Causes of low productivity of cocoa in Ghana: farmers' perspectives and insights from research and the socio-political establishment

E.N.A. Dormon[1,*], A. Van Huis[2], C. Leeuwis[3], D. Obeng-Ofori[4] and O. Sakyi-Dawson[5]

[1] Faculty of Agriculture, University of Ghana, P.O. Box 68, Legon, Ghana
[2] Laboratory of Entomology, Wageningen University, Wageningen, The Netherlands
[3] Communication and Innovation Studies Group, Wageningen University, Wageningen, The Netherlands.
[4] Department of Crop Science, Faculty of Agriculture, University of Ghana, Legon.
[5] Department of Agricultural Extension, Faculty of Agriculture, University of Ghana, Legon.
[*] Corresponding author (e-mail: edormon@hotmail.com)

Received 31 May 2004; accepted 14 December 2004

Abstract

Ghana is a major producer of cocoa in the world and relies heavily on the crop for foreign exchange revenue. However, production declined since the mid-1960s, reaching its lowest level in 1983. Although production has increased consistently since the mid-1980s, it still is less than the level attained in the mid-1960s. The decline is partly a result of decreasing areas under cultivation. Another problem in cocoa production in Ghana is low yields per ha, which is attributed to the incidence of pests and diseases, a low producer price, and non-adoption of research recommendations. Based on the idea that current research and extension messages might insufficiently address farmers' actual problems and context, a diagnostic study was carried out to better understand farmers' views on the problems of cocoa production. The study was conducted in three villages in the Suhum-Kraboa-Coalter District, Eastern Region, Ghana. An action research approach was followed to gather and analyse qualitative data with the objective of stimulating collective action in subsequent research activities with the farmers. Low productivity was identified as the main problem and the causes were classified into biological and socio-economic factors. The biological factors include the incidence of pests and diseases, most of which have received extensive research attention in Ghana, and of epiphytes, which have been neglected. The socio-economic causes were indirect and include the low producer price and the lack of amenities like electricity, which leads to migration, with as a result labour shortages and high labour costs. From the study it can be concluded that the biological and socio-economic causes of low productivity are inter-related in

such a manner that tackling them separately will not overcome the problem unless the socio-technical nature of the causes are recognized and tackled in a holistic way. In this context, current interventions by research and extension seem to ignore important aspects of the problematic situation. Although the study shows the relevance of using a diagnostic approach, it is argued that outcomes may be affected by various contextual factors, including stakeholder selection and the relationship between the researcher and the participants. Hence, the outcomes of a diagnostic study should be approached with care.

Additional keywords: diagnostic study, participatory action research

Introduction

Ghana is one of the major producers of cocoa in the world. The crop contributed about 3.4% to total gross domestic product annually and an average of 29% to total export revenue between 1990 and 1999 (Anon., 2001) and 22% between 2000 and 2002 (Anon., 2003). However, production levels have consistently declined from 568,000 Mt in 1965 to its lowest level of 160,000 Mt in 1983. Since the mid-1980s, production levels have risen gradually to an average of 400,000 Mt during the late 1990s (Anon., 1999; Abekoe *et al.,* 2002), which still is considerably less than the production levels attained in the mid-1960s. The decrease in production in the early 1980s was attributed by government to adverse weather conditions that led to widespread bush fires, destroying many cocoa farms (Anon., 1999). Although some burned cocoa farms have been replanted with cocoa, other ones have been abandoned or the land has been used for the production of other crops, thereby reducing the area under cultivation (Anon., 1999).

Generally, yields of cocoa are lower in Ghana than in other major producing countries. Whilst the average cocoa yield in Malaysia is 1800 kg ha^{-1}, and 800 kg ha^{-1} in Ivory Coast, it is only 360 kg ha^{-1} in Ghana (Anon., 1999; undated). Reasons for the low productivity include poor farm maintenance practices, planting low-yielding varieties, and the incidence of pests and diseases (Anon., 1999; Abekoe *et al.,* 2002). Poor farm maintenance practices are attributed to the low prices paid to Ghanaian cocoa farmers (Anon., 1999). The above reasons largely represent the views and perceptions of policy makers and researchers, and not necessarily those of farmers.

In an attempt to increase production, the government has been implementing policies aimed at reforming the cocoa sector since the early 1990s. In 1999, the government adopted a development strategy with the objective of improving the performance of the cocoa sector. Under this strategy, production levels are expected to reach 700,000 Mt by the year 2010 (Anon., 1999). The resulting reforms have led to the liberalization of the internal marketing of cocoa and to increases in the producer price from 56% to 70% of the fob ('free on board') price over the period 1998/1999–2004/2005 (Anon., 1999). The fob price is the price at which government sells cocoa to foreign buyers and includes, apart from a profit margin, all costs incurred in buying and transporting the beans to the port. The cocoa sector development strategy has also involved shifting responsibility for cocoa extension services from the Cocoa Services Division, a subsidiary of the Ghana Cocoa Board (COCOBOD) to the Ministry of Food

and Agriculture (MoFA). In addition, since 2001 the government has mass-sprayed all cocoa farms under the Cocoa Diseases and Pests Control programme at no direct cost to the farmer. Since 2003, the government has also started an interest-free credit scheme called the Cocoa 'Hi-Tech' Programme, which aims at increasing productivity by providing fertilizers and pesticides. In its first year, 50,000 farmers benefited from this programme, a number that increased to 100,000 one year later. The 'Hi-Tech' Programme is managed jointly by the Cocoa Research Institute of Ghana (CRIG), COCOBOD and MoFA.

The extent to which the government's cocoa sector development strategy would adequately meet the needs and aspirations of farmers remains yet to be seen. Although the strategy attempts to tackle both economic (liberalized market and pricing policy) and technical issues, the overall strategy remains essentially a top-down linear approach with limited institutional reforms. Also the agenda for research on cocoa is drawn up in the linear fashion of technology development and transfer (Chambers *et al.,* 1989): CRIG develops technologies that are carried by the agricultural extension system as recommendations for farmers to adopt. Some of the technologies include the development of high-yielding hybrid varieties, breeding of cocoa types resistant to Swollen Shoot and Black Pod disease, control of capsids with insecticides, various cultural practices to control shade, and weed control (see Anon., 1997; 2000a). However, most of these recommendations have not been widely adopted by farmers, who either do not find the recommendations relevant, not applicable at the farm level, or not compatible with the prevailing production systems. For instance, a survey of 1750 cocoa farmers in 1997/1998 showed that full adoption of research recommendations for pest and disease management was only 3.5% (Gerken *et al.*, 2001).

