even under favorable soil conditions, it will have the bulk of its feeding roots just below the surface of the soil. This presents the smallholder with a double challenge. In unshaded coffee, the ground can rapidly be covered with rhizomatous grassy weeds that compete strongly with the coffee and that can, in time, reduce the crop almost to zero. At the same time, regular deep digging required to eliminate such weeds can do extensive damage to the coffee’s roots and have an adverse impact on yields. Estates usually overcome this problem by using a combination of mechanical slashers and herbicides. Smallholders have four main options. These are:

(a) leave the coffee under heavy shade. If coffee is grown in thinned forest under quite heavy shade, the weed population will be limited to rather soft dicotyledons that can be slashed occasionally and that offer little competition to the coffee. The shade suppresses coffee yields but, if it is thinned to increase sunlight penetration, the weed population will change to grasses and, if the farmer is not prepared to allocate the time required to control the weeds, yields will drop as a result of shade reduction. Advice to reduce shade must, therefore, be made in the light of the farmer’s overall strategy for the crop;
(b) interplant the crop in a permanent banana or plantain crop that both shades out weeds and provides a large volume of mulching material that effectively smothers weeds. Although this system leads to reduced coffee yields, its returns to labor have led to its adoption by tens of thousands of East African farmers;

cut and carry mulch from the surrounding country. Smothering weeds at an early stage with a thick cover of cut grass is a most effective method of weed control. The mulch has other benefits, which are discussed below, and provides farmers with one of the most effective ways of raising their yields. It also requires a lot of labor (but usually during a slack period), which has confined its use to the more enthusiastic producers with access to abundant uncultivated land near their farms; and

d) herbicides. There are effective products on the market that control the creeping grasses, which are the most serious challenge to coffee. At times of high coffee prices in countries with effective distribution systems for agrochemicals, they have gained considerable popularity with farmers. The absence of both of these factors in many areas has greatly limited their overall impact on the crop.

Weed infestation is a major cause of low yields in smallholder coffee. Devising systems that can counteract weed challenge, and yet be in line with farmers' overall objectives, requires an understanding of the crop and the farming system. Intercropping with short annual food crops in the early years, combined with a balance of shade and mulching as the crop becomes established, provides the most likely effective combination.

Mulching of coffee has other benefits than just suppressing weeds. Among the most important are:

(a) the stabilization of soil temperature. A layer of banana or plantain trash or grass not only prevents overheating of the soil during the day but also greatly reduces diurnal variation in soil temperature;

(b) the protection of the soil from rainbeat and surface capping and the facilitation of water penetration into the soil; and

(c) the raising of the level of soil nutrients available to the coffee bush. Farmers who cannot afford fertilizer can achieve a good crop of coffee just from the nutrients supplied by mulch.

Where farmers do not have a source of mulch within the farm (e.g., banana trash), extension staff should be looking for alternative sources and identifying niches in the pattern of labor demand that could provide the opportunity to move mulch to the coffee plot. This option is not universally available but is still possible in a number of areas.
Pruning

The regular pruning of Robusta coffee by smallholders is uncommon. The most effective way of keeping Robusta in regular production is to maintain a bush with four main stems and remove the oldest one each year and replace it with a new shoot. “Specialist” smallholders with pure-stand coffee do practice this system, but many others simply allow their bushes to develop unchecked. Under favorable growing conditions, this leads to a dense rank growth of plants from which harvesting becomes difficult and in which much of the plant is so shaded that it does not produce. At the same time, such bushes provide good weed control. Under less favorable conditions, bushes consist of tall bare branches with a tuft of leaves and fruit at the apex, especially when they are unshaded. These are not productive and they do not suppress weeds. Once a farm has reached this condition, it can only be rejuvenated by cutting back to about 50 cm all but one of the main stems to the stump and starting a new cycle of growth that can then be moved into a regular pruning cycle. Low coffee prices do not encourage the expenditure of labor on this work, but that is the best time to encourage a heavy pruning if it is necessary. When prices are high, farmers are reluctant to cut off branches which are seen to bear any crop, however small.

Conditions vary so much between individual gardens that it is not possible to provide even indicative figures on the impact of pruning. For this reason too, it is not prudent to offer any universal recommendation as to the system of pruning and its timing because of the wide variation in farmers’ production systems. What is clear is that neglected and overgrown stands of erect types of Robusta coffee will require some severe pruning if they are to be brought back to higher levels of production. It makes for better farming if regular control is maintained over plant shape to avoid periodic drastic action. Extension staff need to be alert to the particular patterns of production of different groups of farmers and then to tailor their advice on regular pruning to those needs.

The Use of Purchased Inputs

Robusta coffee is particularly free of serious pests and diseases when grown in its favored environment. In consequence, the only purchased input used by smallholders on this crop is fertilizer.

Under good management, the response of coffee to nitrogenous fertilizers is closely linked to shade. The effect of shade on the coffee plant is to depress yield. Under suitable soil conditions, the plant is then able to sustain its production from the nutrients available in the soil without stress. When shade is removed, the production of coffee cherry can increase strikingly. If the plant is not then provided with adequate nitrogen, it can suffer severe stress resulting in die-back or biennial bearing. In this latter situation, the plant only bears a crop every other year when it has had a year to grow new wood on which to bear the next crop. Unshaded coffee, therefore, requires regular feeding with either nitrogenous fertilizer or farmyard manure. Conversely, heavily shaded coffee will show little response to any form of fertilizer application. The response to such added nutrients, however, will also depend on effective weeding and pruning. Several African governments (including Cameroon and
CAR) have, in the past, supplied heavily subsidized fertilizer to coffee growers. Under ideal conditions of management, coffee bushes can yield 5 to 10 kg of additional clean coffee per kg of N, which provides an attractive return even at the depressed coffee prices of the 1990s. On the other hand, farmers whose yields are constrained by overgrown bushes, low plant populations and poor weed control are unlikely to reap any significant benefits from the use of a fertilizer. In situations in which fertilizer is supplied to growers at heavily subsidized prices, it is likely to go mostly into food crops, with lesser quantities being used by "specialist" coffee growers on that crop. Depressed coffee prices lead to a decline in labor input on the coffee crop, and hence to a reduced likelihood that the use of a fertilizer would be the most effective means of raising productivity.

SUMMARY OF FACTORS INFLUENCING THE PRODUCTIVITY OF ROBUSTA COFFEE

Robusta coffee is capable of giving yields of one to two tons of clean bean per ha with known technology and with a minimum of purchased inputs, but with a substantial labor input for mulching, pruning and harvesting. There have been periods over the past twenty years when the returns to such labor input have appeared to be highly attractive and yet recorded national yield levels indicate that few farmers have been prepared to invest the necessary effort or resources into the crop, or they have adopted production systems (e.g., interplanting coffee in long-term plantain plantations or in forest) that preclude the achievement of high yields. In considering the five major Robusta coffee producers of Africa - Angola, Côte d'Ivoire, Uganda, Cameroon and Zaire - four factors can be identified that, in one or the other of them, have deterred large numbers of farmers from intensifying their production. These are:

(a) political instability;
(b) long-delayed payment for the crop;
(c) competition with cocoa for labor; and
(d) an overvalued currency.

