PHOSPHONIC ACID: AN ALTERNATIVE APPROACH TO THE CONTROL OF BLACK POD DISEASE OF COCOA CAUSED BY *PHYTOPHTHORA MEGAKARYA*.

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SUMMARY

Cocoa is the main commodity crop of Ghana and is financially important for the livelihood of many rural communities. The relatively recent arrival of the more aggressive black pod pathogen *Phytophthora megakarya* and its continued progress westwards threatens the cocoa farming communities. In a wider context its recent arrival in Ivory Coast, currently the worlds largest producer of cocoa, has implications for West Africa and global cocoa production. In Ghana it has already led to some farmers abandoning cocoa in Ashanti and to a lesser extent in the Western regions.

Studies undertaken by scientists at CRIG have shown that although cultural practices are effective for the control of *P.palmivora* they are inadequate for the control of *P.megakarya*. The supplementation of cultural practices with chemical application is essential to reduce the impact of *P.megakarya*. Recently CRIG scientists reported that fungicide adoption is on the increase in *P.megakarya* infected districts. Current recommendation is for the application of copper/metalaxyl formulations. The Ghanaian government has initiated a national spraying programme, centrally funded. However, in the long-term an alternative to the current copper based products is required. The application of these chemicals is expensive and often incorrectly applied by farmers, in addition the accumulation of these compounds in the environment could have long-term effects on soil biology and productivity of the cocoa agro-ecosystem. Phosphonic acid has been shown to be an effective, economically viable and environmentally safer alternative control agent of *Phytophthora* spp. in cocoa and other crop systems around the world.

Results are presented of field trials carried out over 3 years to assess the potential of Phosphonic acid applied as stem injection, pod spray and paint in comparison to spray application of copper compounds. Six spray applications of the copper compounds and Phosphonic acid were made over the season, in accordance with current recommendations for copper fungicides. Stem injection of phosphonic was applied once in a growing season. Comparative studies were implemented in Bechem, where *P.megakarya* is present and at Tafo where only *P.palmivora* is present.

Application of phosphonic acid as a one-off stem injection was shown to reduce the incidence of *P.megakarya*. Control achieved was similar to that achieved with the current recommended control regime. Implication of these results for the implementation of stem injection of Phosphonic acid as an effective, economically viable and environmentally safe alternative to copper fungicides is discussed.

INTRODUCTION

In West and Central Africa, *Phytophthora palmivora* and *P.megakarya* are the main causal agents of black pod disease. *P.megakarya* is the most aggressive pathogen on cocoa. Originally restricted to Central Africa it had by the end of the 1980's moved into Ghana. Crop losses due to *P.palmivora,* prior to the appearance of *P.megakarya* in Ghana, were between 4.9 – 13.5% (Dakwa, 1984). The subsequent appearance of *P.megakarya* led to crop losses of 60 – 100% (Dakwa, 1987). *P.megakarya* is still in an invasive phase within Ghana, and was observed to be moving towards the Ghanaian cocoa belt near to the border with the Ivory Coast (Opoku *et al*., 1997) and has recently been reported to be spreading rapidly into western Ivory Coast, although at present only accounting for losses of 1% (Kebe *et al*, 2001)**.** The continued progress of *P.megakarya* through the cocoa producing countries of West Africa has the potential to significantly reduce the world's cocoa production and to impact on resource-poor farmers within the region.