It has been argued by many that the most promising way to make research findings and government policies relevant and acceptable to farmers is to base research and policy assumptions on the needs as expressed by the farmers and on the difficulties they face. In the early 1970s, farming systems research and on-farm research were introduced to help researchers better understand farmers' technology needs and attempt to meet those needs (Okali & Sumberg, 1986; Chambers *et al.,* 1989; Ashby, 1991). Although farming systems research has helped in improving the understanding by scientists of production systems and in identifying gaps in existing technologies, it still has some limitations. One criticism of farming systems research is that it pays little attention to policy issues (Okali *et al.,* 1994). Other shortcomings include the late involvement of farmers, mostly at the testing and adapting stage of technology development – which was basically a linear technology development process – rather than in the initial stage of identifying and prioritizing research problems. It is also characterized by initiatives coming from researchers and not from farmers, who are given a reactive rather than a proactive role. So one of the major challenges of farming systems research and extension that remained was how it could be made into a genuinely participatory activity in which farmers are not passive recipients of technology but key players in identifying, analysing, designing and implementing research activities (Conway, 2001). Following the shortcomings of farming systems research, farmer participatory research has been proposed (Okali *et al.,* 1994). Two key principles of farmer participatory research are: (1) farmers actively seeking and testing new

techniques and ideas, and (2) the potential synergy through interaction of formal agricultural research and farmers' own research (Okali *et al.*, 1994). The aim of participatory research at a technological level is for the stakeholders to understand the characteristics and dynamics of the agro-ecosystem within which the community operates, to identify priority problems and opportunities, and to experiment with a variety of technological options based on the ideas and experiences derived from indigenous knowledge and formal science. Although the proponents of farmer participatory research have tried to distance it from farming systems research, Okali *et al.* (1994) argue that they share many common roots. A limitation of participatory research with farmers is that it tends to have a strong local and technology focus and frequently fails to address wider social issues. In other words, by focusing on 'appropriate technology', there is a risk that current social arrangements and conditions are taken for granted and left intact, even if these conditions would merit change. This is at odds with recent insights from innovation studies, emphasizing that successful innovations consist of a coherent package of both new technical devices and practices and new social-organizational institutions and relationships at various societal levels (see e.g. Rip, 1995; Geels, 2002; Leeuwis & Van Den Ban, 2004).

Taking into account these earlier attempts at involving farmers in research and the challenges that were encountered, a project called 'Convergence of Sciences' (CoS) was set up. This CoS Project is experimenting with a farmer participatory research approach that adopts technographic and diagnostic studies as a method of identifying opportunities for both social and natural science investigation, and grounding such research and its design in farmers' needs (see Röling *et al.*, 2004). During the initial phase of the CoS project, cocoa was identified as an important public crop in Ghana and was one of three crops on which technographic studies were carried out. The technographic study on cocoa identified the incidence of pests and diseases as a major problem facing cocoa production. It also identified, amongst other things, poor extension services, weak farmers' associations, and low producer prices, as affecting the cocoa industry. Whereas technographic studies focus on the national level and aim at identifying opportunities for innovation by mapping the technological landscape in a specific sector (e.g. cocoa), diagnostic studies identify and analyse specific research problems with the active participation of farmers, evaluating options and selecting possible solutions that would work in their conditions. Therefore, as a follow-up to the technographic studies on cocoa, the objective of this study was to use a 'diagnostic' approach to determine farmers' perceptions about the problems facing cocoa production vis-à-vis the views from research and government officials, as a first step in an interactive participatory research process with farmers.

Materials and methods

Research approach

An action research approach has been adopted for the whole research process, including this diagnostic study. In action research, theory and practice are constantly

reviewed through experience, reflection and learning (Bawden, 1991; Scoones, 1995; Dick, 1997a, b). This approach was useful for the study because it brought some commitment on the part of the farmers and other stakeholders, an important pre-condition for further joint action and learning in subsequent research activities.

To collect information on the social dynamics and perceptions of farmers, qualitative methods were adopted in gathering data and information for the diagnostic phase. Various tools and techniques such as the problem tree, scoring, and ranking exercises were used in a participatory manner to gather and analyse qualitative data for joint planning and collective action in subsequent research phases. Semi-structured interviews were used to gather the views and seek clarifications on issues raised by farmers, from extension agents, researchers, licensed cocoa buying companies and policy makers.

The study area

The diagnostic study was carried out between September 2002 and February 2003 in the Suhum-Kraboa-Coaltar District, Eastern Region, Ghana (Figure 1). The district, with Suhum as capital, is located in the forest zone. The average daily temperature in the district ranges from 24 to 29 °C with a relative humidity between 87 and 91% (Anon., 2000b). Annual rainfall varies between 1270 and 1651 mm (Anon., 2000b). Out of a total population of about 170,000 inhabitants, 64% are farmers by occupation (Anon., 2000b). About 40% of all farmers in the district cultivate cocoa (Y. Dotse, District Director of Agriculture, personal communication) on an area of 8720 ha, representing about 20% of the total area under cultivation (Anon., 2000b).

The Suhum-Kraboa-Coaltar District was selected because of a long history of cocoa production and its proximity to CRIG. Another reason was that the implementation of the Eastern Region Cocoa Project in the study area between 1970 and 1979 resulted in the rehabilitation of cocoa farms and the training of farmers in improved methods of cocoa production (Amoah, 1998). Three villages, Adarkwa, Achiansah and Kojohum, were selected for the study in consultation with the District Director of Agriculture after initial visits to six villages with three extension agents of the District Agricultural Office (Figure 1). The determining factor for selecting the three villages was an assessment of the importance of cocoa production.

Adarkwa

Adarkwa is about 8 km from Suhum. The main occupation of the people in the village is farming with cocoa as major crop. All cocoa farmers produce food crops in addition to cocoa and some of the male farmers engage in other income-generating activities like tapping palm wine and masonry. For the women petty trading is common. Generally, women who do not own cocoa farms help their husbands on their farms. All cocoa farmers in the community were invited to participate in the study.

Achiansah

Achiansah is about 20 km from Suhum and is located in one of the major cocoa growing areas in the district. The agricultural extension agent (AEA) helped in selecting

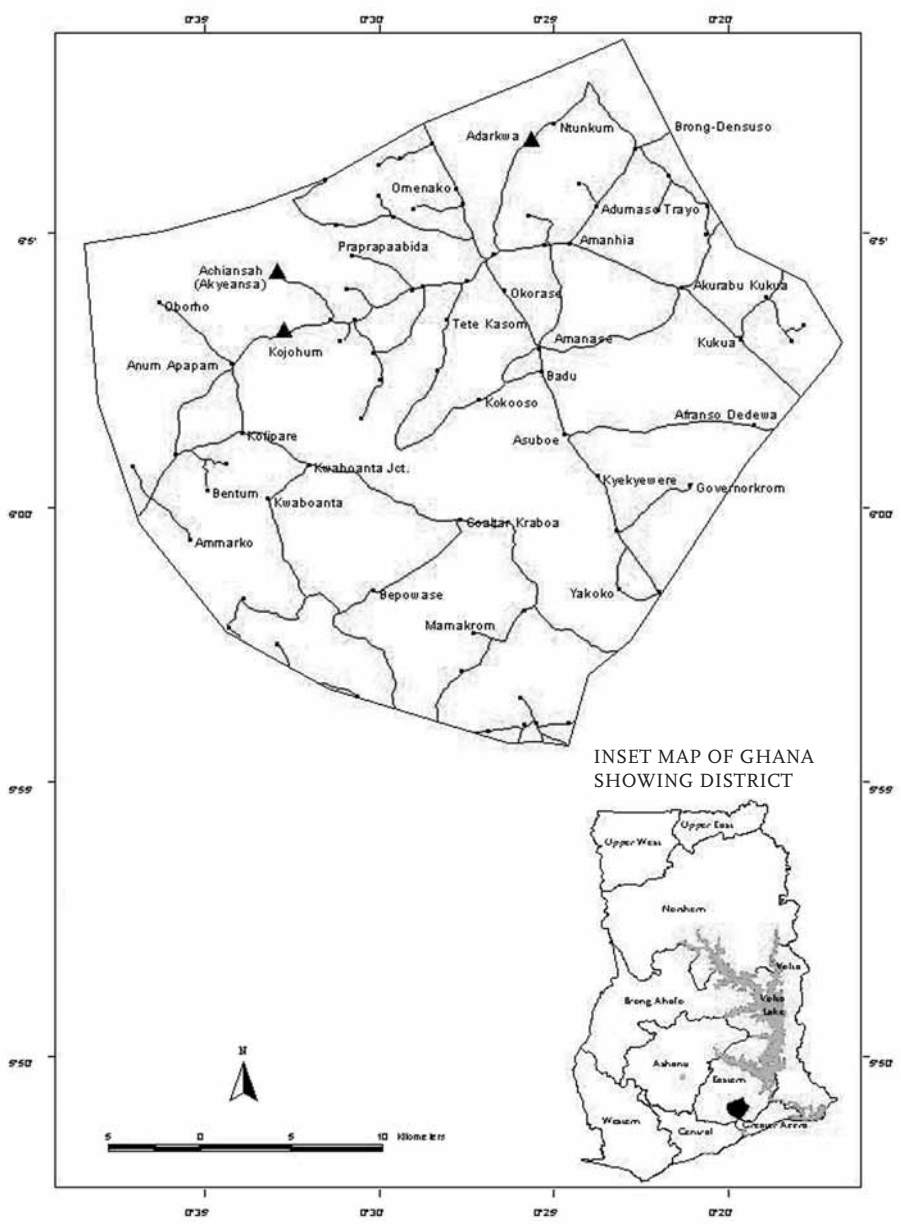

Figure 1. Map of Suhum-Kraboa-Coaltar District, Ghana, indicating study areas (▲).

