CROP PROTECTION PROGRAMME

Biology and Control of Armoured Bush Crickets in Southern Africa

R8253 (ZA0547)

FINAL TECHNICAL REPORT

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Executive Summary

Armoured bush crickets (ABC) are destructive, sporadic pests of smallholder cereal crops in semi-arid areas of southern Africa. This one year project extension sought to further test and promote strategies for ABC pest management that were developed in Botswana by the project (R7428) during the previous 3 years.

On-farm testing of the baited trench was a priority. This control method previously performed well in on-station tests and is acceptable to farmers. Unfortunately, ABC numbers in 2003 were below outbreak levels and few field sites had sufficient crickets to stage trials. Ultimately, 3 paired-comparison trials were completed, but the findings were not conclusive. Mean numbers of ABC were lower in the treated halves of fields, but not significantly so. It was felt that if the trenches had received daily maintenance then they would have performed better. Nevertheless, thousands of ABC were killed, which impressed the farmers.

Attention was again paid to environmental impact. Vertebrate scavengers apparently were not attracted to the baited trench, but certain beneficial beetles were often found dead, trapped in the trenches.

Large scale trench construction was laborious, especially in heavy soils, and this concerned the farmers. Furthermore, hired labour is costly. An economic evaluation suggests that the baited trench method is likely to be cost-effective only in high yielding years when there is an ABC outbreak, and only for sorghum, not for maize.

Field observations of ABC nymphs were undertaken to assess methods for estimating ABC population size well in advance of potential field invasion. Nymphs were found to bask in exposed positions, especially in *Acacia* bushes, in the early morning, making this the most favourable time of day for counting ABC. Aggregations in bushes in 2003 were at comparable densities to those photographed during the 2000 national outbreak, when there were many more crickets. This suggests that population density on individual bushes is subject to behavioural regulation and that many individuals are forced into less preferred microhabitats at high population density. This means that monitoring ABC population densities on bushes alone is unlikely to be a reliable method of assessing population size.

A poster was produced, in English and Tswana, to aid recognition of all ABC stages. The poster advises farmers to contact extension if high numbers of ABC nymphs are seen around their fields, to be advised on the need for trench preparation or other control measures.

Dissemination of the project's findings (R7428 and R8253) was achieved by staging a symposium entitled: "*Integrated Control of Armoured Bush Crickets in Southern Africa*" at the biennial congress of the Entomological Society of Southern Africa. The symposium, which was attended by an audience of approximately 60, included presentations by delegates from Botswana, Namibia, Zambia, South Africa, Zimbabwe, Malawi and Mozambique, as well as by UK researchers. The meeting provided a valuable opportunity for ABC specialists working in relative isolation to come together and share information and ideas on strategies for management of ABC.

A booklet entitled: "*The Biology and Control of Armoured Bush Crickets*" was subsequently drafted for publication, to be distributed to extension and agricultural researchers in all countries affected by ABC.

Finally, the use of ABC as a dietary supplement for chickens was assessed. Nutritional analysis demonstrated ABC has high crude protein content (63%). Farmers' chickens were observed to devour ABC, dispatching them with vigorous thrashing that causes crickets to discharge their defensive chemicals. The cricket is then wiped on the ground before ingestion. In a feeding trial, commercial broilers were found to consume dried ABC mash, prepared from drowned ABC (drowning causes discharge of defensive chemicals), although they preferred commercial feeder pellets. Chickens given ABC diet supplement grew faster than controls initially, but these later caught up, probably because ABC became scarce in the later stages. Some farmers apparently are reluctant to eat ABC-fed chickens, despite the nutritional benefits. However, ABC specialists in Botswana and elsewhere re keen to pursue the poultry feed aspect further.

Background
Sorghum and pearl millet are the main subsistence food crops in eastern Botswana and throughout much of southern Africa. Both crops suffer sporadic serious damage due to outbreaks of Armoured Bush Cricket (ABC), principally *Acanthoplus discoidalis* and *A. speiseri*, which can cause >30% crop losses in affected areas. Farmers in Botswana currently have no effective methods of protecting their crops during ABC outbreaks and consequently most take no action.

