CROP PROTECTION PROGRAMME

Control of *Phytophthora megakarya* diseases of cocoa with phosphonic acid

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FINAL TECHNICAL REPORT

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PROJECT SUMMARY

The project was directly concerned with the development and evaluation of an operator-safe fungicide and application technique against a disease of major importance in a crop grown extensively in the high potential systems of West Africa. The programme was particularly concerned with understanding the current issues surrounding chemical use by smallhold farmers in Ghana and with ensuring that application systems are optimized to the benefit of both farmers and consumers.

Through an extensive survey across 4 regions of Ghana, the project examined the human and socio-economic constraints to the adoption of disease management technologies among smallholder farmers and identified key issues requiring resolution in the development of effective and viable disease control measures. Through the survey, existing fungicide sprays were found to be considered expensive and very difficult to apply, while few farmers owned the necessary equipment. Cocoa farmers in Ghana were identified as predominantly older people, with cocoa being used to assure a supply of income over a long period of years and with low input, low yield systems. Despite these constraints, fungicide use has clearly increased in recent years in response to the spread of *P. megakarya*.

Long-term field trials conducted in an area affected by *P. megakarya* showed that stem injection or foliar sprays with potassium phosphonate gave control comparable to that obtained with existing recommendations for metalaxyl + cuprous oxide. As a base commodity, often marketed as a foliar fertilizer, potassium phosphonate is not protected by patent and is likely to be considerably cheaper in product and application than commercial organic formulations. The compound has a markedly lower toxicity than persistent copper compounds. However, experimental modification of formulations reduced but did not eliminate localized phytotoxicity resulting from phosphonate injection, which causes potential issues of acceptability to farmers.

A residue analytic capability was established at the Cocoa Research Institute of Ghana and new methods and staff skills successfully developed to monitor phosphite (phosphonate) ions in cocoa tissues. Phosphite was detectable in beans from injected trees, but at levels well below health thresholds. This issue has been extensively discussed with chocolate manufacturers, who are concerned at possible negative publicity from any form of application residue, but recognize also that the phosphite residue is akin to phosphate and may require a different philosophy from that for conventional fungicides. Preliminary work with induced resistance demonstrated some evidence of an indirect mode of action through localized stimulation of resistance compound production by the plant, but significant induced systemic resistance has not so far been demonstrated. Studies on environmental contamination showed that the present foliar spray recommendations and equipment used lead to extensive non-target contamination and wastage. Operator contamination is significant, but does not present a health hazard with the fungicides presently used (although there are implications for similar practices with the more toxic insecticides). While levels deposited are unlikely to lead to significant environmental effects in short-term use, the spray nozzles used are clearly causing extensive wastage of a large proportion of the product applied. Copper compounds are highly persistent and could accumulate in soils over the longer term. Existing spray recommendations were costed at equivalent to 193kg dry bean /ha, unlikely to give a significant return to low-output producers. Comparative cost:benefit relationships are difficult to establish in Ghana as existing recommendations are supported through government bulk purchase and there is at present a mass black pod control programme aiming to provide free applications to all cocoa farmers as part of a cocoa support programme. These relationships also depend on other cultural inputs used and potential yield returns. However, members of the project team sit on the managing

group for this national black pod programme and so are able to directly bring project outputs into public practice.

The project outputs provided significant progress towards the project goal of improving yields and sustainability of high potential cropping systems by cost-effective reduction in losses due to pests. Project survey work demonstrated a real need and desire among farmers for more appropriate and usable alternatives to existing spray recommendations. Exploration of the use of potassium phosphonate has shown that it represents a viable alternative in efficacy terms and opens up alternative application system options for small farmers. Studies on environmental contamination have shown that current practices lead to extensive off-target contamination and waste, a finding that has significant implications for a large-scale government black pod control programme presently operating in Ghana. These issues require further exploration through participatory research with farmers to determine what is truly appropriate and effective for their use.

EXECUTIVE SUMMARY

Cocoa is the main commodity crop of Ghana and the country’s second most important export earner, providing livelihoods and revenues for numerous rural communities across the country. However, the recent spread of black pod disease (*Phytophthora megakarya*) threatens the livelihoods of Ghana’s many cocoa farmers. This damaging disease has spread rapidly westwards across the country and has now entered Côte d’Ivoire, the world’s largest producer.

This project set out to explore the implications of potential alternative management measures for black pod disease in Ghana, through a field research programme implemented by the Cocoa Research Institute of Ghana, with advisory and technique development inputs provided by CABI Bioscience (cocoa pathology and induced resistance), Natural Resources Institute (residue analysis and sprayer studies) and University of Reading (biometrics). This was supported by the establishment of analytical facilities and procedures at the Cocoa Research Institute, Ghana to enable analysis of chemical residues within cocoa tissues. Phosphonate and other disease management options were assessed for control of *P. megakarya* and *P. palmivora* under different conditions over three successive production seasons.

The impact of the disease and farmers’ ability to manage it was assessed through an extensive farmer survey, using participatory appraisal techniques, across 4 regions of the country. Farmers in badly-affected regions reported losing an average of three quarters of their production as a result of the disease in wetter years (i.e. those particularly favouring the disease), with some reporting total crop loss. On these figures, production is reduced to a harvest-only basis, with little prospect of improving production or livelihoods.

Farmer surveys under the project have shown that farmers do use considerably more fungicide than was previously the case to manage black pod disease. The disease is spreading westwards into the more productive areas of the country. Because of the central importance of the crop to Ghana’s economic development, the Government of Ghana has recently embarked on an ambitious and expensive centrally-funded programme to provide black pod disease control sprays to all cocoa farmers. There are significant questions as to the efficacy and effects of this approach, which require addressing if inputs are to be optimized financially and environmentally.

Existing government recommendations for control with a combination of sanitation and metalaxyl/copper sprays are not being effectively implemented by farmers for reasons of cost and are of marginal benefit in the absence of other inputs. Farmers lack knowledge of the disease cycle and confidence in measures for its effective management. Nonetheless, the proportion of farmers attempting control has increased markedly over the last decade as the disease has become more widespread.

The project examined the activity of potassium phosphonate in reducing field disease losses to *Phytophthora megakarya* and *Phytophthora palmivora* pod rot. The project has established that use of phosphonate can provide an effective and cost-competitive alternative to existing spray recommendations. Potassium phosphonate is a base commodity compound of low toxicity that is not subject to any patent and is marketed as a foliar fertilizer. It’s actions are at least in part through a stimulation of induced systemic resistance in the tree. These properties mean it can be a viable alternative for poor farmers, of lower toxicity and cost than existing contact fungicides and with less environmentally-negative properties. As a base industrial chemical it is not subject

to any patent and offers a potential low cost alternative measure. Its toxicity is comparable to that of phosphates and earlier studies have shown no flavour taint from treatment.

The project investigated application of potassium phosphonate by a variety of means, stem injection, pod paints, stem paints and sprays, in comparison with existing spray recommendations. Potassium phosphonate injection has given disease control to a level at least as good as that from the current best available fungicide and in some cases better, with a yield gain of up to 80% compared with the untreated control. Stem injection has provided the best control, requiring a single application per season rather than the 6-9 applications required for sprays and using low unit-cost injectors rather than capital-intensive sprayers. Set against these advantages is a concern over the internal localized scorch seen around the injection site and its potential acceptability to farmers. Adjustment of the pH used has reduced this damage, but the issue remains.

Treatment effects have been further explored with the development of an analytical technique for determining phosphite ions within cocoa tissues. Staff from the Cocoa Research Institute of Ghana have been trained and equipped to undertake these analyses, but practical problems of equipment maintenance have constrained the scale of sampling possible. The residue analysis developed under the project has shown detectable phosphite levels within the beans from injected trees. While these are considerably below levels of health concern and the issue has not arisen in other contexts where phosphite is considered and marketed as primarily a fertilizer, the chocolate industry is highly sensitive to anything termed a residue and would need to take a view on this usage should large scale treatment be considered. Discussion with the chocolate industry has been positive and the industry has been well informed of the issues involved through both informal interaction and presentations at public meetings.

Environmental and operator contamination studies have shown that the great proportion of conventional fungicide applied via sprays does not reach the intended target and there is considerable contamination of both the operator and environment. This raises concerns over costs and in the case of the Class II toxin copper, over the long term environmental side-effects of repeated applications. The moderate to low toxicity of fungicides used means this is unlikely to present a health risk to operators, but this is a significant concern for application of more toxic insecticides. Copper spray application is expected to result in long term accumulation in the soil, although no clear effect was found in effects of copper-containing sprays on leaf litter turnover.

The project has shown the potential value of alternative measures in reducing environmental contamination and providing effective control of black pod disease. Further work is required to examine the integration of such approaches into farmer practices and to develop disease management measures through direct participation of farmers to ensure efficacy and acceptability of measures.

BACKGROUND

Previous studies conducted under the (then) ODA-funded study of cocoa farming systems in Ghana (FSU3-7/90) by C.P. Henderson and A.P. Jones determined that around 30% of cocoa farmers are women and that cocoa was the principal source of income for over 75% of farm households in the Ashanti region. Nearly all farmers are smallholders and there are no significant estate plantings in Ghana, although in some cases tenant farmers farm trees belonging to others, for a proportion of the income raised from the crop.

Farmer typologies classified farmer's intensity of cocoa management into:
Low (non-adoption of recommendations with the possible exception of hybrid seed, small scale, often producing less than 1000kg of cocoa annually).
Intermediate (partial adoption of recommendations, particularly in terms of pest control, larger scale, producing in excess of 1000kg of cocoa annually, 'financially secure')
High (follow all recommended practices, employ permanent waged labourers and 'financially secure'

A key factor determining production constraints is age of the plantings, old plantings were moribund in many cases and were mostly associated with low input growers. Low-input growers made up 69% of those surveyed, with intermediate growers 30% and high only 1%. In terms of potential uptake for use of phosphonic acid, the intermediate and high sectors would be the most likely users, although the 16% of low input growers who have replanted recently could also benefit from disease control if dissemination linkages can be established. Disease control measures applied in isolation to neglected and moribund cocoa are unlikely to be cost-effective. Most farmers using chemical control during the survey were applying by mistblowers, which had considerable problems with maintenance (among those surveyed, 25 out of 37 were broken down), capital costs and supply of fuel. Mistblowers are usually owned by cocoa buying societies and these societies may also provide a means of applying phosphonic acid on a contract basis so that farmers may not have to invest directly in injectors or alternative delivery mechanisms.

Fungicide adoption in Ghana used to be relatively low. However, with the advent of *P. megakarya*, the situation is changing. Without fungicide application, losses to black pod disease can be as high as 80-100%. Studies by CRIG have shown that, unlike *P. palmivora*, cultural practices alone are inadequate for the effective control of *P. megakarya* and that cultural practices have to be combined with chemical application. At present, *P. megakarya* has affected 5 districts in Brong-Ahafo, 4 in Ashanti, 3 in Western and all districts in Volta region and now covers around one quarter of all cocoa land in Ghana Spread to other regions and to Côte d'Ivoire is probably now only a matter of time. Until resistant cultivars are developed (still a long way off), cultural practices will have to be supplemented with chemical means if economic production is to be sustained. It is also likely that many of those with low yielding or moribund plantings will abandon cocoa altogether if they can no longer obtain the minimum yields required for cash flow purposes. In recent CRIG fungicide trials on farmers fields in 7 selected districts where the efficacy of fungicide application was clearly demonstrated (Akrofi *et al.*, in press), fungicide adoption in these areas is on the increase.

The use of stem injection with neutralized phosphonic acid (phosphorous acid) is a recent development in chemical control of *Phytophthora* that offers significant prospects for application in the Ghanaian situation. The material is available either as a pre-mixed formulation, or as the base commodity chemicals which can be mixed as required. In extensive trials on cocoa in

Papua New Guinea, phosphonic acid injection has been found to be of comparable efficacy to metalaxyl sprays against *P. palmivora* pod rot, and to give significantly better control of *P. palmivora* cankers. The injection technique entails a single application every six months or even per year (compared with every 3 weeks for sprays) and utilizes low-cost spring-loaded syringes, inserted into holes drilled by hand-drill into the trunk. Operator and environmental contamination are minimized by this method as no sprays are involved and wearing of rubber gloves is all that is required to prevent skin contamination. The phosphite ion is highly mobile in the plant, being phloem as well as xylem-mobile. This allows a systemic protective effect to be produced around the plant from the injection points at the stem base.

The work is not a direct continuation, but preliminary evaluation studies were performed under the ODA-funded Cocoa Rehabilitation Project in Ghana in the early 1990s. Black pod was identified as a priority area for further work at the conclusion of this programme. Phosphonic acid is presently being evaluated against *P. megakarya* in a small pilot scheme in Ghana and early results have shown good indications of control of *P. megakarya.* However, there are some deleterious side-effects (local phytotoxicity around the injection site), that have caused concern and must be addressed before the method would be acceptable and suitable for recommendation to growers. Optimal application system, timing, frequency and dosage thus need to be determined for cocoa under Ghanaian production systems and alternatives explored to reduce the phytotoxicity problem. The cost:benefit relationships of treatment over an extended time period also require elucidation. Ghanaian cocoa trees are of different genetic origin and are slower growing than those in the volcanic soils of the Asia-Pacific region, but have a longer economic life. These factors would need to be brought into consideration, as would the extent of losses to *P. megakarya* compared with *P. palmivora*.

The mobility of phosphite within the plant means that monitoring the fate of residues is of importance if the measure is to become acceptable to cocoa producers and consumers. Alongside the field research programme, determination of the movement and fate of residues is thus required to quantify the movement of phosphite within the plant and so elucidate optimal treatment methods, rates and frequencies under Ghanaian conditions (and determine the ED50 within target plant tissues) and to ensure the acceptability of any residues within the product (bean) on the world market. Preliminary determinations by Nestlé have indicated that the latter is unlikely to present a significant barrier. The pesticide residue involved (the phosphite ion) is considered to be of a low mammalian toxicity, comparable to that of phosphate and the residue is the same as that produced from Fosetyl-Al, which has been widely used around the world for a variety of food crops over the last decade.
The nature of phosphonic acid as an inducer of systemic resistance merits further exploration as this aspect may allow treatment with much less chemical, if placed strategically to induce pod resistance to infection. This might be feasible through use of paints or gels that would be applied externally but stimulate resistance in inner tissues, without significant residue accumulation in bean tissues. Another product recently released on the market in Europe ‘Bion’ (Novartis) operates as an inducer of systemic resistance to *Phytophthora* diseases and Novartis agreed that the product could be included in comparative trials to determine whether this effect can be utilized in protecting cocoa against *Phytophthora*. Comparison is required against All treatments would be evaluated in comparison with and combination with cultural control measures, such as the manual removal of infected pods.

Phosphonic acid is available as the base product, a commodity chemical, which can be pH-neutralized by addition of potassium hydroxide, another readily available commodity chemical. The pre-mixing is done commercially by a company in Australia, which ships and markets the neutralized formulation at as high a concentration as is practical. The main difficulties in importing and using the base commodity are instability of the acid in storage if the material becomes wet (perhaps an issue in humid climates) and the exothermic nature of the neutralization reaction, which would make it unsafe for farmers to undertake the latter themselves, but would be well within the capacity of a Ghanaian manufacturer (such as the Cocobod) to undertake for themselves under more rigorously-controlled conditions. Whether there is a significant saving to be had through neutralization in country is rather dubious, as this would depend on imported volumes and supply arrangements and there may be issues of quality control and operator safety in such a process, particularly if the phosphonic acid was sourced from less reputable suppliers on the world market or if temperatures are not controlled during the neutralization process.

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PROJECT PURPOSE

Environmentally acceptable herbicides, fungicides and bactericides and agrochemical use systems for application by smallholders and estate workers developed and promoted.

The project aimed to evaluate the potential of neutralized phosphonic acid and other ISR compounds for the control of *Phytophthora* diseases of cocoa in Ghana and to determine the technical and economic feasibility of such control in fertilized cocoa farms. The project was directly concerned with the development and evaluation of an operator-safe fungicide and application technique against a disease of major importance in a crop grown extensively in the high potential systems of Ghana. The chemical used (potassium phosphonate) has been shown to be effective against similar pathogens elsewhere and has a low mammalian toxicity.

The programme was particularly concerned with the modification of treatments to suit Ghanaian conditions and with ensuring the acceptability of such technologies to Ghanaian farmers. Over the project lifetime, application techniques were compared and developed to maximise disease control while minimizing deleterious effects, efficacy of disease control was measured and the likely profitability of the technique assessed in the field. The research aimed to provide an objective assessment of the acceptability and value of the fungicide and application techniques under Ghanaian conditions.

RESEARCH ACTIVITIES AND OUTPUTS

The programme addressed a number of activities to deliver the required outputs:

1. 1: FIELD-SCALE COMPARISON OF APPLICATION TECHNOLOGIES

Purpose:
This large scale field experiment comprised the comparison of potassium phosphonate (phosphonate) injection, at doses working down from that known to be effective, against a range of alternative application methods and alternative fungicides on a field scale, allowing determination of yield effects, long-term effects of treatments and comparison of effects under different environments. These experiments ran for the duration of the project, but individual treatments were reviewed each year and amended in light of new information from other studies. The key initial concern was the comparison of phosphonate injection against existing sprays, but the design also allowed consideration of alternative application technologies.

Design
The design made use of natural blocks within the fields reflecting local conditions and the environment. The design principle allowed full replication of the key treatments, while less crucial treatments were represented at a lower level of replication in some years (i.e. randomized incomplete block design).

Sites: Bechem (*P. megakarya)* and Tafo (*P. palmivora*)

Treatments used, Year 1:

1) Injection: 2 x 20 ml, single time point injection, 40% solution.
2) Injection: 2 x 20 ml, single time point injection, 20% solution.
3) Injection: 2 x 10 ml, single time point injection, 40% solution
4) Stem painting, 2 x 20cm wide bands (+ starch) without wounding, equivalent dose to 1).
5) Stem painting, 2 x 20cm wide bands (+ starch) with bark scraping (wire brush), equivalent dose to 1).
6) Pod spraying, knapsack pressure sprayer to 2.5m, equivalent dose to 1, + sticker)
7) Pod painting to 2.5m, equivalent dose to 1, + colour dye + sticker or starch)
8) Existing recommendations for 6 pod sprays with metalaxyl (Ridomil+72) and copper
9) Pod sprays with metalaxyl (Ridomil+72) and copper at current national recommendations
10) Untreated control (maintained to a standard comparable to other treatments)

Treatment rationales
- Rationale for injection treatments is that 1) represents a treatment known to be effective from previous field trials, but without causing the more extensive phytotoxicity associated with higher rates. Treatments 2-4 represent a range of alternative doses, reducing either volume or concentration to attempt to retain disease control while reducing phytotoxicity.
- Stem painting was examined as a means of providing an alternative means of uptake without the internal scorch and drill damage associated with injection. However, the bark presents a physical barrier to uptake, so scraped bark was compared with intact bark.
- Rationale for pod painting was that the chemical is highly systemic and so may be able to move around to protect all pod tissues, even if applied to only part of the pod surface.

- Rationale for pod sprays was that the chemical can be applied to directly protect the pod using existing spray technologies, avoiding physical damage to the tree.
- Sprayed control plots allow comparison with existing recommendations (6 treatments per pod season at 3 week intervals, Ridomil + 72 or cuprous oxide) and with spraying according to seasonal needs.
- Unsprayed controls reflect farmer practice in terms of basic cultural management of the disease (+ infected pod removal by hooking at harvest time, no chemical usage, + weeding, + pruning)

Experimental design

Tree availability was limited so the design reflected the relative significance of the injection vs existing recommendations treatments, while including elements of alternative application technologies. Plot size was 5 x 4 trees in all cases, with 7 replicate blocks.

The design aimed for greater replication rather than losing trees to regularly laid out guard rows. The plots were laid out by map to avoid including too many missing tree points, which in turn meant that trees acted as untreated guard rows among the plots.

Standard cultural practices were applied across all plots. No fertilizer was applied (reflecting general farmer practice). Normal insecticide recommendations were applied for capsids (2 sprays per year). Stem borers were treated as required.

Data collected:

1. <u>Yields per plot</u> – monthly harvests according to most farmer's practices. Recorded as healthy and useable yields, on stem (up to 2.5m) and in canopy (above 2.5m) by pod count. (converted by standard pod scale to give dry bean yield).
2. <u>Black pod incidence</u>
   2.1. stem pods (to 2.5m) (usable & unusable).
   2.2. canopy pods (above 2.5m) (usable and unusable).
   The reason for the height differentiation is that 2.5 m is a typical height to which knapsack pressure sprayers can effectively reach, so that pods above this are unlikely to be treated in sprayed plots
3. <u>Cherelles</u> – were assessed fortnightly, on a sub-set of trees selected within each plot. Selection was derived by using ranked sets for the trees within each row (ranked according to tree vigour) and randomly allocating a tree vigour number per row.
   3.1. cherelle losses to Ppr – up to a certain height up the tree.
   3.2. cherelle losses to physiological wilt.
4. <u>Canker incidence</u> before and after treatment (3 month intervals).
5. <u>Bean, pod and leaf phosphite residues</u> – initially performed at NRI, then transferred to CRIG when equipped for the analysis. Sub-sample 1kg dry bean from bulked plot sample (this needs to be supported by some determinations of variation within plot samples).
6. <u>Meteorological data</u> – daily records of rainfall were taken by CSD

In year 2, treatments were modified. An alternative metalaxyl formulation was evaluated and the bark painting treatments, found to be ineffective in the first year, were replaced with a further pod spraying evaluation:

Treatment	
1	40% Potassium phosphonate solution, 2 x 20 ml injection
2	20% Potassium phosphonate solution, 2 x 20 ml injection
3	40% Potassium phosphonate solution, 2 x 10 ml injection
4	Ridomil plus 72 w.p. pod spray (12% metalaxyl & 60% cuprous oxide, 50g product/15l)
5	Callomil plus 72 w.p. pod spray (12% metalaxyl & 60% cuprous oxide, 50g product/15l)
6	40% Potassium phosphonate solution, pod spraying
7	40% Potassium phosphonate solution, pod painting up to 2.5m from ground
8	Ridomil plus 72 w.p. pod spray (12% metalaxyl & 60% cuprous oxide, 50g product/15l)
9	20% Potassium phosphonate solution, pod spraying
10	Untreated control

In year 3, treatments were again modified to enable evaluation of the effects of alternative formulation of potassium phosphonate, found to reduce phytotoxicity in trials on avocado in Australia. A copper formulation was also evaluated without metalaxyl. In light of preliminary studies on the potential for exploitation of induced systemic resistance (ISR), injection and spray treatments were also modified to evaluate the effects of Bion as an inducer of ISR.:

Treatment	
1	40% Potassium phosphonate solution, 2 x 20ml injection, pH 6.5
2	20% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5
3	20% Potassium phosphonate solution, 2 x 20ml injection, pH 6.5 + Bion
4	40% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5 + Bion
5	40% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5
6	Ridomil plus 72 + Bion pod spray
7	20% Potassium phosphonate solution, pod spraying, pH 7.5 + Bion
8	Ridomil plus 72 w.p. pod spray (12% metalaxyl & 60% cuprous oxide)
9	Nordox Super 75 pod spray (86% cuprous oxide w.p., 100g product/15l)
10	Untreated control

The specific treatments each year were all decided by scientists at CRIG, building on their knowledge of acceptability and efficacy of practices in Ghana. Initial design and plot layout in year 1 followed a detailed discussion workshop with inputs from CABI and University of Reading Applied Statistics. Treatments were constrained by problems in obtaining customs clearance for imported chemicals in year 2. Access to sites proved challenging over the life of the project; Bechem is some distance from CRIG in Tafo and logistical constraints regarding travel permits limited the frequency of visits by CRIG scientists.

COMPARATIVE ENVIRONMENTAL IMPACTS OF CHEMICAL TREATMENTS

The relative environmental and operator safety of the treatments is a key development concern and phosphonic acid is seen as a possible way of reducing environmental concerns in cocoa production. Phosphonates are markedly less toxic to animals than copper compounds (in particular) or metalaxyl. However, effects on possible biological control organisms on the plant surface, on soil microbiota and organic matter cycling have not been evaluated previously. It is also assumed that use of injection or paints carries less risk of operator contamination than do sprays, but this requires confirmation.

Experiments were established to address the following questions:

1) Do phosphite injection or paints reduce operator contamination relative to sprays of phosphite, Ridomil or copper and what is the relative anticipated contamination from each?

2) Do Ridomil/copper sprays reduce microbial activity at the soil surface and reduce soil organic matter incorporation/turnover more than does phosphite?

A further series of environmental questions were proposed at the project outset but proved difficult to implement in practice, largely due to delays in developing an effective phosphite residue analysis system.

3.1 Operator contamination

Operator contamination was assessed at Tafo on individual trees. Assessment of spray contamination was undertaken using overalls with absorbent filter ‘targets’ at various points on the sprayer’s body. Fungicide deposited is then analysed from each filter. This data also has relevance to insecticide use, where the same spray technology is used but chemicals are generally more toxic to humans.

Soil surface microbial activity and organic matter turnover

It is likely that spray drift and run-off would lead to deposition of significant amounts of sprayed chemical on the leaf litter layer and the effects of this on organic matter turnover will be of environmental interest as well as through implications for plant nutrition and soil water retention. A series of biological assays is proposed to be undertaken, using the Tafo field site where different application technologies and chemicals are being compared:

a) Leaf decay rates.

Leaves of cocoa were picked, transferred to flat cages made from nylon mesh in a layer 3-5 leaves deep (using a constant number of leaves per cage) and weighed. The cages were placed on the ground, in contact with bare soil over the entire area of the cage and in as constant a set of environmental conditions as possible (aiming for similar canopy density and soil slope). The chemicals were applied to plots as above by the appropriate method and over the relevant period. Leaf bags were removed at intervals over the experimental period and dry weight of the leaves obtained.

Residue Analysis

There are various methods of analysis available, including ion-exchange chromatography, gas chromatography with flame photometric detection and high performance ion chromatography. Each of these offers specific advantages in time, cost or accuracy and so a comparative approach is required to exploit the appropriate advantages of each technique and equip CRIG with the pertinent skills.

FARMER SURVEY

Farmer constraints (human and socio-economic) to adoption of disease management technologies were determined through an extensive survey developed and undertaken by socio-economists at CRIG across the main cocoa-growing areas of the country.
A farmer survey was conducted across 4 of the 6 cocoa-growing Regions of Ghana, Ashanti, Volta and Western regions (all areas affected by *P. megakarya*) and Eastern region (affected by *P. palmivora*). This baseline survey aimed to determine and compare farmer perceptions of these diseases and explore the opportunities and constraints to measures used for their control. A semi-structured questionnaire was used, based around a combination of specific questions, open-ended questions and participatory tools (ranking etc). A wide range of themes were explored, to obtain a picture of farmers concerns and wider livelihood interests, creating a context for specific exploration of the issue of black pod and its management. The questionnaire is given in Annex 1. The survey procedure was pilot-tested in Bechem area, allowing revision and refinement before full implementation.

250 farmers were sampled across the country, with a 90% response rate. Staff of CRIG Social Science and Statistics Unit led the survey, linking with staff of the Ministry of Food and Agriculture (MOFA) and Cocoa Services Division as required. Questionnaires were completed through one-to-one discussion with individual farmers.

The survey enabled comparison with earlier farmer surveys on black pod management undertaken by the Farming Systems unit of CRIG in conjunction with an earlier DFID-funded programme in 1989 and 1991[1] (Offinso District, Ashanti) and the 1995 Ghana Government Task Force study.

Data on farmer yields and reported losses were used to assess potential cost-benefit relationships of different application measures. This information is regarded as crucial to understanding the reasons for non-adoption of existing measures and the constraints to taking up new approaches to disease management.

The survey was conducted in three *P. megakarya* areas (PMA), namely Ashanti, Volta, and Western regions; and one Non- *P. megakarya* area (NPMA) namely, the Eastern region of Ghana. In all a total sample size of 250 cocoa farmers was randomly selected, using methods developed by Casley and Kumar (1989) for the World Bank, out of which 224 respondents were interviewed, giving a response rate of about 90%. The main objectives of the survey were:

(a) To determine and compare farmer perceptions of black pod disease in *P. megakarya and Non-P. megakarya* areas, and,
(b) To determine measurable indicators for assessing possible technical and socio-economic impact of using Potassium phsophonate for chemical control of cocoa black pod disease.

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[1] Farming Systems Unit Research Paper 3, Survey to quantify adoption of CRIG recommendations, Cocoa Research Institute of Ghana

RESEARCH OUTPUTS

ANALYSIS AND DISCUSSION OF SURVEY FINDINGS

The baseline survey was undertaken to determine farmer's perceptions of the significance of the P. megakarya black pod problem, its socio-economic context and the challenges faced by farmers in addressing the problem. While the survey addressed general background context, it did not probe further through subsequent follow-up on issues raised. This was in large part because of socio-economic staff redeployment into the reorganization of Cocobod bodies, which prevented follow-on survey activities.

Structure of the cocoa farming population in Ghana

The cocoa farmers of Ghana are predominantly male and of advanced age, particularly in the long-established cocoa systems of Ashanti region, where farmers had a median of around 40 years of cocoa growing experience. Volta region farmers were generally the youngest. This age structure may cause significant issues in the management of diseases through spraying as the spray equipment used is heavy and bulky. Most farmers owned their own land, particularly in the areas of Western and Volta Regions that have been relatively recently opened up to cocoa, whereas the proportion of caretaker farmers involved in cocoa production was greater in the old-established areas of Ashanti and Eastern. Women producers ranged from 0 to 22% of the farming population. Education levels reflected the differences in education provision between regions and over time; in most regions around half the farmers had received at least some basic education, but few had received tertiary or vocational education other than among the younger farming population in Volta.

Despite price insecurities, cocoa growing is the main occupation for the great majority of Ghanaian cocoa farmers. Only in Volta region were other occupations clearly apparent, but it was not made clear whether this was due to the effects of black pod disease or due to other socio-cultural/socio-economic reasons.

The age of farmers is reflected in years of experience in growing cocoa, with many years of experience in Ashanti and a much younger profile in Western region. Most land was received via gifts or by purchase but the land settlement pressures in Ashanti have clearly led to more scattered farms.

Relative Importance Of Black Pod Disease On Farmers' Farms

The results of the analysis indicate that, in both disease-affected and non-*P. megakarya* areas, farmers are aware of the nature of the black pod disease of cocoa and its effects in severe attacks. However, in areas free from *P. megakarya* it is not accorded the same importance because the damage caused *by P. palmivora*, the prevalent fungal type in those areas is seldom very severe. In areas affected by *P. megakarya,* where farmers can frequently lose over 50% of their crop and in some cases everything, there is much more concern about the incidence of black pod disease. Cocoa yields per hectare reported in *P. megakarya*-affected areas were in the main part below yields reported in the areas not yet affected, suggesting that black pod disease caused by *P. megakarya* also caused substantial economic loss, although other factors are also certain to be involved.

Efficacy Of Cocoa Black Pod Disease Control And Poverty Reduction

Income from cocoa forms a substantial percentage of the annual household incomes of cocoa farmers. Pests and diseases of the cocoa crop which cause substantial reductions in the output of cocoa consequently contribute to maintaining poverty among cocoa farmers. Estimates of annual income levels from cocoa farming indicated that farmers depending mostly on cocoa income in the Ashanti and Volta regions, both *P. megakarya* endemic areas, were operating considerably below the national poverty line. Cocoa farmers in the affected areas will therefore welcome methods that can control the disease to economic advantage, but questions remain as to the viability of sole cocoa production as a means of livelihood maintenance.

Farmers' Perception Of Relative Efficacy Of Chemical Control Methods

The majority of farmers in the *P. megakarya* affected area indicated that chemical control methods were considered the most effective, yet were costly and much more difficult to apply than cultural measures. Despite these constraints, in the Western Region 57% of respondents reported spraying chemicals 4 times or more, while 29% reported spraying 3 times or less. Nevertheless, only 36% of respondents could say the method was effective. Similarly in the Volta region, where 43% reported spraying their farms more than 4 times, and 29% 3 times or less, only 52% of respondents using chemical methods of control were able to confirm its effectiveness. It would appear that farmers were aware that if they did not spray their farms the recommended number of times for the whole length of the rainy season when black pod disease was most active they would not achieve the right results. Against this is the cost of existing application systems and the likelihood of productivity gains being constrained by other agronomic and economic factors. If this is the case then the need to find affordable and environmentally appropriate methods for controlling cocoa black pod disease becomes imperative.

Constraints Militating Against Efficient Cocoa Black Pod Disease Control

Among the constraints that were identified by farmers as militating against cocoa black pod disease control were cash-flow problems, finance and credit and labour availability. To a significant extent, the availability and cost of access to black pod control spray equipment were also mentioned. Any strategy to combat the disease should consider how to overcome these constraints.

Environmental Hazards Of Black Pod Disease Control

Farmers were clearly cognisant of the health hazards associated with pesticide application and adverse effects were reported with metalaxyl and copper fungicide products as well as the more toxic insecticides. These are significant concerns as effects reported ranged from the irritant to the harmful. Coupled with off-target contamination effects monitored through the field programme, there are real grounds for concern regarding pesticide application systems presently in use.

Sources Of Cocoa Farmer Knowledge Of Pests And Diseases Control

Farmers acknowledge that they obtained most of their knowledge in pests and diseases control from the levy-funded Cocoa Services Division extension service. Over the course of the project this was phased out due to external monetary pressures and staff have to some extent been absorbed into the national agricultural extension system, covering a broad range of crops & contexts. This potential loss of relevant technical capacity and farmer connection was a cause of considerable concern in interviews with farmers and scientists in Ghana.

Farmer Perceptions Of Government Involvement In Black Pod Control

The direct involvement of government (except in the form of extension services) and the private sector were reported to be minimal. However, there were signs that given the right environment and incentives, some private sector entrepreneurs would be willing to collaborate with cocoa farmers in pest and diseases control. This was demonstrated by some respondents who reported being introduced to chemical control of black pod disease in the Western region and in some areas where spray gangs were being contracted to perform spray operations. Subsequent to the survey, the Government of Ghana has embarked on a major campaign to provide black pod and mirid control treatment to all cocoa farmers in Ghana. This high profile campaign is a direct result of pressure from farmers for government support against these major pest problems. Application aims to reach all farms and follow national spray recommendations, but faces many logistical challenges in delivering on this scale.