two of his farmers' groups for the study, the Victory Farmers Group and the *Gye se wobre* Group. The Victory Farmers Group has 16 members all of whom are Akwapims and also belong to the same church. The *Gye se wobre* Group is made up of 15 farmers

belonging to the Krobo ethnic group, and has a somewhat broader interest in both crop (including cocoa) and livestock production. ('*Gye se wobre*' literally means 'you must work hard before you can achieve your objectives'.) The farmers in both groups are descendants of migrant farmers who settled at Achiansah in the early part of the 1920s with the objective of growing cocoa.

The AEA had been working with these two groups since 2000. The decision to select specific farmer groups was the result of the experience with the 'open' invitation to all cocoa farmers in Adarkwa, which turned out to be cumbersome because of the large number of farmers that turned up for the meeting. So existing farmer groups were selected instead, which resulted in relatively more homogeneous groups in the sense that they had come together to interact with the extension agent on agricultural issues. Selecting farmer groups with whom the AEA had been working for some time also provided a different scenario from Adarkwa and hence an opportunity to observe and learn from any difference that this approach could make in determining the outcomes of the study.

Kojohum

The third village, Kojohum, is about 30 km from Suhum. It serves as a centre for many settlements of cocoa farms within a radius of about 2 km. However, after six months Kojohum was dropped from the study because we made little progress probably due to the approach adopted for selecting farmers in this village. We did not select particular farmer groups (as we did in Achiansah) or invite all cocoa farmers in the community (as was done in Adarkwa). Instead, the chief farmer invited representatives from five surrounding villages and hamlets to Kojohum, the village where he lives. This is a normal practice when they have to meet and discuss issues relating to cocoa production or development issues in general. This approach seemed attractive as it offered a scenario different from the two other villages. Unfortunately, different people kept turning up and on each occasion the new persons attending the meeting had not been briefed by the previous participant thereby retarding progress (only about four out of 20 farmers attended the meetings regularly). This situation defeated the action research philosophy where continuity in the action, reflection and learning cycle is an important ingredient.

The research process

In each village, the process started with a community meeting followed by community mapping, participatory problem identification, analysis, prioritization and action planning. The overall research process is illustrated in Figure 2. This paper presents the results of the process from community meeting up to the prioritization phase. The methods used at the three research sites are summarized in Table 1.

The study started in Adarkwa with a community meeting to explain the objectives of the study to the farmers, followed by similar meetings in Achiansah and Kojohum. The participatory action research philosophy of the study was explained to the farmers, who were encouraged to be frank and open in their interaction with us and to learn from each other. The objective of the community-mapping step was to bring to the

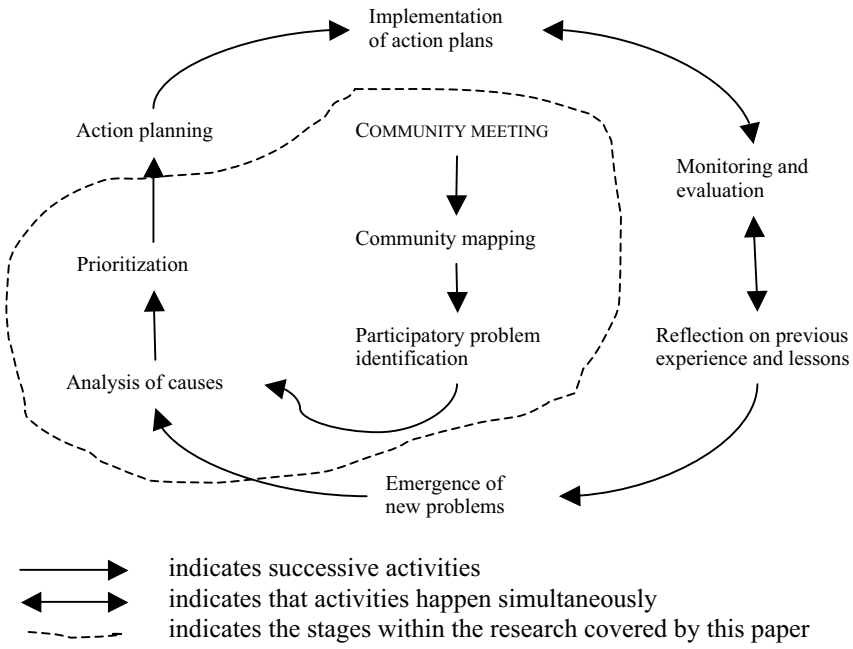

Figure 2. Overall set-up of the action research.

open the resources available in the community through visualization. The pictorial representations of information formed a central element of participatory analysis and learning by stimulating participants' memories and facilitating discussions by both literate and illiterate participants (see Pretty *et al.,* 1995). Farmers showed a lot of enthusiasm in sketching maps of their community. Because of the large number (126) of farmers present in the case of Adarkwa, sub-groups were formed enabling each person to participate in the exercise. Each sub-group produced their own sketch of the community and the leader of each sub-group presented their sketch to a plenary session. The fun and enthusiasm created a good atmosphere for interaction and this was capitalized upon to carry the farmers' interest and enthusiasm into the next step by asking them to recollect that exercise on the next meeting day when problem identification commenced. In Achiansah and Kojohum, each of the farmer groups mapped their community for the same reasons as in Adarkwa.

The next phase involved problem identification. Farmers mentioned all the issues considered as problems that affected cocoa production. In Adarkwa about 30 issues were listed after which the issues were discussed in detail and analysed. The farmers explained the cause and effect relationship between the issues and categorized them into main problems, causes and effects of the problem. In Adarkwa, a problem diagram was constructed to show the relationship between the categories of issues listed. Because of the large number of issues that were raised at Adarkwa, the use of the problem-tree technique was appropriate in facilitating the visualization of the relation-

Table 1. Processes and methods used in the three study areas for the identification and prioritization of the causes of low cocoa yields.