Research funded by ICRISAT in Namibia in the 1990s started to address the ABC problem and tested out several control methods, including application of insecticide baits around field edges to intercept invading crickets (Wohlleber 2000). Whilst the project led to important advances in our understanding of ABC, none of the control methods tested proved to be effective in the field.

From 1999, a 3 year DFID CPP-funded project (R7428) sought to develop and promote a sustainable IPM strategy against ABC, working in collaboration with smallholder farmers and the MoA in Botswana. The project achieved two main research objectives. Firstly, extensive ecological research greatly improved our understanding of the population dynamics of ABC and led to the development of an ABC outbreak forecasting system.

Secondly, a range of environmentally benign ABC control measures appropriate for resource-poor farmers were developed and tested. A farmer survey found major concerns about pesticide safety and surface application of baits was unacceptable. An effective, acceptable new technique, the baited trench, was subsequently developed and systematically refined. Teaspoon quantities (2.5g) of carbaryl/bran bait (3g/kg) applied at 3m intervals inside a 30cm deep trench retained and killed 93% of crickets in on-station trials. This method was not field-tested. Barrier application of fipronil spray (175g-ai/ha) around field plots was field-tested under outbreak conditions and resulted in a 65% reduction in ABC.

An environmental impact assessment of the baited trench and barrier spray control methods demonstrated that both methods had only a transient impact on non-target invertebrates. The baited trench in particular is seen as a method that farmers could implement for themselves, with only minor assistance from extension. Following a very successful training day in 2002, most interviewed farmers were keen to test out the baited trench during the next ABC outbreak.

Hence, there was clear demand for at least a short follow-up project, principally to work closely with farmers to field-test the baited trench.

Project Purpose.
Semi-arid Purpose 2, Output SA203: ***"Improved methods for the management of principal insect pests of cereal-based cropping systems developed and promoted where they are a major constraint to production".***

This one year extension aimed to build on the achievements of the previous 3 year project (R7428) by field-testing certain control technologies, assessing the economics of ABC control, developing an ABC monitoring protocol to "ground-truth" outbreak forecasts in the field and assessing ABC as a poultry diet supplement. Dissemination of the project's findings was achieved through a symposium on ABC control (in Pretoria) and an ABC information booklet written for extension and researchers in ABC-affected countries.

The outputs of this project should significantly improve farmers' ability to manage this pest throughout the region, and thereby lead to improved food security and the alleviation of poverty.

Research Activities.
The single output of this one year project extension was:
"Improved strategies for management of ABC, appropriate for resource-poor farmers further tested and promoted". This was achieved through the following research activities:

1.1 ABC management technologies field-tested and economic analysis of control methods performed.
In this final technical report, activity 1.1 will be will be split into its two separate aspects:
1.1a ABC management technologies field-tested.
and **1.1b Economic analysis of control methods performed.**

1.2. Participatory ABC population monitoring methodologies established to supplement forecasts.

1.3. International symposium held on ABC pest management

1.4. Poultry rearing trial conducted to test ABC as a poultry feed supplement.

Research Activities and Outputs.

The research activities described below contributed to the project's single specified output: "***Improved strategies for management of ABC, appropriate for resource-poor farmers further tested and promoted***".

1.1 ABC management technologies field-tested and economic analysis of control methods performed.

For the purposes of the final technical report, this activity will be will be split into its two separate aspects, namely:

1.1a ABC management technologies field-tested.
and **1.1b Economic analysis of control methods performed.**

1.1a ABC management technologies field-tested.

1.1a.1 Background.

The project's farmer training day, staged in April 2002, demonstrated several ABC control methods, as well as providing information about others, to more than 200 farmers. In particular, the baited trench (a 30cm deep, vertical sided trench containing small quantities of carbaryl/ bran bait) was promoted as the most appropriate control method for smallholder farmers to deploy against ABC. This method was tested successfully on-station, at Sebele in 2001, but there has not been an ABC outbreak in Botswana since then and consequently the project has had no opportunity to test the method on-farm. Such an evaluation is advisable before the method is promoted in Botswana and neighbouring countries. A substantial majority of farmers interviewed at the training day stated they wanted to test out the baited trench during the next ABC outbreak, so it was felt that a great opportunity existed for extensive on-farm testing of this method during the present one-year project extension.