The current cultural and chemical control strategies for the control of black pod are poor. A study in Cameroon on phytosanitary practices observed 40–50% losses despite the implementation of cultural control measures (Despreaux *et al*., 1987). In Ghana, control of black pod by the use of regular phytosanitary procedures is only successful in areas where cocoa is affected by *P. palmivora.* In areas affected by *P. megakarya,* yields continued to decline despite the best effort of the farmers (Opoku *et al*., 2000). *P. megakarya* is a more aggressive pathogen, producing more spores and with a reservoir of inoculum in the soil, and large production losses can occur despite use of chemical sprays. Recommendations for the use of fungicides to control black pod involve the spraying of copper or copper + metalaxyl (Ridomil plus 72) every 3 weeks resulting in 8 or more applications in a growing season. Most farmers are unwilling to commit to this spraying programme or find it prohibitively expensive. Consequently they do not treat their farms at all or apply only one or two applications per year resulting in heavy crop loss (Opoku *et al*., 1997). Moreover, these copper-based products are of concern due to operator and environmental contamination. In addition the accumulation of copper within cocoa plantations may have long-term impact on the cocoa trees themselves (Wood & Lass,). Better application and targeting can reduce problems of cost, environmental effects and efficacy in the crop, but these problems will continue to discourage pesticide use. Thus an effective and environmentally sustainable means to control *Phytophthora* diseases, particularly *P.megakarya,* is urgently required.

An alternative strategy which has been used with some success in a range of crops is the application of Phosphonic acid (Aberton *et al*., 1999; FernandezEscobar *et al*., 1999; Greenhalgh *et al*., 1994). Phosphonic acid has direct fungicidal effects against *Phytophthora* spp. *in-vitro* but its primary action *in-planta* is considered to be through induced resistance. In field trials in Papua New Guinea, applications of phosphonic acid were shown to give comparable control of black pod (*P. palmivora),* when applied as a stem injection, to conventional metalaxyl/copper oxide sprays (Holderness, 1992). Studies carried out in Ghana in the 1990's provided evidence that Phosphonic acid may be effective against the black pod pathogens in Ghana (Opoku *et al*., 1998). This study aimed to develop this work to assess the potential of Phosphonic acid as a sustainable, cost-effective, environmentally and operator friendly means to combat the black pod pathogens, in particular the aggressive *P.megakarya*.

METHODS AND MATERIALS

Trial sites

Trial sites were chosen to enable the comparison of the efficacy of phosphonic acid treatments against *Phytophthora palmivora* and *Phytophthora megakarya*. One site, located at Bechem in Brong Ahafo region, an area affected by *P. megakarya*, the second site at Tafo in Akim region, where *P.megakarya* is not present, but *P.palmivora* is well established.

Field Trial

The field trial was designed using natural blocks within the fields. Tree availability was limited so the design allowed full replication of the key treatments, while less crucial treatments were represented at a lower level of replication in some years. The experiment was set-up as a randomized incomplete block design with plot size of 5 x 4 trees, with 7 replicate blocks.

Treatments used, Year 1:

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	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	Untreated control

In year 2, treatments were modified. An alternative metalaxyl formulation was evaluated and the bark painting treatments 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 modified to evaluate the effects of an alternative formulation of potassium phosphonate and a copper formulation (without metalaxyl). Injection and spray treatments were also modified to evaluate the effects of Bion (Novartis), an inducer of systemic resistance:

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

Stem injections were applied using spring loaded injectors placed in holes drilled into the trunk of the tree. This was carried out once for each crop cycle. Fungicides were applied as 6 sprays following local guidelines.

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

Assessment and data analysis

The incidence of black pod was assessed for pods on the trunk and in the canopy upto a height of 2.5m (this is the height a knapsack sprayer can reach) as useable and unuseable pods, to give the number of infected pods. These were combined to give the total number of infected pods. Monthly harvests were carried out according to standard practice. The yield per plot was recorded as useable and unuseable yield on trunk and in the canopy (to 2.5m for both) by pod count. This was converted to dry bean yield (kg/ha) using the standard pod scale (ref?). Results were assessed using a mixed model analysis using the SAS programme (ref?).