Stage in the diagnostic study	Study area			
	Adarkwa	Achiansah		Kojohum
		Victory Farmers Group	*Gye se wobre* Group	
Community meeting	The whole community was invited.	All members (16) of the group were invited.	All members (15) of of the group were invited.	Four representatives of 5 surrounding villages were invited.
Problem identification	Problems were identified and listed by all members of the community present. A problem diagram was used to show the relationship between the main problem, its causes and the effects.	Problems were identified by members of the group. The main problem was identified and causes listed and discussed.	Problems were identified by members of the group. The main problem was identified and causes listed and discussed.	Problems were identified by representatives of the surrounding villages. The main problem was identified and causes listed and discussed. The process, however, stopped during the analysis phase.
Prioritization (ranking) of causes of the main problem	All members of the community present prioritized the causes using a pair-wise ranking method.	Members of the group prioritized the causes using a simple scoring and ranking method.	Members of the group prioritized the causes using a simple scoring and ranking method.	
Action planning	Strategies to overcome the listed causes of low yields were formulated by all members of the community present at the meeting.	Strategies to overcome the listed causes of low yields were formulated by the group members.	Strategies to overcome the listed causes of low yields were formulated by the group members.	

ships between different factors. The groups in Achiansah raised fewer issues, which were easy to relate to the main problem, so that it was not necessary to use the problem tree. Kojohum was dropped from the study at this phase because of inconsistencies in problem identification and analysis resulting from different persons representing their villages at each meeting (see above).

A pair-wise matrix ranking technique was used for determining the relative importance of the causes of low cocoa yields identified in Adarkwa. With this method a

matrix was developed where the farmers compared each item they listed as a cause of low yields directly with all the other causes. This turned out to be extremely cumbersome and difficult because of the large number of factors under consideration (16 × 16 matrix): it took two meetings to complete the process. As a result, the simpler techniques of scoring and ranking were adopted with the Achiansah groups. After the exercise, each factor in the matrix was reflected upon in order to increase our understanding of the complex situation in terms of relationships between causes, problems and effects. In the action planning, specific strategies and activities were identified through discussions involving the nature of causes. In the case of pests and diseases, the mode of spread and the type of damage were discussed. Strategies were agreed upon through negotiations after considering the options available and the role that various stakeholders could play in tackling them.

Semi-structured and informal interviews were held with some farmers to get a better understanding of issues that were not exhaustively discussed during group meetings. They also provided a better understanding of the history of cocoa production in the area, which was important in getting the right context of the issues discussed during group meetings. Notable among the farmers interviewed was the Chief of Adarkwa (Nana Adarkwa Yiadom II), who was 80 years old and knew a lot about the history of cocoa production in Ghana. Also officials of some licensed buying companies (LBCs) were informally interviewed. They included the regional manager of Kuapa Kooko Ltd, the managing director of Federated Commodities Ltd (FEDCO), and purchasing clerks of Kuapa Kooko, FEDCO and Adwumapa Ltd. Informal interviews were also held with officials of the Ghana Cocoa Board, the District Cocoa Officer at Suhum, and some scientists at CRIG. Most of these discussions were to clarify issues farmers had raised and to feed back that information to the farmers in subsequent meetings.

Some information was gathered during visits to the research location through participant observation. This was done during meetings by observing the interactions between the farmers and the persons who spoke about the issues. This was useful in providing some explanations about the views expressed by different people and, in some cases, why they took particular positions.

Validations were done in two stages, firstly through community feedback meetings with each group in their communities, and secondly through a workshop to which all the actors in the cocoa sector were invited. The actors included researchers, cocoa LBCs, commercial and rural banks, the Cocoa Services Division, and staff from the extension services of MoFA. After presenting the results of the study, each category of actors was invited to comment. Although the issues raised by farmers had been discussed with the other actors independently, bringing everybody together in this validation workshop allowed for a more representative forum for mirroring diverging perspectives on the situation. The workshop also helped to develop a better mutual understanding of the problems and to explain why some of these had persisted for such a long time.

Results and discussion

The problems in Adarkwa

The main problem identified by the farmers in Adarkwa was the low yield of cocoa, which was attributed to several factors. The causes and effects of low yields are illustrated in Figure 3. Issues about mistrust (mistrust among fellow farmers, not trusting government officials especially regarding government policies on cocoa, LBCs, research, etc.) kept surfacing as part of the reasons why certain causes persisted although 'mistrust' was not specifically listed as a cause of low yields. The farmers ranked the low producer price paid to cocoa farmers and the lack of electricity as the two most important causes of low yields (see Table 2).

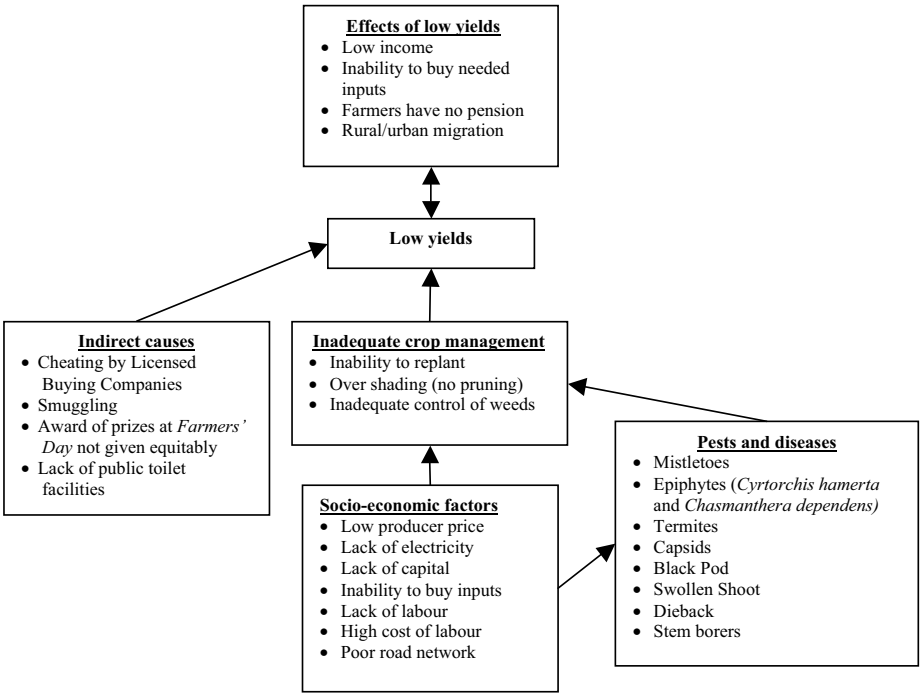

Figure 3. Problem diagram constructed jointly with farmers in Adarkwa.

The problems in Achiansah

The Victory Farmers Group identified low yield as the main problem facing cocoa production, estimating that current yield levels were between half and one-third of what they obtained 15–20 years ago. A remarkable difference between causes identified by

Table 2. Causes of low cocoa yields as ranked by the farmers in Adarkwa and Achiansah (Victory Farmers Group and the *Gye se wobre* group) , and their relative importance.

Ranking	Adarkwa (n = 62)		Achiansah (Victory Farmers Group) (n = 14)		Achiansah (*Gye se wobre* Group) (n = 15)	
	Cause	Relative importance (%)	Cause	Relative importance (%)	Cause	Relative importance (%)
1	Low producer price	20.0	Mistletoe *(Tapianthus bangwensis)*	17.5	Capsids	16.6
2	Lack of electricity	18.7	Epiphyte (*Bulbophyllum* spp.)	15.7	Non-availability and high cost of spraying equipment for pest and disease control	16.4
3	Lack of labour	17.3	Capsids	13.6	Black Pod disease	15.7
4	Inability to buy inputs & lack of capital	14.7	Swollen Shoot disease	12.5	Mistletoe *(Tapianthus bangwensis)*	11.9
5	Inability to replant old farms & high cost of labour	13.3	Shield bugs	10.7	Non-availability on open market of pesticide (Confidor; a.i. imidacloprid) for capsid control	7.6
6	Swollen Shoot disease & mistletoe *(Tapianthus bangwensis)*	9.3	Epiphyte (*Chasmanthera dependens)*	9.6	High cost of input	6.1
7	Capsids, orchids, woody climbers, termites and stem borers	5.3	Stem borers	7.1	Insufficient capital and no access to credit	5.7
8	Black Pod disease	1.4	Black Pod disease	6.4	Epiphyte (*Bulbophyllum* spp.)	4.6
9			Black ants	3.9	Swollen Shoot disease	4.0
10			Termites	3.0	High interest rates	3.5
11					Stem borers	2.3
					Non-availability of hybrid seedlings or pods	2.3
12					High labour costs	1.7
13					Sudden death of cocoa trees around a tree locally called *cocoa gbe tso* (literally 'the tree that kills cocoa')[1]	1.6

[1] This problem was mentioned by two farmers only; most others did not know about it. Enquiries at the Cocoa Research Institute of Ghana could not confirm that the tree was responsible for the death of the cocoa trees around it.

farmers in this group and those in Adarkwa was the focus on technical issues rather than on socio-economic and infrastructural development.