Farmers' Perceptions Of Relative Costs Of Cocoa farm Operations

Cocoa farmers have strong ideas about relative costs of cocoa farm operations. Analysis of farmer perceptions indicated that labour for weeding the farm, and in the form of caretaker or sharecropper services accounted for about 75% of cost of operations. From the farmers' point of view, labour inputs accounted for 82% of all farm operational costs, while capital inputs constituted about 18% of all operational expenditures. The cocoa industry in Ghana can thus be considered labour intensive. However, visual evidence suggests that in disease-affected areas farmers are no longer weeding as returns are too low. The crop becomes a harvest-only process, with minimal inputs of any kind.

Potential impacts of changed practices

Suggested indicators for monitoring the impact of potassium phosphonate on cocoa black pod disease control were reviewed. The implicit assumptions used were that the chemical would be available in sufficient quantities and be sold at affordable prices. Opportunities for increased returns to suppliers over time would depend upon the benefits that farmers derive from its use in terms of increased incomes, which in turn could lead to an increase in demand.

Potential indicators for impacts of alternatives to existing chemical control recommendations

Drawing from the survey outcomes, areas of particular concern (and of potential value as indicators of impact of practices) highlighted by farmers were:

Suggested Indicators for Measuring Impact of Use of Potassium phosphonate in Cocoa Black Pod Disease Control on farm.

Description	**Average Value in Base Year**
Relative score[2] of farmers regarding black pod disease as very important on their farms (*P. megakarya*-affected area, PMA).	85%
Relative score of farmers regarding black pod disease as very important, *P. megakarya*-free area (NPMA).	59%
Yield of cocoa per hectare without potassium phosphonate (PMA)	138

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[2] Measures Farmers' Perception of importance of black pod disease relative to other diseases and pests on their farms.

Yield of cocoa per hectare without potassium phosphonate (NPMA)	219
Cost of chemical control/ha	
Mean Net Real Income Per Hectare (PMA)	¢272,149
Mean Net Real Income Per Hectare (NPMA)	¢449,626
Percentage of farmers opting to use potassium phosphonate for black pod control in trial area.	0%
Percent of Farmers Using Protective Clothing (PMA).	39.67%
Percent of Farmers Using Protective Clothing (NPMA).	17%
Percent of Farmer Participants Complaining of Side Effects Using Chemical Control (PMA).	39.12%
Percent of Farmer Participants Complaining of Side Effects Using Chemical Control (NPMA).	17%
Percent of Farmer Participants Complaining of Side Effects Using Potassium phosphonate	Na
Percent Cocoa Trees Damaged Due To Application of Potassium phosphonate	Na

Na = not applicable; ie. these indicators would be estimated during and after on-farm-trials.

15. **Conclusion And Recommendation**

From the analysis so far conducted it is concluded that cocoa black pod disease caused by *P. megakarya* is a serious problem that needs immediate control and containment. Apart from the annual losses suffered by farmers, sometimes approaching 100% of crops and income, its spread poses a potential risk to the survival of the cocoa industry if it is not controlled. Farmers have shown their preference for chemical control but are not applying available chemical control methods satisfactorily for effective control due to perceived high costs, poverty and operational difficulties. Attention should therefore be focused on efficacious but less costly and user friendly chemical methods of cocoa black pod disease control.

RESIDUE ANALYSIS

Alongside the field studies, phosphite residue analysis techniques were developed to enable the monitoring of chemical movement in the plant and determination of residues in plant parts.

Previous methods used elsewhere were found to be imprecise and required considerable further development by the analytical team at NRI. The method developed was based on the determination by gas liquid chromatography of the ester derivative (dimethyl phosphonate) produced by the reaction of phosphonic acid with diazomethane, using a Flame Photometric detector (FPD). This included methods for the safe and controlled preparation of diazomethane, a potentially hazardous reaction.

Two laboratory analysts from CRIG were trained at NRI in the use of this method and procedures were developed between the CRIG and NRI staff for safe handling of the materials and reactions involved under containment conditions available at CRIG. Detailed instrumental operating notes were jointly developed to ensure sustainability of procedures. An FPD system to fit the Ai Qualitek Model 93 gas chromatograph used by CRIG (originally supplied under the earlier DFID Ghana Cocoa Project) was provided by the project and installed by a company engineer in May 2000.

Unfortunately, it was subsequently found that the CRIG detector had markedly lower sensitivity than that used at NRI, a difference that may be due either to the different detector or to the analytical columns available at NRI being more effective than those commercially available for the CRIG gas chromatograph. This required preparation of new analytical standards based on the sensitivity of the CRIG machine.

Problems were experienced over the last year of the project with gas supply from the hydrogen generator used and with the mass flow controller, in-line moisture filters and temperature control on the gas chromatograph. As a result of these practical problems in equipment function and maintenance, the number of samples actually analysed has been greatly reduced from the originally intended number.

Some samples from leaves and dried beans have been analysed, but analysis of samples from stem tissues has proved impossible due to the high level of gummosis produced in cut stems and sampling phosphite in soil has also proved unfeasible due to soil binding.

Sampling of leaves was done in September, October, November, and January following phosphonic acid application in August 2000. Phosphonic acid residues in leaves were determined in duplicate or triplicate samples after random sampling in the given blocks. Phosphonic acid residues were determined by the diazomethane method.

Later in the project, priority was shifted to the analysis of the dry beans. Bean samples were taken from blocks at Bechem where treatments were applied in August 2001: Trt 2: 2x20, 20%, pH 7.5; Trt 4: 2x20,40% + bion pH 7.5; Trt 5: 2x20, 40% pH 7.5; Trt7: Phosphonic acid spraying, 20% + bion solution, pH 7.5. Four harvests of ripe pods were done from September to December 2001 and dry samples taken from each harvest. September and October analyses were completed.

Phosphonate residues in samples from other plantations:
Dry cocoa samples were taken from three other CRIG plantations, Worakese, Wantram and Acherensua respectively in the Central, Western and Brong Ahafo regions of Ghana. Samples have been collected for October, November and December (2001). The October samples have been analysed. No phosphonic acid residues were detectable in these samples.

Assessment of Contamination by Current Spray Application Methods

Present recommendations for black pod management in Ghana are for a combination of cultural sanitation practices (shade thinning, removal of infected pods, weeding and pruning etc) and chemical sprays. Apart from the survey conducted under this project, little information is available on the level of sprayer ownership or fungicide use in Ghana.

In any spraying operation involving manual equipment such as lever-operated knapsack sprayers or motorized knapsack mistblowers, it is inevitable that spray operators risk being exposed to pesticide contamination. The extent to which this occurs depends on the duration of exposure, the concentration and volume of pesticide, the nature of the crop and the skill of the operator.

To assess the level of pesticide contamination experienced by spray operators during the course of fungicide (or insecticide) application, a series of spray applications were made in mature cocoa plantings at Bechem and Tafo using the fungicide ‘Ridomil plus 72’ (metalaxyl/cuprous oxide). Ridomil has both semi-systemic and residual properties and is recommended by CRIG for black pod control.

All applications were made by experienced and previously trained spray men. Each trial was conducted using a sprayer tank of Ridomil mixture (50g/15l), with or without tartrazine (30g). Tartrazine was used to determine whether spectrophotometry might provide a simpler alternative to gas chromatography for metalaxyl residue analysis. Absorptive pads (foil-backed glass fibre filter papers) were attached to the men’s overalls at 9 key points and cotton gloves worn on the hands. After timed spray periods the pads and gloves were removed, bagged, dried and refrigerated then frozen before analysis. To assess the proportion of emitted spray deposited on the ground, plastic Petri dishes were placed in a circle 0.75m away from the stem base.

Environmental effects of treatments

In addition to the soil surface spray deposition measurement outlined above, experiments were established to determine the effects of treatments on leaf litter decomposition (turnover of organic matter) and accumulation of copper residues in soils. Recently-fallen cocoa leaf litter was divided into equal fresh weight portions, bagged in nylon mesh bags and placed on the plantation floor, at equidistant points from particular trees. Soil samples were also collected for chemical content determination. Bags were removed at 2 monthly intervals, samples oven dried and dry weight determined.

Determination of Induced Systemic Resistance

Preliminary experiments were carried out to determine the appropriate methodology and the feasibility of the use of elicitors in the control of *Phytophthora* diseases of cocoa. A leaf disc assay based on the method for resistance testing employed at CRIG was modified to screen for local induced resistance. Initial results were inconclusive due to a number of factors and it was suggested that an agar based system may be more effective. Experiments were also established with detached pods and whole plants to look initially at local induced resistance, then at systemic induced resistance.

Determination of Cost-Benefit Relationship of Treatments

Economic costs and benefits of treatments were calculated based on 2002 cocoa prices and labour costs. Costs were derived from actual retail costs and times required from experience of CRIG staff. The basis for these is:

Number of Ridomil plus 72 fungicide sachets/hectare = 10	
Cost of one sachet of Ridomil plus 72	Cedis 10,000
Number of sprays per season = 6 (recommendations can be up to 9)	
Sub total chemical cost per hectare	*Cedis 600,000*
Cost of hired labour	
One sprayer/ha/day	Cedis 20,000
Cost of fetching water	Cedis 10,000
Assume 6 sprays /season	
Sub total labour cost	*Cedis 180,000*
Protective equipment per annum[3]	Cedis 42,300
Capital cost of sprayer per annum[4]	Cedis 55,000
Sub-total equipment cost[5]	*Cedis 18,460*
Outgoings cost per annum	***Cedis 798,460***
Informal sector interest @50% of total	Cedis 399,230
Overall total	**Cedis 1,197,690**
Cocoa prices to farmer (2002) Cedis 387,500/62.5 bag	Cedis 6,200/kg

It can be seen from these data that even without credit repayment requirements, the cost of existing recommendations is, for many farms, similar to the value of production. Farmers would thus have to make a significant leap of faith to adopt present full recommendations rates on the assumption that yields would increase in a manner to justify the outlay.

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[3] Simple face mask (33,750), goggles (13,500), gloves (22,000), rubber boots (50,000) & overall (50,000), anticipated life 4 years

[4] Sprayer expected working life 5 years, capital cost 500,000 Cedis, interest at 10%p.a

[5] capital costs divided by 5 for median farm size of 5 ha

Results – Field Experiments

Bechem

The Bechem site is located in Brong Ahafo region, an area affected by *P. megakarya* and to some extent *P. palmivora.* Results were obtained from large scale field trials over a 3 year period, with experiments managed and data collected by local counterparts in CRIG, Ghana. The experiments were complicated by the need to modify and explore new treatments as the years progressed, which meant that some plots remained with the same treatments throughout, while others were changed. As a result and due to the associated covariance effects, the experiments could not be analysed over the experimental period as a normal randomized block experiment. Results were analysed by the University of Reading Applied Statistics Service, using a mixed model analysis, via the SAS programme.

Effects of black pod control treatments on yields

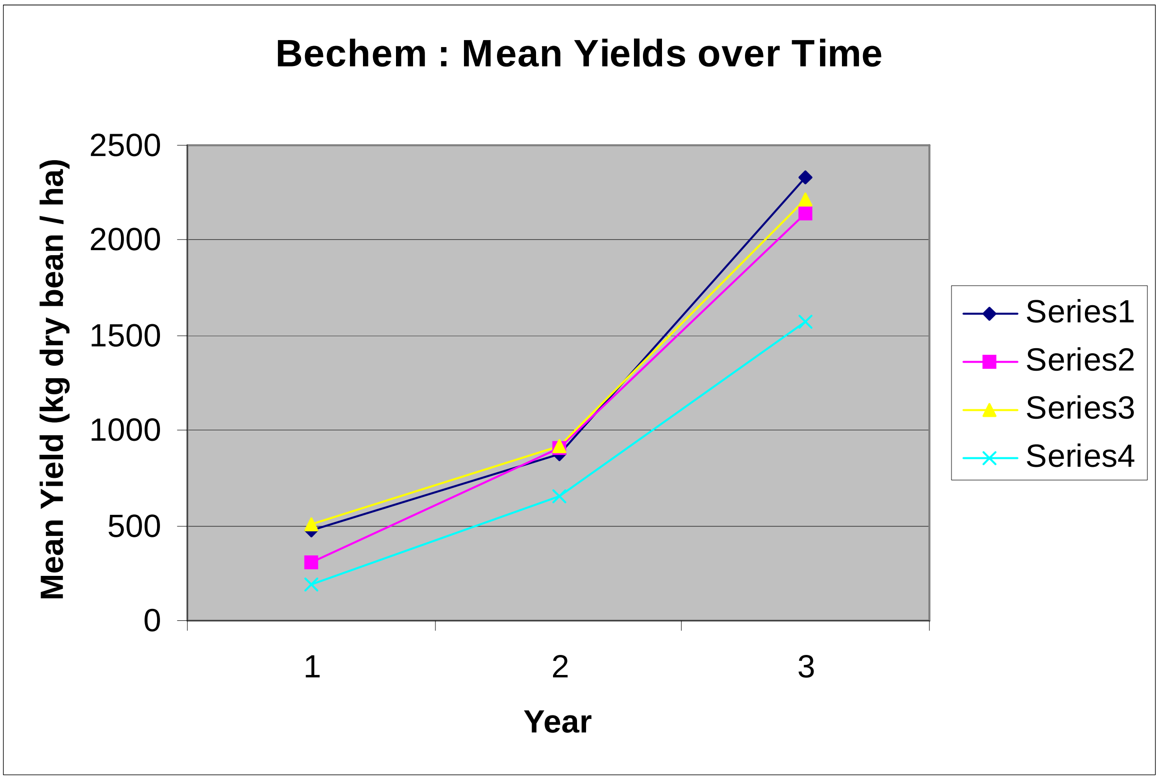
By using the same plots over the course of the 3 years, the experiments entailed a built in covariance for successive years. The differences between plots also entailed a higher variance with higher yields. Consequently, results were analysed together across all treatments and years using a mixed model analysis. Yield results were converted to dry bean/ha (the product sold by farmers).

Results from different types of treatments were combined and analysed together to examine overall treatment effects between application systems (injected vs sprayed phosphonate vs standard spray recommendations vs untreated control). In this overall analysis, treatments were found to be different (significant, $P<0.05$), but relative effects varied between years (significant, $P<0.05$). The effect of year was also marked; over the three years of the experimental programme yields increased considerably across all plots. This is believed by the Ghanaian scientists involved to be due to combination of season-season differences and the overall effect of treatments and associated crop husbandry on what had been a neglected field site. Both injection and sprays of potassium phosphonate gave yield increases that were at least as good as the existing best recommendation of Ridomil sprays (themselves applied at recommended rates that most farmers fail to achieve in practice). Overall, black pod control treatments gave yield increases of around 50% above those in the untreated control.

Table of Adjusted Mean Yields (kg dry bean / ha) by Overall Treatment coding and Year (taken from SAS output)

		Year			
	Treatment	1	2	3	Overall (S.E.)
1	Potassium phosphonate Injection	473	874	2334	1227 (54.0, 89 d.f.)
2	Potassium phosphonate Spray/Paint	305	912	2139	1119 (79.2, 116 d.f.)
3	Standard Ridomil sprays	512	918	2214	1215 (54.8, 108 d.f.)
4	Untreated control	195	657	1573	808 (123.6, 63 d.f.)
	Overall	371	840	2065	

Plot of Adjusted Mean Yields (kg dry bean / ha) by Year using Overall Treatment coding



Further treatment comparisons were extracted from the mixed model analysis, these showed that the composite of sprays & paints for potassium phosphonate gave yields that were indistinguishable from those in injected plots in years 2 and 3. However, in year 1, the ineffective stem paints used reduced the overall mean effect of these treatments.

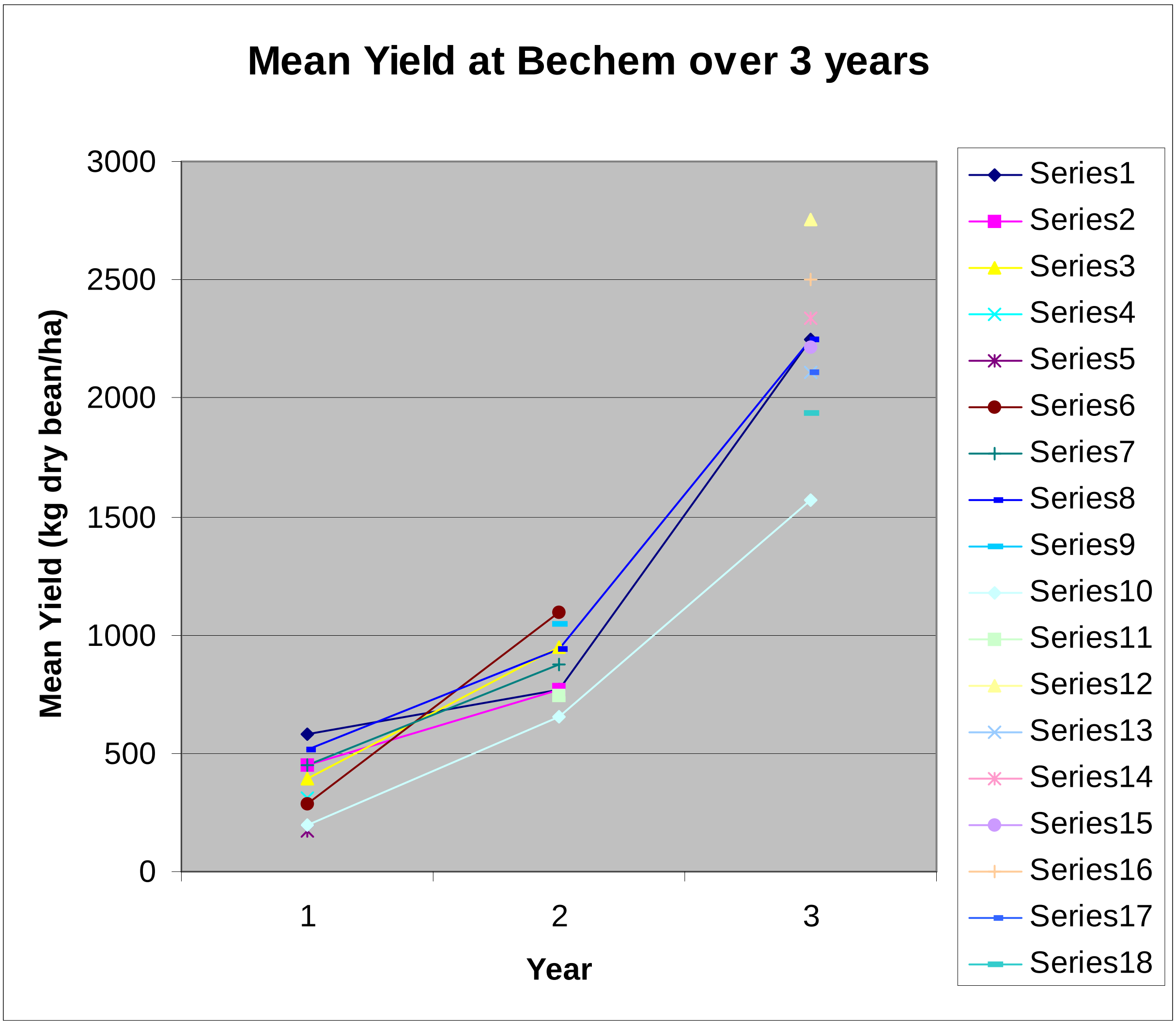
Results showed significant differences in pod yields between treatments ($P<0.05$) and between years ($P<0.0001$). There was some evidence that treatments had differing effects in different years (interaction significant at $P = 0.053$), but this should be interpreted with caution as not all treatments were used over all years and so this is the effect of some specific treatments only.

Yield effects were also examined for each treatment:

Table of Adjusted Mean Yields (kg dry bean / ha) by Treatment & Year
(taken from SAS output)

		Year		
	Treatment	1999/ 2000	2000/ 2001	2001/ 2002
1	40% Potassium phosphonate 2 x 20ml inj	577	765	2251
2	20% Potassium phosphonate 2 x 20ml inj	450	771	
3	40% Potassium phosphonate 2 x 10ml inj	393	949	
4	40% Potassium phosphonate stem painting	307		
5	40% Potassium phosphonate stem painting + scraping	169		
6	40% Potassium phosphonate pod spraying	283	1095	
7	40% Potassium phosphonate pod painting	450	872	
8	Ridomil 72 plus (12% metalaxyl & 60% cuprous oxide, 50g/15l)	516	938	2249
9	Callomil plus 72 w.p. pod spray (12% metalax. & 60% cupr. ox, 50g /15l)		1044	
10	Untreated control	195	657	1573
11	20% Potassium phosphonate solution, pod spraying		740	
12	40% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5			2752
13	20% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5			2110
14	20% Potassium phosphonate solution, 2 x 20ml injection, pH 6.5 + Bion			2339
15	40% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5 + Bion			2215
16	Ridomil plus 72 + Bion pod spray			2498
17	20% Potassium phosphonate solution, pod spraying, pH 7.5 + Bion			2105
18	Nordox Super 75 pod spray (86% cuprous oxide w.p., 100g /15l)			1934

Plot of Adjusted Mean Yields by Treatment & Year:



The overall pattern was that yields were considerably increased by black pod control treatments, with the best treatments increasing yields by a factor of x3 in the first year and around x2 in years 2 and 3. Relative treatment effects varied between years but both injection and sprays of potassium phosphonate gave yield increases through control of black pod disease. Across the years, the efficacy of specific phosphonate injection and spray treatments ranged around that of the standard recommendation (Ridomil sprays), with no consistent evidence of a dose:response effect from different application concentrations and volumes. In year 3, adjusting the acidity of the phosphonate solution used to pH 7.5 from pH 6.5 did not appear to affect control efficacy, but did considerably reduce visual evidence of application scorch. Pod sprays also caused a superficial scarring effect on the pods but had no visual effect on internal tissues.

Effects of treatments on incidence of black pod disease

Effects on the number of fully expanded pods affected by black pod disease were explored using the same analysis principles as for yields of healthy pods. Although data was collected for both usable (i.e. those that were still fit for inclusion in the ferment as the fungus had not yet reached the beans) and unusable pods, for the purpose of this analysis these were combined as an expression of the number of infected pods.

When overall treatment effects were explored, little effect of any treatment was observed in the first year of treatment, but as the field trials progressed, losses of pods to black pod disease were approximately halved in years 2 & 3 as a result of either phosphonate injection or sprays or by standard Ridomil sprays. Treatments were indistinguishable in their effects in reducing black pod incidence. It should be noted that black pod affects yields through both effects on expanded pods and on losses of cherelles and infected flower cushions. Monthly measurements of cherelle losses were also taken, but these did not show any clear trends between treatments either. The increased effect in year 2 can probably be explained as a result of long term benefits of treatment to the trees, through reduced canker and saprobic survival of the pathogen, together with reduced general inoculum in the field as a result of treatments; while numbers of black pods increased steadily, this increase was markedly below the increases in yields.

Table of Adjusted Mean Number of Black Pods* by Overall Treatment coding and Year (taken from SAS output)

* total count i.e. usable and unusable

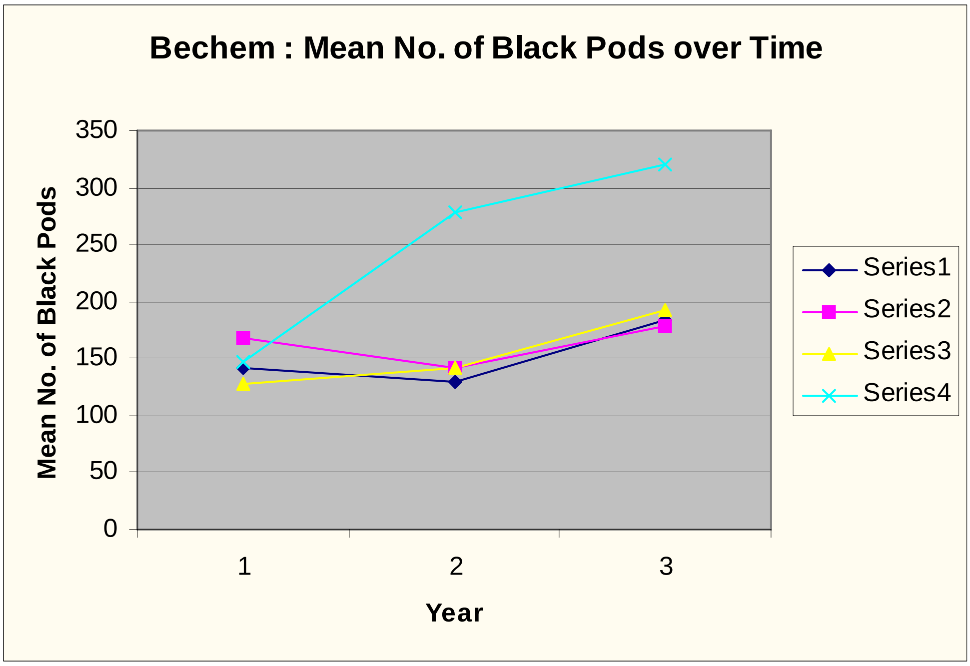
		Year			
	Treatment	1	2	3	Overall (S.E.)
1	Phosphonate injection	142	129	184	152 (9.5)
2	Phosphonate Spray/Paint	168	141	178	162(10.2)
3	Ridomil/Cu spray	127	142	193	154 (10.5)
4	Untreated	148	278	321	249 (22.8)
	Overall	146	172	219	

Tests of effects;

Effect	Num. d.f.	Den. d.f.	F Value	Probability ratio > F
Replicate	6	60.7	3.08	0.011
Overall treatment	3	95.1	5.43	0.002
Year	2	84.4	93.24	<0.001
Treatment x year	6	93.3	1.93	0.084

Plot of Adjusted Mean Number of Black Pods[*] by Year using Overall Treatment coding

[*] total count i.e. usable and unusable



When treatments were examined individually, while there were large differences between years there was no interaction between treatment and year. Differences among treatments were significant at $p<0.05$.

Table of Adjusted Mean Number of Black Pods[6] by Treatment & Year (taken from SAS output)

		Year		
	Treatment	1	2	3
1	40% H3PO3 2 x 20ml inj	104	123	168
2	20% H3PO3 2 x 20ml inj	143	134	
3	40% H3PO3 2 x 10ml inj	181	117	
4	40% H3PO3 stem painting	183		
5	40% H3PO3 stem painting + scraping	155		
6	40% H3PO3 pod spraying	115	138	
7	40% H3PO3 pod painting	214	170	
8	Ridomil 72 plus	128	122	173
9	Callomil plus 72 w.p. pod spray (12% metalax. & 60% cupr. Ox, 50g/15l)		175	
10	Untreated control	148	278	321
11	20% Potassium phosphonate solution, pod spraying		135	
12	40% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5			215
13	20% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5			188
14	20% Potassium phosphonate solution, 2 x 20ml injection, pH 6.5 + Bion			180
15	40% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5 + Bion			167
16	Ridomil plus 72 + Bion pod spray			190
17	20% Potassium phosphonate solution, pod spraying, pH 7.5 + Bion			209
18	Nordox Super 75 pod spray (86% cuprous oxide w.p., 100g product/15l)			184

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[6] total count i.e. usable and unusable

While injection gave a significant ($P<0.001$) reduction in black pod incidence compared with the untreated control, there was no discernible difference in efficacy between phosphonate injection and the current 'best practice' spray recommendation, nor with pod sprays of phosphonate.

Differences between specific levels of particular treatments were generally not consistent across years. Pod and stem paints of potassium phosphonate gave poor control by comparison with pod sprays. Results for Ridomil and Callomil sprays were at some variance given that these contain the same active ingredients. Among the injection treatments, there was no consistent trend of increasing phosphonate concentration or dosage, indicating that the lowest rates used would give the best economic returns and minimize local treatment damage. Addition of Bion to Ridomil sprays gave no advantage in black pod reduction and there was no detectable effect of adding Bion to injected phosphonate.

Overall summary - Bechem data

Long term field experiments at Bechem showed clearly that control efficacy and yield benefits obtained with phosphonate injection or sprays were at least as good as those obtained with the current standard spray recommendation for Ridomil and copper. While pod sprays were applied at the same intervals as the standard sprays, injection was performed as a one-off operation each season. Results from the farmer survey showed that in practice farmers rarely applied chemical control according to recommendations, so in reality field control with standard recommendations is likely to be less effective than under these experimental conditions. Yield data from farms also suggests that the costs of disease control by existing recommendations are unlikely to be recovered by farmers where yield potential is not increased by other crop husbandry inputs. Localized phytotoxicity was apparent on trees treated with either phosphonate sprays or injections. However, there was no evidence to suggest any deleterious effects of these treatments over the 3 year treatment period of the experiment.

These effects represent a composite of control of *P. megakarya* and the less aggressive *P. palmivora,* so comparable experiments were instituted at Tafo to determine the component due to *P. palmivora* and how this responded to disease control treatments.

Tafo

Tafo area is so far free from *P. megakarya,* but the less virulent *P. palmivora* is well established. Treatments used echoed those in Bechem, except that delays in supply of potassium phosphonate from the manufacturer (due to batch production) prevented an experiment in year 2.

Treatments used and yields obtained (kg dry bean/ha) were:

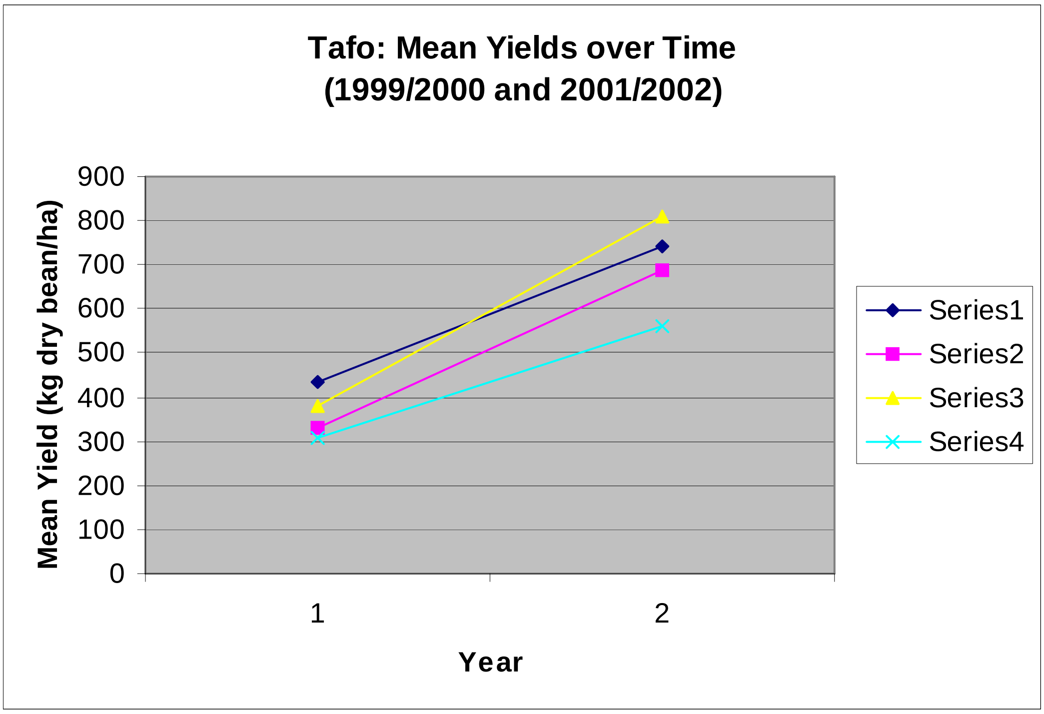
		Year	
	Treatment	1999/2000	2001/2002
1	40% H3PO3 2 x 20ml injection	519	731
2	20% H3PO3 2 x 20ml injection	415	
3	40% H3PO3 2 x 10ml injection	373	
4	40% H3PO3 stem painting	293	
5	40% H3PO3 stem painting + scraping	369	
6	40% H3PO3 pod spraying	359	
7	40% H3PO3 pod painting	278	
8	Ridomil 72 plus (metalaxyl 12% + cuprous oxide 60%, w.p.)	380	768
9	Untreated control	306	560
10	40% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5		749
11	20% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5		765
12	20% Potassium phosphonate solution, 2 x 20ml injection, pH 6.5 + Bion		816
13	40% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5 + Bion		647
14	Ridomil plus 72 + Bion pod spray		844
15	20% Potassium phosphonate solution, pod spraying, pH 7.5 + Bion		672
16	Nordox Super 75 pod spray (86% cuprous oxide w.p., 100g product/15l)		837

As before, results were analysed by the University of Reading Applied Statistics Service, using a mixed model analysis, via the SAS programme.

The treatments used had no effect on dry bean yields, but there were significant ($P<0.001$) differences in yields between years as yields increased considerably between years 1 and 3. A similar effect was seen in Bechem and this is again presumably the result of a combination of favourable climatic factors and the general attention to crop husbandry across the experimental plots. There were no apparent differential effects of treatments between different years.

Results were also analysed by examining overall effects of the different types of treatments; phosphonate injection, phosphonate sprays, metalaxyl/copper sprays and untreated:

Plot of adjusted mean yields (kg dry bean/ha) in 1999/2000 and 2001/2002, by overall treatment (from SAS analysis):



Treatment code	Overall effect	Estimate	S.E.	d.f.
1	Phosphonate injection	588	35.8	69
2	Phosphonate sprays/paints	509	60.4	70
3	Ridomil + Cu sprays	596	45.5	69
4	Untreated control	433	72.4	52

Overall comparisons showed no clear differences between treatments, but there were some indications that both phosphonate injection and metalaxyl/copper sprays may have been giving some yield benefits when specific comparison was made with untreated plots (both differences significant at P<0.07).

Comparison of the number of pods affected by black pod disease at Tafo showed no measurable effects of any of the treatments on disease incidence as expressed in diseased expanded pods.

It can be concluded from Tafo that in the absence of *P. megakarya*, disease losses due to *P. palmivora* were insufficient to show an effect of chemical control treatment through increased yields or reduced black pod incidence.