Barrier spray application of fipronil was previously tested on-farm against ABC during the 2000 outbreak and found to be effective. A subsequent environmental impact assessment demonstrated that both barrier spraying and the baited trench had only a short-term effect on non-target invertebrate species. These two control methods appear to be the most promising, both in terms of their effectiveness and the likelihood of their being adopted. In his PhD thesis, Mosupi (2003) has argued that the most effective ABC management strategy during outbreaks in Botswana should be for farmers to implement the baited trench at field edge locations where ABC nymph populations build up prior to crop heading, *i.e.* before the invasion of the crop fields by ABC, and for extension to implement barrier spraying with fipronil in situations where the build up of ABC was too sudden to predict.

In addition to these two control methods, it was also felt that a third management option against ABC, the unbaited trench, merited field-testing if an opportunity arose. Although a 30cm deep unbaited trench did not perform nearly as well as the equivalent baited trench when tested on-station, a somewhat deeper (50cm) unbaited trench did retain 79% of crickets for 24 hours. Since many farmers have misgivings about using pesticides (Matsaert et al, 2000) this method would be more acceptable to some farmers.

Field trials for on-farm testing of 1) the carbaryl-baited trench, 2) barrier spraying using fipronil and 3) the unbaited deep trench, were planned for the 2003 growing season. The location selected for the trials was the Shoshong area in central eastern Botswana, an area that is severely affected by ABC and where the project had previously established good relations with farmers and local extension staff.

An ABC outbreak was necessary for the present trials to properly evaluate the three control methods. Early rains in 2003 were poor however, and by mid February, field reconnaissance suggested that it was unlikely to be an outbreak year. However, the numbers of ABC nymphs present in scrub fallow areas (their favoured habitat) were markedly higher than during the two previous seasons and so preparations for the trials went ahead. As the growing season progressed and the sorghum crop reached the heading stage, aggregations of ABC gathered at some field edges and an ABC field invasion later took place. This was, however, some way short of the sustained influx of ABC that is seen in a full-blown outbreak situation.

Figure 1.1, 1.2: ABC gathered around fields prior to the field invasion.

1.1a.2 Methods.
Owing to the lack of rain, many farmers did not plant in 2003 and consequently the number of trial replicates that could be conducted for each treatment was limited to 5. Those fields where ABC nymph populations in the surrounding scrub were apparently highest were selected for use in the evaluation of the baited trench. All fields were planted with sorghum and some also included maize. Field size at the trial sites varied,

the smallest was c.60 x 40m, whilst the largest was estimated at c.200m x 150m. In each case the field selected was divided into two halves, with equivalent amounts of *Acacia* scrub bordering onto each. It was anticipated that the subsequent influx of ABC toward each half of the field would be roughly equal. Trenches were constructed manually around one field half (selected at random) at the ten trench treatment sites, in the second half of February.

Crop development and ABC population build up were monitored closely at the field sites, and application of fipronil barrier spray and carbaryl/bran bait in the 30cm trenches was undertaken between 10th and 18th March, as the first sorghum panicles emerged and flowered. At the same time, at each site both field halves were cleared of any ABC that had already entered into the field. Population monitoring was then conducted twice weekly, from 21st March until the demise of the ABC population on 9th May, comparing treatment and control as paired samples. The sampling method of Mosupi (2003) was used, which involves making a zigzag walk diagonally across the field (and returning along a parallel zigzag in smaller fields), in this case with vectors of 5m, counting all ABC within an arm's length radius at each of 50 sampling point per sampling occasion.

1.1a.3 Results.

- **Insufficient ABC were present for a conclusive evaluation.**

The fields used for the baited trench evaluation were, in the event, the only ones which had anywhere near sufficient ABC to conduct an assessment of the control methods, and even in those the cricket numbers were far short of an outbreak. This was a huge disappointment after so much effort went into setting up the trials. Further trials with more replicates, conducted under proper outbreak conditions, are to be recommended.