The group did not focus on lack of infrastructure although the members live in a deprived outskirt of Achiansah (at about 2 km distance) with a very poor road leading to the community; they have no electricity, no schools or other social amenities. The only non-residential building in the community is the church.

The *Gyese wobre* Group identified low cocoa yields as the main problem. They explained that they obtain an average of 248 kg ha^{-1} against 496–620 kg ha^{-1} 15–20 years ago. The average yield figures given are difficult to verify because the farmers do not keep long-term records of production levels or areas under cultivation. The farmers identified, scored and ranked the causes of low yields (see Table 2).

The *Gye se wobre* Group identified both technical and socio-economic causes of the low yields. These included the incidence of capsids and Black Pod disease and the difficulties in acquiring spraying equipment and chemicals to control these pests. The group was unhappy with the fact that in 2001 government took over the spraying of their farms under the 'mass spraying' exercise. They would have preferred that the government had paid them the money for the mass spraying directly or indirectly through better producer prices. However, they admitted that they had not sprayed their cocoa to control capsids or the Black Pod disease for at least 10 years until the government started the spraying exercise and also that most farmers would not spend their money on buying pesticides even if better producer prices were paid. The farmers complained that the people recruited by the government to spray their farms (the spraying gang) were not doing a good job. They argued that because the gangs are paid on the basis of area covered, they aim at spraying as much acreage as possible rather than patiently spraying the canopy to target the capsids.

The group identified other socio-economic causes, including the level of producer prices paid by government to cocoa farmers, difficulties in accessing credit, high cost of labour, and high interest rates charged by moneylenders.

Persistence of pests and diseases, and their effect on yield

The biological causes identified by the farmers were pests and diseases, and parasitic and epiphytic plants. The incidence of pests and diseases has persisted and contributed to low yields because of inadequate crop management (Figure 4). We analysed the farmers' understanding and perception of the biological causes of low yield vis-à-vis the views of actors like researchers, extension workers and policy makers.

The incidence of cocoa pests and diseases as a cause of low yields has been known and documented by many researchers over the years. Insect pests such as capsids, shield bugs, and diseases like Black Pod and Swollen Shoot have received extensive research attention (Thorold, 1975; Wood & Laas 1985; Anon., 1997; Acquaah, 1999; Wilson, 1999). The farmers were very familiar with these pests and diseases and admitted receiving information from extension agents about control methods. Most farmers, however, did not control any of these pests and diseases and attributed this to the high costs of pesticides, spraying equipment, and labour. The farmers argued that

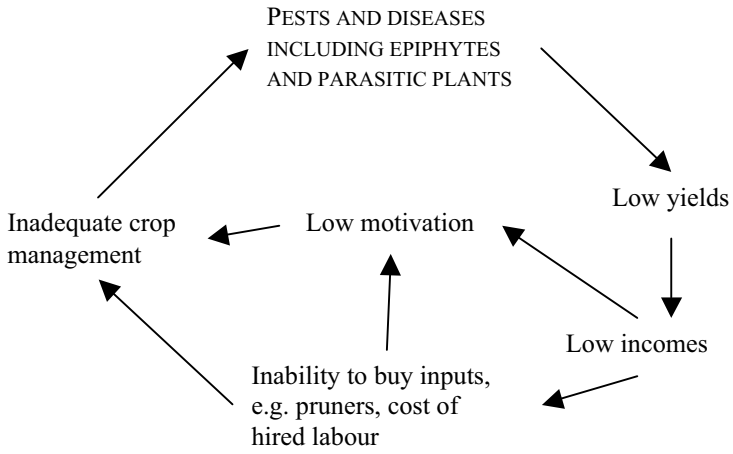

Figure 4. Effects of pests and diseases on yield.

their inability to buy the necessary inputs was due to the low producer prices paid by government. This point will be discussed below.

During the problem-analysis phase in the three study areas, it turned out that although the farmers had in-depth knowledge of some of the common pests and diseases, in some cases they did not know their mode of spread. An example is the Black Pod disease. Farmers admitted receiving advice on chemical control as well as on agronomic practices like shade management to reduce humidity, but they did not know the mode of spread probably because of the invisibility of the spores of the fungus to the naked eye. In situations where farmers could easily visualize the mode of spread, it was easy for them to explain and appreciate the direct benefit of adopting certain practices. An example is the spread of mistletoes. Here the farmers were aware that birds feed on the seeds and spread them to other trees when they clean their beaks after feeding, i.e., the same mode of spread recorded by Wilson (1999). According to Wood & Laas (1985), however, mistletoes are spread through the birds' faeces. The seeds pass the birds' digestive system undigested and germinate on the bark of young branches. For the farmers the birds cleaning their beaks and leaving seeds behind was visible but they did not know about the seeds spreading via the faeces. Also other authors observed that farmers have good knowledge about objects in nature they can easily observe whereas less conspicuous ones may escape their attention (Van Huis *et al.*, 1982; Bentley, 1992; Van Huis & Meerman, 1997).

The parasitic mistletoe *Tapinanthus bangwensis* was identified as a cause of low yields in the study area. Epiphytes identified were *Bulbophyllum* spp., *Chasmanthera dependens* and *Cyrtorchis hamerta*. The Victory Farmers Group ranked mistletoes and *Bulbophyllum* spp., as the two most important causes of low yields. In Adarkwa, the farmers ranked the parasitic and epiphytic plants as the second most important causes of low yields after the socio-economic ones. Mistletoes have been documented as parasitic plants of cocoa (Thorold, 1975; Wilson, 1999). However, there is little information

on *Chasmanthera dependens* and *Cyrtorchis hamerta* as epiphytic plants on cocoa and their impact on cocoa yields.

Although epiphytes have been observed as pests of cocoa (Thorold, 1975), it was not expected that a group of farmers would rank them as the most important cause of low yields because generally, epiphytes have not been considered major pests of cocoa by formal research. This is evidenced by the fact that a review of 24 publications from CRIG and the Cocoa Services Division between 1977 and 1997 (see Anon., 1997), which formed the basis of extension messages on cocoa, did not mention anything on the incidence and control measures for epiphytes. Discussions with a researcher at CRIG as well as with farmers suggested that epiphytes have become major pests in the study area because of long neglect and non-maintenance of cocoa farms (Kojo Acheampong, personal communication).

Bulbophyllum spp. have a very aggressive root system that covers the stem completely if not removed in an early stage. Where the root system covers the stem completely, it is possible that the epiphyte will interfere with the development of buds on the plant's stem (Thorold, 1975), probably causing substantial yield loss. Thorold (1975) reported that studies in Nigeria on foliaceous epiphytes in cocoa did not show any apparent effect of their presence on the number of pods per tree. Observations at Achiansah, however, learned that although the incidence of *Bulbophyllum* spp. is not prevalent on the farms, in isolated cases where they occur, they appear to have a smothering effect on the infested trees: the trees showed signs of dying. At CRIG, work on *Bulbophyllum* spp. has been carried out since 2000.