Because Robusta coffee is mostly grown in comparatively land-plentiful areas, it has been possible for farmers partly to counteract the deterrents outlined above by adopting low-input systems. The highest recorded national yields in 1987 (Table 12) were in Uganda, where coffee is grown in a more densely populated area and returns to land become more important.

For many farmers, a switch to a more intensive production pattern would involve

(a) the removal of permanent intercrops;
(b) the reduction of forest cover;
(c) the drastic pruning of the coffee involving in the short run a high cost in labor and forfeited crop; and
(d) a long-term commitment to annual mulching and/or herbicide and fertilizer purchase.

Only if farmers can be given long-term confidence in the efficiency of the marketing system are they likely to move from a low-labor to a high-labor input system. If they are prepared to make such a change, then mulching, weed control and pruning are likely to be the technical changes that will have the greatest impact on productivity.

ARABICA COFFEE

In its indigenous environment in the highlands of Ethiopia, Arabica coffee grows as a wild plant along rivers at the margin of forests and much of that country’s production has come from such natural stands. Elsewhere on the continent, where the crop has been moved from its native ecological conditions, it requires more intensive management than Robusta to achieve even quite modest yields. The main reasons for this are its susceptibility to moisture stress, diseases and insect pests, which are of minor importance on Robusta. As with Robusta, however, the technology for producing high yields is well-known and these are achieved by some growers. Table 14 gives an indication of the range that recorded in the late 1980s.

Table 14. Yields of Clean Coffee from Different Countries and Production Systems (kg/ha)

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya best estates - indicative for the mid-1980s</td>
<td>2,000</td>
</tr>
<tr>
<td>Kenya estate average 1981-1985</td>
<td>1,078</td>
</tr>
<tr>
<td>Kenya smallholders average Muranga &amp; Nyeri 1988</td>
<td>1,050</td>
</tr>
<tr>
<td>Kenya smallholders average all districts 1963-66</td>
<td>996</td>
</tr>
<tr>
<td>Kenya smallholders average all districts 1981-85</td>
<td>605</td>
</tr>
<tr>
<td>Madagascar national average 1987</td>
<td>367</td>
</tr>
<tr>
<td>Cameroon national average 1987</td>
<td>291</td>
</tr>
<tr>
<td>Ethiopia national average 1989</td>
<td>239</td>
</tr>
</tbody>
</table>

Sources: Coffee Board of Kenya Annual Reports and FAO (1988).

The reasons why the differences exist include pricing policies, speed of payment, efficiency of input and marketing organizations, comparative returns to other crops and varying degrees of ecological suitability in the growing areas, and climatic variability. The causes of the differences include the type of production system being used, the quality of planting material, and variations in agronomic practices and in the use of purchased inputs. These are covered in the following sections.
PRODUCTION SYSTEMS

Arabica coffee is harvested from natural forests in parts of Ethiopia, but elsewhere in Africa it is a plant of cultivated fields and, unlike Robusta, is not often planted into forest. There are three main production systems used by smallholders in which the coffee is:

(a) planted in permanent banana plantations. This is typical of the Kilimanjaro area of Tanzania and the sides of Mount Elgon in Uganda;

(b) planted with annual food crops. This is typical of southern Tanzania and Cameroon; and

(c) planted in pure stand. This is the system used in Kenya, which was originally required by law.

Interplanting among bananas reduces the yield of Arabica and, in Tanzania, coffee yields in the zone in which it is interplanted between bananas are approximately one-half of those obtained in the southern highlands, where the crop is interplanted with short-stature annual crops such as beans. The system has been adopted in areas of high population pressure and allows families to satisfy both their food needs and cash requirements from a small area of land. It also gives the family some flexibility, and the space and farmyard manure allocated to bananas and coffee can be varied according to which is providing the better returns at any given time.

Farmers who interplant their coffee with beans, peas, potatoes and vegetables can reduce the cost of weeding of the coffee and also provide themselves with some food, as well as flexibility in the management and output of the mixed garden. Moisture stress is a key factor, especially 12-16 weeks after flowering. Coffee yields suffer less from this competition than that from bananas, as long as the crops are not too near the trees. The main objection to this system is that chemical sprays used on the coffee may contaminate the intercrops and be a health hazard. Sound extension advice and some care in the selection of plant protection products are, therefore, necessary in this situation.

Coffee in pure stand has the potential to provide the highest yields and it is noticeable that those obtained by Kenyan smallholders, who use this system, are on average the highest on the continent. The system faces the problem of competition for land for food crops in densely populated areas. It also offers the farmer no flexibility when prices or marketing arrangements are unattractive. The smallholder coffee industry in Kenya faces both of those challenges in the early 1990s.

PLANTING MATERIAL

Fungal disease has been one of the main constraints on Arabica coffee production since its introduction to African countries other than Ethiopia early in the twentieth century. For the first half of the century, the main concern was with Coffee Leaf Rust, and selection
programs were initiated in East Africa in the 1930s to provide material to farmers that would be resistant to the disease. Widespread collections of parent material have been made and a number of promising lines produced over the years. Unfortunately, early hopes of field resistance have often not been sustained in the longer run under field conditions, so that the existing plants on farmers' fields all require regular spraying under conditions in which Leaf Rust flourishes. Despite this lack of success in obtaining high levels of resistance to Leaf Rust, the breeding program started in the 1960s made considerable progress in providing farmers with seed that had a high yield potential and produced a superior quality of coffee. In Kenya, the best quality cultivars from the 1930s and 1940s belonged to a group designated by the letters SL (Scott Laboratories). Unfortunately, a major new disease, Coffee Berry Disease (CBD), originally identified in 1923, started to spread rapidly in East Africa in the 1950s and has subsequently extended to the Arabica growing areas of the whole continent; SL varieties proved to be particularly susceptible to its attack. Chemical control of this disease is much more costly than for Leaf Rust and, in consequence, breeders have been focusing on plants that have resistance to CBD. The two major programs have been in Kenya and Ethiopia. In the latter, selections were made from indigenous trees that showed high levels of resistance. With considerable levels of self-pollination in Arabica coffee, the progeny of these trees have also shown good levels of resistance to both Leaf Rust and CBD. They do not, however, produce particularly good quality coffee; nor do they have high yield potential. They fitted into the pattern of low-input production of Ethiopia and many millions of these seeds have now been distributed. This material did not meet the much more exacting quality standards of the Kenyan industry. In that country, the aim has been to produce a bush that is resistant to both main diseases, high yielding, with a compact frame suited to intensive cultivation and capable of producing high-quality coffee. This combination of characteristics has been embodied in a newly released hybrid named Ruiru 11, which includes genetic material developed in plant breeding programs in Brazil and Colombia.