Table 1.1 Results of the baited trench evaluation trials

Farmer	**CONTROL** Mean no. of ABC in plot	**BAITED TRENCH** Mean no. of ABC in plot	Cumulative total dead ABC in baited trench	Probability (Wilcoxon)
Matimela	4.909	2.455	170	0.055
Bagasi	4.545	3.636	1223	0.641
Dikube	0 [eaten by cattle]	3.727	1084	n/a
Merafe	4.091	3.000	84	0.301
Mototo	2.818 [crop stunted]	7.636	194	n/a

*A sign rank test for paired samples: non parametric test avoids unjustified assumption of equal variance

The above results are not conclusive, but nevertheless the findings are of interest. In one farmer's field (*Mototo*), surprisingly, the average number of ABC per sampling occasion was *significantly higher* in the treated half of the field. But in that case, for reasons that are not fully understood, the crop in the control half of the field was generally stunted and sparce and it was clear that the ABC invasion was concentrated towards the healthy crop in the trenched half of the field. At one of the other sites, unfortunately the control plot was eaten by stray cattle.

- **In 3 valid comparisons, mean number of ABC was lower in baited trench plots, but not significantly so.**

Considering the remaining 3/5 field trials, which appeared to be valid comparisons, the mean number of crickets per sampling occasion was greater in the control plot in each case, but never significantly so.

- **Baited trenches killed many ABC**

Whilst the field population of ABC was not significantly reduced by the baited trench in the present trials, it should be noted that at all 5 field sites the baited trench killed ABC effectively, and in 2/5 cases this amounted to over a thousand dead crickets.

1.1a.4 New insights into the baited trench method as applied in farmers' fields.

In the present trials the trenches were dug by hired labour, often including farm family members. The construction of earthworks on such a large scale was a very informative exercise, even if the trial outcome was not really satisfactory, and the following observations are worth reporting.

1.1a.4.1 Trench construction.

- **Trench construction is laborious on heavy soils.**

It is clear that some soils are much more conducive to trench construction than others. It was very hard work indeed to dig the trenches manually to the required specifications in heavy soils - to such an extent that at such locations it might well be impractical to attempt trench-based control measures. In sandier soils, the going was much easier and trenches of a uniform good quality could be dug quickly.

- **Further testing of mechanised digging devices was undertaken.**

Further progress was made in assessing the use of mechanised tools to aid trench construction, with the design and manufacture of a prototype "trench plough". This device consists of a disc cutting blade attachment secured onto a standard plough (see Fig.1.3 below). It produces a steep-sided furrow, the rational being that the near vertical side should border onto the field to impede ABC entry. It has an advantage over the more sophisticated trench digging tool that was tested previously in that it requires only animal traction (although it was tested on this occasion using a small tractor). At the time of testing, the soil was so dry that the near vertical side of the furrow that was produced crumbled in many places and it would not have formed an effective trap for ABC. The device will be further tested next growing seasons after there has been adequate rain.


Figures 1.3, 1.4. The plough with trench wall cutting attachment. Unfortunately, the soil was too dry for effective testing on this occasion.

1.1a.4.2 Effectiveness of trenches.

- **Trench effectiveness depends on soil type.**

Coupled with the problems encountered digging trenches in heavy soils, observations on the behaviour of ABC that had fallen into trenches suggest that crickets are more readily able to escape from heavy soil trenches. This was not subjected to rigorous testing, but it seemed that ABC escape was assisted by the firm vertical soil face which allowed the cricket a better grip with less chance of soil slippage, and the presence of more plant material such as small roots, which were much more difficult for labourers to pull out whilst digging trenches in clay/loam soil, providing further assistance to the climbing ABC.

- **Trench maintenance is important for successful control of ABC.**

It is clear that trench maintenance is necessary if the trench is to function effectively. Left unattended, trenches accumulate debris such as wind-blown plant material which can provide an easy escape route for any trapped ABC. The partial collapse of trench walls is another concern, although at the present field sites this was less of a problem than had been anticipated. Had heavy rain fallen during the invasion period then some repair of trench walls would certainly have been necessary. In the present trials, farmers did rather less in the way of trench maintenance than had been expected and this was probably a major reason why significant reductions in ABC populations were not achieved in the protected field plots. With a little daily maintenance, especially removal of plant debris, the performance of the baited trenches would certainly have improved.

1.1a.4.3. Effects on non-target organisms.