Inter-relationship of socio-economic and biological causes of low yield

From the results it appears that the farmers' inability to carry out adequate pest and disease control measures can be attributed largely to socio-economic factors. The most important ones are the low producer price of cocoa, leading to low investment in crop management, labour shortage and high cost of labour, and poor infrastructure in farming communities.

In Adarkwa, out of 16 causes of low yields identified, the farmers ranked the price paid for cocoa as the most important one of low yields.

Both the Victory Farmers Group and the *Gye se wobre* Group expressed their displeasure at the producer price of cocoa although they did not list it as a direct cause of low yields. The farmers articulated the relationship between the low producer price and low yield as illustrated in Figure 5. A low producer price leads to low income per unit cocoa produced. The farmers contended that they do not invest part of the income from cocoa in their farms because what they earn is not adequate to meet their needs. They also argued that it was the government that benefited most from cocoa because it does not only tax their produce directly but also enjoys taxes from the numerous LBCs. In the farmers' view, the one who benefits most from cocoa production should be responsible for the enterprise and therefore the government should invest in cocoa farms by providing free or subsidized inputs. They illustrated their relationship with the government as one of an *abusa* system, where the government is behaving like the landlord and taking two-thirds of the revenue, as is the normal practice with the *abusa*

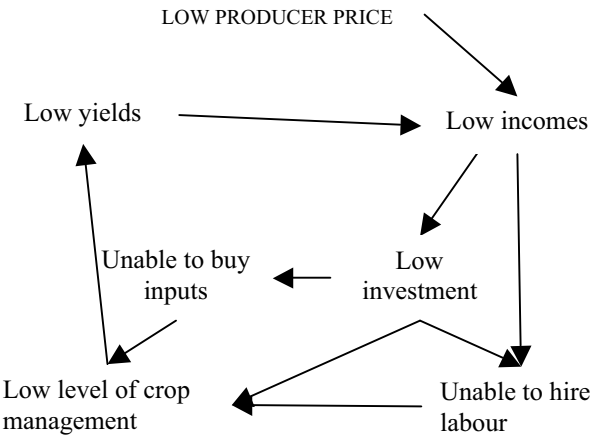

Figure 5. Effects of low producer prices on yield.

tenure system. The farmers' reference to the *abusa* system symbolizes their feeling of being cheated by the government, which – in their view – does not meet its responsibilities as the prime beneficiary. At the same time, it is indicative of the farmers' perspective regarding the 'ownership' of cocoa production and its problems.

A low producer price as a disincentive to cocoa farmers has been noted by some researchers (Koning, 1986; Acquaah, 1999) and by the government of Ghana (Anon., 1999). In the 1983/1984 season, when the lowest cocoa production level was recorded in Ghana, the producer price paid to farmers was 21.3% of the fob price (COCOBOD records cited in Amoah, 1998). Currently, as part of the government policy in revamping the cocoa sector, producer prices have been increased to 68% in 2003 and are expected to reach 70% in 2004. These increases are intended to motivate farmers to produce more cocoa. However, the farmers do not believe that the government is paying anything close to 68% of the fob price and they quote the world market price to support their position, but the world market price is different from the fob price. Government on the recommendation of the Cocoa Price Committee sets the fob price and the farmers have a representative on that committee. The fob price usually differs from the world market because of the 'forward sales' policy of the COCOBOD. This means that cocoa delivered to foreign buyers at any point in time has already been sold at an earlier date and the price at which it was sold is not necessarily the same as the world market price at the time cocoa is delivered.

The government considers many factors when setting the producer price of cocoa. Among these factors are: world market price trends, the objective to establish a price stabilization fund, the general expectation of farmers that the producer price should only be increased or at least maintained irrespective of the trend of world market prices, and the anticipated effect of producer price on the farmers' morale (Amoah, 1998). Because of the farmers' perception of being cheated by government, they question why they are not allowed to sell their cocoa freely on the international market like

with fruits such as pineapple. The farmers do not have adequate knowledge of the complex nature of international trade in primary commodities like cocoa and therefore do not realize that they cannot easily sell their produce directly on the international market. They attributed the smuggling of cocoa to neighbouring countries by some farmers to the low producer price, a point also noted by Koning (1986) and Acquaah (1999). A significant observation during the study was that extension messages focus on technical issues and not on government policies, so most farmers are unaware of government policy regarding producer prices and how the farmers' share of fob is determined. Such information is only available at a high level of the COCOBOD and not to farmers and extension staff in the field.

In Adarkwa, the lack of electricity was ranked as the second most important cause of low yields. The farmers showed a direct relationship between the lack of electricity and youth migration to the cities (Figure 6). Youth migration creates labour shortage, leading to high labour costs. Youth migration also leaves the aged farmers in the village to take care of the farms. The relatively old age of cocoa farmers, estimated at 55 years (Addo, 1973; Anon., 1999), was listed as one of the reasons for the low production of cocoa over the years.

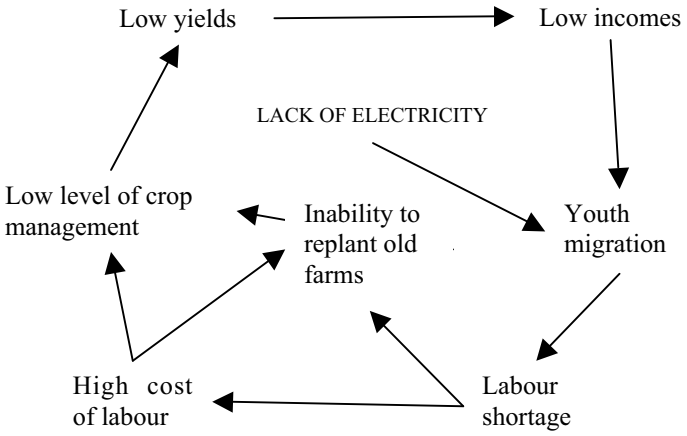

Figure 6. Effects of lack of electricity on yield.

Cocoa production requires many cultural practices that are labour intensive: four weeding rounds per year, removal of mistletoes and other epiphytes, shade management through pruning, and removal of basal suckers. In addition to the cultural practices there are other labour intensive activities like harvesting, opening the pods, fermenting and drying the beans. Various researchers have estimated the labour requirements for cocoa production: Bray (1959) 136 man-days per ha over 10 years; Urquhart (1961) 105 man-days per ha over 8 years; Becket (1973) 109 man-days per ha over 10 years. However, Okali (1973) estimated the annual labour requirement of 1–12 months old cocoa at 45.6, of cocoa between 13 months to full bearing at 16, and for a

full bearing crop at 12.3 man-days per ha. Since these studies were made, there has been no mechanization of cocoa production so that these figures still remain valid. The only way an old cocoa farmer can meet his/her requirements is to either hire labour or to rely on family labour. Most farmers cannot afford the costs of hired labour or are not willing to invest capital in it. The high labour requirement for young cocoa farms (Okali, 1973) in combination with the problem of labour shortage contributes to the difficulties farmers face in replanting their old cocoa farms.

The farmers explained that in the 1950s and 1960s foreign migrants constituted a large proportion of the work force on the cocoa farms. Addo (1972) estimated that before the 'Aliens Compliance Order' of 1969 about 47% of the permanent employees on cocoa farms in Ghana were immigrants from neighbouring countries but that this percentage fell to about 25 thereafter. The provisions of the order state that alien residents in Ghana without the necessary immigration papers are to obtain them within a period of two weeks from the date of publication of the order. Failure to do so necessitated their departure from the country. The problem with inadequate labour for cocoa production could probably have started at this point in time. It is estimated that 56% of the labour on cocoa farms not employing permanent labour is from the farmer, his/her spouse, children and other dependants (Addo, 1973). Therefore, the current out-migration of the youth from their villages to the cities due to lack of social amenities like electricity has aggravated the labour scarcity problem. So it is not surprising that the farmers in Adarkwa ranked the lack of labour as the third and the high cost of labour as the fifth most important cause of low yields (Table 2).