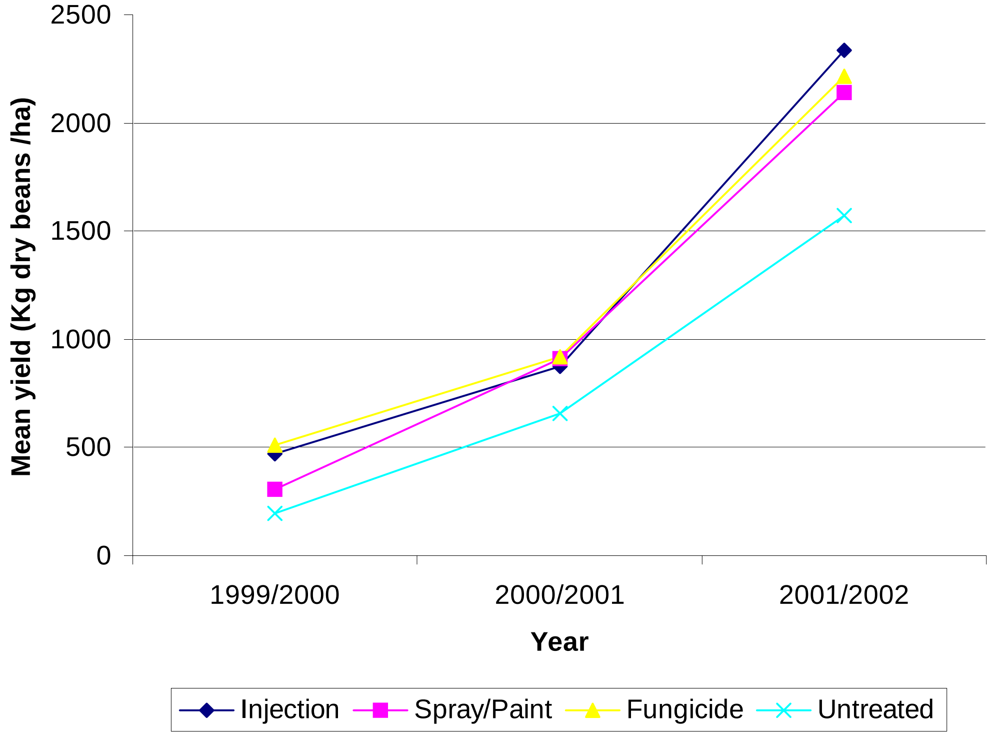
RESULTS

Effects of black pod control treatments on yield

Results were analysed across all treatments and years due to the in-built covariance within the field trials. Results from different types of treatments were combined and analysed together to examine overall treatment effects between application systems (injected vs sprayed phosphonic acid vs standard fungicide spray recommendations vs untreated control).

Analysis of the main effects in the Bechem trial (figure 1) showed treatment effects to be significantly different ($P \leq 0.05$), but relative effects varied significantly between years ($P \leq 0.05$). The effect of year was also marked; over the three years of the experimental programme across all plots. This was due to the impact of the treatments and cultural practices on a previously 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. Overall, black pod control treatments gave yield increases of around 50% above those in the untreated control.