It is claimed that Ruiru 11 will give a 50 percent increase in yields over existing plantings and will not require fungicidal spraying. It is generally considered as a major breakthrough in terms of improved Arabica planting material. The main problem with it at present is the production of adequate quantities of seed. Ruiru 11 is a first-generation hybrid and the current method of production requires the emasculation of the flowers of the mother plants, followed by hand-pollination. Unfortunately, most coffee flowers open at one time of the year over a period of two or three days. In order to produce enough seed to plant 5,000 ha/year, there need to be 6.5 million emasculations over a brief period of time. This requires the rapid mobilization of a large, skilled and dedicated group of people at short notice when it is seen that the flowers are about to open. This is the number of plants that would be required to replace Kenya's current coffee area with the new material over the next 25 years. Three possible alternatives exist to overcome this constraint. The first is an intensive program of selfing and selection in order to stabilize the desirable characteristics of Ruiru 11 so that seed could be produced from an isolated seed garden without emasculation or hand-pollination. This would be a lengthy process and would produce more variable material than the present system. The second is to initiate a program of vegetative propagation. The techniques for this are well known and plant production is not difficult. The unknown factor is the type of root system that this clone would produce under these conditions and the danger that a shallow rooting system would result in weaker plants and high mortality rates in dry years. There is a need to test the performance of such plants over
several seasons before promoting widespread adoption. The third is to graft scions of Ruiru 11 on to proven seedling material (e.g., SL28). This could be carried out on existing plants in the field or on new seedlings raised in polythene tubes. This would require the dedication of Ruiru 11 plots to the production of grafting material and the training of extension and nursery staff in grafting techniques. The final choice of technology should be weighted in favor of a system that maximizes the role of the farmer and local extension agent in production and avoids the disadvantages of large centralized nurseries. Tissue culture may play a role in the future, but there are still a number of technical and logistical problems to be overcome before this will be of widespread benefit to smallholders.

Hopefully, the success of the Kenya program in combining these desirable genes will stimulate similar work in other African Arabica-producing countries and, in time, reduce the need for the frequent fungicidal spray programs that are such a heavy burden on farmers. It has to be appreciated, however, that even the production of highly-attractive new planting material will not lead to large-scale new planting over a short period. Because of the high cost of crop foregone in pulling up existing coffee, combined with the labor required to establish a new planting from seedlings or cuttings, few smallholders are likely to embark on a program of varietal replacement until their existing coffee has reached a low level of productivity and is too old to be rejuvenated by agronomic means. This is particularly true in areas in which land is in short supply and farmers cannot plant new material whilst continuing to harvest from an existing old garden. In the face of depressed coffee prices and restricted markets, it is likely that new releases of improved planting material will have only a minor impact on smallholder Arabica production in Africa over the next decade. The main thrust of extension work under such circumstances should be on encouraging farmers to infill gaps in their gardens with the new planting material. This alone would absorb most of the seed and planting material that is likely to be produced from any hybrid programs.

AGRONOMIC PRACTICES

Planting

As with Robusta coffee, there is widespread evidence that digging large holes and refilling them with top soil and, where possible, some farmyard manure, has a favorable impact on growth and production for some years after planting. Holes should be refilled to at least 5 cm above the surrounding land to compensate for subsequent sinking. This ensures that the base of the stem will not be below ground level. Careful planting of either bare-root or potted plants can have a significant impact on the productivity of the bush for many years. All too often, there is a sense of hurry about getting the plants in, which results in poor standards of control over depth of planting and root placement. Good extension can have a significant impact on long-term productivity at this stage of development of coffee nurseries and gardens.
Plant Populations

There are great variations in the density at which Arabica coffee is planted. The extremes range from 5,000 trees/ha on intensively-managed and irrigated estates in Kenya and Zimbabwe to less than 1,000 trees/ha in mixed stands with bananas. For smallholders, planting in pure stand or with minor annual crops interplanted, a population of 1,600/ha is usually considered a good general recommendation. With Ruiru 11 which contains the dwarfing gene from Caturra coffee, the population should be increased to 2,000 and up to 2,500 according to soil and rainfall conditions. As with many smallholder crops, rigid universal guidelines are not particularly useful and it should be the role of the extension service (through well-trained subject matter specialists) to assess the likely optimal population in the light of natural conditions, available resources to provide added fertility and production objectives (single crop or mixed cropping). In many areas, such an approach will involve reorientation of the extension staff's approach to this subject.

Weeding

Weed competition has just as adverse an impact on Arabica coffee as has been described earlier for Robusta. The main difference between the two crops is that Arabica is grown in areas with a longer dry season than is usually the case with Robusta and, in consequence, weed competition for moisture can become a serious constraint on yields. Even when weeds are brought under control in the dry season, weed competition can have a major impact on yields, as is illustrated by the early but still relevant results summarized in Table 15:

Table 15. Effects on Yields of 30-year Old Arabica Coffee of Three Systems of Weed Control in Kenya (mean of 5 years expressed in t/ha fresh cherry)

<table>
<thead>
<tr>
<th>System</th>
<th>Yield (t/ha fresh cherry)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean-weeded</td>
<td>29.4</td>
</tr>
<tr>
<td>Weeds slashed during the rains, clean-weeded at start of dry weather</td>
<td>18.7</td>
</tr>
<tr>
<td>Weeds unrestricted during the rains, clean-weeded at start of dry season</td>
<td>15.6</td>
</tr>
</tbody>
</table>

Source: Pereira and Jones (1954).

The adverse impact of poor weed control on the production of Arabica coffee is particularly significant because, unlike Robusta, good yields are dependent on effective disease and pest control. Coffee, which is weakened by weed competition, will not give an economic response to plant-protection chemicals, and yields will be further depressed if these are not used. Conversely, in areas where these inputs are supplied in such a way that individual farmers do not pay directly for their cost (e.g., in Tanzania and Cameroon), much of the value of these inputs tends to be wasted on coffee that has been poorly weeded.
As with Robusta, the main method of weed control on estates is often with herbicides. Smallholders have the following options:

(a) plant between bananas and use the trash from the bananas to mulch the coffee and smother the weeds;

(b) intercrop with beans, etc., and by keeping these weeded, reduce the weed challenge between the rows. The immediate area around the bushes and the whole garden in the dry season will also require handweeding with a digging fork;

(c) mulch with material (perhaps from weeds) either from inside or from outside the farm. In the highland areas in which Arabica is commonly grown, this is ceasing to be a practicable proposition in the face of population growth and competing uses, except for farmers near to coffee-processing plants who can use the waste as mulch;

(d) handweed the whole garden with a digging fork. This task clashes with the weeding of food crops on other fields when coffee is grown in pure stand. When coffee prices are high and payment is prompt, families have been able to muster the necessary resources for this task. When prices are low or payments uncertain, the task is neglected. Under such circumstances, it would be better for the crop to be interplanted with a non-competitive food crop than to be unweeded;

(e) use herbicides. Apart from the Kenyan smallholders, who grow their crop in pure stand, the use of herbicides has not been an applicable technology for small-scale Arabica farmers. Some herbicides have been used by Kenyan farmers in the past, but declining coffee prices and problems of late payment and cash flow have recently acted as a disincentive to herbicide use.