Reflections on the diagnostic approach

The most valuable contribution a diagnostic approach makes to research is the potential to bring farmers' perceptions and needs into focus when defining research problems and therefore increasing the likelihood that research would be working on problems that address the real needs of farmers. However, it is important to critically consider how and to what extent certain factors can affect the findings of diagnostic studies. These include factors like the method of selecting farmers, the context in which the study is carried out, the history of the community, the people present during data collection and analysis, and the way working methods and tools are introduced and used.

Although the three farmer groups that took part in this study identified low yield as the main problem they face with cocoa production, the method used in selecting the farmers appears to have affected the extent to which the causes of low yield either tilted towards socio-economic or technical factors. Dealing with a situation in which all cocoa farmers in the community were invited to be part of the study, as in the case of Adarkwa, seemed to have tilted the focus of discussions towards socio-economic issues. On the other hand, in Achiansah, where the farmer groups selected had previously been working with the extension agent, their focus was more on technical issues. One reason for this could be that in Adarkwa the heterogeneous environment created by so many people with varying interests did not only create a very open

atmosphere for discussions but also generated ideas on a wide range of issues. Another reason could be the proximity of Adarkwa to the district capital, where the farmers see many amenities that are not available in their village. In contrast, the groups in Achiansah focused on technical issues probably because their minds were conditioned by working with the Agricultural Extension Agent and by their perception of us belonging to MoFA. It is possible that the farmers in Achiansah were telling us, perceived as being staff of MoFA, what – in their opinion – we wanted to hear. This view is strengthened by the fact that the Achiansah group only brought out the issue of low producer price during the analysis and action planning phase, five months after the study had started when a lot of interaction had taken place and an appreciable level of trust had been built between them and us.

In Kojohum, the network structure between farmers in communities around Kojohum gave the impression of a promising study but the village was dropped after it became obvious that communication within the 'perceived network' of farmers was not effective because there was no feedback to the communities from the representatives attending the meetings. Also, the farmers did not see an immediate benefit because each time a new person attended the meeting he/she came up with the suggestion to provide credit or free inputs like cutlasses and boots, and seemed less interested in engaging in a long-term trajectory of collaborative work. Considering the distances that some of the farmers had to walk to attend the meetings there was little incentive to motivate the same person to consistently attend on behalf of his/her community. Therefore, in such circumstances it might be better for researchers and extension workers to visit the farmers in their hamlets and interact with them at that level.

A shortcoming of the diagnostic study is that the nature of some causes of the main problem, especially some social ones, and the reasons why they have persisted are not possible to fully understand in the relatively short period of six months that this study lasted. So the objective of identifying problems and basing research on an analysis of the problem may not be achieved if diagnostic studies are treated as a 'stand alone' study. On the other hand, if the study is carried out as part of a flexible action research programme – as is the case with this study – where it serves as a first step to put relevant problems on the agenda for further inquiry and action, then the nature of the problems can become clearer as they are probed beyond the diagnostic phase. Research can then focus on tackling the root causes more effectively as they become clearer and better understood in the research process beyond the diagnostic phase.

Conclusions

From this study it can be concluded that the cocoa farmers recognized low yield as the major problem facing cocoa production in Ghana. They attributed this to various causes that can be categorized into socio-economic on the one hand and technical or biological on the other. Since these two categories of causes are closely inter-related it would have been better to look at them holistically; their separate treatment in some

sections of this paper was a matter of convenience. The farmers attached a high level of importance to the socio-economic constraints even though these have an indirect relationship with the main problem. They were able to articulate and make clear the links between the socio-economic and technical factors. For instance, issues like the producer price paid to farmers, the – in their view – exploitative behaviour of the government, the lack of social amenities like electricity, and the way these affect labour and non-investment and lack of maintenance of the cocoa farms were clearly demonstrated by farmers.

Another significant conclusion from the study is the way research methods can affect the results obtained. Although the issues raised by farmers as constraints were similar, the three different groups of farmers in the study ranked the importance of the issues differently. In Adarkwa, where a community approach was adopted, and hence a more heterogeneous group participated, the main focus of the farmers was on socio-economic constraints although they recognized the importance of the technical issues. In contrast, the relatively more homogeneous farmer groups in Achiansah ranked the technical causes as more important although they articulated the impact of socio-economic constraints as well. So the results of diagnostic studies need to be treated with care and cannot be taken at face value or generalized. Also, when preparing such a study, it is important to reflect critically on the implications of choices made regarding boundaries of the discussion, selection procedures and methods used, as well as on how previous contacts may affect the outcomes.

A caution when using a diagnostic approach that focuses on farmers' perspectives is that farmers' perceptions may not always be a balanced or valid reflection of the situation because of inadequate information on certain issues. This was evident in the case of the fob price. However, it exposed communication gaps between the COCBOD on the one hand and extension workers and farmers on the other. Such communication gaps – for instance on how producer prices are determined – creates room for mistrust and the objective of motivating farmers with higher producer prices is not achieved as some of them monitor world market prices on the radio. It would be beneficial to all stakeholders if COCOBOD takes steps to bridge this gap. It is therefore important that a diagnostic study should look at multiple stakeholders and gather information from all of them to gain an understanding of the broader context of the problems diagnosed.

Finally, the diagnostic approach raises awareness of shortcomings in the technology development and the dissemination process and potentially identifies areas that researchers and policy makers need to direct their attention to, to facilitate the development of coherent innovations. Our study of social and technical factors and problem perceptions revealed that the current policy emphasis on increasing prices, introducing high-yielding varieties and stimulating specific pest control measures is likely to yield limited success since certain important social and technical issues are overlooked. Such neglected issues include the problem of epiphytes, out-migration and labour shortages, and diverging interpretations regarding the distribution of 'ownership', responsibilities and benefits of cocoa production between farmers and government. A coherent package of social and technical solutions for cocoa production in Ghana will have to include arrangements and strategies for tackling these problems.

In connection with this it is important to note that reflection is needed on which organizations will have to take the lead in dealing with these issues, as there may well exist a vacuum in this respect. For example, it is questionable whether current mandates of research and extension organizations in Ghana allow and/or equip such organizations to work on arrangements for reducing labour shortages, the provision of amenities and/or on facilitating dialogue between farmers and government regarding the division of benefits and responsibilities. In any case, it is the ambition of our ongoing action research with farmers to work on locally adapted innovations for cocoa production that include a more balanced mix of technical and social arrangements. As part of this trajectory, we also hope to contribute to a reflective dialogue among regional and national institutions involved in cocoa production, including organizational bodies that may not have been previously looked at as relevant in this respect.

Acknowledgements

We wish to acknowledge the contribution of Mr S.Y. Dotse, District Director of Agriculture for Suhum-Kraboa-Coalter District for his assistance in selecting the research locations and for his advice and information about the district and its agriculture. Messrs Seidu Gariba and Felix Ahu, Agricultural Extension Officers in whose operational areas the research was carried out, are thanked for the role they played in this study and for the immense support in organizing farmers for the numerous meetings that were held during the fieldwork. Finally we wish to thank Mr Samuel Adjei-Boateng, Research Assistant of the Convergence of Sciences Project in Ghana, for his hard work and contribution to the study.