Residue Analyses and Spray Application Studies (see Annexes 2 & 3 for results)

Ground deposition

Studies of ground contamination showed that 40 to 130ml of spray were deposited per m^2. This represents a very considerable off-target wastage as total volumes applied per tree ranged from only 120 to 325 ml. **These results suggest that a very significant proportion of spray applied is failing to be deposited on the target pods and that much of a farmer's investment in chemicals is wasted money as a result of poor spray systems.** The position is not quite so bleak if the life cycle of *P. megakarya* is taken into account, as the fungus is believed to have a soil phase that could feasibly be affected by fungicide falling to the ground, but there is no evidence to date to suggest this is an effective control measure. Furthermore, the progressive deposition of copper on the soil will over time lead to its accumulation.

From observations of the application technique of the sprayer operators involved in the exposure studies, it was seen that little attempt was made to spray pods much higher than two to three metres above ground level. The operators involved said this was because the length of the spray lance made it difficult to do so and because pods higher than three metres are relatively little affected by black pod disease compared with those nearer the ground. Lever operated knapsack sprayers are therefore well suited to this kind of work and with care and use of a suitable nozzle are reasonably efficient.

However, it appeared that the nozzles fitted to the sprayers used in the operator exposure trials were not ideally suited to pod spraying since the narrowness of the target (trunk/pods), and seemingly high spray emission rate led to significant levels of spray run-off and ground deposition. Use of lower flow rate nozzles and narrow angle hollow cone nozzles combined with appropriate operator training in spray application would significantly lower application costs through reduction in spray run-off and wastage with consequent financial benefits for the cocoa farmer and the wider environment in general. Use of a nozzle shield to confine spray to the vicinity of the pod/trunk may also be worthy of investigation. Reduced volume application rates would also contribute towards minimizing operator exposure during spray application.

Alternatives to the use of lever operated knapsack sprayers for the application of pesticides to cocoa include pod painting and trunk injection with buffered phosphonic acid, both currently under evaluation by CRIG. Trunk injection, if successful, has advantages over lever operated knapsack sprayer application in that the cost of the injection equipment is significantly less than that of a sprayer and phosphonate fungicide costs would be expected to be lower than conventional products such as metalaxyl. Moreover, a single injection of phosphonic acid may be sufficient for a whole season's protection against black pod, whereas six or more spray applications of fungicide are required. However, the tree calluses caused by repeated trunk injections may be unattractive to farmers and sprayer ownership may be more appealing for those farmers able to afford such equipment because of the knapsack sprayer's wider range of use.

Experiments to determine the effects of sprays and injection on leaf litter turnover showed no evidence of differential rates of leaf matter degradation over the time period used, but it could well be the case that more subtle changes are occurring in the soil biosphere that were not picked up by this relatively large scale and crude method.

Operator contamination

The exposure levels experienced by the sprayer operators during the application of metalaxyl ranged from 1.74 to 19.6 mg/hour, (mean 10.7 mg/hour, SD 5.6), suggesting that considerable reduction in levels of operator exposure could be obtained through appropriate training in application techniques. Given that the highest levels of contamination were found on the hands and arms it is clearly important that suitable gloves be worn during spraying as well as during the preparation of spray mixtures for application. In the application trials carried out the use of simple cotton overalls and some form of head covering appeared sufficient to protect the operator against significant metalaxyl contamination. Further trials are required to establish whether this would be true when much larger numbers of pods were present and spraying therefore more arduous and time consuming. Again, the use of lower flow rate and better directed nozzles would reduce the volume application rate and the amount of liquid deposited on the spray operator. If this is matched by the same concentration of chemical then exposure would be considerably reduced.

Phosphite residue analyses

Analysis of leaves and cocoa beans showed that detectable levels of phosphite ions were present in beans from treated trees, both injected and sprayed. Levels found ranged from 60-177 mg/kg (ppm) of dry bean. There was an approximate proportionality to these, with more phosphite applied leading to higher levels of the ion in tissues. Levels found were well below toxicity L.D.$_{50}$ levels for the ion. These phosphite levels have been discussed with chocolate industry representatives in the UK and Ghana, but their ultimate acceptability is very much a matter for further rational consideration by the industry, primarily revolving around whether these are viewed as a nutrient akin to phosphate ion residues or as a fungicide because of their antifungal properties. Other food crop industries have so far found no cause for concern yet the chemical is used widely in the avocado industry. Levels of 5-7 mg/kg were detected in the controls, which are presumed to be a detection artefact as spray drift would have been minimal and phosphite becomes ‘locked up’ in the soil in the same way as phosphate ions.

DISSEMINATION OUTPUTS

Capacity building

3 international study attachments were included in the programme:

Dr Isaac Opoku spent two weeks in the UK studying systemic acquired resistance with Dr Keith Holmes and including discussion with specialists in the field at Scottish Crops Research Institute. He then attended a major international conference on induced systemic acquired resistance in Greece.

Dr Jemmy Takrama and Mr Joseph Boafo both spent two months at NRI, working with Dr John Cox, Delphine Aigreau and Bill King in developing and refining the phosphonate analysis procedures for Ghana and practising their usage.

Publications:

No formal publications as yet as field results were required over the full 3 years.

HOLDERNESS, M., HOLMES, K., OPOKU, I.Y., AKROFI, A.Y., KING, W.J. and AIGREAU, D. (2002) Towards new control options for black pod disease in Ghana. Paper presented at CABI Cocoa Review meeting, Egham, U.K. June 2002.

VOS, J.G.M. and HOLDERNESS, M (2002) Farmer participatory training to address cocoa pest problems. Paper presented at Sustainable Tree Crop Programme Workshop, Accra, Ghana, November 2002.

Internal Reports:

HOLDERNESS, M. (1999) Back to Office Report on visit to Ghana. CAB International, Wallingford, Oxon, U.K. (unpublished)

KING, W.J. (1999) Back-to-Office Report: Visit to the Cocoa Research Institute of Ghana to support and review the analytical facilities for the determination of phosphonic acid residues in cocoa beans. Natural Resources Institute, University of Greenwich, Chatham, Kent, UK (unpublished)

KING, W.J. (1999) Technical review of the laboratory facilities for the determination of phosphonate residues in cocoa beans at the Cocoa Research Institute of Ghana. NRI Report 2434, 8pp Natural Resources Institute, University of Greenwich, Chatham, Kent, UK (unpublished)

HOLMES, K. (2000) Back to Office Report, Visit to Cocoa Research Institute of Ghana. CAB International, Wallingford, Oxon, UK (unpublished)

HOLMES, K. (2000) Back to Office Report on a visit to Cocoa Research Institute of Ghana, 23 October to 2 November 2000. CABI Bioscience, Ascot. 6pp. (unpublished)

OPOKU, I.Y. (2002) Report on visit to UK and attendance at International Conference on induced resistance. Cocoa Research Institute of Ghana (unpublished)

AIGREAU, D. & KING, W.J. (2000) Back to Office Report, Visit to Cocoa Research Institute of Ghana. Natural Resources Institute, University of Greenwich, Chatham, Kent, UK (unpublished)

AIGREAU, D. (2000) Back to Office Report on a visit by D. Aigreau and W. J. King to the Cocoa Research Institute of Ghana to assist in implementing an analytical method to determine phosphorous acid residues in cocoa material and to review pesticide application methods and spray operator exposure. 19 November 2000 to 1 December 2000. Natural Resources Institute, Chatham. 3pp. (unpublished)

AIGREAU, D. and KING, W.J. (2001) Implementation of an analytical method for the determination of phosphonic acid residues in cocoa material, assessment of spray operator exposure and review of pesticide application methods at the Cocoa Research Institute of Ghana. Report 2575. Natural Resources Institute, Chatham. 25pp. (unpublished)

HOLMES, K. (2001) Visit to CRIG, Ghana for the DFID Phosphonic acid Project, 4-11 November 2001. CAB International, Wallingford, Oxon, UK (unpublished) 3pp.

COX, J.R. and KING, W.J. (2001) Visit to CRIG, Ghana to support trials on the use of phosphonic acid to control Phytophthora megakarya, 19-29 November 2001. Natural Resources Institute, Greenwich.

COX, J.R. and KING W.J. (2002) Analysis of phosphonate residues in treated cocoa beans. Laboratory Analytical Report No 02AC, Natural Resources Institute, Chatham, 10pp

Other Dissemination of Results:

Results taken up into processes of national programme for the management of cocoa black pod and mirids (I.Y. Opoku)

Training courses for extension officers at Cocoa Research Institute of Ghana, 2001 and 2002

Listing and reference to key datasets generated:

Field notebooks and excel spreadsheets of disease data & experimental results (held at Cocoa Research Institute of Ghana)

Survey records for farmer survey across Western, Ashanti, Eastern and Volta Regions, Ghana (held at Cocoa Research Institute of Ghana)

Analytical notebooks for cocoa bean and leaf residues (held at Natural Resources Institute and Cocoa Research Institute of Ghana)

Photographs of cocoa diseases.

Notes from visits and project discussions

Project logical framework

Narrative Summary	Measurable Indicators	Means of Verification	Important Assumptions
Goal: Yields improved and sustainability enhanced in high potential cropping systems by cost-effective reduction in losses due to pests	By 2005, crop losses caused by pests reduced by half in at least two high potential systems in two target countries	Reports of target institutions National Production statistics Evaluation of crop protection programmes Research programme reports Monitoring against baseline data	Enabling environment (policies, incentives, markets, institutions) for widespread adoption of new technologies and strategies exist.
Purpose: Environmentally-acceptable herbicides, fungicides and bactericides and agrochemical use systems for application by smallholders and estate workers developed and promoted.	Guidelines for the use of sprayers developed for tree crops; appropriate technology developed for agrochemicals use by smallholders in one other cropping system by 2005	Programme reports, NARS reports, national crop production statistics	(Purpose to Goal) • World cocoa prices sufficiently high to maintain production and agronomic inputs by Ghanaian cocoa farmers • Distribution systems in Ghana and extension programmes allow effective dissemination of most appropriate & effective practices to farmers.
Outputs: 1. Mechanisms of phosphonic acid activity and evidence for induced systemic resistance established in cocoa. 2. Optimal phosphonic acid application frequency and timing determined and application targeting optimized, treatment compared with alternative control measures 3. Farmer constraints (human and socio-economic) to adoption of disease management technologies determined and appropriate measures defined for further study. 4. Preliminary cost: benefit relationship determined in representative farming systems in comparison with other control measures. 5. Environmental impact and human health considerations assessed for phosphonic acid in comparison with alternative compounds and control measures. 6. Residues of optimized treatment established as negligible through discussion with interested parties at all levels. 7. Ghanaian scientists resourced to carry out subsequent farmer-led investigations on disease management.	1. Extent of ISR and scope for its exploitation established by end year 1. 2. Comparative studies established on-station by 6 months and experiments established to determine long-term control efficacy over remainder of project. Residue movement and fate monitored in all phosphonic acid treatments 3. Farmer participatory survey completed and results compiled and incorporated with existing information by end year 1. 4. Cost:benefit relationships established for optimal treatments by end year 3 5. Assessment completed by end year 2 6. Using data from 2., discussions held with Ghanaian and UK organizations over course of project to establish comparative acceptability of treatments. 7. Appropriate equipment supplied and functional by end year 2, Ghanaian scientist trained at NRI by end year 2	Research publications, conference proceedings, project reports, CRIG bulletins Research publications, reports from Ghanaian authorities and overseas importers and manufacturers. Incorporation into relevant Ghanaian extension recommendations, subsequent uptake by growers (post-project).	(Output to Purpose) • 3-year research period may not be sufficient to determine long-term efficacy and economic impact against *P. megakarya* under Ghanaian production systems. • Mechanisms for subsequent farmer evaluation and uptake allow effective subsequent dissemination under existing funding & agencies or with additional subsequent funding. • Acceptability of use of phosphite or any other fungicide to world market may be subject to other factors outside the scope of the project.

Activities: 1. Prospects for deployment of ISR induction evaluated in a range of cocoa clones through leaf assays and whole plant experimentation. 2.1 Phosphonic acid compared in on-station field experiments over consecutive seasons against other newly-available agents of resistance induction ('Bion'), conventional systemic and contact fungicides, (metalaxyl and copper) and newly-released compounds ('Strobulin') and with cultural control measures and different agronomic inputs. 2.2 Phosphonic acid injection compared with sprays, paints and root drenches and movement and fate of residues within the plant determined to optimize application regimes (method, volume, dosage, frequency and timing). 3. Through review of previous studies and participatory discussion with farmers, determine potential constraints (financial returns, labour availability, relative ergonomics, competing demands etc) to adoption of different disease management technologies. 4. Relative cost:benefit relationship of phosphonic acid established in comparison with fungicides and cultural control measures under field experimentation, extrapolated to farmer yield expectations (established under 3). Field evaluation through on-farm testing of optimized regimes initiated under farmer-led trials. 5. Relative environmental impact of phosphonic acid, and other novel compounds assessed by literature review of animal toxicity in comparison with existing recommendations, operator contamination compared experimentally under alternative application technologies and relative impact of existing and novel approaches on ecosystem determined *in vitro* against a range of indicator microorganisms. 6. On the basis of data for optimized treatments, discussions held with relevant authorities in Ghana, cocoa exporters and the chocolate industry to determine and ensure acceptable residue tolerances for the crop. Residue analyses from beans used to confirm the acceptability of the optimal disease control regime. 7. Ghanaian scientists trained in pathological and analytical techniques required and CRIG analytical laboratory equipped to undertake appropriate residue analyses. Training attachment for a Ghanaian scientist at NRI in residue analysis techniques.	Inputs/Resources (£): Staff costs 73,563 Equipment 6,000 Overseas travel 20,120 Other costs 64,813 Total Costs 164,496	Research progress reports and final technical report. Training reports, employers reports.	(Activity to Output) • Availability of appropriate field trial sites in the desired areas. • Normal rainfall pattern allowing appropriate environmental (climatic) conditions for disease development. • Availability of suitable alternative formulations/delivery systems compatible with phosphonic acid and other compounds under evaluation. • Farmer cooperation in off-station trials.

CONTRIBUTION OF OUTPUTS

Through an extensive survey across 4 regions of Ghana, the project examined the human and socio-economic constraints to the adoption of disease management technologies among smallholder farmers and identified key issues requiring resolution in the development of effective and viable disease control measures. Through the survey, existing fungicide sprays were found to be considered expensive and very difficult to apply, while few farmers owned the necessary equipment. Cocoa farmers in Ghana were identified as predominantly older people, mostly male, with cocoa being used to assure a supply of income over a long period of years and with generally low input, low yield systems. Despite these constraints, fungicide use has clearly increased in recent years in response to the spread of *P. megakarya*.

Long-term field trials conducted in an area affected by *P. megakarya* showed that stem injection or foliar sprays with potassium phosphonate gave control comparable to that obtained with existing recommendations for metalaxyl + cuprous oxide. As a base commodity, often marketed as a foliar fertilizer, potassium phosphonate is not protected by patent and is likely to be considerably cheaper in product and application than commercial organic formulations. The compound has a markedly lower toxicity than persistent copper compounds. However, experimental modification of formulations reduced but did not eliminate localized phytotoxicity resulting from phosphonate injection, which causes potential issues of acceptability to farmers.
A residue analytic capability was established at the Cocoa Research Institute of Ghana and new methods and staff skills successfully developed to monitor phosphite (phosphonate) ions in cocoa tissues. Phosphite was detectable in beans from injected trees, but at levels well below health thresholds. This issue has been extensively discussed with chocolate manufacturers, who are concerned at possible negative publicity from any form of application residue, but recognize also that the phosphite residue is akin to phosphate and may require a different philosophy from that for conventional fungicides. Preliminary work with induced resistance demonstrated some evidence of an indirect mode of action through localized stimulation of resistance compound production by the plant, but significant induced systemic resistance has not so far been demonstrated.

Studies on environmental contamination showed that the present foliar spray recommendations and equipment used lead to extensive non-target contamination and wastage. Operator contamination is significant, but does not present a health hazard with the fungicides presently used (although there are implications for similar practices with the more toxic insecticides). While levels deposited are unlikely to lead to significant environmental effects in short-term use, the spray nozzles used are clearly causing extensive wastage of a large proportion of the product applied. Copper compounds are highly persistent and could accumulate in soils over the longer term. Existing spray recommendations were costed at equivalent to 193kg dry bean /ha, unlikely to give a significant return to low-output producers. Comparative cost:benefit relationships are difficult to establish in Ghana as existing recommendations are supported through government bulk purchase and there is at present a mass black pod control programme aiming to provide free applications to all cocoa farmers as part of a cocoa support programme. These relationships also depend on other cultural inputs used and potential yield returns. However, members of the project team sit on the managing group for this national black pod programme and so are able to directly bring project outputs into public practice.

The project outputs provided significant progress towards the project goal of improving yields and sustainability of high potential cropping systems by cost-effective reduction in losses due to pests. Project survey work demonstrated a real need and desire among farmers for more appropriate and usable alternatives to existing spray recommendations. Exploration of the use of potassium phosphonate has shown that it represents a viable alternative in efficacy terms and opens up alternative application system options for small farmers. Studies on environmental contamination have shown that current practices lead to extensive off-target contamination and waste, a finding that has very significant implications for a large-scale government black pod control programme presently operating in Ghana. These issues require further exploration through participatory research with farmers to determine what is truly appropriate and effective for their use. In addition, further research is required to refine and optimize application technologies for sprays used for both fungicides and insecticides. At present there is an unacceptably high level of off-target contamination and wastage with existing nozzles used. Earlier studies in Papua New Guinea have shown that through use of low flow rate nozzles, control efficacy can be maintained while product applied is considerably reduced, particularly where farmers are trained not to spray beyond the point of run-off. By incorporating these elements into work with farmers and the national black pod management programe there is scope for considerable economic saving for the Government of Ghana.

WHAT FURTHER RESEARCH IS NECESSARY

While the project has explored the feasibility and efficacy of the use of potassium phosphonate as an alternative to existing recommendations, because of the concerns among project staff about taking new chemical approaches direct to farmers, experimental work has so far been confined to field stations. This has been the preferred approach of CRIG for work in most research areas as recommendations have traditionally been passed to Cocoa Services Division for extension and farmer engagement. During the life of the project, the closure of CDS and the shifting institutional need for cocoa researchers in Ghana to become engaged directly with farmers have radically changed this operating framework so that technology development directly with farmers is fast becoming commonplace.

Alongside this, there is a strong awareness among the project team that the use of chemical management measures of any form will only be worthwhile if other crop husbandry inputs are performed to avoid gains being lost to other constraints and allow farmers to benefit economically from controlling black pod. Farmer participatory research is an essential next step in this process, to determine and work from farmers perceptions of what are acceptable disease management practices and what measures work for their own conditions, rather than under the managed experimental conditions of a field station. Future research needs to investigate how measures to reduce the use of more toxic materials can be integrated with cultural management practices to optimize disease control in relation to its epidemiology and spread with each rainy season. Similarly, the significance of local phytotoxicity and of residual phosphite can only ultimately be resolved by farmers and those further up the market chain understanding the issues and determining the advantages and disadvantages in practice and from their own perspectives.

Project outputs have shown that there is considerable scope for reducing wastage in existing applications and for exploring alternative management options with farmers to determine what measures are acceptable and relevant to their circumstances. These issues are proposed to be taken up into a farmer-participatory technology development and validation programme linked to other CPP work on mirids and underpinning the regional Sustainable Tree Crops Programme (STCP, funded by the chocolate industry and USAID) and enabling uptake and impact in four countries of west Africa. STCP programmes will engage CRIG direct with the farmer and trading cooperative Kuapa Kokoo in Ashanti Region and farmer participatory research in this frame will allow farmers to evaluate alternative black pod management methods for themselves. Alongside these farmer based studies, further exploration of alternative application systems would have considerable value, both in reducing unnecessary wastage and environmental contamination and in reducing operator exposure to applied chemicals.

PATHWAYS WHEREBY PRESENT AND ANTICIPATED FUTURE OUTPUTS WILL IMPACT ON POVERTY ALLEVIATION OR SUSTAINABLE LIVELIHOODS

Cocoa remains the mainstay of the rural economy in Ghana and much of the 'forest belt' of west Africa. An almost exclusively smallholder-grown crop, it provides direct cash income to farmers and brings export earnings direct into rural communities in a way that mineral commodities, the other main export earner for Ghana, cannot. Cocoa prices are strongly cyclical and determined by global market forces, but are presently providing a better return than over the last decade or so. Farmers in Ghana grow cocoa as a long term investment and agronomic inputs tend to vary with cocoa prices. It is clear that rural families in the southern cocoa growing belt of Ghana are highly dependent upon the crop and its successful production as a source of revenue. Despite this, smallholder revenues at present are still disappointing as yields and financial returns are also low from typically low-input systems.

Alternatives such as vegetables tend to be grown in shifting cultivation by leasehold farmers, and bring cash revenues, but this entails recycling of local revenues rather than generating export income. Cocoa remains one of the few export commodity crops that can be grown in large quantity by farmers of the region and which produces a reasonable rate of return in international trade. The cocoa farmer composition in Ghana is primarily male and of advanced age. This reflects the long term nature of the crop and the place it has in the social system of Ghana. However, it traditionally provides much of the revenues required for long-term family financial commitments such as school fees and the perennial nature of the crop means that it has been relied on for continuing steady income in this way. In W Africa, the owner-farmer population tends to be ageing, younger farmers have lived through low cocoa prices for many years, so are generally less committed to cocoa. This is compounded by problems of land access in long-term cultivated areas. Without long-term land security and price incentives, younger farmers tend to turn to quick-return vegetable crops, or to urban drift. The combination of soils of declining fertility, black pod disease and an ageing farming population poses some significant challenges to traditional cocoa producing areas such as Ashanti Region. Without an ability to manage the disease and provide agronomic inputs to do more than harvest the crop, the cocoa industry is unlikely to be able to reform and deliver the rural incomes desired to encourage economic growth in rural areas and reduce the social problems of urban drift and dependency on food imports. In the Western region the farmer profile is rather different. Here younger farmers have moved in to settle cleared forest land and yields are higher from such fertile soils.

However, the arrival of *P. megakarya* has changed the situation dramatically. Farmers can no longer rely on their crops to continue to produce and to recover yield potential after low-input periods as once the disease is established the pathogen survives in the soil and roots and remains a threat to pods and flower cushions. The disease is now rated the number one constraint to production in affected areas by both scientists and, as was seen in the project survey, farmers themselves. The Government of Ghana has instituted a major spray programme in direct response to the threat posed by black pod and mirids to farmers livelihoods and is centrally funding this across the entire country. However, the project has shown that there is considerable scope to explore alternative methods to manage black pod. The use of low flow rate nozzles could reduce current application rates by around half without reducing control efficacy, simply by more efficiently depositing spray on the target pods. Current chemicals used are proprietary products, which brings associated costs of such chemicals. These costs are presently not apparent, as much is purchased centrally by the Government and the price driven down accordingly. Similarly the price paid by farmers has previously been subsidized. In addition, the current practices are depositing large amounts of copper, a cumulative and toxic chemical, into the field soils and may itself be having long-term effects on soil biology and system productivity.

The future linkage of work to control black pod with direct farmer participatory training and research processes is seen as essential to farmers appreciating the issues and contexts around chemical usage and disease control. At present, most farmers are unable to even contemplate using chemical control methods as the spray equipment is too expensive to own and spray application methods are considered impractical and difficult to use. In many cases there is a lack of understanding of the disease cycle and pathogen ecology that prevents cultural management being effectively implemented before chemicals are even contemplated. A history of science-based recommendations for agronomic inputs without specific reference to social context has meant that farmers are unwilling or unable to experiment for themselves with new approaches. Alternatives such as injection may provide a less capital intensive solution and one that requires a less continuous time commitment from farmers than is demanded from current spray regimes. The demonstrated efficacy of potassium phosphonate as a pod spray also opens up the possibility of an economic alternative to copper-based sprays.

The issue of product registration and acceptance for use in cocoa requires further resolution. The chemical has been applied to manage *Phytophthora* diseases in a wide variety of food crops around the world, often while registered as a foliar fertilizer and it is often considered as a fertilizer rather than a fungicide. The detectable phosphite in the beans causes some concern to the chocolate industry which is highly sensitive to anything that could be described as a residue, but this is largely a matter of how the industry ultimately chooses to regard the chemical.

Whichever practices are adopted, there is potential for small enterprise development in the chemical management of cocoa. Skilled applicators could provide considerable cost and time savings to farmers and provide a hire service rather than requiring equipment purchase. However, it must be recognized that there is not at present the level of income, or trust and assurance in service providers present in the cocoa industry for farmers to feel comfortable paying others to provide specific crop management inputs. A clear exception are the indigenous methods of land leasing used in which in some cases, inputs are provided by the landowner. Various local systems facilitate access to land, e.g. in Ghana:
‘Abunu’: half the land is given to the sharecropper, proceeds divided equally but the sharecroppers provide the inputs, materials and equipment themselves
‘Abusa’: Sharecropper has a third of the land but the landlord provides the material, inputs etc.
Such systems are crucial as they are a) locally relevant & accepted and b) facilitate long-term land access for the landless. Abusa tends to be adopted by the young farmers, which could link effectively to new ways of managing the disease and the crop itself.

In terms of direct impacts of the project outputs, there are several immediate pathways by which this can and should happen.

The Sustainable Tree Crops programme in West Africa will allow transformation of outputs into farmer participatory training materials and their use in farmer participatory technology development and research activities. This programme covers Ghana, Nigeria, Côte d'Ivoire and Cameroon and so allows rapid awareness of the project outputs across the region. The projects outputs have been presented in meetings of the STCP, allowing rapid awareness of the issues involved and generating demand for improved methods of managing the disease.

The national campaign to control black pod and mirids provides an immediate mechanism in that Dr Opoku sits on the advisory committee for that programme. At present sprays of Ridomil are being applied by spray gangs, intended to reach every farm in the country. The programme is an initiative of the new President of Ghana and so has the highest possible level of support. By adopting some of the outputs from this project and incorporating them into further research and technology development around this programme, the potential contribution of the project to reducing costs and environmental impacts of this government funded initiative and equipping farmers to manage the disease for themselves is significant.

Discussion with the chocolate industry in Europe and in Ghana has established awareness of the need and potential to reduce wastage and environmental contamination in black pod control. The industry is already funding the STCP (see above) and in a number of cases cocoa buyers are also acting as suppliers of inputs and loan facilities to farmers to enable them to produce cocoa. By establishing more efficient, cost-effective and environmentally-benign means of disease management, the buyers are able to reduce their outlay and produce a product that is more acceptable on the market. Increasingly this includes high value niche markets such as fair trade chocolate and the Coop stores in the UK are now sourcing all its own-brand cocoa in this way. The work done under this project helps to create more sustainable practices that meet the criteria of such niche markets and so secures a long term future for small producers in W Africa.

ANNEX 1

Report On Baseline Survey To Determine And Compare Farmer Perceptions Of Black Pod Disease In *P. megakarya* And Non-*P. megakarya* Areas

Undertaken by Dr EG Asante, CRIG

The survey was conducted in three *P. megakarya* areas (PMA); Ashanti, Volta, and Western regions; and one Non- *P. megakarya* area (NPMA); the Eastern region of Ghana. In all a total sample size of 250 cocoa farmers was randomly selected, using methods developed by Casley and Kumar (1989) for the World Bank, out of which 224 respondents were interviewed, giving a response rate of about 90%. The main objectives of the survey were:

(c) To determine and compare farmer perceptions of black pod disease in *P. megakarya and Non-P. megakarya* areas, and,
(d) To determine measurable indicators for assessing possible technical and socio-economic impact of using potassium phosphonate for chemical control of cocoa black pod disease.

A summary of the findings of the survey is presented below.

1. DEMOGRAPHIC CHARACTERISTICS

1.1 Age Groups

Farmers' age groups in the survey areas are presented in Table 1 below.

Table 1. Age Distribution Of Respondents

	Less than 50 Years	**Greater than 50 Years**	**Total**
Ashanti region (N=58)	22%	78%	100%
Volta region (N=23)	56%	44%	100%
Western region (N=56)	39%	61%	100%
All PMA (N=137)	39%	61%	100%
Eastern region(NPMA)(N=87)	42%	58%	100%
All Areas (N=224)	39.75%	60.25%	100% .

Source: Survey data (1999-2000), N=Number of respondents.

In most regions, the majority of farmers were over 50 years old, a trend that is particularly marked in Ashanti. This age distribution concurs with other surveys of the general age distribution of cocoa farmers in the country, which also record a generally old farming population (Rep. of Ghana, 1995; 1998). (NB discrepancies between percentages shown and numbers of respondents are due to rounding errors in the percentages, used for simplicity of presentation)

1.2. Gender

Men constituted 88.67% of the sample in the PMA while women comprised 11.33%. In the NPMA, men constituted 94% while women comprised 6% of the sample. Assuming sampling accurately reflects the overall cocoa farming population, this indicates a strongly male-dominated industry (Table 2). Age distribution by gender has not been examined.

Table 2. Distribution Of Respondents By Gender

	Male	Female	Total
Ashanti region (N=58)	78%	22%	100%
Volta region (N=23)	100%	0%	100%
Western region (N=56)	88%	12%	100%
All PMA (N=137)	88.67%	11.33%	100%
Eastern region(NPMA)(N=87)	94%	6%	100%

Source: Survey data (1999-2000); N=Number of respondents

1.3. Status of Respondents

Most farmers were farm owners rather than caretakers, but this varied between regions (Table 3). The proportion of caretakers ranged from zero in Western region (an area of generally newly established farms and younger farmers working newly cleared land), to 28% in the old established plantings and relatively high land pressure of Eastern region.

Table 3. Status Of Respondents

Region	Caretakers % of Respondents	Farm Owners % of Respondents
Ashanti (N=58)	15	85
Volta region (N=23)	4	96
Western (N=56)	0	100
All PMA (N=137)	6.33	93.67
Eastern (NPMA) (N=87)	28	72

Source: Survey Data (1999-2000); N=Number of respondents.

1.4. Literacy Rate

The basic literacy rate varied between regions. In Ashanti, which contained the oldest cocoa farming population (78% over 50 years old), the great majority of farmers had received little or no basic education. However, in other regions around half of farmers had received at least basic education, with 18-22% having been through secondary, vocational or professional education. These age-related differences between regions probably reflect differences in access to education over the last 50 years (Table 4). NB variations from 100% total are due to rounding errors)

Table 4. Literacy Rate Among Respondents

Class	Ashanti Region	Volta Region	Western Region	Mean PMA	Eastern Region
	% Respondents	% Respondents	% Respondents	% Respondents	% Respondents
No Formal Education	66	22	39	47.18	26
Basic Education	28	57	43	39.22	56
Secondary Education	7	13	14	10.97	14
Vocational	-	-	2	0.85	2
Tertiary/ Professional	-	9	2	2.36	1
Sample Size	58	23	56	137	87

Source: Survey data (1999-2000)

1.5. Employment History

The great majority of farmers (over 90% of respondents in both the PMA and NPMA) had cocoa farming as their main occupation. Farmers who had other occupations but cultivated cocoa as a supplementary occupation formed 9.67% of the PMA sample and 8% of the NPMA sample. Mixed occupations were particularly prevalent in Volta region (Table 5). Highest proportions of farmers growing cocoa only were found among the older farming population in Ashanti and the farmer working newer cocoa land in Western region.

Table 5. Main And Supplementary Occupations Of Respondent Farmers

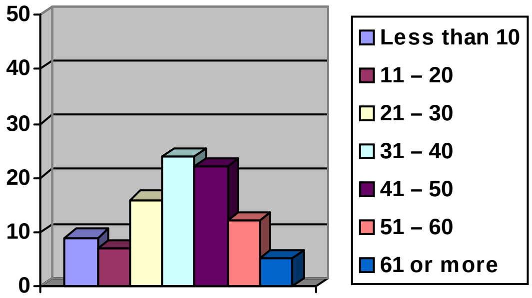
	Cocoa Cultivation As Main Occupation	Cocoa Cultivation As Supplementary Occupation	Sample Size
REGION	% Of Respondents	% Of Respondents	N
Ashanti Region	95	5	58
Volta Region	78	22	23
Western Region	98	2	56
All PMA	90.33	9.67	137
Eastern Region (NPMA)	92	8	87

Source: Survey data (1999-2000)

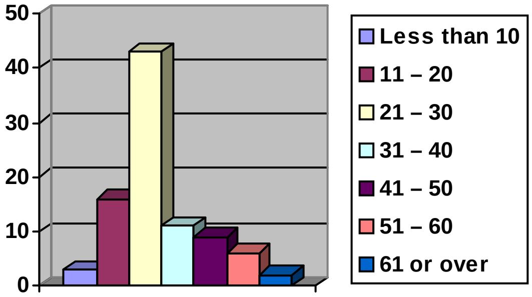
1.5.1. Experience In Cocoa Farming

Of the farmers who reported cocoa farming as their main occupation, the longest experience was in Ashanti with its older farmer group, 74% of whom had cultivated the crop for between 21 and 60 years with a median of 31 to 40 years. The distribution for farmers in the Volta region (70%) was between 11 and 40 years with a median of 21 to 30 years, while in the Western region 48% of respondents had been cultivating cocoa for between 11 and 40 years with a median of 21 to 30 years. About 17% of respondents in the Western region had less than 10 years experience in cocoa cultivation, indicating that the region attracts more prospective farmers than the other regions and is relatively recently cultivated to cocoa. In the NPMA, the distribution of years in cultivation of cocoa for the majority (70%) was between 11 and 40 years, with a median of 21 to 30 years. The median for all farmers in the PMA was the same as for the NPMA, that is the median was also 21 to 30 years (Table 6).

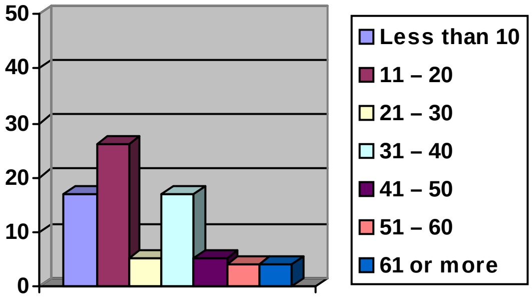
Number Of Years Cultivating Cocoa.