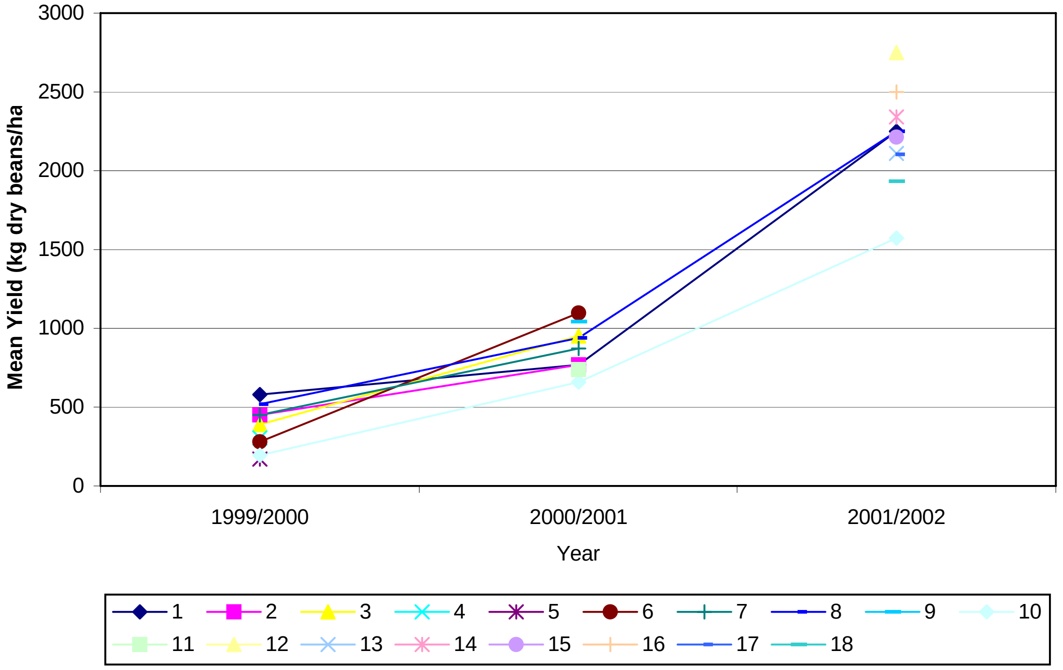
Figure 1. Cocoa yield (kg dry beans/ha) at Bechem field site over a three year period 1999-2001 for main effects.



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

Results showed significant differences in pod yields between treatments ($P \leq 0.05$) and between years ($P \leq 0.0001$). There was some evidence that treatments had differing effects in different years (interaction significant at $P \leq 0.053$).
Further exploration of the data to look at the effect of individual treatments (figure 2) showed the best treatments increased yields by a factor of 3 in the first year and approximately 2 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 three years, the efficacy of specific phosphonate injection and spray treatments was equivalent to 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 caused a superficial scarring effect on the pods but had no visual effect on internal tissues.

Figure 2. Cocoa yield (kg dry beans/ha) at Bechem field site over a three year period 1999-2001 for individual treatments.