As is often the case, extension staff need to be able to offer farmers advice on sub-optimal solutions to their weeding problems. Mulching is the ideal technology but is increasingly not possible. Herbicides may look attractive in theory in some situations but may be inapplicable because of farm cash flow problems. They also suffer in relation to hand-labor in any adjustment of exchange rates to more realistic levels. In many cases, intercropping with non-competitive food crops combined with good disease control to ensure maximum shade from the coffee plants may provide the best compromise solution.

Pruning

Arabica coffee, which is allowed to develop unpruned under favorable growing conditions, will turn into a tangled mass of branches in five or six years. On such plants, the control of pests and diseases becomes extremely difficult and harvesting is also slowed down. Pruning is intended to encourage renewed growth evenly distributed over the coffee tree pattern and facilitates pest control and crop harvesting. The two main systems in use are "single stem" and "multiple stem" pruning. Both systems have their advocates, but the best choice for a given farmer will depend on a variety of factors. These include severity of disease challenge, method of production, degree of skill of the farmer and the altitude at
which the crop grows. It is, therefore, essential for extension staff to have as full an
understanding as possible of the underlying principles of pruning so that they can provide
appropriate advice to farmers with diverse skills and production systems, because no one
method is universally the best. Both the timing and efficiency of pruning can have a
significant impact on yields. The extent of the impact will depend upon both managerial and
ecological factors, but this is an aspect of coffee production in which good farmer training
can result in long-term improvements in productivity.

The Use of Purchased Inputs

High yields of Arabica coffee are dependent upon the use of considerable quantities
of purchased inputs in the form of fertilizers, insecticides and fungicides. Of these, it is the
last that can have the greatest impact on yields and that is given the greatest priority by
farmers with restricted resources. The three will be treated separately in the following
sections.

Fertilizer

The response of Arabica coffee to fertilizer is dependent upon three major factors:

(a) the degree of shade under which it is grown;
(b) the amount of off-farm mulching material available; and
(c) the general level of husbandry and the constraints on yields imposed by
management practices.

Well-weeded and pruned coffee that is growing in pure stand without shade and with
adequate protection from disease will usually require regular feeding if yields are to be
maintained. The exception to this is on volcanic soils of high fertility where good yields are
obtained without fertilizer. The levels to be used and the responses that might be obtained
vary so widely (in relation to soil type, climate, age of trees and system of production) that
generalizations are of little use. Nitrogen is usually the element that gives the greatest
response. Most impact is usually obtained from three or four dressings per year rather than
a single application. As an example of the quantity required, experience in Kenya is that 80
kg N per ha is needed for a crop of 1000 kg/ha, 140 kg for 1500 kg and 200 kg N for 2000
kg. Phosphorus seldom gives a positive response in mature coffee, but potassium can be a
limiting factor unless the garden is receiving an adequate grass mulch. Again, very high
levels of mulch lead to excessive potassium that, in turn, may induce a magnesium deficiency
that may respond to appropriate amelioration (perhaps through a kieserite-based fertilizer).

Much of the smallholder coffee in Africa does not comply with the criteria laid down
at the start of the previous paragraph. Poorly-weeded coffee with little or no disease control
will give little response to fertilizer and, under these circumstances, the focus of attention
should be on overcoming these constraints, rather than supplying subsidized fertilizer.
Coffee is also susceptible to a range of minor nutrient deficiencies. These include zinc, iron, manganese, sulfur and boron. These can effectively inhibit the impact of regular fertilizer applications. An alert and informed extension worker should be able to assess accurately whether poor growth and production are the result of defective management or minor-nutrient deficiency. Many estates ensure high yields though the use of regular micronutrient foliar feeds or they resort to leaf analysis to detect problems. Neither of these options is open to the great majority of smallholders who, therefore, have to depend on their extension staff to diagnose such deficiencies. Certainly, there is scope for extension staff also to make more use of foliar analysis.

**Insecticides**

Some 850 insects have been recorded as feeding on coffee plants. Fortunately, the great majority are not of economic importance but, all the same, Arabica coffee is more susceptible to insect attack than Robusta. This paper will not provide a detailed account of the pests of coffee and their control. The authoritative work on this can be found in Le Pelley (1968). Pests and the methods for their control vary from one area to another and this paper will, therefore, focus on a few key issues with regard to the use of insecticides. These include:

(a) the safety of the operator. Apart from the factors mentioned on p. 21 with regard to cotton spraying, there is an additional hazard with spraying tall bushes in that it is much more likely that operators will get spray on their eyes and mouth. In assessing the technology for insect control on smallholder coffee, it should always be assumed that the operator of spraying equipment will not wear any protection over the face;

(b) the great majority of insects attacking coffee are, in fact, controlled by their natural predators. There are a number of examples in the modern history of coffee production of the damage done by persistent insecticides that kill off large numbers of predators and thereby cause major new insect attacks. The choice of suitable insecticides should usually focus attention on products with short persistence and a narrow range of activity to minimize the destruction of beneficial insects;

(c) insecticides should never be included as a matter of course in regular programs of fungicidal sprays. The control of insects with chemicals should be a strategy of last resort, not part of a repetitive spray program;

(d) the recent banning of dieldrin in many countries does pose a serious technical problem in the control of white stem borer, which can cause substantial loss of crop and the death of young trees. Long-term protection has been achieved in the past by painting the lower part of stems with dieldrin. This also served to control the ants that protect mealy bugs from attack by predatory wasps. Fresh advice is needed for farmers who now cannot make use of this simple, effective (but dangerous) technology; and
(e) there is scope for minimizing insect damage through correct pruning (for *Anestia*) and careful removal from the field of all berries, which act as sources of infection for berry borer. In a situation in which the preservation of the predator population is so important, extension staff need to accentuate the potential of control by good management rather than just advocating regular chemical spraying.

Government policy has often included the issue of free or heavily-subsidized insecticidal concentrate to smallholders. This is actually a situation in which such a policy may not just be disadvantageous on the grounds of economic efficiency, but also contains the potential to do long-term harm to a specific garden or group of gardens. There are undoubtedly times when good yields of coffee can only be achieved if insecticides are used to control a major pest attack, but farmers should be aware of the full cost of this strategy so that they can be discouraged from unnecessary spraying and can compare the real costs of chemical control with purely agronomic strategies.

**Fungicides**

Arabica coffee suffers from a number of different diseases but the most important ones for the African smallholder are Coffee Leaf Rust (CLR) and Coffee Berry Disease (CBD), both of which are caused by fungal infections. In more limited areas, Bacterial Blight of Coffee (BBC) can also be a serious constraint on production. Chemicals are available that provide sufficient control to enable farmers to achieve high yields, but they are expensive. A Kenyan smallholder with management standards that would give a yield of 850 kg/ha of clean coffee would require the value of about 250 kg (30 percent) to pay for the fungicides at 1990 prices. In fact, smallholders use sub-optimal doses of chemicals and lose a lot of crop as a result. Table 16 gives some indication of this situation from Kenya.