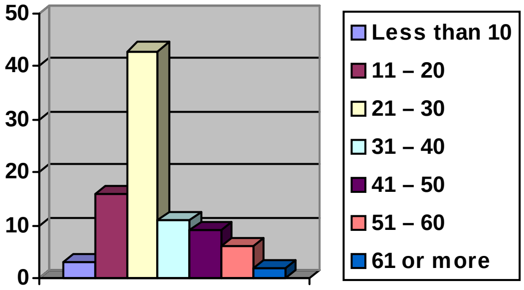
Years of cocoa-growing experience, Ashanti Region



Years of cocoa growing experience, Volta Region



Years of cocoa-growing experience, Western Region



Years of cocoa-growing experience, Eastern Region

The survey showed that there were distinct differences between regions in the extent of cocoa growing experience among farmers. In Ashanti Region, the greater age of farmers was reflected in a greater number of years of growing cocoa than in other regions. This reflects the earlier planting pattern of Ashanti having historically been a centre of cocoa production, but also that farmers of this region have maintained a very long-term commitment to their cocoa plantings, in preference to other crop options. However, in other regions, the younger farmer age profile also reflects a younger and generally more educated farming population that have often opened up new forest areas to cocoa planting. This is most marked in Western region, the area of youngest (and therefore generally most productive) cocoa plantings, which is nonetheless still affected by *P.megakarya*.

2. CHARACTERISTICS OF COCOA FARMS

2.1. Number Of Farms Owned

The total number of farms reported by the farmers were 411, consisting of 98 in the Ashanti region, 44 in the Volta 94 in the Western region and 175 in the Eastern region. The maximum number of farms owned by some individual cocoa farmers was four. Multiple farm ownership was most prevalent in Volta and Eastern regions (Table 7).

Table 7. Number Of Farms Owned

No. of Cocoa Farms Owned	Ashanti % respondents	Volta % respondents	Western % respondents	Eastern % respondents
1	52	26	50	37
2	34	57	34	31
3	7	17	14	26
4	7	0	2	6
No. of Respondents	58	23	56	87

Source: Survey data (1999-2000)

The high fragmentation of cocoa farms points to scarcity of large contiguous forestlands for development of large plantations. It may also reflect patterns of land acquisition and inheritance around established communities.

2.2. Mode of Farm Acquisition

Six modes of farmland acquisition were reported by the farmers. The distribution varied between regions. In the Ashanti region the most reported mode was through gifts (39%), followed by purchased land (37%), then family land (30%), inheritance (19%), sharecropping (13%) and then leasehold (6%). The mode of acquisition in the Western region was also dominated by gifts (39%), followed by purchased land (34%) as in Ashanti. However the similarity ends there. The next important mode of acquisition was reported as inherited land (13%), with only 5% of land being family land. The apparent unpopularity of family land use in cocoa cultivation in the Western region may be a consequence of the existence of a relatively higher proportion of migrant farmers in this newly developed region. In the Volta region, however, the most popular mode of farmland acquisition for cocoa farming was through family land and was reported by 70% of the respondents, followed by inherited land (61%), then gifts (30%), sharecropping (17%), purchased land (9%), and then leaseholds (4%) (Table 8).

Table 8. Modes Of Farmland Acquisition

Region	Ashanti	Volta	Western	All PMA	Eastern
Description	% Reporting	% Reporting	% Reporting	% Reporting	% Reporting
Family Land	30	70	5	35	15

Purchased land	37	9	34	27	24
Leasehold	6	4	2	3	14
Inherited	19	61	13	31	27
Gift	39	30	39	36	12
Sharecropping	13	17	7	12	21
Sample Size (N)	58	23	56	137	87

For the NPMA, the reported modes of land acquisition from the highest to the lowest were inherited land (27%), purchased land (24%), sharecropping (21%), family land (15%), leaseholds (14%) and gifts (12%). While this trend shows some differences from disease-affected areas it is not known whether the disease has caused a real shift in transfer of cocoa lands.

2.3. **Distance From Residence**

The mean distance of farms from settlements/places of residence were 6.51 km, 2.92 km. and 3.34 for Ashanti, Volta, and Western regions respectively. The mean distance for Eastern Region was 2.49 km. (Table 9). Distances travelled in Ashanti were markedly higher than elsewhere, which may again reflect the longer-established nature of cocoa plantings and associated land pressures in Ashanti

Table 9. Mean Distance Of Residence/Settlements From Farms

	Ashanti	Volta	Western	Eastern
Farm 1 (km.)	5.87 (58)	2.67 (23)	3.83 (56)	2.00 (87)
Farm 2 (km.)	5.59(28)	3.5(17)	2.81(28)	3.02(55)
Farm 3 (km.)	10.2 (8)	1.87(4)	1.73(9)	3.02(28)
Farm 4 (km.)	14.4(4)	-	4.8(1)	2.21(5)
Average	6.51(98)	2.92(44)	3.34(94)	2.49(175)

Source: Survey data (1999-2000); Number of Farms (N) in parenthesis.

2.4. **Type Of Cocoa Grown**

Types of cocoa grown included *Amelonado*, *Amazon* and *Hybrids*. The proportion of high yielding cocoa hybrids grown tend to be concentrated in the newer farms and mixed farms where they are being used to replace the low yielding *Amelonado* type.

In the Ashanti region *Amelonado* was reported on 16% of the farms while *Amazon* was reported on 35% of the farms. This contrasts with the younger plantings of the Western Region, which show a greater proportion of hybrids used (Table 10).
The data shows no evidence of any apparent link between type of cocoa grown and impacts of *P. megakarya* on planting materials used.

Table 10. Percent Distribution Of Farms By Cocoa Types Grown

	Ashanti	Volta	Western	All PMA	Eastern
Amelonado	16	33	0	16	12
Amazon	35	8	54	32	35
Hybrid	9	14	28	17	28
Mixed Cocoa	40	44	18	34	25
Sample Size	58	23	56	137	87

Source: Survey data (1999-2000)

2.5. Cocoa Age Groups, Farm Sizes and Yields

Cocoa yield per hectare was comparatively higher in the NPMA than in the PMA. The weighted average yield in the PMA was 138 kg/ha, while weighted average yield in the NPMA was 218 kg/ha. Nevertheless, yield in the Western region, an area affected by *P. megakarya*, was 217kg /ha. This is likely to be due to the relatively recent spread of planting in Western Region, giving a younger (and therefore more productive) tree population and that Western and Eastern Region are those most planted to the higher yielding hybrid and Amazon cocoa, rather than the Amelonado types with which Ghana was first planted. (Table 11 & Table 10). The specific impact of *P. megakarya* cannot be determined from this data, but typical yields in the disease-affected older plantings of Ashanti and Volta are clearly very low.

Table 11. Mean Age Of Cocoa Farms, Mean Farm Size , And Mean Yields/ha

	Ashanti	Volta	Western	All PMA	Eastern
Mean Age of Cocoa Farms (Yrs)	33.31	23.74	19.05	25.67	21.74
Mean Farm Size(ha)	3.41	1.98	5.21	3.89	2.43
Mean Yield/ha	93	76.5	217.1	138	218.7
Sample Size	58	23	56	137	87

Source: Survey data (1999-2000)

The Western region reported higher farm sizes than all the other regions, having a mean farm size of about 5.21 ha, compared to 3.41 ha in Ashanti, 1.98 ha in the Volta region and 2.43 ha in the Eastern region. This reflects the lower land pressure in the newly developed Western region. On the average farm size for the PMA was 3.89 ha.

2.6. Management

The cocoa farms were mainly managed by either the owners or by *abusa* sharecroppers[7]. In the PMA the distribution between owner-managed and *abusa*- managed farms were the same, whereas in the NPMA there were more *abunu* sharecroppers (29%), and fewer *abusa* sharecroppers (14%). Taken individually by regions, Ashanti, Volta and Eastern regions were predominantly owner-managed, 50%, 72% and 57% respectively, whilst in the Western region the farms were predominantly managed by *abusa* sharecroppers (65%), reflecting the younger farming population and new development of this land (Table12).

Table 12. Percent Distribution Of Cocoa Farms By Type Of Management

REGION	Ashanti	Volta	Western	All PMA	Eastern
TYPE OF MANAGEMENT	% Reporting	% Reporting	% Reporting	% Reporting	% Reporting
OWNER	50	72	32	47	57
ABUNU SHARECROPPER	9	8	3	6	29
ABUSA SHARECROPPER	41	20	65	47	14
Sample Size (N)	58	23	56	137	87

Source: Survey data (1999-2000)

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[7] 'Abunu' system: half land given to the sharecropper, proceeds divided equally but the sharecroppers provide the inputs, materials and equipment themselves
'Abusa' system: Sharecropper has a third of the land but the landlord provides the material, inputs etc. Young farmers tend to do this

2.7. Previous Land Use.

A relatively high percentage of respondents reported cultivating some of their farms on forest lands and this again reflected patterns of land development over time. The older plantings in Ashanti were often originally cleared from primary forest, while there was a much higher proportion of secondary forest clearance in the Western region. In the Eastern region the greater proportion of farms (33%) were cultivated from secondary forests. In addition it was reported that food farms and other tree crops farms were converted into cocoa farms in this region (Table 13). This suggests that the Eastern region (NPMA) is relatively more intensively cropped to cocoa than the PMA, which may reflect farmer confidence in the crop when free from *P. megakarya*.

Table 13. Percent Distribution Of Cocoa Farms By Previous Land Use Patterns.

REGION	Ashanti	Volta	Western	All PMA	Eastern
TYPE OF LAND USE	% Reporting	% Reporting	% Reporting	% Reporting	% Reporting
BUSH	14	35	18	19	19
COCOA FARM	22	14	9	15	22
FOREST	49	25	35	39	1
SECONDARY FOREST	6	9	21	13	33
VIRGIN FOREST	9	17	17	14	0
TREE CROPS	0	0	0	0	4
FOOD FARM	0	0	0	0	21
Sample Size	58	23	56	137	87

Source: Survey data (1999-2000)

3.0. GENERAL PEST AND DISEASES PROBLEMS IN THE AREA

Farmers were asked to rank in order of importance what they perceived to be the most frequently encountered problems in production in their areas. All farmers in the PMA (Ashanti, Volta and Western regions), agreed that "**black pod disease**" was the first problem they faced. However, from then on, variations in opinion began to show up as various rankings were assigned to the other farm conditions. (Table 14).

Table 14. Ranking Of General Farm Management Problems

REGION	Ashanti	Volta	Western	Eastern
TYPE OF PROBLEM	Ranking	Ranking	Ranking	Ranking
Labour	4	4	3	7
Finance and Credit	2	5	2	1
Input Prices	6	2	5	6
Black pod disease	1	1	1	2
CSSVD	9	8	9	8
Capsids	3	6	4	4
Weed Control	7	3	9	5
Mistletoe	8	7	6	3
Cocoa Prices	5	9	8	9
Sample Size (N)	58	23	56	87

Source: Derived from Survey data (1999-2000).

In the area not yet affected by *P. megakarya*, "**black pod disease**" was rated the second most important problem, the first problem being "**finance and credit**", while '**labour**' was ranked relatively very low at 7. The rankings were subjected to a Spearman's Rank correlation (Rs) to confirm the general trends between the regions. The results indicated that rankings in all the regions were positively correlated suggesting agreement in the rankings, however, only the tests for Ashanti and Western, and the test between Western and Eastern regions were statistically significant (Table 15).

Table 15. Spearman's Rank Correlation Coefficients, Critical values And Statistical Significant Levels

Paired Test Regions	**Correlation Coefficient (Rs)**	**No. of Ranked Items (N)**	**Critical Values for Rs (P $_{0.05,N}$) Rs (P $_{0.01,N}$)**	**Statistical Significance level**
Ashanti vs Volta	0.4333	9	0.600;0.683	ns
Ashanti vs Western	0.8333	9	0.600;0.683	**
Ashanti vs Eastern	0.5167	9	0.600;0.683	ns
Volta vs Western	0..4833	9	0.600;0.683	ns
Volta vs Eastern	0.4500	9	0.600;0.683	ns
Western vs Eastern	0.6167	9	0.600;0.683	*

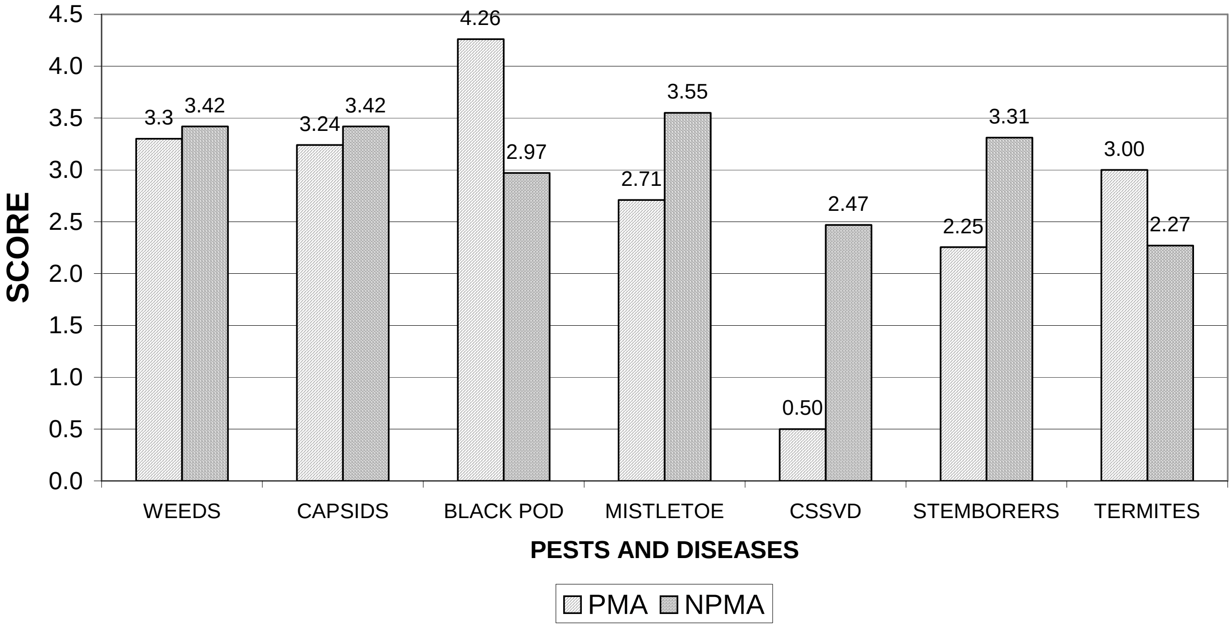
*= Statistically significant at 5% level; **= Statistically significant at 1% level. Ns = not statistically significant. Source: Estimates based on survey data (1999-2000), and Kenkel (1989) (pp 927-928; and Table A12).

Explanations given by farmers for the ranking of problems included low yields due to black pod disease, non-availability of credit to pay for chemical inputs and labour, high cost of equipment, non-availability of equipment, which when available is very costly relative to farmers' incomes. Black pod disease is clearly seen as the primary constraint to production in disease-affected areas.

4.0. RELATIVE IMPORTANCE OF PESTS AND DISEASES ON COCOA FARMS

Farmers were asked to score on a scale of 5 which pests and diseases on their cocoa farms they considered important, scoring 5 for the most problematic to 1 the least important pest or disease. Farmers in the NPMA tended to place more importance on the incidence of other diseases and pests than black pod. However, farmers in the PMA scored highest on black pod disease, confirming the earlier ranking. Thus incidence of mistletoe, weeding, capsids damage and stem borer damage appear more important in the NPMA with scores of three and above. On the other hand farmers in the PMA regard black pod disease, capsids, weeds and termites damage as the four top problems in cocoa diseases and pests incidence by scoring them at three and above. (see Fig. 1 below).

FIG. 1. RELATIVE IMPORTANCE OF COCOA PESTS AND DISEASES ON COCOA FARMS IN PMA AND NPMA AREAS



5.0 FARMERS' RESPONSE TO PERSISTENT INCIDENCE OF BLACK POD DISEASE ON THEIR COCOA FARMS

The majority of black pod disease-affected farms were reported to be still in production in all areas. In areas affected by *P. megakarya* some of the farms had been abandoned, mainly in the Ashanti region, with a small proportion in the Western region. However, few of these had been converted to other crop use. In the non-affected areas none of the farms have been abandoned, but a small proportion (about 1%) had been cut out and replanted (Tables 16a-16d). Anecdotal evidence suggests also that other crop management inputs have often also been greatly reduced in *P. megakarya* affected farms.

Table 16a. Status Of Black Pod Disease Affected Cocoa Farms At Time Of Survey

Ashanti Region	Farm 1	Farm 2	Farm 3	Farm 4
Abandoned	5%	11%	13%	25%
In Production	88%	79%	88%	75%
Grubbed and Replanted	0%	0%	0%	0%
Converted to Other use	0%	0%	0%	0%
Number of Farms	58	28	8	4

Source: Survey data (1999-2000)

Table 16b. Status Of Black Pod Disease Affected Cocoa Farms At Time Of Survey.

Volta Region	Farm 1	Farm 2	Farm 3	Farm 4
Abandoned	0	0	0	0
In Production	100%	100%	100%	0
Grubbed and Replanted	0	0	0	0
Converted to Other use	0	0	0	0
Number of Farms	23	17	4	0

Source: Survey data (1999-2000)

Table 16c. Status Of Black Pod Disease Affected Cocoa Farms At Time Of Survey

Western Region	Farm 1	Farm 2	Farm 3	Farm 4
Abandoned	2%	0%	0%	0%
In Production	98%	100%	100%	100%
Grubbed and Replanted	0%	0%	0%	0%
Converted to Other use	0%	0%	0%	0%
Number of Farms	56	28	9	1

Source: Survey data (1999-2000)

Table 16d. Status Of Black Pod Disease Affected Cocoa Farms At Time Of Survey

Eastern Region	Farm 1	Farm 2	Farm 3	Farm 4
Abandoned	0%	0%	0%	0%
In Production	93%	91%	96%	100%
Grubbed and Replanted	1%	0%	0%	0
Converted to Other use	0%	0%	0%	0%
Number of Farms	87	55	28	5

Source: Survey data (1999-2000)

6.0. FARMERS' PERCEPTION OF BLACK POD DISEASE AND DAMAGE

Farmers were aware of black pod disease and the extent of its damage to output and effects on their incomes from cocoa. Various names have been given to the disease in the various localities to identify the disease. Among some of the names given in local dialects are *asokuo, anonom, and apropro* in the Ashanti region. Similar names are used in the Eastern and Western regions. In the Volta region names such as *cocoa bubu, cocoa nana,* and *cocoa vuvu* are used to identify the disease.

Farmers are also aware of the time of its incidence and the period of severest damage to the cocoa crop. In general farmers were aware that the disease usually occurs between May and November each year, with the severest months being from June to September. Effects on output were variable from region to region. In the Ashanti region average output loss of about 79% was reported. In the Western region and Eastern region average losses of 66% and 49% were reported respectively. It is however evident that crop losses are more severe in the *P megakarya* endemic areas than in the non-*P megakarya* areas.

7.0. FARMERS’ USE AND PERCEPTIONS OF THE EFFECTIVENESS OF CONTROL METHODS

Farmers listed five main methods of black pod disease control. These were shade adjustment, weeding farms regularly, removal of black pod infected pods, pruning, and chemical control. The first four methods, usually referred to as **cultural control** methods, appeared to be more popular with farmers as they did not require much financial input. Tables 17a - 17d indicate the levels of farmers’ preferences for these control methods. Although the proportion of farmers using cultural methods were generally higher in all the regions than for chemical control, farmers in the Volta region and in the Western Region reported greater use of chemical control methods than the Ashanti and Eastern regions.

Table 17a. Farmers' Use And Perception Of Effectiveness Of Control Methods

Ashanti Region (N = 58)									
	Control Methods Used					Effectiveness			
	Number of Times					**Good**	**Average**	**No Effect**	**Indifferent**
	1	**2**	**3**	**4 or more**	**Total**				
Shade Adjustment	2%	7%	5%	2%	16%	2%	9%	3%	
Weeding	5%	28%	3%	2%	38%	9%	7%	5%	
Removal of Infected pods	5%	3%	14%	57%	79%	14%	12%	21%	
Pruning	5%	10%	12%	10%	37%	7%	10%	9%	
Chemicals[8]	2%	5%	7%	7%	21%	2%	2%	0%	

Source: Survey data (1999-2000)

Table 17b Farmers' Use And Perception Of Effectiveness Of Control Methods

Volta Region (N=23)									
Method	Control Methods Used					Effectiveness			
	Number of Times					**Good**	**Average**	**No Effect**	**Indifferent**
	1	**2**	**3**	**4 or more**	**Total**				
Shade Adjustment	52%	0%	0%	0%	52%	30%	4%	4%	0%
Weeding	22%	26%	4%	0%	52%	17%	17%	13%	0%
Removal of Infected pods	7%	9%	35%	19%	70%	35%	22%	13%	0%
Pruning	4%	17%	0%	0%	21%	13%	13%	0%	0%
Chemicals	4%	13%	13%	43%	73%	43%	9%	9%	0%

Table 17c. Farmers' Use And Perception Of Effectiveness Of Control Methods

Western Region (N=56)

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[8] Metalaxyl with copper, or copper-based formulations

Method	Control Methods Used					Effectiveness			
	Number of Times					**Good**	**Average**	**No Effect**	**Indifferent**
	1	**2**	**3**	**4 or more**	**Total**				
Shade Adjustment	23%	20%	9%	5%	57%	7%	9%	0%	
Weeding	2%	23%	45%	4%	74%	20%	7%	0%	
Removal of Infected pods	2%	8%	15%	16%	41%	20%	18%	0%	
Pruning	7%	27%	11%	13%	58%	16%	13%	0%	
Chemicals	2%	11%	16%	57%	86%	32%	4%	5%	

Source: Survey data (1999-2000)

Table 17d. **Farmers' Use And Perception Of Effectiveness Of Control Methods**

Eastern Region (N=87)									
Method	Control Methods Used								
	Number of Times					**Good**	**Average**	**No Effect**	**Indifferent**
	1	**2**	**3**	**4 or more**	**Total**				
Shade Adjustment	8%	8%	6%	2%	24%	20%	2%	1%	0%
Weeding	13%	21%	18%	1%	53%	29%	10%	8%	0%
Removal of Infected pods	5%	11%	25%	32%	73%	28%	28%	16%	0%
Pruning	13%	14%	5%	11%	43%	22%	6%	2%	0%
Chemicals	3%	6%	6%	5%	20%	11%	1%	1%	0%

Source: Survey data (1999-2000)

In figures 2, 3 and 4, the intensity of use of cultural and chemical methods for cocoa black pod disease control are compared for the PMA and the NPMA on a regional basis. Figure 2 shows that the main method of cultural control of black pod in the Ashanti region, which largely contains aged stands of cocoa, is removal of infected pods. In the Eastern region, which is, so far, free from *P. megakarya,* farmers depend mainly on cultural control methods. Figures 3 and 4 indicate that in the Volta and Western regions, cocoa farmers depend more on chemical control and shade adjustment for black pod control than in areas free from *P. megakarya*. This reflects the relatively high productivity of, and inputs into these younger plantings. Farmers in the Western region use more chemicals and also apply more weeding, shade adjustment, and pruning. These factors may be part of the contributing factors to the relatively higher yields per hectare reported in the region when compared with the NPMA which has a less virulent form of cocoa black pod disease.

FIG. 2. COMPARISON OF RATES OF USE OF BLACK POD CONTROL METHODS IN THE ASHANTI (ASH-PMA) AND EASTERN (NPMA-EAST) REGIONS OF GHANA

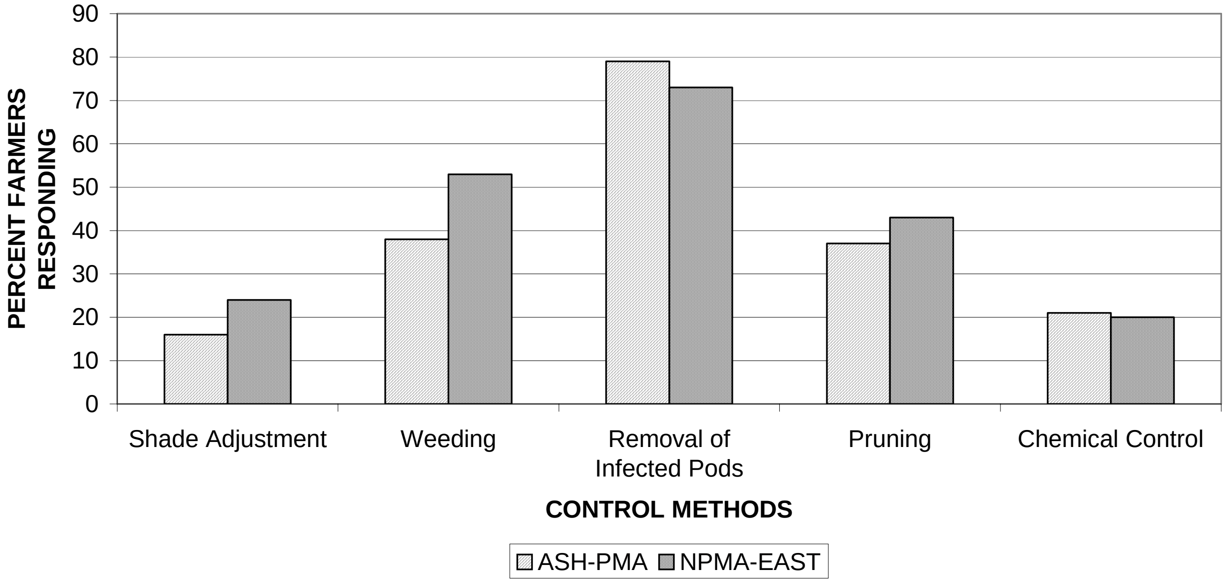


FIG. 3. COMPARISON OF BLACK POD DISEASE CONTROL METHODS USED IN THE VOLTA(VOLT-PMA) AND THE EASTERN(NPMA-EAST) REGIONS OF GHANA

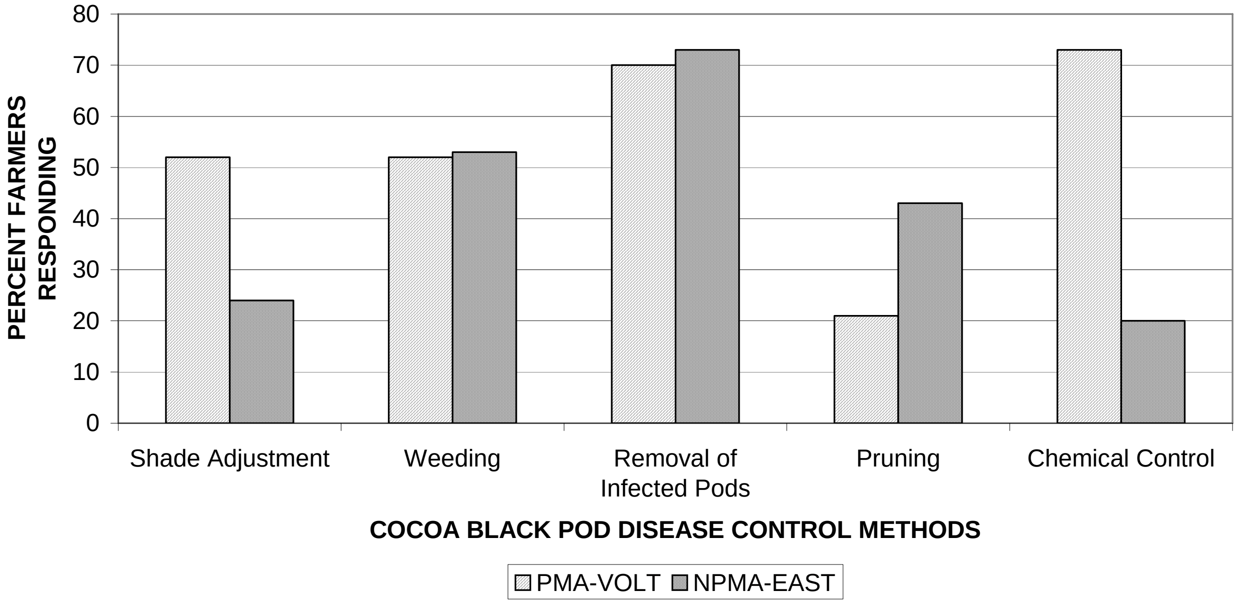
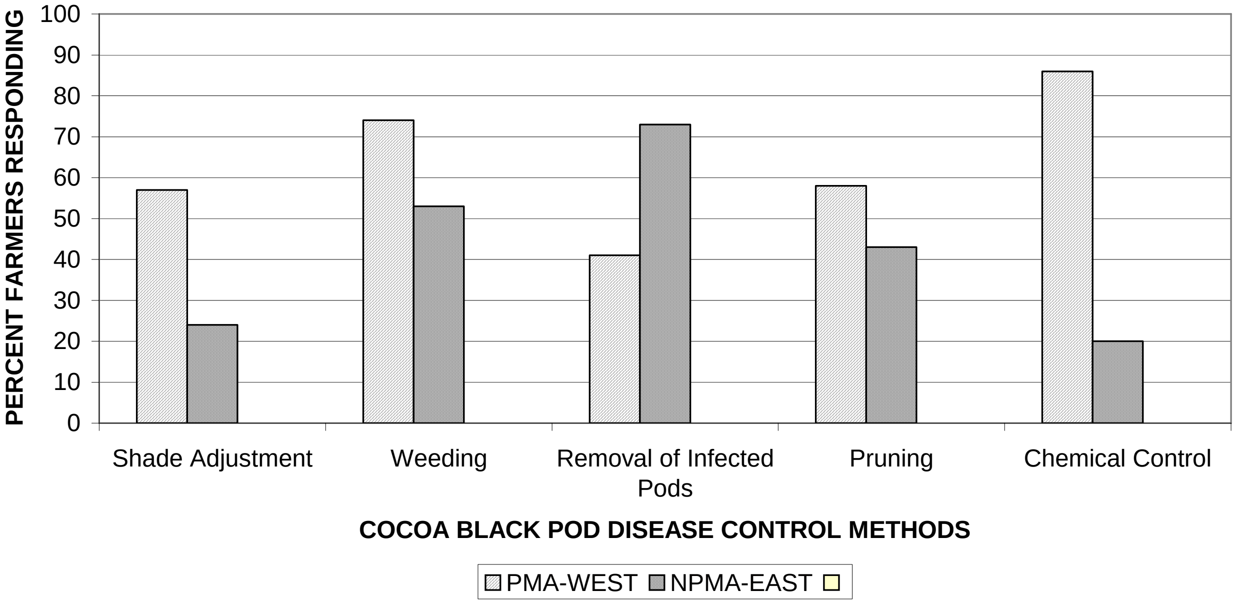


FIG. 4. COMPARISON OF COCOA BLACK POD DISEASE CONTROL METHODS USED BY FARMERS IN THE WESTERN (PMA-WEST) AND EASTERN (NPMA-EAST) REGIONS IN GHANA



7.1. Effectiveness of Control Measures

Farmers reported observing positive effects in respect of the various control measures used. However, in most cases the percentage of farmers reporting benefits from these treatments fell short of the percentage reporting their use.

In the Ashanti region while 79% reported of using ‘removal of infected pods as a major control method, only 26% could vouch for its effectiveness (Table 14).

In the Volta region all the 70% reported on the effectiveness with 13% claiming they could see no effect. For chemical control 52% of farmers reported seeing some effects, with 9% reporting no effect.

All the 41% respondents in the Western region who reported using removal of infected pods to control black pod reported seeing positive effects. For chemical control, however, only 36% reported seeing some effects with 5% reporting that they observed no effects.

In the Eastern region 73% reported using removal of infected pods to control the disease. Of these 56% reported seeing some effects.

The inability of some of the respondents to determine the level of success of their methods of control could be due to inconsistency in the modes of application. Thus for cultural control some farmers apply the control methods for up to 4 times per year or more, while a significant percentage applied the methods only once or twice. Similarly for chemical control, while it has been determined by research that optimum disease management is obtained where measures are applied between 6 and 9 times per year, up to 30% spray less than 3 times a year. Under such circumstances it would be difficult to observe positive effects most of the time. These trends reflect farmer's reluctance or inability to spend on inputs to manage black pod, even where it is known to be a primary production constraint.

7.2. Farmers' Perceptions Of General Chemical Control

Farmers were asked to state their opinions on the efficacy, costs and ease of application of existing chemical control measures (fungicide sprays). The results are presented in Tables 18a to 18d .

In the Ashanti region, about 75% of the farmers indicated that use of chemical control was either good or very good for black pod disease control. When it came to costs, about 38% said prices were reasonable, while about 44% indicated that it was expensive. In addition, 75% of respondents said that the methods were cumbersome and not easy to use. Similar responses were made in the Volta region and Western regions, although in Western region cost was a major deterrent to use. In the Eastern region (NPMA), where over 80% prefer cultural methods of control and chemical use is less common, response to the enquiry was very limited.

Table 18a. Farmers Perceptions Of Efficacy Of Chemical Control Methods, Their Cost, And Ease Of Application

Ashanti Region (N=58)				
Efficacy of chemicals :	Very Good	Good	Bad	Indifferent
% Farmers	44	31	25	
Cost of chemicals :	Reasonable	Expensive	Unaffordable	Indifferent
% Farmers	38	44	19	
Ease of application :	Easy	Not Easy	Indifferent	
% Farmers	25	75		

Source: Survey data (1999-2000)

Table 18b. Farmers Perceptions Of Efficacy Of Chemical Control Methods, Their Cost, And Ease Of Application

Volta Region (N=23)				
21. FARMERS' PERCEPTION OF GENERAL CHEMICAL CONTROL				
Efficacy of chemicals :	Very Good	Good	Bad	Indifferent
% Farmers	17	43	13	26
Cost of chemicals :	Reasonable	Expensive	Unaffordable	
% Farmers	26	39	9	26
Ease of application :	Easy	Not Easy	Indifferent	
% Farmers	17	52	30	

Source: Survey data (1999-2000)

Table 18c. Farmers Perceptions Of Efficacy Of Chemical Control Methods, Their Cost, And Ease Of Application

Western Region (N=56)				
Efficacy of chemicals :	Very Good	Good	Bad	Indifferent
% Farmers	80	20	0	0
Cost of chemicals :	Reasonable	Expensive	Unaffordable	Indifferent
% Farmers	7	91	2	
Ease of application :	Easy	Not Easy	Indifferent	
% Farmers	2	98	0	

Table 18d. . Farmers Perceptions Of Efficacy Of Chemical Control Methods, Their Cost, And Ease Of Application

Eastern Region (N=87)				
Efficacy of chemicals :	Very Good	Good	Bad	Indifferent
% Farmers	12.64	8.1	-	-
Cost of chemicals :	Reasonable	Expensive	Unaffordable	Indifferent
% Farmers	5.8	9.2	4.6	-
Ease of application :	Easy	Not Easy	Indifferent	
% Farmers	9.2	11.5	-	

Source: Survey data (1999-2000)

8.0. CONSTRAINTS TO BLACK POD CONTROL

8.1. Availability Of Chemicals

The cocoa farmers identified four main chemicals in use. These were Ridomil (metalaxyl + copper), Kocide, Nordox and Caocobre (the latter three being copper formulations). Other chemicals mentioned to a lesser extent were Champion (copper based) and Califan (a metalaxyl-based compound). In the Ashanti and Eastern regions, where the use of chemical control methods appear limited, very few farmers reported on the availability of the chemicals. However, in the Volta and Western regions where the majority of farmers use chemicals for black pod control, Ridomil appeared to be the most popular and easily available according to the farmers. In the Western region 79% of the respondents reported easy availability of Ridomil. The next most popular chemicals were Kocide in the Volta region and Champion in the Western region.