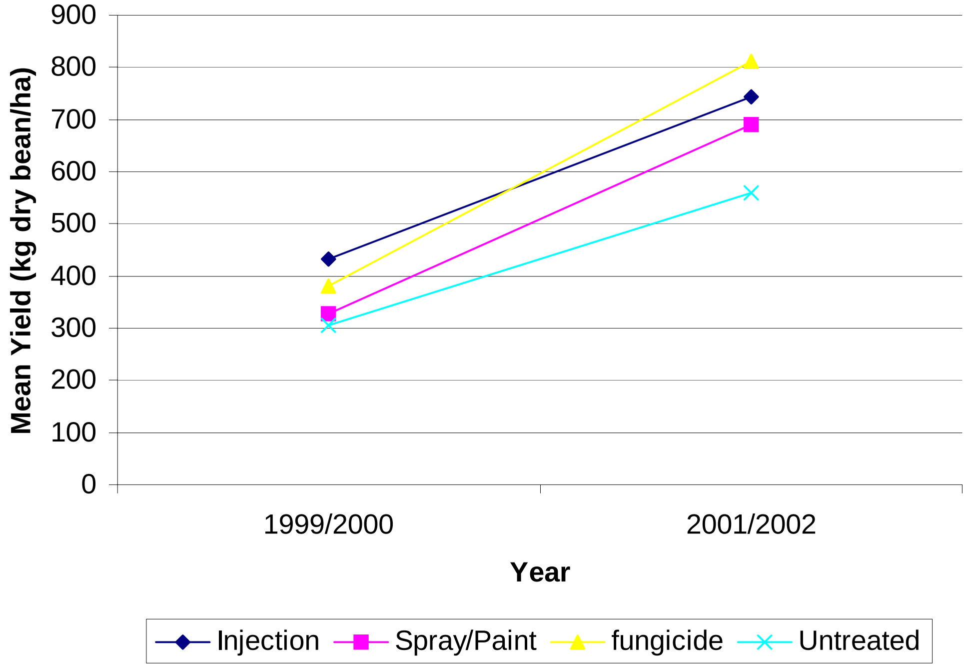


1. 40% Potassium phosphonate solution 2. 20% Potassium phosphonate solution, 2 x 20 ml injection 3. 40% Potassium phosphonate solution, 2 x 10 ml injection 4. Stem painting, 2 x 20cm wide bands without wounding (equivalent dose to 1). 5. Stem painting, 2 x 20cm wide bands with bark scraping (wire brush), (equivalent dose to 1). 6. Pod spraying, knapsack 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. Pod sprays with metalaxyl (Ridomil+72) and copper at current national recommendations 9. Callomil +72 pod spray 10. Untreated control 11. 20% Potassium phosphonate, pod spraying 12. 40% Potassium phosphonate solution, 2 x 20ml injection, pH 6.5 13. 20% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5 14. 20% Potassium phosphonate solution, 2 x 20ml injection, pH 6.5 + Bion 15. 40% Potassium phosphonate solution, 2 x 20ml injection, pH 7.5 + Bion 16. Ridomil plus 72 + Bion pod spray 17. 20% Potassium phosphonate solution, pod spraying, pH 7.5 + Bion 18. Nordox Super 75 pod spray.

Similar results were obtained in the Tafo area where *P.megakarya* is absent. Treatments used were the same as those in Bechem, except that delays in supply of potassium phosphonate from the manufacturer (due to batch production) prevented a field trial being carried out in year 2.

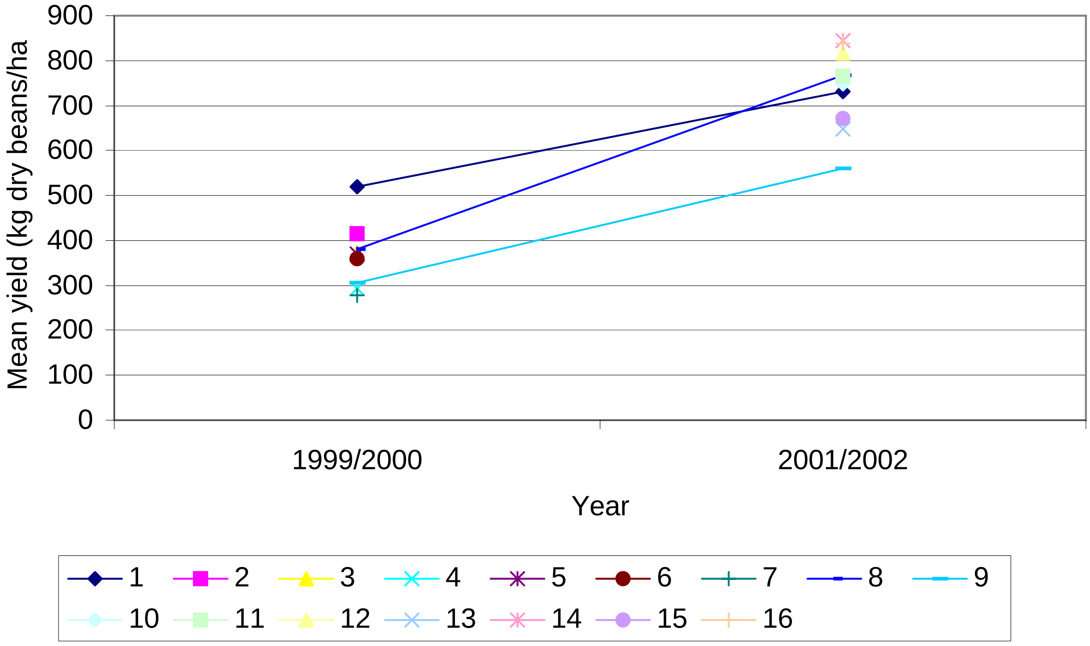
Comparison of the main effects showed no clear differences between treatments (figure 3), but there were some indications that both phosphonate injection and metalaxyl/copper sprays may have been giving some yield benefits when specific comparison was made with untreated plots (both differences significant at $P \leq 0.07$).