<table>
<thead>
<tr>
<th>% of Group</th>
<th>Level of Input Use</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>44</td>
<td>Low</td>
<td>360</td>
</tr>
<tr>
<td>38</td>
<td>Medium</td>
<td>600</td>
</tr>
<tr>
<td>18</td>
<td>High</td>
<td>940</td>
</tr>
</tbody>
</table>

Since the time of that survey, coffee prices have fallen and payment to farmers has been seriously delayed, which combine to act as a strong disincentive to the use of fungicides.

Elsewhere, these chemicals have been applied by government workers at no cost to the farmer (Cameroon) or supplied "free" to farmers on the basis of area of coffee planted and the cost recovered by an overall adjustment of the price paid to all growers. Both of these systems lead to inefficiency of input use. This derives from:

(a) the application of chemicals on poorly-managed coffee, which gives an inadequate yield to cover its cost;

(b) inappropriate timing as a result of public-sector supply and application constraints. This can render the spray program ineffectual;

(c) the use of expensive chemicals when cheaper substitutes would do. Organic fungicides are easier to mix and to apply than inorganic copper compounds but the cost per ha of the former is more than double that of the latter. When farmers are not exposed to the real cost of the chemicals, they are likely to choose the easiest to use without appreciating that they are thereby increasing the level of deductions made against their crop; and

(d) the issue of chemicals to farmers on the basis of the area of coffee planted, which are paid for out of a cess on all coffee. This situation is illustrated in Table 17 from an actual case in Tanzania, which reveals the high losses incurred, especially by the more technically efficient producers.

As the terms of trade for disease control move against farmers, they are in need of the best that they can be offered in terms of technical advice, the timely availability of credit and inputs, combined with a clear perception of the true costs to them of any particular control strategy.

Recent developments in plant breeding offer hope of the availability of planting material that is more resistant to the main diseases. Despite this, for the next decade, the great majority of African smallholder Arabica coffee will consist of existing plants. It will, therefore, require chemical protection against disease if its general management is to offer the prospect of more than minimal yields.
Table 17. Example of Disadvantages of "Free" Issue of Chemicals to Coffee Farmers Based on Tanzanian Experience for 1988/89 (Values in Tsh)

<table>
<thead>
<tr>
<th>Description</th>
<th>Tsh/kg parchment</th>
<th>Tsh per 0.4 ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual price which could be paid to farmers per kg parchment coffee</td>
<td>233</td>
<td></td>
</tr>
<tr>
<td>Deduction made per kg of parchment to all farmers for value of chemicals supplied (irrespective of quantity received)</td>
<td>143</td>
<td></td>
</tr>
<tr>
<td>Actual price paid to farmers</td>
<td>90</td>
<td></td>
</tr>
</tbody>
</table>

The cost implications of the above pricing policy for two farmers each with 0.4 ha of coffee, each issued with an identical quantity of chemicals

(a) to a poor manager producing 150 kg of parchment coffee                    | 21,450           |                |
(b) to a good manager producing 500 kg of parchment coffee                    | 71,500           |                |

Lowest cost of recommended chemical package by direct purchase for 0.4 ha     | 5,056            |                |

Loss implied by issue of "free" chemicals relative to lowest-cost practice   |                  |                |
(a) to the poor manager (21,450 - 5,060)                                     | 16,390           |                |
(b) to the good manager (71,500 - 5,060)                                     | 66,440           |                |

Source: Kilimanjaro Cooperative Union records.
SUMMARY OF THE FACTORS INFLUENCING THE PRODUCTIVITY OF ARABICA COFFEE

Unirrigated Arabica coffee under good management gives annual yields of 1.5 ton/ha and yet many smallholders only harvest 20 percent of that amount. The reasons for these low yields include the fact that the coffee is semi-wild (Ethiopia) or that it is grown amongst bananas (Tanzania and Uganda). But even under these conditions, yields tend to be well below their potential. In Kenya, where much of the crop has been grown in pure stand, the difference between what can be achieved and what often is achieved is the most striking.

Thirty years ago, Kenyan smallholder average yields were over 1100 kg/ha. Even today, Muranga and Nyeri achieve average yields of over 1000 kg/ha. On the other hand, Kiambu and Meru with the same ecological conditions have yields that are little more than 500 kg/ha. Among the reasons for disparities and declines in yield, the following appear to be the most important:

(a) delayed coffee payments. There has been a growing trend to delay payment for the crop 9 to 18 months after delivery. This not only undermines the farmers' interest and commitment to the crop but also means that, in a situation of rapid depreciation in currency value, there may be a loss of 30-40 percent in the real value of the payment received. Delays also create problems of cash flow that limit the use of the inputs that are of crucial importance to the achievement of high yields;

(b) excessive deduction from the price that the coffee realizes prior to payment to the farmer. In Kenya some cooperatives only pay their members 65 percent of the price received from the Coffee Board. Tanzania's pricing system for coffee has involved a 50 percent reduction to farmers to cover the cost of the "free" chemicals that had been delivered to the region. Such cuts at a time of falling world prices push farmers into allocating labor, manure, space and fertilizer to intercrops or alternative enterprises, and coffee plants suffer accordingly; and

(c) late delivery of inputs. The fungicides, which play such an important role in determining yields in areas where CBD is important, have to be applied regularly from the start of the rainy season. If they are delivered late, the fungus becomes established on the young berries and they are lost. Inefficient and complex procurement procedures all too often have led to delayed deliveries in recent years.

The best average district yields in Kenya are associated with cooperatives that are run efficiently and are, therefore, able to pay promptly, minimize deductions and deliver inputs on time. If farmers' confidence in the crop can be restored by addressing the policy of disincentives outlined above, the technical interventions that are most likely to restore or increase yields are:

(a) reducing the competition from tall intercrops on the coffee bushes;
(b) reducing weed competition;
(c) efficient control of pests and diseases;
(d) providing additional nutrients with organic or mineral fertilizers;
(e) appropriate and efficient pruning; and
(f) infilling with better planting material.

In situations where population pressure is leading to a shortage of land for food-crop production, it will also become necessary to focus attention on two other issues that will impinge upon the productivity of Arabica coffee. These are:

(a) the provision (in areas of food insecurity) of an efficient and dependable food market so that farmers are prepared to focus resources on coffee in the confidence that the cash that it realizes can be used for the purchase of food; and

(b) the provision of technology and inputs for increasingly intensified food production so that space can continue to be allocated to coffee, either intercropped or in pure stand.

In summary, technologies are available that are applicable to smallholders, and that can substantially raise yields over present levels. They have been applied widely in some areas in the past and high yields have been achieved. To encourage their re-adoption will require policies to reduce marketing and processing costs, maximize returns by focusing on the quality of marketing, eliminate long delays in payments to farmers and ensure the timely availability of the lowest cost but efficient inputs for the control of diseases and pests. Purely agricultural interventions, in the form of extension and research, will have little impact in the absence of such policy reforms.
Chapter 3

TEA

African smallholder tea-growing is concentrated in Eastern Africa and, although it is not a major smallholder crop for the continent, it has played an important role in the development of cool highland areas with difficult soils. In other major African tea-producing countries, much of the crop comes from estates with only little smallholder participation. An unusual feature of the crop is that, under favorable conditions, it has to be harvested on a regular basis throughout the year. This has the great advantage of providing households with a regular monthly income. The corresponding disadvantage is the constant demand for labor, irrespective of the requirements of other farming and household enterprises. This fact has a considerable bearing on the productivity of smallholder plots and on the potential for raising their yields, matters that will be covered in this chapter.