Table 19. Distribution Of Farmers Reporting Easy Availability Of Fungicides

Chemicals	**Ashanti**	**Volta**	**Western**	**All PMAs**	**Eastern**
Ridomil	12%	43%	79%	44.6%	2%
Kocide	3%	22%	4%	6.6%	10%
Nordox	0%	4%	20%	8.9%	0%
Caocobre	3%	4%	2%	2.8%	1%
Champion	0%	0%	32%	13.1%	0%
Califan	0%	0%	2%	0.8%	0%
Size of sample (N)	58	23	56	137	87

Source: From Survey data (1999-2000);

8.2. Market Towns And Frequency Of Visits

The farmers obtained these chemicals from market towns which were about 12 to 15 kilometres away from their farms. The farmers visited the market towns often, at most 5 times a week and at least once a month in all cases. In the Ashanti region average distance from the market towns was 15.5 km and 86% of the farmers reported visiting the market towns at least once a week. In the Volta region 60% reported visiting the towns twice a week, with an average distance of 12.7 km, while in the Western region the farmers 64% reported visiting the market towns which were on average 12.8 km from their settlements, two to three times a month. In the Eastern region average distance from the farms was 8.4 km, where 52% of the farmers reported visiting the markets about 1 to 5 times a week and 48% reported visiting the town once per month.

8.3. Availability of Equipment

8.3.1. Distribution Of Ownership

The majority of the respondent farmers did not own equipment for pest and disease control, whether mistblowers for capsid control, knapsack sprayers for black pod disease control or pruners for mistletoe control.

In the Ashanti region percentage of respondents who reported owning mistblowers, knapsack sprayers and pruners were 17%, 14% and 5% respectively. In the Volta region none of the respondents owned a pruner, but 30.4% and 4.35% owned mistblowers and knapsack sprayers (Table 20). Levels of equipment ownership were generally highest amongst the younger farmers of Western region.

Table 20. Farmers Reporting Ownership of Equipment

Region	Ashanti	Volta	Western	All PMA	Eastern
EQUIPMENT	% Reporting	% Reporting	% Reporting	% Reporting	% Reporting
Mistblowers	17	30.4	43	30.3	4.6
Knapsack	14	4.4	39	23	21.8
Pruners	5	0	4	3.7	10.4
Sample size(N)	58	23	56	137	87

The distribution of equipment reflect need. Thus in the PMA where there is more concern for capsid and black pod control, the greater proportion relative to the NPMA owned mistblowers, while a higher percentage of respondents had pruners in the NPMA where there were more reports of mistletoe problems.

8.3.2. Service Condition of Equipment

Compounding the problem of inadequate supply of equipment was that about half of the existing equipment had broken down (Table 21).

Table 21 Percent Distribution of Functional Mistblowers, Knapsack Sprayer, and Pruners In The Survey Areas

Region	Ashanti	Volta	Western	All PMA	Eastern
EQUIPMENT	% Functional	% Functional	% Functional	% Functional	% Functional
Mistblowers	25	87.5	62.5	51.4	50
Knapsac	20	100	82	59.7	53
Pruners	66.7	0	0	27.3	44
N	58	23	56	137	87

8.3.3. Replacement Costs

Some of the equipment was purchased as far back as 1970 and prices have increased thousands of times (Table 22), making replacement difficult or prohibitive.

Table 22.

	Price in 1987 (¢)	Price In 2000 (¢)	Percentage Change
Mistblower	23,000	3,000,000	13,040%
Knapsack Sprayer	4,500	600,000	13,330%
Pruner	1,352	150,000	11,095%

Sources: Asante (1992), and Survey data (1999-2000).

8.2.4. Borrowing And Custom Hiring

For pest and disease control some farmers reported hiring the equipment from friends, the Chief farmer, and neighbours (Table 23). Cost of hiring equipment varied from ¢500 to ¢3,000 per day. Others reported borrowing equipment from relatives, the PBC *'kilo kilo'* Societies, or from friends, about 50% of which they complained were often faulty and easily broke down. Thus even though borrowed equipment were supposed to be free of charge one often had to incur expenses repairing them. Hired equipment reportedly broke down just as frequently as those borrowed.

Table 23

	Ashanti	Volta	Western	Eastern
	% Reporting	% Reporting	% Reporting	% Reporting
Hiring	20.69	43	38	38
Borrowing	32.76	9	29	16
Sample Size (N)	58	23	56	87

Source: From Survey data (1999-2000)

8.4. Technical Knowledge And Support

Farmers were asked to indicate their sources of knowledge of the various methods of black pod disease control. Four sources of knowledge were identified. These included the Extension Service (CSD), Research (CRIG), Relatives and other farmers, usually friends of the respondent. The percentage of farmers reporting in the four regions for the various sources of knowledge are presented in Tables 24a-24d. In the Western region a small percentage of farmers reported that they were introduced to chemical control through an LBC (Table 24c). The central importance of the Cocoa Services Division (CSD) in advising farmers in disease-affected areas is particularly significant as this service is being absorbed into wider Ministry extension services and will have less focus on cocoa in the future.

Table 24a SOURCE OF KNOWLEDGE ON BLACK POD CONTROL METHODS (Ashanti Region)

	SOURCE			
METHOD	CSD	CRIG	RELATIVE	SELF
Weeding	44%	6%	6%	44%
Removal of Infected Pods	46%	2%	6%	5%
Pruning	64%	5%	9%	22%
Chemical Control	88%	6%	0%	6%

Source: From Survey data (1999-2000), N=58

Table 24b SOURCE OF KNOWLEDGE ON BLACK POD CONTROL METHODS (Volta Region)

SOURCE				
METHOD	CSD	CRIG	RELATIVE	SELF
Weeding	35%	9%	9%	4%
Removal of Infected Pods	52%	9%	17%	9%
Pruning	30%	4%	4%	4%
Chemical Control	57%	9%	9%	0%

Source: From Survey data (1999-2000), N=23

Table 24 c. SOURCE OF KNOWLEDGE ON BLACK POD CONTROL METHODS (Western Region)

SOURCE					
METHOD	CSD	CRIG	RELATIVE	SELF	LBC
Weeding	83%	0%	7%	10%	0%
Removal of Infected Pods	85%	0%	0%	15%	0%
Pruning	89%	0%	2%	9%	0%
Chemical Control	89%	0%	5%	5%	4%

Source: From Survey data (1999-2000); N=56

Table 24 d. SOURCE OF KNOWLEDGE ON BLACK POD CONTROL METHODS (Eastern Region)

EASTERN REGION SOURCE OF TECHNOLOGY/KNOWLEDGE					
	CSD	CRIG	RELATIVE	SELF	RADIO
Weeding	9%	0%	20%	28%	0%
Removal of Infected Pods	28%	0%	29%	29%	1%
Pruning	10%	0%	21%	18%	0%
Chemical Control	11%	0%	1%	1%	0%

Source: From Survey data (1999-2000); N=87

8.5. Performance Of Farm Operations

8.5.1 Labour For Pests And Diseases Management.

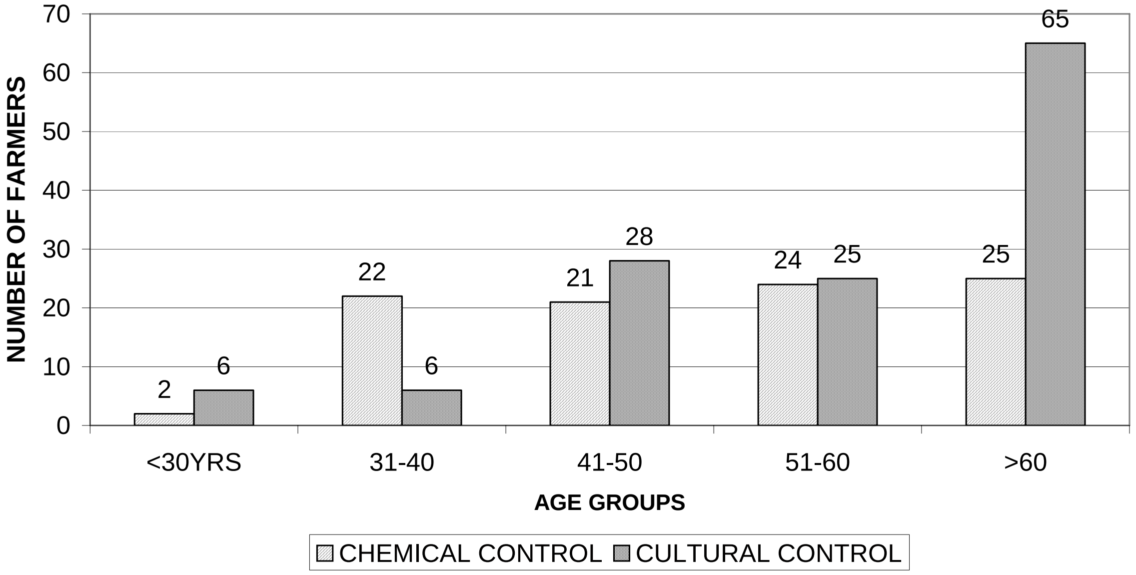
Farmers in the Western region depended most on caretakers (sharecroppers) to perform farm operations on diseases and pests control (Table 25). In the Ashanti and Volta region as well as the NPMA the greater proportion of farmers took up the responsibility of performing the operations by themselves. In the Ashanti region the farmers did not engage in much chemical control. It is noteworthy that in the Volta region where they apply more chemical control measures the farmers are also younger (56% below 50 years, Table 1). This latter point is reinforced by the apparent preference of older farmers for cultural methods of black pod disease control rather than chemical control (Fig 5).

Table 25 Percent Distribution of Labour For Pests And Diseases Control In The Survey Areas

Region	Ashanti	Volta	Western	All PMA	Eastern
PERFORMER	% Responding	% Responding	% Responding	% Responding	% Responding
Farmer	59	57	16	23	61
Family Labour	5	39	2	9.4	1
Hired Labour	7	9	5	6.5	18
Caretaker	29	4	77	45.1	8
PAYMENTS					
Farmer	100	100	100	100	84
Caretaker	0	0	0	0	16
N	58	23	56	137	87

Source: From Survey data (1999-2000)

FIG. 5. APPLICATION OF COCOA BLACK POD DISEASE CONTROL METHODS BY FARMER AGE GROUPS



In the PMA payment for all pests and diseases control are made by the farmers. However, in the NPMA the farmers bear about 84% of the costs while the caretakers bear 16% of the costs (Table 25). It is not known whether this reflects a previous regional difference or a direct response to the need for disease control in *P. megakarya*-affected areas

8.5.2. Farmer Preferences For Control Methods

Table 26 shows farmers preferences for black pod disease control methods. Even though in practice more farmers use cultural methods than chemical methods of control, the farmers interviewed expressed preference for chemical control, followed by removal of infected pods, then pruning and lastly weeding. Farmers appear to perceive a value in chemical control and presumably if other constraints facing farmers in cocoa disease management were removed, more farmers would seek to apply chemical control methods.

Table 26 Ranking of Farmer Preferences For The Control Methods In The Survey Areas

Region	Ashanti	Volta	Western	Overall PMA	Eastern
Weeding	4	1	4	4	3
Removal of Infected Pods	2	4	1	2	2
Pruning	3	2	3	3	4
Chemical Control	1	3	2	1	1
N	58	23	56	137	87

Source: From Survey data (1999-2000)

8.5.3. Ease Of Application Of Control Methods

Farmers preferences did not appear linked to ease of application. In the PMA all farmers agree that chemical control methods were relatively very hard to apply, yet they ranked these as the most preferred method. This means farmers also take efficacy into account. As noted earlier (Section 7.2, Tables 18a-18d) farmers in all the PMA agreed that relative to other methods, chemical control was the most effective method for controlling black pod disease of cocoa.

Table 27a Ease Of Application Of Methods: Ashanti

	Hard	Moderate	Light
Weeding	80%	15%	5%
Removal of Infected Pods	45%	28%	28%
Pruning	48%	33%	19%
Chemical Control	75%	13%	13%

Source: From Survey data (1999-2000); N =58

Table 27b Ease Of Application Of Methods: Volta

	Hard	Moderate	Light
Weeding	48%	0%	0%
Removal of Infected Pods	22%	26%	30%
Pruning	22%	4%	9%
Chemical Control	70%	4%	0%

Source: From Survey data (1999-2000); N=23

Table 27c Ease Of Application Of Methods: Western

	Hard	Moderate	Light
Weeding	90.7%	9.3%	0.0%
Removal of Infected Pods	49%	31%	20%
Pruning	66%	32%	2%
Chemical Control	98%	2%	0%

Source: From Survey data (1999-2000); N=56

Table 27d Ease Of Application Of Methods: Eastern

	Hard	Moderate	Light
Weeding	53%	5%	0%
Removal of Infected Pods	16%	23%	40%
Pruning	26%	16%	3%
Chemical Control	16%	1%	3%

Source: From Survey data (1999-2000); N =87

9.0 SOCIO-ECONOMIC ASPECTS

9.1. Effects Of Black Pod Disease Of Cocoa On Family Income And Welfare Western Region

The proportion of farmers' total household income attributable to cocoa ranges from 43% in the Eastern region to 84% in the Western region. Proportion of income spent on cocoa farming was estimated at between 25% and 31%.

Most farmers felt that that black pod disease adversely affected family incomes and welfare. Employment opportunities were also perceived to be adversely affected by the cocoa disease. The greater proportion of farmers were also of the opinion that attention to black pod disease increased their emphasis on activities on the farm that were beneficial to the farm as a whole.

In view of the serious effects of the disease on farmers' livelihood, they were asked whether any community action had been taken to combat the disease. To this question, farmers in the Western (84%), Volta (26%), and the Eastern (1%) replied in the affirmative. The farmers in the Ashanti region, even though in the affected area, had seen no need for community action.

9.2. Effect Of Socio-Economic Conditions On Control

9.2.1. Relative Impact Of Socio-Economic Environment On Diseases And Pests Control.

Farmers were asked to give their views on the effects of perceived constraints on their pests and diseases control operations. These included cost of chemicals, non-availability of chemicals, cost of labour, cash-flow problems, non-availability of credit, cost of equipment, high cost of hiring equipment, knowledge level of the diseases and pests, and access to technical advice (Table 28).

9.2.1.1. Cost of Chemicals

The majority of farmers in all the areas indicated that the cost of chemicals had adverse effects on their control operation. Less than 7% of the farmers indicated that there were no effects, whereas from 27% to 74% of the farmers indicated in all the regions that the cost of the chemicals had adverse effects on their operations. The cost of the chemicals, which according to most farmers are expensive, may therefore be considered one of the causes of low chemical use by some farmers.

9.2.1.2. Non-Availability Of Chemicals

Non-availability of chemicals was relatively important in the Ashanti and Volta regions but not in the Western and Eastern regions. For the Western region it appeared because of their high use of chemicals the suppliers make sure they have enough at the right time. In the Eastern region, however, since they do not usually use much chemical, farmers were not worried about availability of chemicals.

Table 28. Farmers Perceptions Of The Effects Of Some Socio-Economic Conditions On Diseases And Pests Control

REGION	Ashanti (N=58) % Reporting		Volta (N=23) % Reporting		Western(N=56) % Reporting		Eastern (N=87) % Reporting	
TYPE OF PROBLEM	No Effects	Adverse Effects	No Effects	Adverse Effects	No Effects	Adverse Effects	No Effects	Adverse Effects
Cost of Chemicals	2	50	4	74	2	27	7	55
Non-Availability of Chemicals	2	10	4	26	4	4	3	8
Cost of Labour	3	16	4	52	0	4	20	28
Cash-Flow problems	2	38	0	78	0	27	7	33
Non-Availability of Credit	2	31	0	65	0	12	2	16
Cost of Equipment	0	0	0	22	0	4	1	21
High Cost of Hiring Equipment	2	12	4	13	0	4	8	9
Knowledge level	2	28	9	13	0	12	7	3
Access to Technical Advice	5	5	17	4	11	0	9	2

Source: Derived from Survey data (1999-2000)

9.2.1.3. Cost Of Labour

The cost of labour appeared to be a problem in the Ashanti and Volta regions. In the Western region there appeared to be localised labour problems, may be due to poor distribution and concentration in certain areas. In the Eastern region labour does not appear to be a problem for pests and diseases control.

9.2.1.4. Cash-Flow Problems And Credit Availability

There appeared to be a general consensus that cash-flow problems affected operations adversely. This is supported by the majority of farmers in all the regions who indicate that credit is scarce. Most of the pests and diseases attack cocoa farms during the lean period (May and September) when farmers have almost spent their annual cocoa incomes. The period also coincides with the period for maintenance operations on both cocoa and food farms. Farmers therefore feel the pinch of lack of accessible sources of cash during the period to purchase much needed inputs such as chemicals and to engage labour. Their operations are consequently adversely affected.

9.2.1.5. Cost Of Equipment And High Cost Of Hiring Equipment

Farmers in the Volta and Eastern region perceive the cost of equipment as an impediment to their pests and diseases control operations. In the Volta region about half the number of farmers practising some form of chemical control indicate that the cost of equipment affects their operations adversely. In the Eastern region more than the number of farmers practising chemical control indicated that the cost of equipment adversely affected their operations. Except for the Western region, where a small proportion of farmers compared to those who use chemical control methods requiring the use of equipment, indicated that equipment hiring costs adversely affected their operations, relatively significant numbers of farmers in the other regions indicated that the high cost of hiring equipment had an adverse effects on their operations.

9.2.1.6. Knowledge Levels And Access To Technical Advice

Farmers in the PMA indicated that low knowledge level of the disease problem adversely affects control operations. However, there appears to be a trend that access to technical advice has no effect on control operations. This contrast appears to indicate that finacnial constraints are preventing farmers from investigating detailed requirements of chemical control.

9.2.2 Relative Importance Of Socio-Economic Environment To Pests And Diseases Control.

The farmers were asked to rank the nine conditions in order of importance. A Spearman’s Rank Correlation was fitted and subjected to a one-tail test of significance to determine the extent of agreement in the rankings. The test indicated that there existed a community of agreement on the rankings for the Ashanti, Western, and Eastern regions. The rankings for the Volta region were not in agreement with the other regions. On the basis of the tests of significance a final general ranking scheme was worked out for the nine items for the three regions possessing a community of agreement (i.e. Ashanti, Western and Eastern regions) against the ranking from the Volta region (Tables 32 and 33 below), by summing up the rankings by the regions for each item and placing the lowest sum first, followed by the others in increasing order (Ostle, 1969, pp 233-234). The general consensus was that cash-flow was the number one condition adversely affecting diseases and pests control measures. This was followed, in order of importance, by the cost of chemicals, non-availability of credit, cost of equipment, cost of labour, high cost of hiring equipment, access to technical advice, low knowledge level and non-availability of chemicals.

Table 32. Ranking Of Relative Impact of General Socio-Economic Environment On Diseases And Pests Control

REGION	Ashanti (N=58)	Volta (N=23)	Western (N=56)	Eastern (N=87)	Sum of Rankings	Final Ranking
TYPE OF PROBLEM	Ranking	Ranking	Ranking	Ranking		
Cost of Chemicals	3	8	2	2	7	2
Non-Availability of Chemicals	9	5	8	7	24	9
Cost of Labour	7	6	6	4	17	5
Cash-Flow problems	1	7	1	1	3	1
Non-Availability of Credit	2	9	3	3	8	3
Cost of Equipment	4	3	4	5	13	4
High Cost of Hiring Equipment	6	1	7	6	19	6
Low Knowledge level	5	2	9	9	23	8
Access to Technical Advice	8	4	5	8	21	7

Source: Derived from Survey data (1999-2000)

Table 33. Spearman's Rank Correlation Coefficients, Critical values And Statistical Significant Levels

Paired Test Regions	**Correlation Coefficient (Rs)**	**No. of Ranked Items (N)**	**Critical Values for Rs ($P_{0.05,N}$) ; Rs($P_{0.01,N}$)**	**Statistical Significance level**
Ashanti vs Volta	-0.4833	9	0.600; 0.683	Ns
Ashanti vs Western	0.7500	9	0.600; 0.683	**
Ashanti vs Eastern	0.7333	9	0.600; 0.683	**
Volta vs Western	-0.7000	9	0.600; 0.683	**
Volta vs Eastern	-0.7500	9	0.600; 0.683	**
Western vs Eastern	0.8667	9	0.600; 0.683	**

**= Statistically significant at 1% level. Ns = not statistically significant. Source: Estimates based on survey data (1999-2000), and Kenkel (1989) (pp 927-928; and Table A12).

9.2.3 Effects of Family Relationships

Being married was considered very beneficial to pests and diseases control in the Ashanti region. Farmers were relatively equally divided in opinions on the effects of Farm management arrangements, age of farmers, and the value of family connections for black pod control. Similar opinions were expressed in the Volta region. However in the Western and Eastern regions farmers opined that age and family connections are deleterious to their farm operations on diseases and pests control (Table 34a-34d).

Table 34a Effect Of Family Relationships On Black Pod Control Operations

Ashanti Region (N=58)				
		Beneficial	No. Effect	Adverse Eff.
Farm Management Arrangements		38%	2%	28%
Age of farmers		36%	14%	31%
Marital Status		53%	12%	9%
Family Connection		36%	19%	21%

Table 34b Effect Of Family Relationships On Black Pod Control Operations

Volta Region (N=23)				
		Beneficial	No. Effect	Adverse Eff.
Farm Management Arrangements		22%	4%	22%
Age of farmers		26%	17%	22%
Marital Status		35%	17%	17%
Family Connection		30%	17%	22%

Source: From Survey data (1999-2000)

Table 34c. Effect Of Family Relationships On Black Pod Control Operations

Western (56)				
		Beneficial	No. Effect	Adverse Eff.
Farm Management Arrangements		20%	0%	4%
Age of farmers		11%	11%	23%
Marital Status		20%	20%	5%
Family Connection		2%	7%	36%

Source: From Survey data (1999-2000)

Table 34d Effect Of Family Relationships On Black Pod Control Operations

Eastern (N87)				
		Beneficial	No. Effect	Adverse Eff.
Farm Management Arrangements		31%	13%	26%
Age of farmers		24%	13%	57%
Marital Status		51%	24%	13%
Family Connection		20%	39%	30%

Source: From Survey data (1999-2000)

9.2.4. Spraying Gangs

Farmers were asked to indicate whether there were spraying gangs in their areas and whether they utilized them. In the Ashanti region, 17% of the respondents answered that they were aware of spray gangs and 70% of these made use of their services. In the Western region also, 4% of respondents answered in the affirmative 50% of whom patronized the services of the spraying gangs. For the Volta and Eastern regions there appeared to have been no spraying gangs available.

10. ENVIRONMENTAL ISSUES

10.1 Health

Farmers were asked questions about what precautions they took to protect themselves against possible harm from chemicals. The enquiry revealed that a substantial percentage of farmers did not wear protective clothing during pest and diseases control. This was represented by 53% in Ashanti, 65% in Volta region, 66% in the Western region and 83% in the Eastern region. A significant number of farmers complained of having various illnesses associated with pest and diseases control. In Ashanti 47% of respondents indicated they suffered various ailments during pest and diseases control. These included itching bodies, nausea, bodily weakness, eye problems, and running noses (Table 35). Chemicals reported to be associated with these problems were Unden and Gammalin used for capsid control, and Kocide, Ridomil and Califan for black pod control.

Table 35. Farmers' Use of Protective Clothing, To Health Hazards And Pollution Risks.

REGION	**Ashanti (N=58)**	**Volta (N=23)**	**Western (N=56)**	**Eastern (N=87)**
Item	% Reporting	% Reporting	% Reporting	% Reporting
Wearing protective clothing for pest and diseases control.	47%	35%	34%	17%
Reporting of health problems	47%	22%	38%	17%
Type of Chemicals causing sickness	Gammalin, Unden,	Gammalin Unden, Ridomil, Kocide	Gammalin Unden Thionex Nordox	Gammalin, Unden, Kocide Califan,
Pests and disease control programme	Capsids	Capsid, Black pod	Capsid Black pod	Capsid, Balck pod
Types of sickness experienced	Eye, Bodily Weakness, skin itching, running nose	Eye, Bodily Weakness, skin itching, running nose.	Eye, Bodily Weakness, skin itching, running nose	Bodily weakness, skin itching, running stomach
Harm to plant and animal life observed	42.5%	26%	22%	10%
Chemicals causing harm	Gammalin, Kocide	Gammalin, Kocide	Gammalin, Kocide	Gammalin, Kocide
Pests and disease control programme	Capsids, Black pod	Capsids, Black pod	Capsids, Black pod	Capsids, Black pod
Average Distance of farm from nearest water source (km)	0.976 max. = 4.8	0.571 3.2	0.48 max = 4.8	0.445 max = 4.8
Average mixing distance from water source (metres).	816 min. = 16	379 20	432 min = 0.5	322 min = 5

Max = maximum; min = minimum. Source: From Survey data (1999-2000)

10.2 Effects On Wild Life

Farmers also reported noticing harmful effects on wild life. The chemicals associated with these harmful effects were mentioned as including Gammalin, Unden for capsid control and in some cases Kocide and Califan for black pod control.

10.3 Risk of Pollution of Water Bodies

Farmers were asked to indicate how close to water sources their farms were and how close to these water sources they usually mixed chemicals. Farmers reported an average water source closeness to farms of about 500 metres and a maximum distance of about 5 km. Mixing of chemicals could be as close as 5 metres. Mean mixing distance from water sources for Ashanti was 816 meters (minimum of 16 metres). For the Volta region mean mixing distance from water courses was 379 metres (minimum 20 metres). In the Western and Eastern regions mean mixing distances from water sources were 432 metres (minimum 0.5 metres), and 322 metres (minimum 5 metres), respectively.

11. ROLE OF RESEARCH, EXTENSION, GOVERNMENT AND PRIVATE SECTOR

Farmers were asked to indicate how frequently they came into contact with extension and research, and government and private sector involvement with them.

Table 36. Farmer-Research-Extension Linkages, Roles of Government And Private Sector

REGION	Ashanti	Volta	Western	Eastern
Item	% Reporting	% Reporting	% Reporting	% Reporting
Visit by Extension, research, Government, Private sector Agents	68.4	65	91	55
Assistance with pest and disease control from extension and research.	25	35	45	21
Sources of Information				
CRIG	2	0	0	8
Cocoa Extension (CSD)	54	87	84	43
GOG	0	0	0	0
Traders/Salesmen	2	0	2	1
Newspapers	0	0	0	2
Radio/TV	48	26	73	31
Friends/Relatives	2	9	4	-
Reception of material help from govt, etc	2	0	0	4.6
Sample Size	58	23	56	87

Source: From Survey data (1999-2000)

Farmers reported that they frequently received visitors to their farms. Over 50% of respondents agreed in this with the highest percentage of respondents (91%) in the Western region. When it came to assistance from research and disease control, between 21% and 45% by region reported obtaining such assistance. Breakdown of sources of information for pest and diseases control and cocoa production indicate that farmers get most of their information on cocoa production and pests and diseases control from the CSD extension service (43-87% reporting) and Radio and TV programmes (26% to 48% reporting). The results also indicate that farmers make little direct contact with researchers and traders, and obtain little information from newspapers.

12. RELATIVE COSTS OF FARM OPERATIONS IN RELATION TO BLACK POD CONTROL

An attempt was made to obtain relative costs in cocoa production from the farmers' point of view in the survey areas.

12.1. Explicit Costs, Total Farmland Size, Cocoa Farm Sizes And Incomes

The Volta region reported the highest average expenditure per hectare on their cocoa farms with ¢84, 102/ha, followed by the Western region with ¢50,163/ha and Eastern region with ¢42,449/ha. The area reporting the least expenditure per hectare was the Ashanti region with ¢25,519/ha. These expenditures account mostly for explicit costs and since farmers hardly keep any records on farm expenditures, some expenditure may have been forgotten.

Expenditure incurred during harvesting is hardly remembered. Expenditures per ha as estimated are therefore considered on the lower side of actual expenditure. Nevertheless, on the basis of available data, total farm expenditure was estimated for all the regions. Total farm expenditures for Ashanti, Volta, Western, and the Eastern regions were (Cedis ¢):

Table 37a. Ashanti Region (N=58)

GENERAL FARM MAINTENANCE OPERATIONS	
Average Total Cost of Farm Operations (Cedis)	87,021
Average Size Of Cocoa Farm (ha)	3.41
Average Total Farmland Size (ha)	5.72
Average Expenditure/ha (Cedis)	25,519
Average Income /hectare (Cedis)	209,250
Average Annual Expenditure On Farm (Cedis)	87,020
Average Annual Income (Cedis)	713,543

Source: Estimated From Survey data (1999-2000). Producer Price of Cocoa / mt =¢2,250,000; Exch. Rate: 1£ = ¢ 5,040 ; 1US$ = ¢ 3,600.

Table 37b. Volta Region (N=23)

GENERAL FARM MAINTENANCE OPERATIONS	
Average Total Cost of Farm Operations (cedis)	162,522
Average Size Of Cocoa Farm (ha)	1.98
Average Total Farmland Size (ha)	3.3
Expenditure/ha (Cedis)	84,102
Average Income /hectare (Cedis)	172,125
Average Annual Expenditure On Farm (Cedis)	166,522
Average Annual Income (Cedis)	340,808

Source: Estimated From Survey data (1999-2000). Producer Price of Cocoa / mt ¢2,250,000; Exch. Rate: 1£ = ¢ 5,040 ; 1US$ = ¢ 3,600.

Table 37c. Western Region (N=56)

GENERAL FARM MAINTENANCE OPERATIONS	
Average Total Cost of Farm Operations (Cedis)	261,347.84
Average Size Of Cocoa Farm (ha)	5.21
Average Total Farmland Size (ha)	8.79
Expenditure/ha (Cedis)	50,163
Average Income /hectare (Cedis)	488,475
Average Annual Expenditure On Farm (Cedis)	261,349
Average Annual Income (Cedis)	2,544,955

Source: Estimated From Survey data (1999-2000). Producer Price of Cocoa / mt ¢2,250,000; Exch. Rate: 1£=¢ 5,040 ; 1US$ = ¢ 3,600.

Table 37d. Eastern Region (N=87)

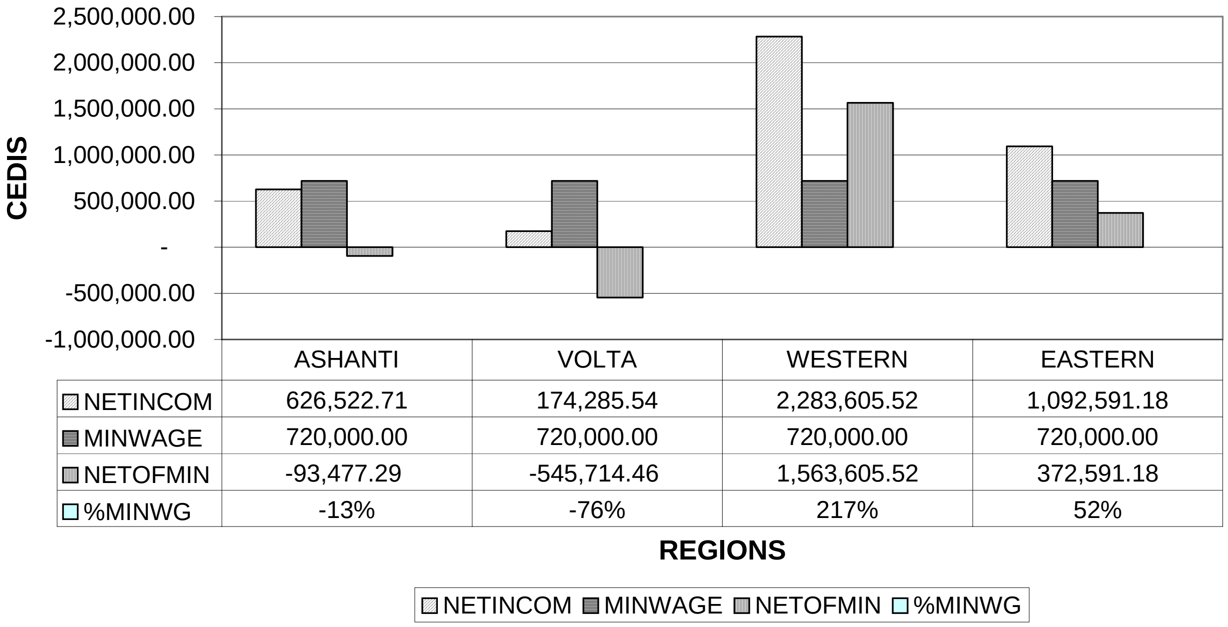
GENERAL FARM MAINTENANCE OPERATIONS	
Average Total Cost of Farm Operations/ha	103,152.14
Average Size Of Cocoa Farm (ha)	2.43
Average Total Farm Size (ha)	4.9
Expenditure/ha (Cedis)	42,449
Average Income /hectare (Cedis)	492,075
Average Annual Expenditure On Farm (Cedis)	103,151
Average Annual Income (Cedis)	1,195,742

Source: Estimated From Survey data (1999-2000). Producer Price of Cocoa/mt ¢2,250,000; Exch. Rate: 1£=¢ 5,040; 1US$ = ¢ 3,600

For the 1999/2000 when the survey was conducted, the NPMA (Eastern region) earned a higher per hectare average income of ¢492,075 at the then prevailing producer price of ¢2,250 per kilogramme due to its higher yield of 281 kg/ha. followed closely by the Western region (a PMA) with ¢488,475. Ashanti and Volta regions, both PMAs, registered average per hectare incomes of ¢209,250 and ¢172,125 respectively in order of magnitude.