Figure 3. Cocoa yield (kg dry beans/ha) at Tafo field site over a three year period 1999-2002 (two study years 1999/200 and 2001/2002).



In the Tafo trial the treatments used had no effect on dry bean yields (figure 4) but there were significant ($P \leq 0.001$) differences in yields between years as yields increased considerably between years 1 and 3. There were no apparent effects of treatments between different years.

Figure 4. Cocoa yield (kg dry beans/ha) at Tafo field site over a three year period 1999-2001(two study years 1999/200 and 2001/2002) for individual treatments.



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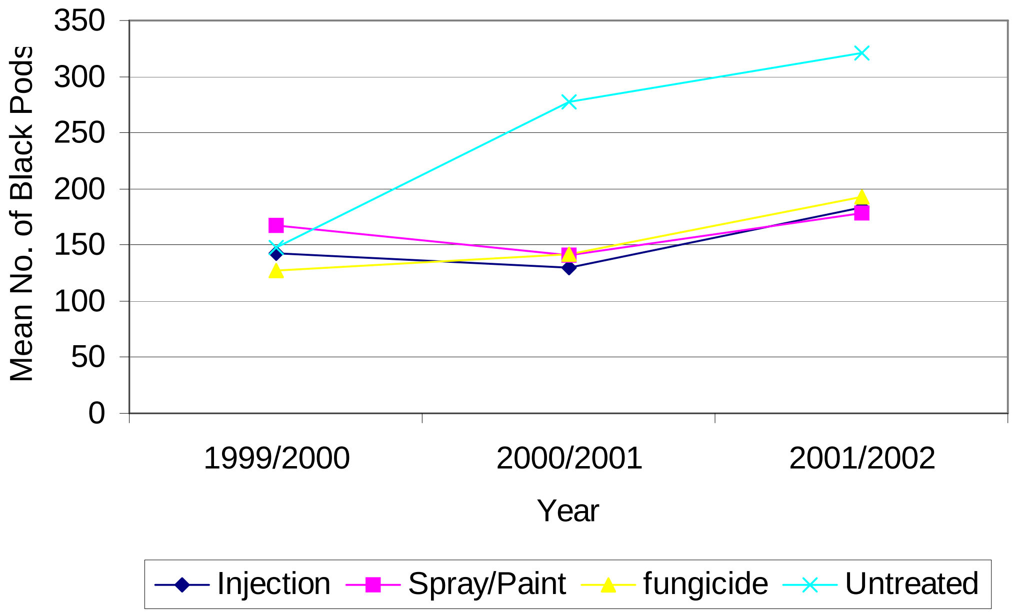
Effects of treatments on incidence of black pod disease

Main effects of treatments (figure 5) showed little treatment effect in the first year, but losses of pods to black pod disease were approximately halved in years 2 and 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. 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.

Figure 5. Mean Number of Black Pods[1] at Bechem field site over a three year period 1999-2001, for main treatments effects.