Uganda has the potential to produce the highest yields of tea in East Africa and both the estate and smallholder sectors expanded rapidly in the 1960s and early 1970s. Unfortunately, political factors brought this development to a halt and the industry is only recovering slowly from that blow. In Tanzania, the expansion of the smallholder tea sector was constrained by both economic and political difficulties in the 1970s when international conditions most favored its expansion. In consequence, it is not nearly as large as it could have been. Kenya has had the greatest success in establishing a smallholder tea sector and, although much of the material in this chapter will be drawn from the experience of its 150,000 growers, its technical aspects are equally applicable in the other countries.

Tea is a long-term perennial crop with a productive life of over 100 years that, once established, is grown in pure stand. Yields of made tea from mature bushes on Kenyan estates have risen from an average of 1300 kg/ha in 1963 to 3200 kg/ha in 1991. Smallholder yields now average around 2000 kg/ha. This chapter will consider the factors that have contributed to the rapid growth in yields and to the disparities between estates and smallholders. It will do so under the broad headings of planting materials, agronomic practices and the use of purchased inputs.

PLANTING MATERIALS

Tea gardens developed from seed show wide variations in habit, leaf quality and productivity between plants. This has long been appreciated by growers but it was only the introduction of plastic sleeves and sheeting which provided a technology that was cheap enough to allow for the use of cuttings as a commercial method of producing tea plants. Careful selection of mother trees and the perfection of propagation techniques have provided smallholder tea growers in recent years with uniform plants with a potential for producing large yields of high-quality tea. This development was a major breakthrough in the technology of tea production and today virtually no seedling tea is planted.
AGRONOMIC PRACTICES

Tea's longevity provides both advantages and disadvantages for the grower. Once it is really well established, it is remarkably tolerant of neglect, and completely overgrown gardens that have not been touched for ten years can be brought back into productive bearing in a few weeks with appropriate pruning. On the other hand, poor practices at the time of establishment and in the shaping of the plant's basic frame can lead to reductions in productivity that can never be corrected. The following sections cover plant establishment, shaping, weed control and plucking as being the major agronomic factors determining productivity.

Plant Establishment

The establishment of a crop that is going to be productive for over a century deserves considerable care in the choice and preparation of its planting site. The general area in which tea is to be planted will normally be checked for the suitability of the soil by the staff of the relevant tea authority. Within such an area, smallholders have to be alerted to the need to avoid old homestead sites and cattle pens on which tea will not grow at all well. A major concern at the time of planting should be the establishment of the tea along the contour with adequate soil conservation measures. A number of tea projects in East Africa have put pressure on staff to achieve planting targets in a given period, which has led to laxity with regard to soil conservation on some of the quite hilly land on which tea can be grown. The result of this was serious soil erosion in the early years of establishment, the exposure of tea roots and a depression in long-term productivity that cannot be reversed by any subsequent action. Precision and care rather than speed should be the hallmarks of a development program for a crop of this longevity. Infilling of gaps in established tea is a difficult operation involving the raising of plants in large pots and in consequence is seldom successful in smallholders gardens.

Shaping the Plant

A tea plant left to grow naturally will develop into a tree about 10 m tall. The objective of the grower is to transform the plant into a multi-stemmed low-spreading bush about 1 m tall. There are two ways of bringing about this transformation. The first is to induce the plant to produce 4 to 5 young branches from ground level and then bend these outwards and downwards when they are about 60 cm tall and yet still supple. This immediately produces a low frame about 1 m wide with the main branches a few centimeters from the ground. The branches are pegged down with bracken stalks or small sticks. If properly carried out, the branches quickly shoot along their entire length and the bushes can be brought into plucking from 4 to 6 months later, depending on climate and soil fertility. The advantages of this system are:
(a) the quick establishment of a low, wide permanent frame which is below the level of any subsequent pruning activities;

(b) quick production of a crop. Tea plants brought into bearing in this way will produce some crop within 18 months. This is especially important for smallholders;

(c) early control over weeds. Because almost total ground cover is achieved quickly, much less weeding is required in the second year of establishment as compared with methods involving pruning; and

(d) the plant quickly develops a large root system because it is not being submitted to the shocks and setbacks of pruning. The system has two disadvantages that have discouraged its use by estates and by some smallholders. These are:

(i) collecting pegs and bending the plant takes longer than simply cutting the stems back; and

(ii) the first two weedings after bending are difficult as the plants are not dense enough to suppress weeds but their shape precludes the easy use of a hoe or herbicide.

For the smallholder, both the shorter and longer term benefits of the system are so great that it is an extension message that deserves to be given high priority in any planting program.

The alternative system is to cut the branches back with a series of three prunings. This leads to the development of an increasing number of branches and the formation of a plucking table. The advantages of the pruning system are its speed and the fact that hoe weeding remains possible throughout bush formation. Its disadvantages are that it takes at least a year longer than bending to bring bushes into bearing, does not provide such a wide, low frame for the permanent bush as is achieved by bending, and it involves more weeding in the early years of development, and after subsequent prunings, because the regrowth does not give such a quick cover as the other method.

Once again, extension staff and farmers need to be reminded that they are determining the productivity of a plant for a century and, in consequence, any skimping or shortcuts to save a little time in the development of the basic frame of the plant is a poor management decision.

Weed Control

Tea is grown in areas with plentiful rainfall through much of the year which encourages weed growth. Traditionally, weeds have been controlled by the use of a wide hoe. This destroyed weeds but destroyed tea roots at the same time. Regular cultivation also inhibits the development of a deep surface layer of natural tea-litter mulch. The introduction of effective herbicides completely transformed this situation on the large estates. Their use resulted in:
(a) A weed-free garden. Once existing seedlings had been killed, no fresh seeds were brought to the surface by hoeing and, in large estates, there was little invasion of new weed seeds;

(b) A deep organic mulch developed on the surface of the soil. This counteracted the damaging action of the constant passage of pluckers on wet soil, and improved water penetration and reduced soil erosion;

(c) The strong growth of a surface root system by the tea bushes. This was able to make much better use of applied phosphorus fertilizer, which had previously had little impact. Because phosphorus deficiencies were counteracted, there were greater responses to applications of nitrogenous fertilizer and a sharp rise in yields; and

(d) A sharp decline in labor requirement for garden maintenance.

In short, herbicides brought about a major change in the management and productivity of large estates.

The same technology, however, has had little impact on smallholders and represents the main difference in management between the two groups. Smallholders adopted the use of contact herbicides when they were introduced but soon found that they did not achieve the weed-free conditions of the estates. This meant that they had to persist with the long-term use of herbicides on a regular basis, which proved too costly an option for most farmers. The reason for this is that a typical smallholder tea plot of 0.5 ha is not surrounded by other weed-free tea but by a range of annual crop and fallow land that provides a constant source of weed seeds to re-infest the tea plot. In consequence, smallholders have had to continue to hoe their tea gardens and, therefore, lose out on the advantages that the estates have gained from herbicides. At present, there appears to be no easy technical solution to this impasse but there may be research opportunities for more cost-effective use of herbicides by smallholders.