The Western region (PMA) reported the highest annual income and this was due mainly to relatively higher yields in younger trees, despite black pod disease problems and larger farm sizes. Thus average annual income in the 1999/2000 season for the Western region was estimated at over ¢2.5 million, followed by the Eastern region (NPMA) with about ¢1.2 million. Average annual incomes in the Ashanti and Volta regions were ¢713,543 and ¢340,808 respectively, reflecting the effects of lack of disease control, tree age and small farm sizes. Deducting annual expenditures from annual income, Net Annual Farm Incomes were estimated as ¢2,283,606 for Western region (PMA), ¢1,092,591 for Eastern region (NPMA), ¢626,523 for Ashanti region, and ¢174,276 for the Volta region. The estimated Net Incomes from cocoa were compared to the then prevailing minimum wage level of ¢720,000 per annum. The results indicated that cocoa farmers in the Volta region depending solely on cocoa for their annual incomes were operating at -¢545,714 or (-76%) below the poverty line, while Ashanti region was operating at -¢93,477 or (-13%) below poverty levels (Figures 6).

FIG. 6. REGIONAL COMPARISON OF MEAN NET ANNUAL COCOA FARM INCOME AND MINIMUM WAGE LEVEL(1999/2000 SEASON)



	ASHANTI	VOLTA	WESTERN	EASTERN
NETINCOM	626,522.71	174,285.54	2,283,605.52	1,092,591.18
MINWAGE	720,000.00	720,000.00	720,000.00	720,000.00
NETOFMIN	-93,477.29	-545,714.46	1,563,605.52	372,591.18
%MINWG	-13%	-76%	217%	52%

12.2. Farmers' Perception Of Relative Costs Of Cocoa farm Operations

A comparison of relative costs of farm operations indicated that labour for weeding and payments made to sharecroppers for their labour account for the greatest proportion of farm expenditures.

It is noteworthy that in the Volta and Western regions where more chemical control methods are used for black pod control, the average percent costs of controlling the disease were around 15% in each region. It also seemed the two most important cocoa pests taking any significant proportions of farm expenditures were black pod and capsids.

The results appear quite consistent and the general average (weighted average) may be taken as reflecting the mean percentage distribution of costs of cocoa production in the survey areas from the farmers’ viewpoint.

Table..38. FARMERS PERCEPTION OF PERCENT DISTIBUTION OF FARM OPERATIONAL COSTS

	Ashanti	**Volta**	**Western**	**All PMA**	**Eastern**	**All Areas**
Operation	**Percent of Total Cost**	**Percent of Total Cost**	**Percent of Total Cost**	**Mean Percentage Cost**	**Percent of Total Cost**	**Mean Percentage Cost**
Weeding	60.35	58.72	8.11	37.96	60	46.52
Capsid Control	6.95	1.35	18.59	10.94	6.05	9.04
Black Pod control	6.0	15.37	15.55	11.62	2.45	8.06
Termite Control	0	0	0	0	0	0
Stemborer Control	0	0	0	0	0	0
CSSVD Control	0	0	0	0	0	0
Shade Control	1.38	5.09	0.33	1.56	0.49	1.14
Pruning	1.07	0	0.33	0.58	2.33	1.26
Harvesting	0	.56	1.77	0.84	7.06	3.26
Amount Paid to Caretaker/ Sharecropper	23.74	16.11	53.18	34.92	20	29.13
Fertilizer	0.39	0	1.99	1.00	0.67	0.87
Replanting/Refilling	0.12	2.8	0.15	0.58	0.95	0.73
TOTAL	**100**	100	**100**	100	100	100
Number of Respondents	**58**	23	**56**	137	87	224

Source: Estimated From Survey data (1999-2000)’

Aggregated input cost distribution indicates that capital inputs (i.e. insecticides, fungicides and fertilizer) account for approximately 18% of cocoa farm operational costs, while labour accounts for approximately 82% of the operational costs. The cocoa industry in the study areas can thus be described as labour-intensive.

13.0 ANALYSIS AND DISCUSSION OF FINDINGS

13.1 Relative Importance Of Black Pod Disease On Farmers’ Farms

The results of the analysis indicates that, in both the ***P. megakarya*** and non-***P. megakarya*** areas (PMA and NPMA respectively), farmers are aware of the nature of the black pod disease of cocoa and its effects in severe attacks. However, in the NPMA, it is not accorded the same importance as in the PMA because the damage caused *by P. palmivora* which is the prevalent fungal type in those areas is seldom very severe. In the PMA where farmers can frequently lose over 50% of their crop and in some cases everything, there is much more concern about the incidence of black pod disease. Cocoa Yields per hectare reported in the PMA were substantially below yields reported in the NPMA suggesting that the type of black pod disease caused by *P. megakarya* also causes substantial economic loss.

13.2 Efficacy Of Cocoa Black Pod Disease Control And Poverty Reduction

Income from cocoa forms a substantial percentage of the annual household incomes of cocoa farmers. Pests and diseases of the cocoa crop which cause substantial reductions in the output of cocoa consequently contribute to poverty for cocoa farmers. Estimates of annual income levels from cocoa farming indicated that farmers depending mostly on cocoa income in the Ashanti and Volta regions, both in *P. megakarya* endemic areas, were operating below the national poverty line. Cocoa Farmers in the PMA will therefore welcome methods that can control the disease to advantage.

13.3 Farmers' Perception Of Relative Efficacy Of Chemical Control Methods

The majority of farmers in the PMA farmers indicated that chemical control methods although costly and much more difficult to apply were still the most efficacious. This perception appeared to be at variance with actual observations obtained from farmers applying chemical methods on their farms. In the Western region 57% of respondents reported spraying chemicals 4 times or more, while 29% reported spraying 3 times or less, yet only 36% of respondents could say the method was effective. Similarly in the Volta region where 43% reported spraying their farms more than 4 times, and 29% 3 times or less, 52% out of a total of 73% of respondents using chemical methods of control were able to confirm its effectiveness. It would appear that farmers were aware that if they did not spray their farms the recommended number of times for the whole length of the rainy season when black pod disease was most active they would not achieve the right results. If this happens to be the case then the need to find affordable and environmentally friendly chemicals for controlling cocoa black pod disease becomes imperative.

13.4 Constraints Militating Against Efficient Cocoa Black Pod Disease Control

Among the constraints that were identified by farmers as militating against cocoa black pod disease control were, cash-flow problems, finance and credit and labour. To a significant extent, the availability, and cost of access to black pod control equipment were also mentioned. Any strategy to combat the disease should consider how to overcome these constraints.

13.5 Monitoring Environmental Hazards Of Black Pod Disease Control

It will be necessary to monitor the effects of any new chemical being introduced for pests and diseases control to determine the hazards and effects on the users (farmers and operators) and on the environment (i.e. effects on other flora, fauna, taint levels in cocoa beans, air and water pollution hazards, and aquatic resources).

13.6 Sources Of Cocoa Farmer Knowledge Of Pests And Diseases Control

Farmers acknowledge that they obtained most of their knowledge in pests and diseases control from the Extension service. This means an effective Extension service is essential if farmers are to contain the spread of black pod disease.

13.7 Farmer Perceptions Of Government Involvement In Black Pod Control

The direct involvement of government (except in the form of Extension services) and the private sector were reported to be minimal. However, there were signs that given the right environment and incentives, some private sector entrepreneurs would be willing to collaborate with cocoa farmers in pests and diseases control. This was demonstrated by some respondents who reported being introduced to chemical control of black pod disease in the Western region.

13.8 Farmers' Perceptions Of Relative Costs Of Cocoa farm Operations

Cocoa farmers have ideas about relative costs of cocoa farm operations. Analysis of farmer perceptions indicated that labour for weeding the farm, and in the form of caretaker or sharecropper services accounted for about 75% of cost of operations. From the farmers' point of view, labour inputs accounted for 82% of all farm operational costs, while capital inputs costs constituted about 18% of all operational expenditures. The cocoa industry in Ghana can thus be classified as labour intensive.

14. INDICATORS FOR MONITORING IMPACT OF POTASSIUM PHOSPHONATE ON BLACK POD CONTROL.

Suggested indicators for monitoring the impact of potassium phosphonate on cocoa black pod disease control are prsented in Table 39. The implicit assumptions are that the chemical will be vailable in sufficient quantities and be sold at affordable prices. Opportunities for increased orices over time woild depend upon the benefits that farmers derive from its use in terms of increased incomes which in turn could lead to an increase in demand.

Table. 39. Suggested Indicators for Measuring Impact of Use of Potassium phosphonate in Cocoa Black Pod Disease Control.

Description	**Average Value in Base Year**	**Average Value in End Year**	**Percent Change**
Relative Score[9] Of Farmers Regarding Black Pod Disease As Very Important On Their Farms (PMA).	85%	Na	Na
Relative Score Of Farmers Regarding Black Pod Disease As Very Important On Their Farms (NPMA).	59%	Na	Na
Yield of Cocoa Per Hectare Without Potassium phosphonate (In PMA)	138	Na	Na
Yield of Cocoa Per Hectare Without Potassium phosphonate (NPMA)	219	Na	Na
Cost Of Potassium phosphonate Control/ha	Na	Na	Na
Cost of Other Chemical Control/ha	¢	Na	Na
Mean Net Real Income Per Hectare (PMA)	¢272,149	Na	Na
Mean Net Real Income Per Hectare (NPMA)	¢449,626	Na	Na
Percentage Of Farmer Participants Opting To Use Potassium phosphonate For Black Pod Control in Trial Area.	0%	Na	Na
Percent of Farmers Using Protective Clothing (PMA).	39.67%	Na	Na
Percent of Farmers Using Protective Clothing (NPMA).	17%	Na	Na
Percent of Farmer Participants Complaining of Side Effects Using Chemical Control (PMA).	39.12%	Na	Na
Percent of Farmer Participants Complaining of Side Effects Using Chemical Control (NPMA).	17%	Na	Na
Percent of Farmer Participants Complaining of Side Effects Using Potassium phosphonate	Na	Na	Na
Percent Cocoa Trees Damaged Due To Application of Potassium phosphonate	Na	Na	Na

Na = not applicable; ie. these indicators will be estimated during and after the on-farm-trials.

15. Conclusion And Recommendation

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[9] Measures Farmers' Perception of importance of black pod disease relative to other diseases and pests on their farms.

From the analysis so far conducted it is concluded that cocoa black pod disease caused by *P. megakarya* is a serious problem that needs immediate control and containment. Apart from the annual losses suffered by farmers, sometimes approaching 100% of crops and income, its spread poses a potential risk to the survival of the cocoa industry if it is not controlled. Farmers have shown their preference for chemical control but are not applying available chemical control methods satisfactorily due to perceived high costs, poverty and operational difficulties. Attention should therefore be focused on efficacious but less costly and user friendly chemical methods of cocoa black pod disease control.

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ANNEX 2

Control of *Phytophthora megakarya* diseases of cocoa with phosphonic acid

CPP Project R7326

1. Implementation of an analytical method for the determination of phosphonic acid residues in cocoa material.

2. Spray application on cocoa and assessment of operator exposure to metalaxyl when applied by lever operated knapsack sprayer.

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1. INTRODUCTION

The visit reported here provided further project support to the CRIG chemists by assisting in the implementation of the analytical method at the CRIG laboratory at Tafo, using equipment provided by project funds. This included a substantial quantity of glassware and other general laboratory equipment and a flame photometric detector (FPD) required for the analysis of phosphorus containing residues. The latter was supplied and installed in May 2000 by the manufacturer, Ai Qualitek, (Ai.) of the Model 93 gas chromatograph already possessed by the CRIG laboratory.

The visit also fulfilled a project commitment to carry out a preliminary assessment of spray application in cocoa and to complete an initial study to quantitatively determine operator exposure to conventional fungicides applied for black pod control.

2. TERMS OF REFERENCE

The terms of reference for the visit were:

(i) To assist CRIG chemists in the implementation at CRIG of the analytical method for determining phosphonic acid residues including sample preparation and extraction and use of the Flame Photometric Detector (FPD) specifically installed for phosphonic acid residue analysis

(ii) To assist CRIG chemists in finalising field sampling procedures for cocoa material.

(iii) To conduct a brief literature review of current pesticide application equipment and methods used by small farmers for the control of pests and diseases on cocoa.

(iv) To assess the efficiency of current application methods in terms of spray retention and run-off.

(v) To quantitatively determine the exposure levels of spray operators to pesticides resulting from spray application in cocoa.

(vi) To investigate and consider, where possible, alternative application methods for poor farmers appropriate to their financial resources and capabilities.

3. SUMMARY

Operating conditions for the FPD fitted to the Ai gas chromatograph located in the Plant Pathology laboratories at the Cocoa Research Institute of Ghana at Tafo were established and practical training in its operation given to the CRIG chemists. This was supplemented with detailed notes on the set-up and operation of the gas chromatograph (see Annex 1). During the course of setting up the FPD it appeared to be up to ten times less sensitive than the Perkin Elmer FPD used at NRI during the development of the analytical method for phosphonic acid residues. However, this difference in sensitivity may not be entirely due to detector factors since due to instrumental differences, the analytical columns used at NRI and at CRIG were not identical.

New phosphonic acid standards were prepared at CRIG to match the sensitivity of the Ai detector. The sulphuric acid based extraction method developed at NRI was practised by the CRIG laboratory staff with laboratory treated leaves and with leaf samples from field trials set up earlier in the year to assess the effectiveness of phosphonate as a control agent for cocoa black pod disease.

The CRIG procedure for the field sampling of leaves and pods for phosphonate analysis was scrutinised and deemed to be satisfactory. A selected number of duplicate cocoa leaf, pod and bean samples were brought back to NRI for comparative analysis, should this be considered necessary (see Annex 6).

Six operator exposure trials in cocoa were carried out using the fungicide ‘Ridomil plus’ either alone or mixed with tartrazine food dye. The latter was used to evaluate the potential for analysis of spray deposits by spectrophotometry as a simpler alternative to metalaxyl determination by gas liquid chromatography. Spray depositing on the operators during spray application was monitored using face masks, cotton gloves and absorptive pads attached to their clothing. The results of the analysis of the pads and other monitoring media are presented in a separate analytical report (Laboratory Analytical Report No.00AV-00BP).

Little current information was found to be available at CRIG on present levels of farmer ownership or access to sprayers, but it is understood that such surveys are planned for the near future. Information from these surveys, together with the results of the operator exposure work, will provide much of the information needed to assess whether simpler methods of pesticide application for resource poor farmers are needed or feasible. The future role of knapsack sprayers in the control of black pod depends to some extent on outcome of the trunk injection studies. If successful in controlling black pod, disease the low cost of the injection equipment would probably make it a preferred option for most low income farmers.

4. RECOMMENDATIONS

It is recommended that:

(i) A specified number of validation samples (solvent blanks/phosphonate spiked samples) should be included during the analysis of field trial and laboratory samples at CRIG. Details have been given in the analytical procedure (see Annex 6) which has been forwarded to CRIG

(ii) CRIG staff should prepare a written account of their field sampling procedure for the collection of cocoa leaves, pods and other materials.

(iii) Because of the large number of cocoa field samples collected by CRIG staff since the beginning of the phosphonate field trial in June/July, a full list of the samples should be prepared by CRIG in order to facilitate decisions on which samples should be given analytical priority.

(iv) Because the operator exposure trials were carried out in partly harvested cocoa, further trials should be carried out to determine exposure when the number of pods per tree, and therefore the time spent spraying, is at a maximum.

(iv) The feasibility of improvements and alternatives to the use of lever operated knapsack sprayers for pesticide application should be more fully explored once the planned survey on farmer use of fungicides and sprayers is complete, and the results of the operator exposure studies are available. The results of the phosphonate trunk injection studies will also have a bearing on the future role of knapsack sprayers for black pod control.

5. LABORATORY WORK

5.1 Overview

The analysis of phosphonic acid residues is based on the determination by Gas Liquid Chromatography of the ester derivative (dimethyl phosphonate) produced by the reaction of phosphonic acid with diazomethane, using a Flame Photometric detector (FPD). An FPD system to fit the Ai Qualitek Model 93 gas chromatograph used by CRIG was provided by the project and installed by an Ai Qualitek engineer in May 2000.

A key objective of the visit was to check and test the FP detector to enable the routine analysis of phosphonic acid residues to be carried out at CRIG. The detector was initially set up based on experience gained at NRI but initial results suggested that its sensitivity was up to ten times less than that of the Perkin Elmer detector used at NRI. However, this disparity in sensitivity may not be entirely due to detector factors but also due to differences in the analytical columns used at NRI during the development of the phosphonate analysis method and those commercially available for the CRIG gas chromatograph.

New analytical standards based on the sensitivity of the Ai Qualitek FP detector were prepared. It was agreed with CRIG staff that new spiked leaf samples corresponding to the Ai detector sensitivity will be prepared by CRIG staff prior to beginning their leaf analysis work.

5.2 Testing and optimisation of the Ai. Qualitek FP detector

One of the three packed GC columns for the Ai. gas chromatograph that were air freighted to CRIG at the time of the visit, was conditioned overnight. Carrier gas flow (N_2) was set based on NRI experience and the detector gas flows (H_2/air) adjusted to the settings recommended in the Ai Qualitek operating manual.

The response of the Ai. detector was determined using a 1.0 µg/ml dimethyl phosphonate (DMP) standard. Based on NRI experience, it was expected that this would give a large detector response. However, despite efforts to increase detector response, principally by varying the air flow, it was concluded that the sensitivity attained was up to ten times lower than that obtained with the Perkin Elmer detector used at NRI. This was attributed to either actual differences in detector sensitivities or to differences in the characteristics of the laboratory packed columns used at NRI with a Perkin Elmer GC, and those commercially purchased and dispatched to CRIG for use on the Ai. GC.

On the basis of the optimisation work it was considered that 0.1µg/ml DMP is the lowest level that can be quantified with confidence by the Ai. FPD.

Once the GC and FPD had been satisfactorily set up, practical training in all aspects of their operation was given to CRIG staff and detailed instrumental operating notes prepared for future reference (see Annex 1).

The limit of determination for phosphonic acid residues on leaf samples was estimated to be 3 µg/g for a sample weight of 25 g, based on a limit of detection of 0.1 µg/ml of dimethyl phosphonate. (see Annex 3 for calculation details).

5.3 Preparation of analytical standards

In order to conform to the sensitivity of the CRIG detector, a new set of phosphonic acid standards were prepared and a new DMP calibration range varying from 0. 1µg/ml to 1µg/ml made up. Details of the new standards are included in an updated analytical procedure (Version 2) prepared for retention by CRIG (Annex 2).

5.4 Extraction of leaf samples – field treatments and laboratory validation samples

A small number of leaf validation and field samples (see Tables 1 and 2) were extracted in order to re-familiarise the CRIG chemists with the analytical procedure developed during their training at NRI in February 2000. Details of the analytical procedure dealing with spiking levels and frequency of the validation process are given in Annex 2.

Table 1: Validation samples (leaves)

Sample code	Field code	Sample weight (g)	Treatment	Volume 10 µg/ml phosphonic acid (ml)	Volume H_2SO_4 added (ml)
00UL-1A	(8)6:10-6	25	Untreated	N/A	75
00UL-1B	(8)6:10-7	25	Untreated	N/A	75
00SL12-1A	(8)6:10-9	25	Spiked	1.2	73.8
00SL12-1B	(8)6:10-5	25	Spiked	1.2	73.8
00SL50-1A	(8)6:10-10	25	Spiked	50	70
00SL50-1B	(8)6:10-4	25	Spiked	50	70
00CC12-A	N/A	N/A	Spiked	1.2	73.8
00CC12-B	N/A	N/A	Spiked	1.2	73.8
00CC50-A	N/A	N/A	Spiked	50	70
00CC50-B	N/A	N/A	Spiked	50	70
00RB-A	N/A	N/A	Blank	N/A	75

NB:

- The leaf samples used for the validation were taken from a bulked sample of untreated cocoa leaves. This bulk sample of untreated cocoa leaves was analysed for residues of phosphonic acid.
- Field codes: (8) 6:10-6: “(8)” indicates that the leaves were collected in August before the treatment of the trees; “6” means that they come from block 6; “10” denotes treatment 10: (untreated control); “6” means that it is replicate No 6.
- Laboratory sample codes: UL indicates Untreated Leaves, SL = Spiked Leaves, CC = control check and RB = reagent blank.

Table 2: Field samples from phosphonate treated trees

Sample code	Field code	Sample weight (g)	Treatment	Volume H_2SO_4 added (ml)
00TL-1A	(9)6:1-1	25	Treated	75
00TL-1B	(9)6:1-2	25	Treated	75
00TL-2A	(9)5:1-2	25	Treated	75
00TL-2B	(9)5:1-3	25	Treated	75
00TL-3A	(9)7:1-3	25	Treated	75
00TL-3B	(9)7:1-4	25	Treated	75

NB:

- The treatment of the Bechem trial was carried out between the 30.08.00 and 01.09.00.
- Field sample codes: (9) 6:1-1: “(9)” indicates that the leaves were collected in September; “6” means that they come from block 6; “1” denotes treatment 1: (stem injection 2x20ml, single point injection, 40% neutralised phosphonic acid); “1” means that it is replicate No.1.
- TL indicates treated leaves

5.5: Phosphonate analysis using the Ai. Flame Photometric detector

Detector response

The linearity of the detector response over a range of concentrations is presented in Table 3.

Table 3: **Dimethyl phosphonate calibration response**

Standard	Conc. (µg/ml)	Peak Height (cm)
Dimethyl phosphonate	0.1	1.5
	0.2	3.2
	0.4	6.4
	1.0	13.4

Sample analysis

No residues of phosphonic acid were detected in the untreated leaf sample 00UL-1A (see chromatogram in Annex 4). Analysis of two replicates of leaf samples from the field trials indicated the presence of phosphonic acid residues (see chromatograms in Annex 4). The remaining samples will be analysed at CRIG. The results are presented in Table 4.

Table 4: **Phosphonic acid residues in field trial leaf samples**

Sample Code	Peak height (cm)	Dimethyl phosphonate concentration (µg/ml)	Phosphonic acid residue (µg/g)
00TL-2A	3.6	0.22	6.6
00TL-2B	3.4	0.21	6.3

NB:

- See Table 2 for sample details and Annex 4 for calculation details.
- Spiked leaf and control check samples prepared prior to setting up the Ai FPD were not analysed

6. FIELD SAMPLING

A field visit was made to the joint CABI/CRIG phosphonate field trial at Bechem, a CRIG research station located approximately 60 km northwest of Kumasi (see Annex 5 for a summary of the trial). As part of the trial sampling programme, leaf samples were collected for phosphonate analysis following the sampling procedure developed by CRIG, which was observed and confirmed as satisfactory. A proportion of the leaf samples were later processed in preparation for analysis and replicate sub-samples taken for analysis at NRI to allow any required comparison of analytical results (see Annex 6). Cocoa pods and mature treated beans from earlier samplings were also collected for analysis at NRI should this be considered necessary

7. CURRENT APPLICATION METHODS

7.1 Overview

Only limited information on the current level of fungicide use and ownership or access to sprayers for black pod control was available at the time of the visit. The most recent information, summarised here, was obtained from studies carried out in 1990 (Farming Systems Unit research papers 1/2/3). No other information appeared to be available at CRIG.

7.2 Use of sprayers and fungicide

In the reports of the Farming Systems Unit (FSU) studies on the adoption of CRIG recommendations (FSU Research Paper 1), completed in 1989 in the Offinso district of Ashanti, it is reported that up to 58 mist blowers were owned by cocoa buying societies many of which were unserviceable. The same report series (FSU Research Paper 3) stated that chemical control as a solution to black pod control was seen as too expensive by the cocoa farmers interviewed, including the 12% who had previous experience of applying fungicides for disease control.

Lever operated knapsack sprayers are currently used by some farmers but little detailed information is available on level of sprayer ownership or use of fungicides amongst cocoa farmers (private communication, Dr Opoku). A new survey is planned under the joint direction of the CABI/CRIG cocoa project.

8. OPERATOR EXPOSURE AND SPRAY APPLICATION

8.1 Overview

In any spraying operation involving the manual operation of application equipment such as lever operated knapsack sprayers, it is inevitable that spray operators risk being exposed to pesticide contamination. The extent to which this occurs depends principally on the time spent spraying, the concentration and volume of pesticide spray applied, the nature of the crop involved and, very importantly, the skill of the spray operator. Determination of operator exposure may be achieved through the use of exposure pads fixed to designated areas of the operators clothing. These are worn throughout a timed period of spray application then removed and analysed. The residue levels found on the pads are expressed as the amount of pesticide deposited per unit area of pad, typically as ug/cm^2. These values are then used to calculate the amount of pesticide deposited over the whole body using standard values for specific body areas such as the chest or head (WHO, 1975). The risk to the operator arising from the total quantity of pesticide deposited on the whole body is then expressed as a percentage of the pesticide's dermal LD_{50} deposited on the operator per hour or day.

Use of appropriate spraying equipment is not only essential to minimise operator exposure to pesticides but is also essential for the efficient use of pesticides in crop protection. The use of sprayers and nozzles giving inappropriate droplet spectra or excessively high volume application rates can result in ineffective pest and disease control and costly levels of pesticide wastage through spray run-off.

8.2 Trial methodology

To assess the level of pesticide contamination experienced by spray men during the course of applying pesticides to cocoa for insect and disease control, a series of spray applications were made in mature cocoa plantations at Bechem and at Tafo using the fungicide 'Ridomil plus' (metalaxyl/cuprous oxide). Ridomil possesses both systemic and residual properties and is recommended by CRIG for black pod control.

All spray applications were made by experienced CRIG spray men. Each trial was carried out with two operators each applying a sprayer tank (15 litres) of Ridomil mixture (one 50 g sachet per 15 litres) with or without the addition of tartrazine (30 g). The latter was used to evaluate the potential for analysis of spray deposits by spectrophotometry as a simpler alternative to metalaxyl determination by gas liquid chromatography. The time taken to empty the sprayer tank and the number of trees sprayed were recorded on pre-prepared forms. Details of the spray applications are given in Table 5.

To determine the amount of spray deposited on spray operators clothing, absorptive pads were stapled or taped to the spray men's overalls at nine points, viz. the head, chest, both forearms, the upper back and on the thighs and lower legs. The pads were prepared from glass fibre filter papers (Whatman, 11.0 cm GF/D) backed with aluminium foil and had an exposed area of 8 cm x 8 cm. Cotton gloves were worn on the hands. After timed spray periods of up to 40 minutes the pads and gloves were removed, labelled and placed in plastic bags for return to the laboratory where they were allowed to dry before being wrapped in aluminium foil. All samples were then stored in a laboratory refrigerator until their return to the UK where they were transferred to a laboratory freezer for further storage at –20 to -23^{o}C.

To assess the efficiency of spray application in terms of the proportion of emitted spray deposited on the ground, plastic petri dishes were placed in a circle about 0.75 metres from the bases of the trunks of selected cocoa trees. The dishes (4) were collected after one or more passes of the sprayer, collected spray allowed to dry, then labelled and placed in plastic bags for return to the CRIG laboratory.

8.3 Results

The results of the analysis of the exposure pads and gloves are given in Tables 6 to 8. Full sample analysis details are given in NRI Laboratory Analytical Report No. 00AV-00BP. Details of the potential toxic risk to operators as a result of exposure to metalaxyl are shown in Table 9. Levels of spray losses to the ground are given in Table 10.

Operator exposure to metalaxyl:

Metalaxyl residues were found on all areas of the body. The lowest residue levels were found on the upper back, equivalent to a mean exposure rate of 212 µg/hour, (SD 225 µg/hour) and on the head where the mean exposure rate was 789 µg/hour (SD 931 µg/hour, one sample at 2919 µg/hour). The upper legs gave mean exposure rates of 1113 µg/hour (left) and 883 µg/hour (right) compared with lower leg levels of 849 µg/hour (left) and 846 µg/hour (right). Chest pads gave a metalaxyl exposure rate of 1950 µg/hour (SD3832 µg/hour, one sample at 11876 µg/hour). Exposure rates for the arms as determined from pads placed on the outer forearm were 1376 µg/hour (SD 1095 µg/hour) for the left arm and 2260 µg/hour (SD 2070 µg/hour) for the right arm. From measurements of tartrazine residues on the gloves worn by the operators, estimated mean exposure rates were calculated as 2491 µg/hour (SD 3470 µg/hour) for the left hand and 1512 µg/hour (SD 2573 µg/hour) for the right hand. Details of individual operator exposure rates are given in Table 9.

As determined from the body samplers, total metalaxyl exposure rates (omitting glove measurements) ranged from 1.74 to 19.6 mg/hour. Based on the dermal LD_{50} for metalaxyl of

>3100 mg/kg this corresponds to a potential toxic dose rate of 0.0008% to 0.0090 %/hour for a 70 kg operator. However, the wearing of cotton overalls and wellington boots by the operators or similar clothing by farmers would indicate that actual dermal exposure levels would be considerably less than . Although face masks were worn by the operators during spraying, co-extractives interfered with the metalaxyl analysis and no validated results were obtained. No tartrazine residues were detected on the face masks.

Ground deposition

The volume of spray deposited on the ground during fungicide application to the cocoa pods varied from 39.5 to 132 ml/m^2 (Table 10). Many of the pods from the trial trees had been harvested, suggesting that spray losses could be even higher when the time spent spraying each tree would be greater because of the greater number of pods present. Such losses to the ground represent a considerable proportion of the applied spray and a significant financial loss.

Use of tartrazine as tracer

The use of tartrazine as a tracer proved effective. Comparison of the total operator exposure results given in Tables 6 and 7 shows that the ratio of tartrazine to metalaxyl when applied together give a value of 4.23:1 with a range of 3.50 to 5.32, agreeing well with the analytically determined tartrazine/metalaxyl spray tank ratio of 4.17:1. These results strongly demonstrate the feasibility of using tartrazine tracer as an alternative to the GC determination of metalaxyl in measurement of operator exposure levels. However, a small number of samples gave ratios that differed greatly from that given above, suggesting that more study is required to identify the causes of these anomalies and to refine the overall method.

Quantitative determination of operator exposure – sprayer set-up and application conditions(1)

Trial code(2)	Date	Start of spraying	Spray time (min)	Sprayer model(3)	Nozzle type(4)	No. trees sprayed	Total volume applied (L)
Trial B1/Samuel, 23.11.00, tartrazine only.							
		0953	21	CP15	HC Yellow	29	7.40
Trial B1/1Isaac, 23.11.00, Ridomil only.							
		0953	20	CP15	HC Yellow	27	8.77
Trial B2/Samuel, 23.11.00, tartrazine only.							
		1111	19	CP15	HC Yellow	N/A	7.60
Trial B2/Isaac, 23.11.00, Ridomil only.							
		1111	17	CP15	HC Yellow	N/A	6.23
Trial B3/Samuel, 23.11.00, Ridomil plus tartrazine							
		1230	40	CP15	HC Yellow	N/A	15.0
Trial B3/Isaac, 23.11.00, Ridomil plus tartrazine							
		1230	40	CP15	HC Yellow	N/A	15.0
Trial T2/Johnson, 27.11.00, Ridomil plus tartrazine.							
		1009	21	T18	HC No.12	N/A	15.0
Trial T2/Jonas, 27.11.00, Ridomil plus tartrazine							
		1009	17	T18	HC No.12	N/A	15.0
Trial T4/Johnson, 27.11.00, Ridomil plus tartrazine							
		1147	20	T18	HC No.12	125	15.0
Trial T4/Jonas, 27.11.00, Ridomil plus tartrazine							
T4/2	27.11.00	1147	16	T18	HC No.12	104	15.0

Trial T5/Jonas, 29.11.00, Ridomil plus tartrazine

0945	18.0	T18	HC No.12	75	15.0

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[1] Temperature and humidity during spray application varied from 27-31^{0}C and 65-77% respectively

[2] Sites: T = Tafo, B = Bechem research stations

[3] Sprayers: T = Tecnoma, CP = Cooper Pegler

[4] HC = hollow cone nozzle

Notes:

(1) Spray mixture consisted of the fungicide 'Ridomil plus' (M), at 50 g/15 litres with the addition of tartrazine tracer at 30 g/15 litres (0.2%). 'Ridomil plus' (wettable powder) contains 12% metalaxyl active ingredient.

(2) Body area multiplier: (cm^2):	Head	Chest	Back	Arm	Upp.leg	Low.leg
(from OECD/GD(97)148)	1560	3550	3550	2060	1910	1190

(3) Abbreviations: MS, no sample; NS, not significant; NA, not analysed

(4) Gloves worn by operators not analysed for metalaxyl residues because of difficulties with co-extractives.