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

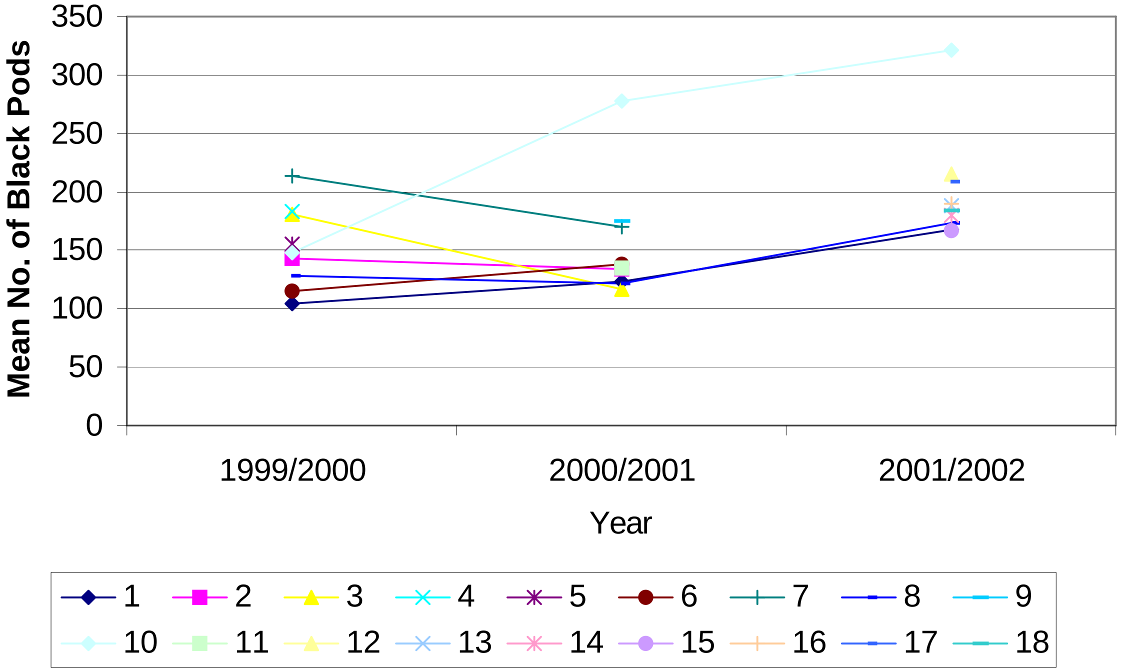


When treatments were examined individually, while there were large differences between years there was no interaction between treatment and year (figure 6). Differences among treatments were significant ($p \leq 0.05$).

While phosphonate injections 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 in 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.

Figure 6. Mean Number of Black Pods[1] at Bechem field site over a three year period 1999-2001, for individual treatments.
[1] total count i.e. usable and unusable



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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.

DISCUSSION

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. These effects represent a composite of control of *P. megakarya* and the less aggressive *P. palmivora*, comparable experiments instituted at Tafo (where only *P.palmivora* is present) showed 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.

At Bechem, while pod sprays were applied at the same intervals as the standard sprays, injection was performed as a one-off operation each season. Farmers rarely apply chemical controls as recommended, with the consequence that field control is generally less effective than was seen in this field study. The one-off application of phosphonic acid is more likely to be implemented with a resulting increase in disease

control. In Papua New Guinea trunk injection with phosphonic acid has been the recommended treatment for black pod (*P.palmivora*) since 1992 (Anon. 1992) and is used effectively within plantations.
One potential barrier to uptake of this technology by farmers, in Ghana, is the localized phytotoxicity which is apparent on trees treated with either phosphonate sprays or injections. These problems were addressed within the experimental design, stem painting was examined as a means of providing an alternative means of uptake without the internal scorch and drill damage associated with injection. Similarly, pod sprays and paints were applied to directly protect the pod, avoiding physical damage to the tree. In the case of pod sprays this also allowed the use of existing technology. However, there was no evidence to suggest any deleterious effects of any these treatments to the cocoa trees over the 3 year period of the experiment.

The application of phosphonic acid provides control of *P.megakarya* equivalent to that of the current standard recommendation for black pod control in Ghana. Phosphonic acid is a foliar fertilizer, not subject to any patent, with lower toxicity than existing contact fungicides. The use of injectors for application of the phosphonic acid provides lower risk of operator and environmental contamination than current spray applications, and is effective with only one application per growth cycle. As such it offers the farmer a safe, cost effective, environmentally sustainable alternative to copper/metalaxyl.

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