**Plucking**

If tea is to give high and sustained yields, plants must be regularly plucked at 7- to 14-day intervals, depending on climate and fertility. There are definite flushes in tea growth so that labor demand is not equally spread throughout the year. If the young shoots are not plucked from the bush at the right time they become overgrown. Their removal then takes much longer as the shoot has to be plucked and the overgrown stem broken back. Such delay also leads to considerably reduced yields, as much of the plant’s energy is used producing stems and leaves that have to be thrown away because they are too mature to sell.

In Kenya, one of the main plucking flushes coincides with peak labor demand on the food farm, which puts a strain on the family’s capacity to obtain all of the potential productivity of its crop. For many smallholder tea growers, the shortage of labor for plucking represents the major constraint on production, and is a significant factor in accounting for the difference in yields between estates and smallholders. A family with
0.5 ha of moderately-managed tea will have to pluck at least 200 kg of green leaf during a week in the flush period. On an estate using skilled workers, this would require about six full labor days. On a smallholding, the figure will be far higher for the following reasons:

(a) collection points serving smallholders have to open early in the afternoon to ensure delivery to a distant factory by nightfall. This considerably shortens the "plucking day" by comparison with an estate with its factory on site;

(b) smallholders typically spend 1 to 2 hours per plucker per day carrying the leaf to a collection point. Estate workers normally have to walk only a few hundred yards to deliver their leaf. This further shortens the "plucking day" for the smallholder by comparison with the estates;

(c) in many smallholder gardens, other management constraints limit the number of shoots per bush and this reduces the amount of leaf that a plucker can remove in a given time; and

(d) finally, although a somewhat different aspect, much smallholder tea is plucked by women who have domestic responsibilities, which naturally limits the time available for plucking; and

These factors put smallholders in a weak position in competing with tea estates for labor. All pluckers are paid on the basis of the weight of leaf delivered to a collecting point. Pluckers working for a smallholder cannot pick as much tea as those working on estates. In addition, the estates offer housing, medical and other social services that the smallholder cannot duplicate. The result is that, in a number of areas, tea remains unplucked because of a labor shortage. Where population densities are higher, this is less of a problem and is reflected in the overall productivity of the tea growers. Elsewhere, there is considerable dependence on children for plucking so that there are surges of leaf deliveries to the factories on saturdays and school holidays.

This severe labor constraint at harvest makes tea unique amongst the crops grown by smallholders. It has implications for the other technical factors that determine yield, because there is little point in producing more leaf if it cannot be harvested. Overcoming the constraint is unlikely to be achieved through any technical innovation in plucking systems. The price paid to smallholders will influence their ability to entice casual labor out of other sectors. The efficiency of the collection system can have a considerable impact on the effective length of the plucking day. Extension staff can help farmers to see that paying higher than average rates for pluckers (which they are usually most reluctant to do) can still be beneficial financially when tea will otherwise become overgrown. Natural population growth may diminish the problem over time. For any new smallholder tea development, it is particularly important to plan in the light of the fact that plucking labor can be a major constraint on the level of yields achieved.
The Use of Purchased Inputs

As has been described above, there are few smallholders who have adopted long-term, regular herbicide use. Fortunately, tea in East Africa has so far suffered from few major pests and diseases, so that there is little need for insecticides and fungicides. The main purchased input used by smallholders is, therefore, fertilizer and this section will focus on that.

Because the cropped part of the tea plant is a leaf and not a seed, the quantity of material removed from the field is greater than for most food crops or coffee, and the nitrogen content of that material is greater. A crop of 3000 kg of made tea contains approximately 150 kg of nitrogen and yield levels cannot be maintained unless the plant is being provided with renewed resources of this element. Thirty years ago, it was common practice in East Africa to apply only nitrogenous fertilizer to tea because phosphorus (P) appeared to give little response under research conditions and experiments with potassium (K) were confined to low levels of application, which had little impact. Tea yields had stabilized at around 1000 kg/ha of made tea and increasing the dose of nitrogenous fertilizer had little incremental effect on yields. Work at the Tea Research Institute of East Africa in the 1960s changed this situation. With less disturbance of the soil from cultivation, the uptake of P increased and tea bushes responded to this nutrient. Quite heavy dressings of K counteracted previously unappreciated deficiencies of that element. As a result of a better balance in the nutrition of the bushes, they responded to higher applications of N and average yields climbed rapidly.

The current practice on estates is to use 750 kg/ha of a compound fertilizer containing 25N, 5P, 5K and 5S (sulfur). This should result in a yield of over 3000 kg/ha of made tea. Planters expect to get about 8 kg of incremental made tea per kg of N in the presence of adequate P and K. This offers an attractive return on investment at current prices. Smallholders have appreciated this fact and use fertilizer if it is possible for them to obtain it. Not all use it equally because, for one thing, they may not be able to harvest the incremental crop that it produces. Survey data on the use of fertilizer by smallholders in Kenya are given in Table 18:

These figures do not entirely tally with the national yield figures but they do indicate that smallholders are fully aware of the value of fertilizer, that the best smallholders are obtaining yields comparable to those of the estates, but that large numbers of smallholders are inhibited by other factors from making full use of this input. As has been noted earlier, it is the inability to handle the plucking of heavy flushes of tea that is a major constraint on smallholders benefiting fully from the fertilizers they are already applying. As individuals find ways of overcoming this constraint, it seems likely that they will follow the pattern of their successful neighbors and increase both fertilizer use and yields.
Table 18. Fertilizer Use and Yields Among Different Classes of Kenya Tea Smallholders  
(Yield in kg/ha made tea)

<table>
<thead>
<tr>
<th>% of Survey Population</th>
<th>Mean Level of Nutrients Used (kg/ha)</th>
<th>Yield</th>
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<tbody>
<tr>
<td>Low-input users</td>
<td>20 50N 10P 10K</td>
<td>920</td>
</tr>
<tr>
<td>Medium-input users</td>
<td>60 125N 25P 25K</td>
<td>1,840</td>
</tr>
<tr>
<td>High-input users</td>
<td>20 200N 40P 40K</td>
<td>3,450</td>
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SUMMARY OF THE FACTORS INFLUENCING SMALLHOLDER TEA PRODUCTION

Of the cash crops grown by African smallholders, tea is the only one that is so perishable that it must be collected and processed within a few hours of harvesting. In consequence, the quality of the collection system is a major determinant of the resources that smallholders will allocate to the crop and, therefore, of the level of its productivity. When such services become unreliable, yields will fall and, in the end, tea gardens may be abandoned (e.g., Uganda).