Table 11: Spray losses during the application of fungicide sprays to cocoa using tartrazine dye tracer

Trial reference	Sprayer model	Total volume applied (litres)	Volume applied per tree (ml)	Spray deposited on ground collectors[1] (ml/m^2)
Trial T2/Johnson, 27.11.00, tartrazine plus Ridomil				
Rep. 1	T18	15	150	**39.5**
Rep. 2	T18	15	150	**132**
Trial T2/Jonas, 27.11.00, tartrazine plus Ridomil				
Rep. 1	T18	15	144	**83.6**
Rep. 2	T18	15	144	**40.7**
Trial T4/Johnson, 27.11.00, tartrazine plus Ridomil				
	T18	15	120	**66.3**
Trial T4/Jonas, 27.11.00, tartrazine plus Ridomil				
	T18	15	148	**46.4**
Trial T5/Jonas, 29.11.00, tartrazine plus Ridomil				
	T18	15	200	**56.1**

(1) Calculated from the quantity of spray deposited in four petri dish collectors placed around the base of cocoa trees, 0.75 metres from the trunk; dish area 63.5 cm^2

Table 6: Operator contamination during spray application on cocoa with lever operate knapsack sprayers at Bechem (B) and Tafo (T); November 2000

Metalaxyl deposition on body targets (ug/cm^2) and on corresponding body areas (ug

Trial code	Head	Back	Chest	Arms		Left leg		Right leg		Total residue	Operator exposure
				Left	Right	Upper	Lower	Upper	Lower	(ug)	(mg/hour)
Trial B1, operator Isaac, 23.11.00, Ridomil only; (spray period: 20 min)											
	0.04	<0.02	<0.02	0.03	0.09	0.03	0.04	0.05	0.06		
Total ug	62	NS	NS	62	185	57	48	96	71	**581**	**1.74**
Trial B2, operator Isaac, 23.11.00, Ridomil only; (spray period: 17 min)											
	0.07	0.18	<0.02	0.09	0.48	0.06	0.09	0.04	0.09		
Total ug	109	639	NS	185	989	115	107	76	107	**2327**	**8.20**
Trial B3, operator Samuel, 23.11.00, Ridomil plus tartrazine; (spray period: 40 min)											
	0.13	0.11	2.23	0.29	0.14	0.35	MS	0.17	0.40		
Total ug	203	391	7917	597	288	669	MS	325	476	**10866**	**16.3**
Trial B3, operator Isaac, 23.11.00, Ridomil plus tartrazine; (spray period: 40 min)											
	0.06	0.06	0.04	0.19	1.41	0.32	0.11	0.06	0.36		
Total ug	94	213	142	391	2905	611	131	115	428	**5030**	**7.54**
Trial T2, operator Johnson, 27.11.00, Ridomil plus tartrazine; (spray period: 21 min)											
	0.09	0.02	0.03	0.26	0.13	0.76	0.37	0.50	0.74		
Total ug	140	71	107	536	268	1452	440	955	881	**4850**	**13.9**
Trial T2, operator Jonas, 27.11.00, Ridomil plus tartrazine; (spray period: 17 min)											
	0.53	0.03	0.22	0.47	0.87	0.11	0.29	0.04	0.37		
Total ug	827	107	781	968	1792	210	345	76	440	**5546**	**19.6**
Trial T4, operator Johnson, 27.11.00, Ridomil plus tartrazine; (spray period: 20 min)											
	0.16	0.04	0.10	0.35	0.17	0.29	0.24	0.43	0.18		
Total ug	250	142	355	721	350	554	286	821	214	**3693**	**11.1**
Trial T4, operator Jonas, 27.11.00, Ridomil plus tartrazine; (spray period: 16 min)											
	0.21	<0.02	0.10	0.32	0.32	0.10	0.60	0.07	0.49		
Total ug	328	NS	355	659	659	191	714	134	583	**3603**	**13.5**
Trial T5, operator Jonas, 29.11.00, Ridomil plus tartrazine; (spray period: 18 min)											
	MS	<0.02	<0.02	0.07	0.13	0.04	0.4	0.12	0.46		
Total ug	MS	NS	NS	144	268	76	476	229	547	**1721**	**5.74**

Table 7: Operator contamination during spray application on cocoa with lever operated knapsack sprayers at Bechem (B) and Tafo (T).

Tartrazine deposition on body targets (ug/cm^2) and on body areas (ug)

Trial code	Head	Back	Chest	Target location						Total residue (ug)
				Arms		Left leg		Right leg		
				Left	Right	Upper	Lower	Upper	Lower	
Trial B1, operator Samuel, 23.11.00, tartrazine only; (spray period: 20 min)										
	0.62	5.23	<0.16	0.65	2.54	0.57	0.35	0.74	MS	
Total ug	967	18567	NS	1339	5232	1089	669	1413		**29276**
Trial B2, operator Samuel, 23.11.00, tartrazine only; (spray period: 19 min)										
	1.18	1.83	<0.16	1.23	4.82	1.74	1.54	2.46	1.13	
Total ug	1841	6497	NS	2534	9929	3323	1833	4699	1345	**32001**
Trial B3, operator Samuel, 23.11.00, Ridomil plus tartrazine; (spray period: 40 min)										
	0.40	0.28	9.17	1.11	0.59	1.37	MS	1.50	0.65	
Total ug	624	994	32554	2287	1215	2617	MS	2865	774	**50764**
Trial B3, operator Isaac, 23.11.00, Ridomil plus tartrazine; (spray period: 40 min)										
	0.16	<0.16	<0.16	0.57	5.75	1.69	0.23	0.16	0.45	
Total ug	250	NS	NS	1174	11845	3228	274	306	536	**22438**
Trial T2, operator Johnson, Ridomil plus tartrazine; (spray period: 21 min)										
	0.18	<0.16	<0.16	1.08	0.65	3.44	1.91	2.15	2.59	
Total ug	281	NS	NS	2225	1339	6570	2273	4107	3082	**59737**
Trial T2, operator Jonas, Ridomil plus tartrazine; (spray period: 17 min)										
	2.01	<0.16	0.96	1.37	3.10	1.01	1.01	0.18	1.47	
Total ug	3136	NS	3408	2822	6386	1929	1202	344	1749	**27015**
Trial T4, operator Johnson, Ridomil plus tartrazine; (spray period: 20 min)										
	0.76	<0.16	0.35	1.37	0.84	3.61	1.23	1.62	1.01	
Total ug	1186	NS	1243	2822	1730	6895	1464	3094	1202	**39544**
Trial T4, operator Jonas, Ridomil plus tartrazine; (spray period: 16 min)										
	0.84	<0.16	0.40	1.25	0.89	0.16	3.31	0.37	2.20	
Total ug	1310	NS	1420	2575	1833	306	3939	707	2618	**20686**
Trial T5, operator Jonas, Ridomil plus tartrazine; (spray period: 18 min)										
	MS	<0.16	<0.16	0.16	0.67	<0.16	1.93	0.35	3.07	
Total ug	MS	NS	NS	330	1380	NS	2297	669	3653	**11628**

Notes:

(1) Spray mixture consisted of either the fungicide 'Ridomil plus' at 50 g/15 litres alone or with the addition of tartrazine at 30 g/15 litres (0.2%).
'Ridomil plus' (wettable powder) contains 12% metalaxyl active ingredient.

(2)

Body area multiplier: (cm²):	Head	Chest	Back	Arm	Upp.leg	Low.leg	Hands
(from OECD/GD(97)148)	1560	3550	3550	2060	1910	1190	410

(3) Abbreviations: MS, no sample; NS, residue not significant;

(4) Gloves residues shown in Table 8

Table 8: Operator exposure during spray application to cocoa using lever operated knapsack sprayers

Tartrazine residues on operator gloves (ug)

Trial reference	Gloves Left	Gloves Right	Time spent spraying (min)	Total exposure Left	Total exposure Right
	Total residue (ug)			(mg/hour)	
Trial B3/Samuel, 23.11.00, Ridomil plus tartrazine					
	1161	1340	40	**1.74**	**2.01**
Trial B3/Isaac, 23.11.00, Ridomil plus tartrazine					
	545	1221	40	**0.36**	**0.81**
Trial T2/Johnson, 27.11.00, Ridomil plus tartrazine					
	14085	498	21	**40.2**	**1.42**
Trial T2/Jonas, 27.11.00, Ridomil plus tartrazine					
	1245	965	17	**4.39**	**3.41**
Trial T4/Johnson, 27.11.00, Ridomil plus tartrazine					
	6135	1152	20	**18.4**	**3.46**
Trial T4/Jonas, 27.11.00, Ridomil plus tartrazine					
	1479	708	16	**5.55**	**2.66**
Trial T5/Jonas, 29.11.00, Ridomil plus tartrazine					
	624	531	18	**2.08**	**1.77**

Table 10: Operator exposure to metalaxyl during spray application on cocoa using lever operated knapsack sprayers

Calculation of potential toxic dose (as % of LD_{50})(1)

Trial reference	Total exposure (mg)	Time spent spraying (min)	Total exposure (mg/hour)	Potential toxic dose/hour(2) (%)
Trial B1/Isaac, 23.11.00, Ridomil only;				
	0.58	20	1.74	**0.0008**
Trial B2/Isaac, 23.11.00, Ridomil only;				
	2.33	17	8.22	**0.0038**
Trial B3/Samuel, 23.11.00, Ridomil plus tartrazine				
	10.9	40	16.4	**0.0076**
Trial B3/Isaac, 23.11.00, Ridomil plus tartrazine				
	5.03	40	7.55	**0.0035**
Trial T2/Johnson, 27.11.00, Ridomil plus tartrazine				
	4.85	21	13.9	**0.0064**
Trial T2/Jonas, 27.11.00, Ridomil plus tartrazine				
	5.55	17	19.6	**0.0090**
Trial T4/Johnson, 27.11.00, Ridomil plus tartrazine				
	3.69	20	11.1	**0.0051**
Trial T4/Jonas, 27.11.00, Ridomil plus tartrazine				
	3.6	16	13.5	**0.0062**
Trial T5/Jonas, 29.11.00, Ridomil plus tartrazine				
	1.72	18	5.73	**0.0026**

(1) Metalaxyl dermal LD_{50} taken as 3100 mg/kg (Pesticide Manual, 9th Edition)

(2) Calculated as: (total exposure x 100)/LD_{50}x70. (Weight of operator taken as 70 kg)

Glove residues not included as these were analysed for tartrazine only.

Table 9: Operator exposure to metalaxyl during spray application on cocoa using lever operated knapsack sprayers

Total metalaxyl deposition on body areas (ug/hour)

Trial				**Arms**		**Left leg**		**Right leg**	
code	**Head**	**Back**	**Chest**	**Left**	**Right**	**Upper**	**Lower**	**Upper**	**lower**
B1/Isaac	186	0	0	186	555	171	144	288	213
B2/Isaac	384	0	0	653	3491	406	378	268	378
B3/Samuel	305	587	11876	896	432	1004	MS	488	714
B3/Isaac	141	320	213	587	4358	917	197	173	642
T2/Johnson	400	203	306	1531	766	4149	1257	2729	2517
T2/Jonas	2919	378	2756	3416	6324	741	1218	268	1553
T4/Johnson	750	426	1065	2163	1050	1662	858	2463	642
T4/Jonas	1230	0	1331	2471	2471	716	2678	503	2186
T5/Jonas	MS	0	0	480	893	253	1587	763	1823
Mean	**789**	**213**	**1950**	**1376**	**2260**	**1113**	**1040**	**883**	**1185**
SD	**931**	**225**	**3832**	**1095**	**2070**	**1224**	**849**	**990**	**846**

Calculated from data given in Table 6

Discussion

Spray application in cocoa.

From observations of the application technique of the sprayer operators involved in the exposure studies, it was seen that little attempt was made to spray pods much higher than two to three metres above ground level. The operators involved said this was because the length of the spray lance made it difficult to do so and because pods higher than three metres are relatively little affected by black pod disease compared with those nearer the ground. Lever operated knapsack sprayers are therefore well suited to this kind of work and with care and use of a suitable nozzle are reasonably efficient.

However, it appeared that the nozzles fitted to the sprayers used in the operator exposure trials were not ideally suited to pod spraying since the narrowness of the target (trunk/pods), and seemingly high spray emission rate led to significant levels of spray run-off and ground deposition. Use of lower flow rate nozzles and narrow angle hollow cone nozzles combined with appropriate operator training in spray application would significantly lower application costs through reduction in spray run-off and wastage with consequent financial benefits for the cocoa farmer and the wider environment in general. Use of a nozzle shield to confine spray to the vicinity of the pod/trunk may also be worthy of investigation. Reduced volume application rates would also contribute towards minimising operator exposure during spray application.

Alternatives to the use of lever operated knapsack sprayers for the application of pesticides to cocoa include pod painting and trunk injection with buffered phosphonic acid, both currently under evaluation by CRIG. Trunk injection, if successful, has advantages over lever operated knapsack sprayer application in that the cost of the injection equipment is significantly less than that of a sprayer and phosphonate fungicide costs would be expected to be lower than conventional products such as metalaxyl. Moreover, a single injection of phosphonic acid may be sufficient for a whole season’s protection against black pod, whereas six or more spray applications of fungicide are required. However, the calluses caused by repeated trunk injections may be unattractive to farmers and sprayer ownership may be more appealing for those farmers able to afford such equipment because of the knapsack sprayer’s wider range of use.

Operator exposure

The exposure levels experienced by the sprayer operators during the application of metalaxyl ranged from 1.74 to 19.6 mg/hour, (mean 10.7 mg/hour, SD 5.6), suggesting that considerable reduction in levels of operator exposure could be obtained through appropriate training in application techniques. Given that the highest levels of contamination were found on the hands and arms it is clearly important that suitable gloves be worn during spraying as well as during the preparation of spray mixtures for application. In the application trials carried out the use of simple cotton overalls and some form of head covering appeared sufficient to protect the operator against significant metalaxyl contamination. Further trials are required to establish whether this would be true when much larger numbers of pods were present and spraying therefore more arduous and time consuming.

9. ACKNOWLEDGEMENTS

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10. REFERENCES

WHO, World Health Organization, 1982. Field Surveys of Exposure to Pesticides. Standard Protocol, VBC/82.1, WHO, Geneva

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Analytical procedure for phosphonate residue analysis in cocoa leaves, beans and pods.

Apparatus:
Scissors
Laboratory mill: Ika A10 or a pestle and mortar
High speed macerator: Omni-mixer system using 400 ml maceration jar
Rotary vacuum evaporator
Balance, precision ±0.1g
Centrifuge, centrifuge tubes
100ml measuring cylinder
25ml, 5ml volumetric flask
50ml round bottom flask, fitted with a stopper
Filter funnel
2ml graduated pipettes
5ml graduated pipettes
Cotton wool
Blow bulb

Reagents:
Concentrated sulphuric acid, AR
Sulphuric acid solution (2 or 10ml/l):
Pipette 4 ml or 20 ml of concentrated acid into a 2000ml volumetric flask half full with distilled water and make up to the mark.
2-propanol, glass distilled grade
Diazomethane

1. Sample preparation

Appropriate protective clothing to be worn during all sample preparation and analytical procedures

1a: Cocoa leaves
1- Allow the cocoa leaf samples to warm up to room temperature.
2- Weigh 25 g of leaves on to a piece of previously labelled aluminium foil and cut into very small pieces using a pair of scissors.

1b: Cocoa beans
1- Allow the cocoa bean samples to warm up to room temperature.
2- Grind the whole bean sample using a laboratory mill or pestle and mortar. Transfer the powder into a large dish or onto a piece of aluminium foil and mix t horoughly to form a bulk sample.
3- Weigh an aliquot of 25 g of cocoa bean powder onto a piece of aluminium foil and label it.

1c: Cocoa pods
1- Allow the cocoa pod samples to warm up to room temperature.
2- Using a knife, cut the pod into 2 equal halves. Take one of the halves and cut it into our equal pieces. Take one of these pieces, (equivalent to a 1/8 of the pod) and weigh it onto a piece of previously labelled aluminium foil.

2. Extraction by maceration

1- Transfer the leaf or bean sub sample into the Omnimixer maceration jar. For pod samples, it is best to cut the sample into small pieces using a pair of scissors (wear gloves).
2- If treating a field sample or a blank sample, add 75 ml of 2 ml/litre sulphuric acid solution to the leaves or beans. If preparing a laboratory spiked sample or a control check sample, add the amount of sulphuric acid solution and spiking solution as specified in the sample list. If analysing cocoa pods, carry out the same procedure but use the 10 ml/litre sulphuric acid solution.
3- Macerate the sample at high speed (between speed control setting 5 and 10) for one to two minutes.
4- Transfer equal amounts of the sample into two centrifuge tubes (each tube should have the same weight – use a balance).
5- Centrifuge the tubes for 10 to 15 minutes.
6- Combine the two filtrates in a small beaker.
7- Pipette 2.5 ml of this extract into a 25 ml volumetric flask and make up to the mark with 2-propanol. Precipitation will occur with the solvent.
8- Filter the solution through a small amount of cotton wool in a filter funnel into a 15 ml volumetric flask.

3. Phosphonic acid derivatisation

1- Pipette 5 ml of the 2-propanol solution into a 5 ml round bottom flask and add the diazomethane reagent to excess (i.e. until the yellow colour persists in the round bottom flask). Stopper the flask.
2- Allow the reaction to proceed for 30 min and then evaporate the excess diazomethane using a blow bulb (always in the fume cupboard).
3- Place the flask on a rotary vacuum evaporator at 40°C and evaporate the extract to about 3 ml. **Do not** allow the sample to go to dryness.
4- Quantitatively transfer the residue solution into a 5 ml volumetric flask and adjust to the mark with 2-propanol.
5- Inject the sample into the GC-FPD.

4. GLC conditions

<u>Analytical Instruments Model 93 GC-FPD instrument:</u>

- Packed column: 20% Carbowax 20m on Chromosorb W AW

- Column specification: 1 metre x 3 mm i.d.

- GC conditions:
  Oven temperature: 160°C
  Detector temperature: about 250°C
  Injector temperature: about 225°C
  Carrier gas flow rate: 60ml/min

  NB: These conditions are specific to the CRIG GC.

- Injection volume: 5µl (manual)

5. Preparation of analytical standards

5a: Stock solution

Phosphonic acid stock solution PAS1 – 200 000µg/ml:
Weigh accurately 10.0000 ± 0.0001g of phosphonic acid powder and quantitatively transfer to a 50ml volumetric flask, dissolve in distilled water and make up to volume.

5b: Intermediary level solutions

Intermediary phosphonic acid solution PAS2 - 4 000µg/ml:
Pipette accurately 2ml of PAS1 into a 100ml volumetric flask and 18ml of 2-propanol and make to volume using 9:1 2-propanol:water.

Intermediary phosphonic acid solution PAS3 - 1 000µg/ml: (used for the preparation of the calibration solutions):
Pipette accurately 6.25ml of PAS2 into a 25ml volumetric flask and make to volume using 9:1 2-propanol:water.

Intermediary phosphonic acid solution PAS4 - 100µg/ml: (used for spiking the untreated samples for validation purposes):
Pipette accurately 5ml of PAS3 into a 50ml volumetric flask and make to volume using 9:1 2-propanol:water.

5c: Working level solutions

Preliminary solutions prior to prepare the calibration range:

Phosphonic acid solution in acidic media PA-AC1 - 100µg/ml:
Pipette accurately 7.5ml of PAS3 into a 100ml conical flask and add precisely 67.5ml of 2ml/l sulphuric acid solution to obtain a final volume of 75ml.

Phosphonic acid solution in acidic media PA-AC2 - 10µg/ml:
Pipette accurately 5ml of PA-Ac1 into a 50ml volumetric flask and make to volume using 2-propanol.

Dimethyl phosphonate standard in acidic media DMP-Ac1 - 10µg/ml:
Pipette 5ml of PA-Ac2 in a 50ml round bottom flask, add diazomethane and let react for 30min. Evaporate to about 3ml and make up to mark in 5ml volumetric flask with 2-propanol.

Calibration solutions:

Dimethyl phosphonate standard in acidic media DMP-Ac2 - 1µg/ml:
Pipette accurately 2.5ml of DMP-Ac1 into a 25ml volumetric flask and make to volume using 2-propanol.

Dimethyl phosphonate standard in acidic media DMP-Ac3 - 0.4µg/ml:
Pipette accurately 10ml of DMP-Ac2 into a 25ml volumetric flask and make to volume using 2-propanol.

Dimethyl phosphonate standard in acidic media DMP-Ac4 - 0.2µg/ml:
Pipette accurately 5ml of DMP-Ac2 into a 25ml volumetric flask and make to volume using 2-propanol.

Dimethyl phosphonate standard in acidic media DMP-Ac5 - 0.1µg/ml:
Pipette accurately 2.5ml of DMP-Ac2 into a 25ml volumetric flask and make to volume using 2-propanol.

6. Validation procedure

Overview

Validation consists of regularly assessing the analytical method being followed and should be performed prior to analysis of samples (to check that the method is working) and during the analysis of samples (to check that the method is continuing to perform satisfactorily).
To validate the method, control samples (untreated cocoa samples), reagent blanks, spike check samples, (samples that are exactly the same as a laboratory spiked sample but which do not contain cocoa material), and spiked cocoa samples for recovery checks should be analysed. All validation checks must go through exactly the same analytical processes as the actual samples.

Validation procedure

Before starting the analysis of the cocoa samples, the following validation samples should be performed:

1) 2 replicates of untreated cocoa samples (control samples)
2) 2 replicates of reagent blanks
3) 2 replicates of each spike check samples
4) 2 replicates of each level of laboratory spiked cocoa samples

During the analysis of the cocoa samples, regular checks on the method should be performed by analysing one reagent blank and one level of laboratory spiked and spike check sample for every 20 cocoa samples analysed (every 10 samples for better quality results) or every time a reagent batch is changed.

Level of spiking

For this analytical method, three levels of spiking should be performed on untreated cocoa material samples and the samples extracted following the normal procedure.. These are in effect, spiked reagent blanks.

Details of the three levels of spiking are given below:

Spiking level	**Amount of Phosphonic acid added (µg)**	**Volume of 100µg/ml phosphonic acid added (ml)**	**Volume of H_2SO_4 added (ml)**
1	120	1.2	73.8
2	250	2.5	72.5
3	500	5.0	70

Annex 3: Calculation of limit of determination

FPD detector limit of determination with leaf samples:

Sample type	*Sample weight (g)* (A)	*Extraction volume (ml)* (B)	*Extract dilution factor* (C)	*DMP concentration (ug/ml) in GC solution* (D)	*Phosphonic acid weight in extract (ug)* (E = D*C*B)	*Phosphonic acid residue in leaf sample (ug/g)* (F = E/A)
Leaf	25	75	10	0.1	75	***3***

Phosphonic acid residues in treated leaf samples:

Sample code	*Sample weight (g)* (A)	*Extraction volume (ml)* (B)	*Extract dilution factor* (C)	*DMP concentration (ug/ml) in GC solution* (D)	*Phosphonic acid weight in extract (ug)* (E = D*C*B)	*Phosphonic acid residue in leaf sample (ug/g)* (F = E/A)
00TL-2A	25	75	10	0.22	165	***6.6***
00TL-2B	25	75	10	0.21	157.5	***6.3***

ANNEX 3

LABORATORY
ANALYTICAL REPORT

ANALYSIS OF PHOSPHONATE RESIDUES IN TREATED COCOA BEANS

Report No.: **02AC**

Report to: **Mark Holderness**
CABI Bioscience

Analysis conducted by: **John Cox and Bill King**

Associate Member, Sustainable Agriculture Group,
Natural Resources Institute
University of Greenwich
Central Avenue
Chatham Maritime
Chatham
Kent, ME4 4TB
UK

Date of Issue of Report: 11 July 2002

Number of Pages of Report:
(+Annexes, top copy only)

Principle Workers:

The work described in this report was carried out by:

Analytical Chemist: John R Cox

Signed:
Date:

Analytical Chemist: Bill King

Signed:
Date:

SECTION A : SAMPLES

Originator: Dr M Holderness

Organisation: CABI Bioscience
UK Centre
Bakeham Lane
Egham,
Surrey, TW20 9TY

Country: Ghana

NRI Project No.: C1261

Laboratory Project code: 02AC

Client Reference No.:

NRI File Reference:

Samples: 10 samples in total representing samples from five separate field treatments each harvested twice.

Date of receipt in Laboratory: 27 June 2002

Condition of samples on receipt: Good; all samples individually wrapped and labelled.

Storage conditions after receipt: In freezer F4 in B109

Study Details (treatment and sampling information):

Samples represent treatments 2, 4, 5, 7 and 10 each harvested in October and November 2001; treatment details not provided.

SECTION B : SUMMARY OF RESULTS

The results of the analyses, expressed in mg/kg are detailed below.
.

1. Phosphonic acid injection trials, Bechem; 2nd harvest (October 2001)

Sample	Treatment	Laboratory code	Residue, mg/kg
Treatment 2	20% potassium phosphonate 2 x 20ml injection pH 7.5	2T2	123
Treatment 4	40% potassium phosphonate, 2 x 20ml injection, pH 7.5 + Bion	2T4	60
Treatment 5	40% potassium phosphonate 2 x 20ml, pH 7.5	2T5	162
Treatment 7	20% potassium phosphonate pod spray pH 7.5	2T7	120
Treatment 10	Untreated control	2T10	7.2

2. Phosphonic acid injection trials, Bechem; 3rd harvest (November 2001)

Sample	Treatment	Laboratory code	Residue, mg/kg
Treatment 2	20% potassium phosphonate 2 x 20ml injection pH 7.5	3T2	96
Treatment 4	40% potassium phosphonate, 2 x 20ml injection, pH 7.5 + Bion	3T4	165
Treatment 5	40% potassium phosphonate 2 x 20ml, pH 7.5	3T5	177
Treatment 7	20% potassium phosphonate pod spray pH 7.5	3T7	101
Treatment 10	Untreated control	3T10	5.4

A reagent blank through the full procedure showed no residues and a lower limit of determination of <1.5mg/kg was calculated.
Comments :
All original calibration data and record sheets are included as Annex 3 of the top copy of this report, held in the main laboratory files; sample chromatograms are held in the laboratory record store.

SECTION C : ANALYTICAL PROCEDURE

(i) Method

The method is appended as Annex 1

The analysis was carried out using a Perkin Elmer model 8500 Gas Liquid Chromatograph fitted with a Flame photometric detector (FPD). The operating conditions were:

Column: 1 metre x 3mm i.d., packed with 20% Carbowax 20m on Chromosorb W (AW), 80 – 100 mesh,

GC conditions:	Oven temperature:	140°C
	Detector temperature:	250°C
	Injector temperature:	250°C
	Carrier gas flow rate:	50ml/min
Injection volume:	5µl (manual)	
Run time:	8.00 min	
Retention time:	3. 5 – 3.6 minutes	
FPD conditions:	Hydrogen:	20psi
	Air:	21.5 psi
	Phosphorous filter	

(ii) Preparation of Reference Standards

Calibration solutions at 0.2, 0.5, 1.0, 2.0 and 4.0 µg/ml were prepared following the procedure detailed in Annex 1.

(iii) Method Validation (recovery studies)

A reagent blank was prepared with each batch (harvest) of samples following the full analytical procedure. No phosphonate residues were detected (residues <LoD).

(iv) Lower Limit of determination (or reporting Limit)

A lower limit of determination of 1.5mg/kg was calculated.

DIAZOMETHANE PRODUCTION

METHOD

Apparatus

MNG Diazomethane apparatus
Rubber septum and cap
Spinbar magnetic stirring fleas
Magnetic stirrer
Clamp
Plastic beakers
Glass weighing boat, spatula
10ml measuring cylinder
1ml gastight syringe fitted with a non-coring needle

Reagents

Diazald
Diethyl ether dried above anhydrous sodium sulphate
Diethylene glycol ethyl ether
Potassium hydroxide solution 40% (w/v)
Glacial acetic acid
Acetone

Procedure

Note: **Always wears safety glasses, gloves, lab coat and perform in fume cupboard; diazomethane is a CARCINOGENIC COMPOUND.**

The MNG diazomethane apparatus should ALWAYS be dry before starting the reaction. The glassware should always be rinsed with plenty of acetone after washing with hot water.

- Prepare the MNG diazomethane apparatus : a plastic beaker containing some water is placed above a magnetic stirrer and the outer tube of the MNG apparatus is held in the middle of the waterbath with a metal clamp.

- Weigh 0.5g ± 0.1g of diazald solid into the glass weighing boat and transfer it carefully into the inner tube of the MNG apparatus with a small spatula.

- Add the stirring flea to the inner tube of the MNG apparatus.

- Add 1ml of dry diethyl ether and 1ml of diethylene glycol ethyl ether to the inner tube.

- Finally, ensuring that the rubber septum is in place, screw the cap onto the tube.

- Raise the inner tube and add 10ml of dry diethyl ether into the outer tube of the MNG apparatus.

- Replace the inner tube and secure the tubes together using the appropriate clip.

- Add ice to the water bath and switch on the magnetic stirrer.

- Inject 1ml of 40% potassium hydroxide solution through the septum cap into the inner tube using a 1ml glass syringe. This should be done dropwise.

- Make sure that the glass safety shield of the fume cupboard is down when starting the reaction.

- Let the reaction proceed for at least 2h or until the yellow colour of diazomethane is well developed.

- Remove the inner tube and carefully pour the diazomethane from the outer tube into a screw capped bottle, secure the cap and store it in a refrigerator.

- Replace the inner tube and stop the reaction by removing the black screw cap and carefully adding 2-3 drops of glacial acetic acid into the inner tube. Leave for 30 seconds with the stirrer turned on and then add another 1ml of the glacial acetic acid to completely neutralise the reaction.

- Leave for about 5-10 minutes

- Empty the inner tube into the sink with a stream of cold water then clean the apparatus with hot water, followed by a rinse of acetone to dry the glassware.

ANNEX 4

AGRICULTURAL RESOURCES MANAGEMENT DEPARTMENT

LABORATORY ANALYTICAL REPORT

Report No.: 00AV-00BP

Report to:

Laboratory Contact: John Cox

Agricultural Resources Management Department
Natural Resources Institute
University of Greenwich
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Kent, ME4 4TB
UK

Tel : 01634-883896

Date of Issue of Report: March 2001

Number of Pages of Report:

Principle Workers:

The work described in this report was carried out by the following staff :

Analytical Chemist:
Signed:

Report Authorised:

Laboratory Manager:

(Bill King)

Date:

OR

Head of Laboratory :

(John Cox)

Date:

SECTION A: SAMPLES

Originator: **W J King**

Organisation: **NRI**

Country: **Ghana**

NRI Project No.: **C1261**

Laboratory Project code: **00AV-00BP**

Client Reference No.: N/A

NRI File Reference: N/A

Samples: Spray targets: Glass fibre filter papers (GFP)
Spray operator cotton gloves
Spray operator spray mask
Petri dish spray collectors
Sprayer tank mixes

Date of receipt in laboratory: 02.12.00

Condition of samples on receipt: Satisfactory

Storage conditions after receipt: The samples were stored prior to analysis at -15^{0}C in freezer No.F4 in Room B109

Study Details

Six spray operator exposure trials in cocoa were carried out using the fungicide ‘Ridomil plus’ either alone or mixed with tartrazine food dye. Two operators at each of two sites applied the fungicide mixture using either Cooper Pegler (Bechem) or Tecnoma (Tafo) lever operated knapsack sprayers. Tartrazine dye was used to evaluate the potential for analysis of spray deposits by spectrophotometry as a simpler alternative to metalaxyl determination by gas liquid chromatography. Spray depositing on the operators during spray application was monitored using dust/mist respirator masks (3M), cotton gloves and absorptive pads (glass fibre filter papers) attached to their clothing. As a measure of spray application efficiency, plastic petri dishes were used to collect spray falling to the ground around the bases of cocoa trees.

During method validation it was found that wax-like materials in the gloves and masks, that could not be readily removed using standard clean up procedures, precluded their analysis by gas chromatography.

As acetone was found to interact with the polystyrene petri dishes, it could not be used to extract metalaxyl residues from the dishes used to collect spray falling to the ground. Hexane was used instead but as this gave recoveries of less than 40% (see Annex 3) the dishes were analysed for tartrazine residues only.

The spray mixtures used in the exposure trials consisted of either one sachet of ‘Ridomil plus’ in 15 litres of water, or one sachet of ‘Ridomil plus’ with 30 g of tartrazine dye. The dye was added to determine whether simple colorimetry could serve as an alternative to gas chromatography in the determination of spray residues.
One sachet of ‘Ridomil plus’ (50 g) contained 12% metalaxyl active ingredient and 60% of cuprous oxide, equivalent to 400 μg/ml of metalaxyl active ingredient in the spray mixture. The corresponding tartrazine concentration was 2000 μg/ml.

Tartrazine dye was not added to the sprays applied in trials B1,B2 (Isaac) and metalaxyl was not applied in trials B1,B2 (Samuel).

The calibration curve for standard solutions of tartrazine in water as obtained from a Corning Model 252 colorimeter using a 430 nm wavelength filter is shown in Annex 1

Examples of chromatograms from the metalaxyl analyses are given in Annexes 2 and 3.

An interpretation and discussion of the analytical results detailed in this report is given in a separate technical report, “Control of *Phytophthora megakarya* diseases of cocoa with phosphonic acid” CPP Project R7326:

1. Implementation of an analytical method for the determination of phosphonic acid residues in cocoa material.
2. Spray application on cocoa and assessment of operator exposure to metalaxyl when applied by lever operated knapsack sprayer.