References

Abekoe, M.K., D. Obeng-Ofori & I.S. Egyir, 2002. Technography of Cocoa in the Forest Zone of Ghana. Report presented at the 'Convergence of Sciences' International Workshop, 23–29 March 2002, Benin. Unpublished project document, 29 pp.

Acquaah, B., 1999. Cocoa Development in West Africa: The Early Period with Particular Reference to Ghana. Ghana Universities Press, Accra, 62 pp.

Addo, N.O., 1972. Employment and labour supply on Ghana's cocoa farms in the pre and post Aliens Compliance Order era. *The Economic Bulletin of Ghana* 2(4): 33–50.

Addo, N.O., 1973. Some employment and labour conditions on Ghana's cocoa farms. In: R.A. Kotey, C.D. Okali & B.E. Rourke (Eds), The Economics of Cocoa Production. Technical Publication No 33, Institute of Statistical, Social and Economic Research (ISSER), University of Ghana, Legon, pp. 204–218.

Amoah, J.E.K., 1998. Marketing of Ghana Cocoa, 1885–1992. Cocoa Outline No 2. Jemre Enterprise, Accra, 208 pp.

Anonymous, 1997. Final Report; Technical Messages in Extension for Cocoa Farmers. Ghana Cocoa Board, Accra, 98 pp.

Anonymous, 1999. Ghana Cocoa Sector Development Strategy. Unpublished government policy docu-

ment, Ministry of Finance, Accra, 94 pp.
Anonymous, 2000a. Ghana Cocoa Board Handbook (8th edition). Ghana Cocoa Board, Accra, 62 pp.
Anonymous, 2000b. Review and Evaluation of the 5-year District Development Plan; Profile of Suhum-Kraboa-Coalter District. Unpublished government document, 144 pp.
Anonymous, 2001. The State of the Ghanaian Economy in 2000. Institute of Statistical, Social and Economic Research (ISSER), University of Ghana, Legon, 162 pp.
Anonymous, 2003. The State of the Ghanaian Economy in 2002. Institute of Statistical, Social and Economic Research (ISSER), University of Ghana, Legon, 164 pp.
Anonymous (undated). Unification of COCOBOD and MoFA Extension Services. Ministry of Food and Agriculture (MoFA), Accra, 45 pp.
Ashby, J.A., 1991. Adopters and adapters: the participation of farmers in on-farm research. In: R. Tripp (Ed.), Planned Changes in Farming Systems: Progress in On-farm Research. Wiley, New York, pp. 273–286.
Bawden, R., 1991. Towards action researching systems. In: O. Zuber-Skerritt (Ed.), Action Research for Change and Development. Aldershot, Avebury, 234 pp.
Becket, W.H., 1974. Akokoaso: a Survey of a Gold Coast Village. Monographs of Social Anthropology No 10, London School of Economics and Political Science, London. Cited in: R.A. Kotey, C.D. Okali & B.E. Rourke (Eds), The Economics of Cocoa Production. Technical Publication No 33, Institute of Statistical, Social and Economic Research (ISSER), University of Ghana, Legon, pp. 3–19.
Bentley, J.W., 1992. The epistemology of plant protection: Honduras campesinos knowledge of pests and natural enemies. In: R.W. Gibson & A. Sweetmore (Eds), Proceedings of a Seminar on Crop Protection for Resource-Poor Farmers, National Resources Institute (NRI), Chatham, pp. 107–118.
Bray , F.R., 1959. Cocoa Development in Ahafo, West Ashanti. Faculty of Agriculture, University of Ghana, Legon. Mimeographed. Cited in: R.A. Kotey, C.D. Okali & B.E. Rourke (Eds), 1974. The Economics of Cocoa Production. Technical Publication No 33, Institute of Statistical, Social and Economic Research (ISSER), University of Ghana, Legon, pp. 3–19.
Chambers, R, A. Pacey & L. Thrupp (Eds), 1989. Farmer First: Farmer Innovation and Agricultural Research. Intermediate Technology Publications, London, 423 pp.
Conway, G.R., 2001. The Doubly Green Revolution: a context for farming systems research and extension in the 21st century. *Journal for Farming Systems Research-Extension*. Special International Symposium Edition 2001, pp. 1–16.
Dick, B., 1997a. "What is action research"? Occasional pieces in action research methodology (2). <http://www.scu.edu.au/schools/gcm/ar/arm/op002.html> Accessed 14 November 2004.
Dick, B., 1997b. Critical thinking (1). Occasional pieces in action research methodology (3). <http://www.scu.edu.au/schools/gcm/ar/arm/op002.html>. Accessed 14 November 2004.
Geels, F.W., 2002. Understanding the dynamics of technological transitions. A co-evolutionary and socio-technical analysis. PhD thesis Twente University, Twente University Press, Enschede, 426 pp.
Gerken, A., J. Suglo & M. Braun, 2001. Crop Protection Policy in Ghana. Integrated Crop Protection Project and Ministry of Agriculture, Pokoase, 185 pp.
Koning, P., 1986. The State and Rural Class Formation in Ghana: A Comparative Analysis. Kegan, London, pp. 43–139.
Leeuwis, C. & A. Van Den Ban, 2004. Communication for Rural Innovation: Rethinking Agricultural Extension (3rd edition). Blackwell Science, Oxford, 412 pp.
Okali, C., 1973. Labour inputs on cocoa farms. In: R.A. Kotey, C.D. Okali & B.E. Rourke (Eds), The Economics of Cocoa Production. Technical Publication No 33, Institute for Statistical, Social and

Economic Research, University of Ghana, Legon, pp. 3–19.
Okali, C. & J.E. Sumberg, 1986. Examining divergent strategies in farming systems research. *Agricultural Administration* 22: 233–253.
Okali, C. J.E. Sumberg & J. Farrington, 1994. Farmer Participatory Research: Rhetoric and Reality. Intermediate Technology Publications, London, 159 pp.
Pretty, J.N., I. Guijt, J. Thompson & I. Scoones, 1995. A Trainers Guide for Participatory Learning and Action. International Institute for Environment and Development (IIED), London, 269 pp.
Rip, A., 1995. Introduction of new technology: Making use of recent insights from sociology and economics of technology. *Technology Analysis & Strategic Management* 7: 417–431.
Röling, N.G., D. Hounkonnou, S.K. Offei, R. Tossou & A. Van Huis, 2004. Linking science and farmers' innovative capacity: diagnostic studies from Ghana and Benin. *NJAS – Wageningen Journal of Life Sciences* 52: 211–235.
Scoones, I., 1995. PRA and anthropology: challenges and dilemmas. *PLA Notes* 24: 17–21.
Thorold, C.A., 1975. Diseases of Cocoa. Clarendon, Oxford, 423 pp.
Urquhart, D.H., 1961. Cocoa (2nd edition). Longmans, Green and Co. Cited in: R.A. Kotey, C.D. Okali, & B.E. Rourke (Eds), 1974. The Economics of cocoa production. Technical Publication No 33, Institute of Statistical, Social and Economic Research (ISSER), University of Ghana, Legon, 3 pp.
Van Huis, A. & F. Meerman, 1997. Can we make IPM work for resource-poor farmers in sub-Saharan Africa? *International Journal of Pest Management* 43: 313–320.
Van Huis, A., R.S. Nauta & M.E. Vulto, 1982. Traditional Pest Management in Maize in Nicaragua: a Survey. Mededelingen Landbouwhogeshool, Wageningen 82-6, 43 pp.
Wilson, K.C., 1999. Coffee, Cocoa and Tea. Commonwealth Agricultural Bureau International (CABI), Wallingford, 300 pp.
Wood, G.A.R. & R.A. Laas, 1998. Cocoa (4th edition). Longman Scientific and Technical, London, 620 pp.