Tea also requires the most sophisticated management of any of the major cash crops. The establishment of vegetative propagation nurseries by smallholders, the laying out of contour lines, the shaping of the plant, the maintenance of the plucking table and the correct feeding of the bushes all require skills that are unfamiliar to new growers. In consequence, an effective extension service is critical to the success of the early years of smallholder tea establishment, until farmers become familiar with the crop.

This chapter has highlighted the constraint that plucking the tea imposes on smallholder productivity. This is a major reason for the difference between smallholder and estate yields. A tea authority can help farmers to overcome this constraint through:

(a) the efficiency and quality of its factory management and marketing. This can make a substantial difference to the price paid to the farmer for green leaf. This, in turn, determines farmers' ability to hire labor and the decision as to how best to allocate family labor; and
(b) ensuring that leaf collection procedures allow as much plucking time as possible, and that the arrangements keep a reasonable balance between the convenience of authority staff and the needs of farmers for more plucking time.

As and when the plucking constraint is overcome, yields are most likely to be raised by a combination of good maintenance of the plucking table with increased fertilizer use. With the exception of weed control, the main reasons for differences in yields of mature tea between estates and smallholders are not linked to differences in the availability of appropriate technology but rather to managerial and institutional constraints.
Chapter 4

A SUMMARY OF SOME PRIORITIES FOR EXTENSION AND RESEARCH

The preceding chapters have highlighted the fact that technical knowledge is available to increase substantially the yields that African smallholders obtain from cotton, tea and coffee and that it is often government policies and managerial performance that limit the use of that technology. Despite the major impact of policies on smallholder performance there are situations in which extension staff can play an important role in helping farmers to increase their productivity, and research workers can help to overcome continuing technical constraints.

With regard to extension staff, a primary concern in many countries must be to reorient the approach of the service so that it becomes responsive to farmers’ actual constraints. All too often, existing extension work consists of exhortations to carry out optimal farming practices without regard for the factors that limit the farmer’s capacity or incentives for adopting them. Examples from the crops being reviewed include the timely planting and weeding of cotton, the reduction of shade and the use of mulch on Robusta coffee, pure-stand planting of Arabica coffee and the regular and timely plucking of tea. The failure of millions of farmers to adopt such advice over the past 25 years has all too seldom been attributed to its lack of relevance but rather to smallholder obduracy. A change in basic attitude and approach is, therefore, a prerequisite for the provision of a more effective service. Some examples of the challenges that such a service could address are given in the following section. This is followed by a brief review of outstanding issues deserving of further research.

CHALLENGES TO EXTENSION

Many of the technical constraints that limit the adoption of ideal practices by farmers for the three crops under review can only be overcome by changes in other sections of the farm. An extension worker who focuses on just one crop will not be effective if the problem can only be solved through changes in the overall cropping system. Whilst there are arguments in favor of specialist staff for high-value cash crops, their effectiveness can be seriously hindered if the fundamental problem lies outside their sphere of influence.

Examples of such situations exist for both cotton and coffee. In the case of cotton, many farmers need help to make changes in their food crop technology so as to reduce the clashes in labor demand at planting and weeding. Row planting and inter-row ox cultivation for weed control in cereals is one such change. Zero tillage or dry planting of grain crops is another possibility. A switch from finger millet to maize on part of a farm would greatly reduce the labor demand for weeding. Land preparation for food crops just after the rains finish is a further possibility. Coffee farmers in areas of high population growth will increasingly need help with the intensification of their food-crop production if they are to
continue to allocate land to pure-stand, high-quality coffee. Alternatively, farmers can
benefit from assistance with the selection of crops and varieties that will provide the best
combination for a coffee and food-crop mixed stand.

With regard to the constraints that are directly related to the crops under
consideration, the challenges to extension workers include:

(a) strategies for achieving rapid but accurate cotton planting on black cracking clay
soils;
(b) the use of ploughs, ridgers or locally made tine cultivators for weeding cotton when
farmers cannot afford more sophisticated ox-drawn equipment;
(c) strategies for the most effective use of limited amounts of pesticides on cotton and
coffee when farmers cannot afford the full recommended regimen;
(d) an understanding of why farmers have largely rejected "scouting" as the basis of
insect control when it has the potential to increase the efficiency of input use on both
cotton and coffee;
(e) assisting Robusta coffee growers to obtain the best balance of coffee plants and shade
trees in relation to their capacity to weed and mulch the crop; and
(f) providing advice on pruning of tree crops on the basis of a thorough understanding
of the fundamental principles involved as they relate to different farmers' needs.

None of these tasks will be carried out effectively by staff who believe that their role
is to exhort or cajole farmers into adopting idealized practices, without reference to the
financial and managerial constraints that have prevented so many farmers from adopting the
same practices in the past.

CHALLENGES TO RESEARCH

This paper has sought to highlight the fact that agricultural research has, at various
points in time, produced technology capable of providing yields that are much greater than
was possible thirty years ago and much greater than those achieved by farmers faced with
managerial constraints at the farm level or with inimical government policies. There are,
however, some areas of the continent and some aspects of production that still call for further
effort. These include:

(a) the problems of cotton production on soils with declining pH. This would involve
the selection of plants with higher than average tolerance to calcium deficiency;
(b) continuing work on lowering both the cost and danger of insect control on cotton and Arabica coffee. In some countries, the advice to farmers has not changed in the past ten years and is often financially unattractive and unacceptably hazardous;

(c) intensifying work on moisture conservation for cotton in drier areas in the face of farmer rejection of the recommended "tied ridges" over so many years;

(d) increasing the ginning-out percentage of cotton. Table 9 indicates the variations that exist between countries and the room for improvement that is possible in areas still accepting out-runs as low as 34 percent;

(e) the development of alternative strategies for reproducing Arabica coffee plants with the desirable features of Ruiru Eleven. The most likely path would appear to be through selfing and selection to stabilize the characteristics of the current hybrid so as to produce seed without hand pollination and emasculation - and also, of course, improved methods of vegetative propagation. Other alternatives include the introduction of a male sterile gene into the female parent line, embryo culture and the use of male gametocide chemicals, and

(f) specific research into weed control in smallholder tea, perhaps involving use of herbicides, because of its difference from estate tea in which research has been so successful in creating an almost weed-free environment.

If any order of priority has to be given to research on these crops, then pest and disease control on cotton and Arabica coffee stands out as a priority area. Pesticide use in Sub-Saharan Africa is dominated by these two crops, and support for both breeding work and the rationalization of the use of chemicals should be seen as priorities on the grounds of human safety, environment considerations and production efficiency. A great deal of relevant research on cotton is available in francophone Africa, whilst coffee breeding has made great progress in Kenya. There is, at present, an abundant scope for expanding the impact of existing information and genetic material, as well as initiating new research programmes. Weed control, including much use of novel herbicides, clearly must also be an on-going research priority.
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The references in the text are used to illustrate specific points relating to the constraints faced by farmers in producing these crops. For a straightforward description of the more detailed aspects of these crops, the reader can refer to the standard textbooks, which for the English reader are typified by those of the Longman Scientific and Technical Series. The references here to research in anglophone Africa are largely drawn from work done prior to 1973 because the Cotton Growing Corporation terminated its research at that time.


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