SECTION B: SUMMARY OF RESULTS

The results of the operator exposure sample analyses are detailed below:

Table 1: Metalaxyl residue analysis:

Identity and date of trial	**NRI sample code**	**Sample type$^{(1)}$**	**Metalaxyl in sample extract (ug/ml)**	**Metalaxyl deposit on filter paper target (ug/cm^2)**
Isaac-B1	00AV/HB1	GFP	**0.36**	**0.04**
23.11.00	00AV/BB1	GFP	**<0.20**	**<0.02**
	00AV/CB1	GFP	**<0.20**	**<0.02**
	00AV/LAB1	GFP	**0.29**	**0.03**
	00AV/RAB1	GFP	**0.96**	**0.09**
	00AV/LLB1	GFP	**0.33**	**0.03**
	00AV/RLB1	GFP	**0.48**	**0.05**
	00AV/LLLB1	GFP	**0.40**	**0.04**
	00AV/RLLB1	GFP	**0.60**	**0.06**
Isaac-B2	00AW/HB2	GFP	**0.73**	**0.07**
23.11.00	00AW/BB2	GFP	**1.87**	**0.18**
	00AW/CB2	GFP	**<0.20**	**<0.02**
	00AW/LAB2	GFP	**0.95**	**0.09**
	00AW/RAB2	GFP	**4.91**	**0.48**
	00AW/LLB2	GFP	**0.59**	**0.06**
	00AW/RLB2	GFP	**0.42**	**0.04**
	00AW/LLLB2	GFP	**0.97**	**0.09**
	00AW/RLLB2	GFP	**0.90**	**0.09**
Isaac-B3	00AX/HB3	GFP	**0.58**	**0.06**
23.11.00	00AX/BB3	GFP	**0.62**	**0.06**
	00AX/CB3	GFP	**0.42**	**0.04**
	00AX/LAB3	GFP	**1.99**	**0.19**
	00AX/RAB3	GFP	**14.5**	**1.41**
	00AX/LLB3	GFP	**3.31**	**0.32**
	00AX/RLB3	GFP	**0.57**	**0.06**
	00AX/LLLB3	GFP	**1.13**	**0.11**
	00AX/RLLB3	GFP	**3.70**	**0.36**

(1) 'GFP' denotes glass microfibre filter papers (Fisher, GF/D, diameter 11 cm), exposed area 8cmx8cm

Table 1: **(continued**

Identity and date of trial	**NRI sample code**	**Sample type**	**Metalaxyl in sample extract (ug/ml)**	**Metalaxyl deposit on filter paper target (ug/cm$_2$)**
Samuel-B3	00BA/HB3	GFP	**1.36**	**0.13**
23.11.00	00BA/BB3	GFP	**1.17**	**0.11**
	00BA/CB3	GFP	**22.8**	**2.23**
	00BA/LAB3	GFP	**2.98**	**0.29**
	00BA/RAB3	GFP	**1.43**	**0.14**
	00BA/LLB3	GFP	**3.55**	**0.35**
	00BA/RLB3	GFP	**1.76**	**0.17**
	Lost during trial	GFP	**N/A**	**N/A**
	00BA/RLLB3	GFP	**4.09**	**0.40**

NB:
Tartrazine alone applied in trials Samuel B1/B2

Table 1: **continued**

Identity and date of trial	**NRI sample code**	**Sample type**	**Metalaxyl in sample extract (ug/ml)**	**Metalaxyl deposit on filter paper target (ug/cm^2)**
Jonas-T2	00BB/HT2	GFP	**5.32**	**0.53**
27.11.00	00BB/BT2	GFP	**2.98**	**0.03**
	00BB/CT2	GFP	**2.20**	**0.22**
	00BB/LAT2	GFP	**4.82**	**0.47**
	00BB/RAT2	GFP	**8.89**	**0.87**
	00BB/LLT2	GFP	**1.09**	**0.11**
	00BB/RLT2	GFP	**0.37**	**0.04**
	00BB/LLLT2	GFP	**2.97**	**0.29**
	00BB/RLLT2	GFP	**3.77**	**0.37**
Jonas-T4	00BC/HT4	GFP	**2.11**	**0.21**
27.11.00	00BC/BT4	GFP	**<0.20**	**<0.02**
	00BC/CT4	GFP	**1.02**	**0.10**
	00BC/LAT4	GFP	**3.22**	**0.32**
	00BC/RAT4	GFP	**3.22**	**0.32**
	00BC/LLT4	GFP	**1.04**	**0.10**
	00BC/RLT4	GFP	**0.70**	**0.07**
	00BC/LLLT4	GFP	**5.98**	**0.60**
	00BC/RLLT4	GFP	**4.88**	**0.49**
Jonas-T5	00BD/HT5	No sample	**N/A**	**N/A**
29.11.00	00BD/BT5	GFP	**<0.20**	**<0.02**
	00BD/CT5	GFP	**<0.20**	**<0.02**
	00BD/LAT5	GFP	**0.74**	**0.07**
	00BD/RAT5	GFP	**1.27**	**0.13**
	00BD/LLT5	GFP	**0.39**	**0.04**
	00BD/RLT5	GFP	**1.15**	**0.12**
	00BD/LLLT5	GFP	**3.93**	**0.40**
	00BD/RLLT5	GFP	**4.57**	**0.46**

Table 1: continued

Identity and date of trial	**NRI sample code**	**Sample type**	**Metalaxyl in sample extract (ug/ml)**	**Metalaxyl deposit on filter paper target (ug/cm$_2$)**
Johnson-T2	00BE/HT2	GFP	**0.88**	**0.09**
27.11.00	00BE/BT2	GFP	**0.25**	**0.03**
	00BE/CT2	GFP	**0.29**	**0.03**
	00BE/LAT2	GFP	**2.65**	**0.27**
	00BE/RAT2	GFP	**1.30**	**0.13**
	00BE/LLT2	GFP	**7.82**	**0.78**
	00BE/RLT2	GFP	**5.14**	**0.51**
	00BE/LLLT2	GFP	**3.83**	**0.38**
	00BE/RLLT2	GFP	**7.59**	**0.76**
Johnson-T4	00BF/HT4	GFP	**1.68**	**0.17**
27.11.00	00BF/BT4	GFP	**0.45**	**0.05**
	00BF/CT4	GFP	**1.07**	**0.10**
	00BF/LAT4	GFP	**3.64**	**0.36**
	00BF/RAT4	GFP	**1.76**	**0.18**
	00BF/LLT4	GFP	**2.98**	**0.30**
	00BF/RLT4	GFP	**4.41**	**0.44**
	00BF/LLLT4	GFP	**2.44**	**0.24**
	00BF/RLLT4	GFP	**1.79**	**0.18**

Comments :

All original calibration data and record sheets are included as Annexes to the master copy of this report which is stored in the laboratory files archive together with all sample chromatograms.

Table 2: Tartrazine residue analysis

Identity and date of trial	NRI sample code	Sample type$^{(1)}$	Tartrazine in sample extract (ug/ml)	Tartrazine deposit on filter paper target (ug/cm^2)
Isaac-B3	00AX/HB3	GFP	**0.20**	**0.16**
23.11.00	00AX/BB3	GFP	**<0.20**	**<0.16**
	00AX/CB3	GFP	**<0.20**	**<0.16**
	00AX/LAB3	GFP	**0.73**	**0.57**
	00AX/RAB3	GFP	**7.37**	**5.75**
	00AX/LLB3	GFP	**2.17**	**1.69**
	00AX/RLB3	GFP	**0.20**	**0.16**
	00AX/LLLB3	GFP	**0.30**	**0.23**
	00AX/RLLB3	GFP	**0.58**	**0.45**
	00AX/LGB3	Cotton glove	**3.63**	**N/A**
	00AX/RGB3	Cotton glove	**8.14**	**N/A**

NB
Metalaxyl alone applied in trials Isaac B1/B2

Table 2: **continued**

Identity and date of trial	NRI sample code	Sample type	Tartrazine in sample extract (ug/ml)	Tartrazine deposit on filter paper target (ug/cm$_2$)
Samuel-B1	00AY/HB1	GFP	**0.79**	**0.62**
23.11.00	00AY/BB1	GFP	**6.71**	**5.23**
	00AY/CB1	GFP	**<0.20**	**<0.16**
	00AY/LAB1	GFP	**0.83**	**0.65**
	00AY/RAB1	GFP	**3.26**	**2.54**
	00AY/LLB1	GFP	**0.73**	**0.57**
	00AY/RLB1	GFP	**0.95**	**0.74**
	00AY/LLLB1	GFP	**0.45**	**0.35**
	00AY/RLLB1	Lost during trial	**N/A**	**N/A**
Samuel-B2	00AZ/HB2	GFP	**1.51**	**1.18**
23.11.00	00AZ/BB2	GFP	**2.35**	**1.83**
	00AZ/CB2	GFP	**<0.20**	**<0.16**
	00AZ/LAB2	GFP	**1.57**	**1.23**
	00AZ/RAB2	GFP	**6.18**	**4.82**
	00AZ/LLB2	GFP	**2.23**	**1.74**
	00AZ/RLB2	GFP	**3.16**	**2.46**
	00AZ/LLLB2	GFP	**1.98**	**1.54**
	00AZ/RLLB2	GFP	**1.45**	**1.13**
Samuel-B3	00BA/HB3	GFP	**0.51**	**0.40**
23.11.00	00BA/BB3	GFP	**0.36**	**0.28**
	00BA/CB3	GFP	**11.7**	**9.17**
	00BA/LAB3	GFP	**1.42**	**1.11**
	00BA/RAB3	GFP	**0.76**	**0.59**
	00BA/LLB3	GFP	**1.76**	**1.37**
	00BA/RLB3	GFP	**1.92**	**1.50**
	00BA/LLLB3	Lost during trial	**N/A**	**N/A**
	00BA/RLLB3	GFP	**0.83**	**0.65**
	00BA/LGB3	Cotton glove	**7.74**	**N/A**
	00BA/RGB3	Cotton glove	**8.93**	**N/A**

Table 2: continued

Identity and date of trial	NRI sample code	Sample type	Tartrazine in sample extract (ug/ml)	Tartrazine deposit on filter paper target (ug/cm^2)
Jonas-T2	00BB/HT2	GFP	**2.57**	**2.01**
27.11.00	00BB/BT2	GFP	**<0.20**	**<0.16**
	00BB/CT2	GFP	**1.23**	**0.96**
	00BB/LAT2	GFP	**1.76**	**1.37**
	00BB/RAT2	GFP	**3.97**	**3.10**
	00BB/LLT2	GFP	**1.32**	**1.03**
	00BB/RLT2	GFP	**0.23**	**0.18**
	00BB/LLLT2	GFP	**1.29**	**1.01**
	00BB/RLLT2	GFP	**1.89**	**1.47**
	00BB/LGT2	Cotton glove	**8.30**	**N/A**
	00BB/RGT2	Cotton glove	**6.43**	**N/A**
Jonas-T4	00BC/HT4	GFP	**1.08**	**0.84**
27.11.00	00BC/BT4	GFP	**<0.20**	**<0.16**
	00BC/CT4	GFP	**0.51**	**0.40**
	00BC/LAT4	GFP	**1.60**	**1.25**
	00BC/RAT4	GFP	**1.14**	**0.89**
	00BC/LLT4	GFP	**0.20**	**0.16**
	00BC/RLT4	GFP	**0.48**	**0.37**
	00BC/LLLT4	GFP	**4.25**	**3.31**
	00BC/RLLT4	GFP	**2.82**	**2.20**
	00BC/LGT4	Cotton glove	**9.86**	**N/A**
	00BC/RGT4	Cotton glove	**4.72**	**N/A**
Jonas-T5	00BD/HT5	Lost during trial	**N/A**	**N/A**
29.11.00	00BD/BT5	GFP	**<0.20**	**<0.16**
	00BD/CT5	GFP	**<0.20**	**<0.16**
	00BD/LAT5	GFP	**0.20**	**0.16**
	00BD/RAT5	GFP	**0.86**	**0.67**
	00BD/LLT5	GFP	**<0.20**	**<0.16**
	00BD/RLT5	GFP	**0.45**	**0.35**
	00BD/LLLT5	GFP	**2.48**	**1.93**
	00BD/RLLT5	GFP	**3.94**	**3.07**
	00BD/LGT5	Cotton glove	**4.16**	**N/A**
	00BD/RGT5	Cotton glove	**3.54**	**N/A**

Table 2: **continued**

Identity and date of trial	**NRI sample code**	**Sample type**	**Tartrazine in sample extract (ug/ml)**	**Tartrazine deposit on filter paper target (ug/cm$_2$)**
Johnson-T2	00BE/HT2	GFP	**0.23**	**0.18**
27.11.00	00BE/BT2	GFP	**<0.20**	**<0.16**
	00BE/CT2	GFP	**<0.20**	**<0.16**
	00BE/LAT2	GFP	**1.39**	**1.08**
	00BE/RAT2	GFP	**0.83**	**0.65**
	00BE/LLT2	GFP	**4.41**	**3.44**
	00BE/RLT2	GFP	**2.76**	**2.15**
	00BE/LLLT2	GFP	**2.45**	**1.91**
	00BE/RLLT2	GFP	**3.32**	**2.59**
	00BE/LGT2	Cotton glove	**93.9**	**N/A**
	00BE/RGT2	Cotton glove	**3.32**	**N/A**
Johnson-T4	00BF/HT4	GFP	**0.98**	**0.76**
27.11.00	00BF/BT4	GFP	**<0.20**	**<0.16**
	00BF/CT4	GFP	**0.45**	**0.35**
	00BF/LAT4	GFP	**1.76**	**1.37**
	00BF/RAT4	GFP	**1.08**	**0.84**
	00BF/LLT4	GFP	**4.63**	**3.61**
	00BF/RLT4	GFP	**2.07**	**1.62**
	00BF/LLLT4	GFP	**1.57**	**1.23**
	00BF/RLLT4	GFP	**1.29**	**1.01**
	00BF/LGT4	Cotton glove	**40.9**	**N/A**
	00BF/RGT4	Cotton glove	**7.68**	**N/A**

Table 3: Tartrazine residue analysis on petri dishes

Identity and date of trial	NRI sample code	Sample type	Tartrazine in sample extract (ug/ml)	Tartrazine mean deposit in petri dish (1) (ug)
Jonas-T2	00BI/A	Petri dish	**42.5**	**1063**
27.11.00	00BI/B	Petri dish	**20.7**	**518**
Jonas-T4	00BK/A	Petri dish	**47.2**	**590**
27.11.00				
Jonas-T5	00BM/A	Petri dish	**28.5**	**713**
29.11.00				
Johnson-T2	00BJ/A	Petri dish	**20.1**	**503**
27.11.00	00BJ/B	Petri dish	**66.8**	**1671**
Johnson-T4	00BL/A	Petri dish	**67.5**	**843**
27.11.00				

NB

(1) Mean deposit per petri dish from four petri dishes per single pass of the sprayer; (samples from Johnson-T4 and Jonas-T4 sprayed twice).

SECTION C: ANALYTICAL PROCEDURE

METHOD:

### A.	Sample extraction:

Glass microfibre filter papers/cotton gloves

The samples were first extracted with acetone for metalaxyl residue analysis, allowed to dry and then re-extracted in distilled water for tartrazine analysis.

Acetone extraction:

Glass filter papers:
Remove the filter paper from its aluminium foil backing using tweezers and insert into a 250 ml conical flask. Using scissors, cut away the front facing borders of the foil to leave the backing only. Put this into a funnel, which is placed above the conical flask. Measure 50 ml of acetone with a measuring cylinder and using a pasteur pipette rinse the aluminium foil with about 10 ml of the acetone. Remove the aluminium foil from the funnel (do not discard the foil); and pour the rest of the acetone into the conical flask using the funnel. Keep the funnel. Fit the conical flask with a stopper and retaining clip and shake on a Stuart shaker for 15 minutes. Insert a glass wool plug into the retained funnel and filter 40 ml of the acetone extract into a measuring cylinder (the filter plug may need to be compressed with a spatula to recover 40 ml of extract). Keep the funnel and glass wool plug. Remove the filter paper from the flask using forceps and allow to dry on aluminium foil. Transfer the 40 ml of acetone extract in a 100 ml round bottom flask. Rinse the measuring cylinder twice with about 3 ml of acetone. Evaporate the acetone extract on a rotary evaporator (water bath at 30°C) and make up the residue to 5 ml with hexane for samples and reagent blanks. For the spiked validation samples, make up to 10 ml. Analyse by GC using a Nitrogen Phosphorus detector (NPD)

Cotton gloves:
The glove samples were not analysed for metalaxyl residues because of the presence of acetone-soluble wax-like co-extractives for which no efficient clean-up method could be developed to allow analysis by GC.

Water extraction:

Glass filter papers:
Take the dried filter paper and foil backing and place in a 250 ml conical flask. Add 50 ml of distilled water to the flask using a measuring cylinder and extract by shaking on a Stuart shaker for 15 min. Filter the extract through the retained glass wool plugged funnel and collect 10 ml of the extract in a volumetric flask or screw topped vial for later analysis by spectrophotometer.

Cotton gloves:
Using scissors cut the glove into 3 or 4 pieces and transfer to a 500 ml conical flask. Measure 150 ml of distilled water with a measuring cylinder and add to the flask. Fit

the conical flask with a stopper and shake on a Stuart shaker for 15 min. Insert a glass wool plug in a funnel, filter and collect 10 ml of the extract in a volumetric flask or screw topped vial for later analysis by spectrophotometer.

Sample extraction: Petri dishes

The dishes were first rinsed with hexane for metalaxyl residue analysis and then with distilled water for tartrazine analysis. Acetone could not be used as this interacted with the polystyrene petri dishes.
The four petri dishes obtained from each spray run were combined to make one sample. For instance, 00BI/A1, 00BI/A2, 00BI/A3, 00BI/A4 were rinsed and combined to make one sample.

Hexane extraction:

Place a suitable funnel above a 50 ml volumetric flask. Rinse the four petri dishes into the funnel with at least 30 ml of hexane using a pasteur pipette and make up to the mark with hexane. Place the dishes in a fume cupboard to dry. Analyse the hexane extracts by GC using NPD.

Water extraction:

When the petri dishes are free of hexane, rinse the four dishes into a 100 ml volumetric flask funnel with distilled water using a suitable funnel and make up to the mark. Analyse by spectrophotometer.

B. Clean-up

No clean-up was necessary for any of the filter paper samples.

C. Analysis

Instrument type:

1. Hewlett Packard 6890 gas liquid chromatograph with Nitrogen Phosphorus detector.
2. Corning Model 252 colorimeter with 430 nm wavelength filter.

Analytical Conditions:

Column: Capillary, 30 m DB5, 0.25 mm id., 0.25 µm film thickness

Oven program:	1	2
Oven temp. (°C):	50	250
Iso time (min):	1.0	
Ramp rate (°C/min):	10	
Detector temp. (°C):	325	

PTV Inlet program:	1	2
Injector temp. (°C):	120	300
Iso time (min):	1.1	

Ramp rate (°C/min): 1700

Carrier gas flow rate:	1.4 ml/min
Run time:	21.00 min
Retention time:	18.45 min

D. Preparation of Reference Standards

Metalaxyl calibration solutions at 0.2, 0.5, 1.0, 2.0, 5.0 and 10 µg/ml were prepared from a freshly prepared 1000 µg/ml metalaxyl reference stock solution.

Tartrazine calibration solutions of 0.2, 2.0, 10.0 and 20.0 µg/ml were prepared from the same batch of commercial tartrazine dye used in the field trials.

E. Method Validation (recovery studies)

1. *Metalaxyl:*

Table 4: Analytical recovery from glass micro-fibre filter papers spiked with metalaxyl

Laboratory code	Amount spiked (µg)	Final extract volume (ml)	Metalaxyl in extract (µg/ml)	Amount recovered(1) (µg)	Recovery(2) (%)
V0.1	10	10	0.95	11.9	**119**
V0.5	50	10	5.30	66.2	**132**
V1.0	100	10	8.74	109	**109**
V2.0	200	10	16.4	205	**103**
V0.8A	10	10	0.82	10.3	**103**
V0.8B	10	5	1.66	10.4	**104**
V1.6A	20	10	1.27	15.8	**79**
V1.6B	20	5	4.22	26.4	**132**
V4.0A	50	10	4.86	60.8	**122**
V4.0B	50	5	8.72	54.5	**109**
V8.0A	100	10	7.96	99.6	**100**
V8.0B	100	10	8.43	105	**105**

NB
Each filter was extracted in 50 ml of acetone of which 40 ml was evaporated to dryness and the residue taken up in the final volume shown in the Table
(1) Amount recovered calculated as: (metalaxyl in extract x extract volume)/(50/40)
(2) Recovery calculated as: (Amount recovered/amount spiked)x100

2. *Tartrazine*

Table 5: Analytical recovery from glass micro-fibre filter papers spiked with tartrazine

Laboratory code	**Amount spiked(1) (µg)**	**Extract volume (ml)**	**Tartrazine in extract (µg/ml)**	**Concentration found in extract (µg)**	**Recovery (%)**
T1	500	50	10.0	10.5	**105**
T2	500	50	10.0	10.0	**100**
T3	250	50	5.0	5.03	**101**
T4	250	50	5.0	5.00	**100**
T5	125	50	2.5	2.38	**95**
T6	125	50	2.5	2.38	**95**

(1) Filter papers spiked with 1 ml (T1,T2), 0.5 ml (T3,T4) and 0.25 ml (T5,T6) of 500 µg/ml of tartrazine standard solution

Table 6: Analytical recovery from gloves spiked with tartrazine

Laboratory code	**Amount spiked(1) (µg)**	**Extract volume (ml)**	**Tartrazine in extract (µg/ml)**	**Concentration found in extract (µg)**	**Recovery (%)**
T7	500	150	3.3	3.3	**100**
T8	500	150	3.3	3.3	**100**

(1) Gloves spiked with 1 ml of 500 µg/ml of tartrazine standard solution

Table 7: Analytical recovery from plastic petri dishes spiked with tartrazine

Laboratory code	**Amount spiked(1) (µg)**	**Extract volume (ml)**	**Tartrazine in extract (µg/ml)**	**Concentration found in extract (µg)**	**Recovery (%)**
P1	500	100	5.00	4.88	**98**
P2	500	100	5.00	5.03	**104**
P3	1000	100	10.0	10.3	**103**
P4	1000	100	10.0	10.5	**105**

(1) Petri dishes spiked with 1 ml (P1,P2) and 2 ml (P3,P4) of 500 µg/ml of tartrazine standard solution

F. Lower limit of determination (or reporting limit)

The limit of detection for metalaxyl was found to be **0.2 µg/ml** on GC-NPD.
The limit of determination on the filter paper target was therefore:

$\{0.2\ (\mu g/ml) \times 5\ (ml) \times 50/40\ (ml)\}/64\ (cm^2)$

= 0.02 $\mu g/cm^2$

NB:

Filter extracted in 50 ml acetone of which 40 ml were taken to dryness and the residue made up in
5 ml of hexane.
Filter papers had an exposed area of 8 cm x 8 cm.

The limit of detection for tartrazine using the Corning Model 252 colorimeter was found to be **0.20 µg/ml**. The limit of determination on the filter paper target was therefore:

$0.20\ (\mu g/ml) \times 50\ (ml)/64$

= **0.16 $\mu g/cm^2$**

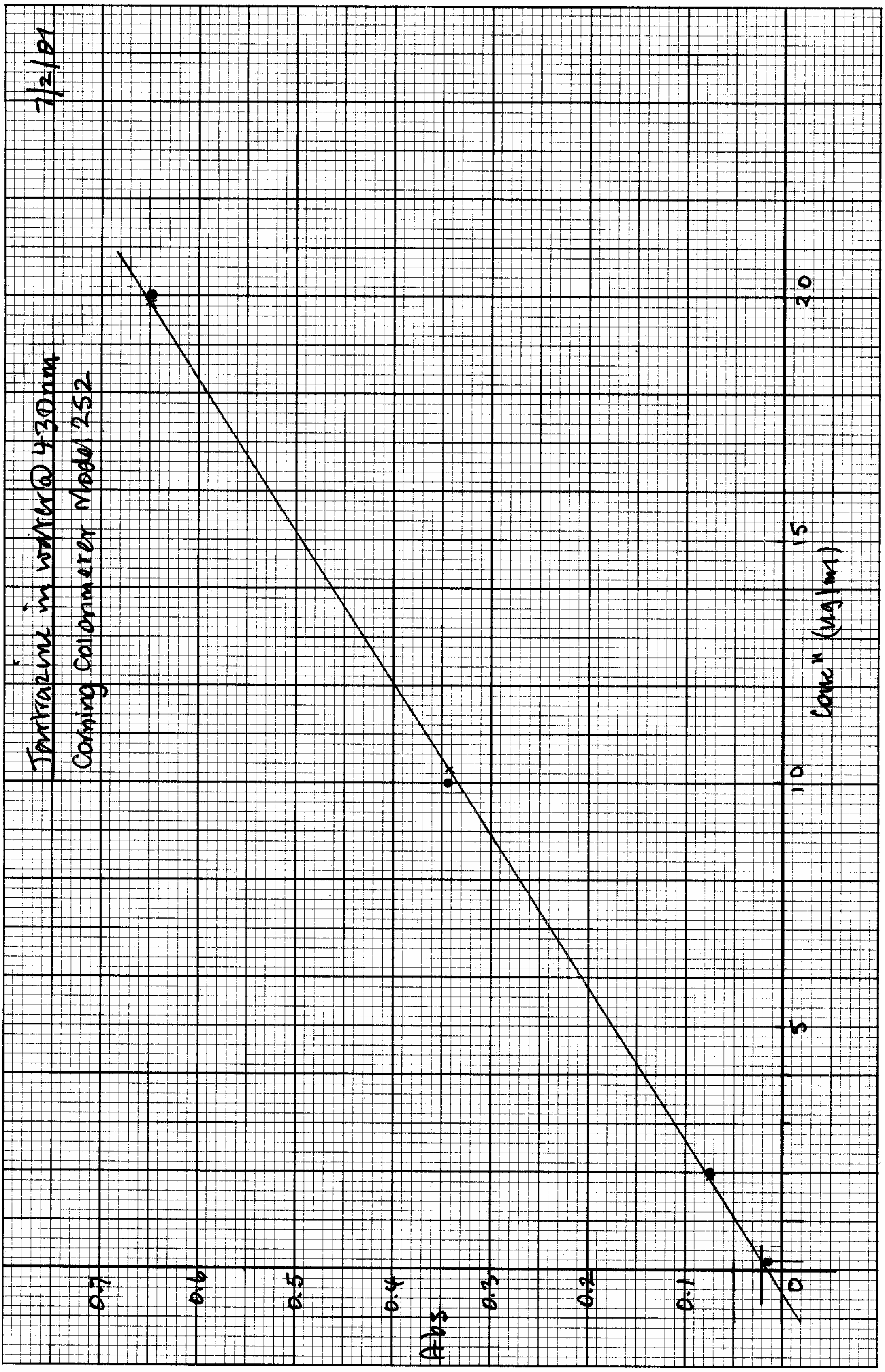
NB:

Filter extracted in 50 ml of water, an aliquot of which was directly measured in the colorimeter.

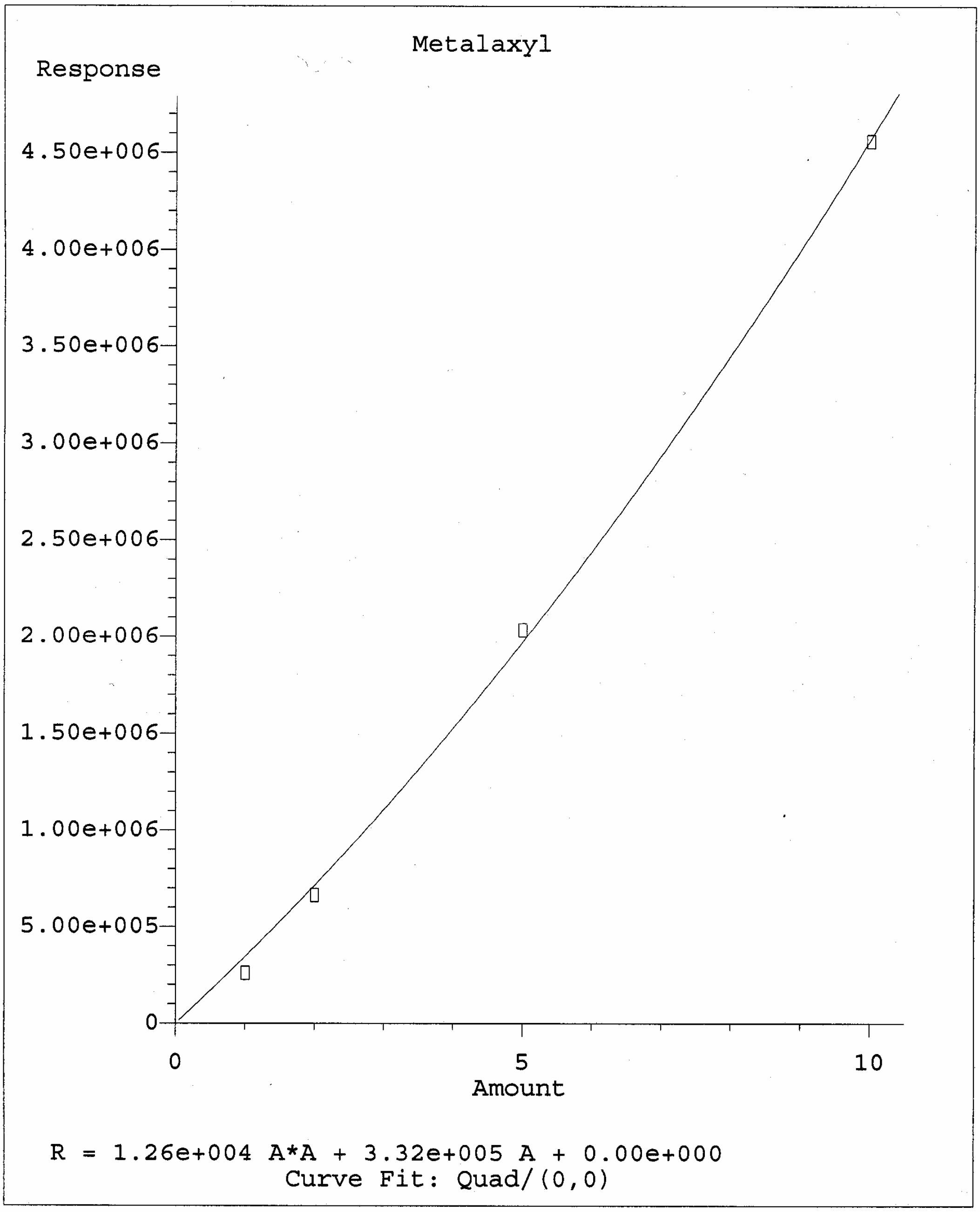
Annexes:

Annex 1. Tartrazine calibration curve
Annex 2, 3. Example chromatograms from metalaxyl analyses

Annex 1: **Calibration curve of tartrazine in distilled water**



Run Feb15A



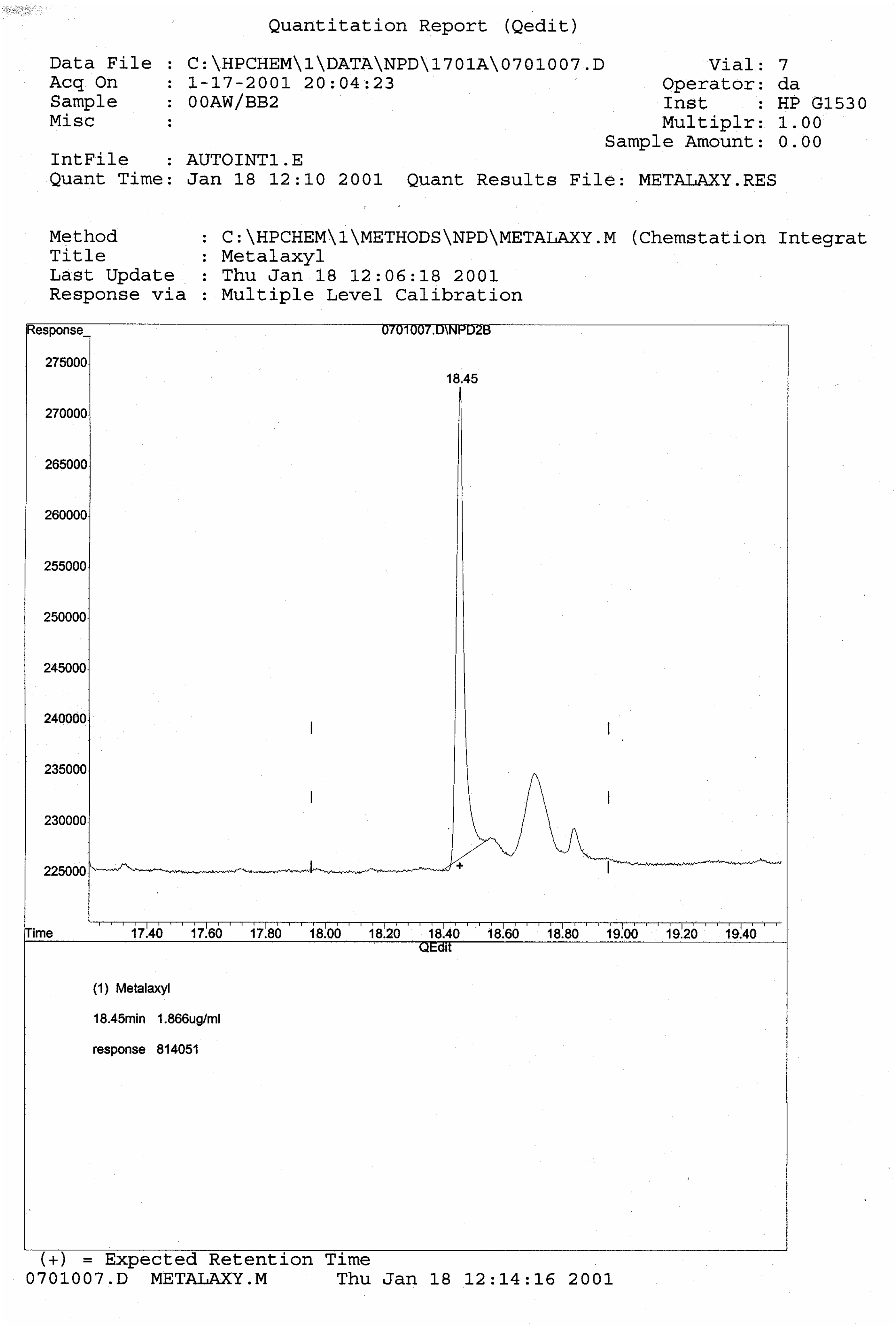
R = 1.26e+004 A*A + 3.32e+005 A + 0.00e+000
Curve Fit: Quad/(0,0)

```
Method Name:  C:\HPCHEM\1\METHODS\NPD\METALAXY.M
Calibration Table Last Updated: Thu Feb 15 11:20:13 2001
```

1 injectn – 4 pts Calibratn (1→10)

<u>Annex 2:</u> Calibration chromatogram from metalaxyl residue analysis

Annex 3: Sample chromatogram from metalaxyl residue analysis Analysis of glass fibre filter paper



```
                     Quantitation Report (Qedit)

Data File : C:\HPCHEM\1\DATA\NPD\1701A\0701007.D          Vial: 7
Acq On    : 1-17-2001 20:04:23                        Operator: da
Sample    : 00AW/BB2                                  Inst    : HP G1530
Misc      :                                           Multiplr: 1.00
                                                 Sample Amount: 0.00
IntFile   : AUTOINT1.E
Quant Time: Jan 18 12:10 2001  Quant Results File: METALAXY.RES


Method        : C:\HPCHEM\1\METHODS\NPD\METALAXY.M (Chemstation Integrat
Title         : Metalaxyl
Last Update   : Thu Jan 18 12:06:18 2001
Response via  : Multiple Level Calibration
```

```
(1) Metalaxyl

18.45min  1.866ug/ml

response  814051

 (+) = Expected Retention Time
0701007.D  METALAXY.M      Thu Jan 18 12:14:16 2001
```