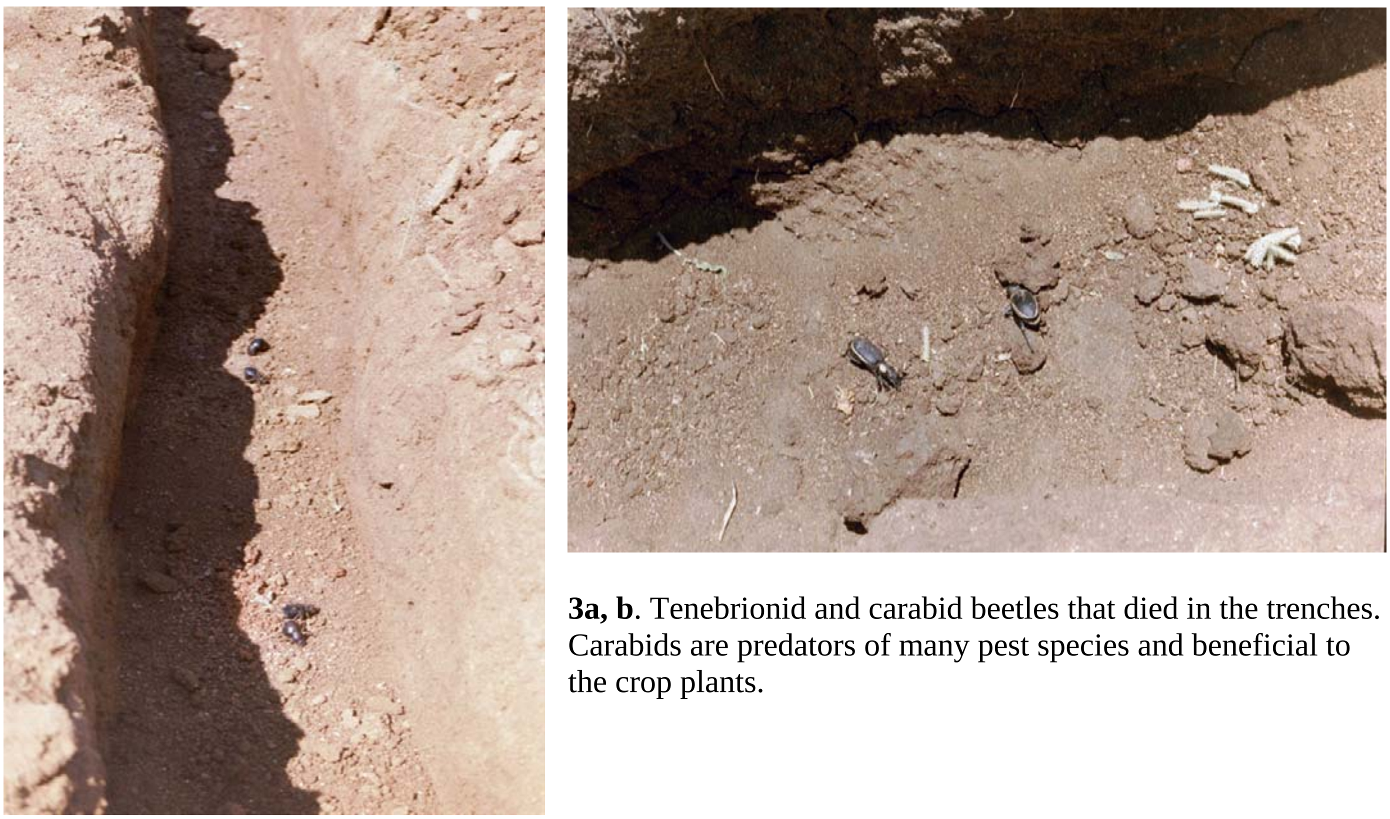
- **The baited trench did not attract vertebrate scavengers.**

Farmers were asked to be vigilant and report back if any animals were seen eating dead or trapped ABC inside the trenches. In particular, it was considered quite likely that

Abdim's storks might be attracted to feed on trapped crickets. But in the event, no reports of storks or other animals feeding on the crickets were received and so on the present evidence it would appear that the baited trench probably does not present a serious hazard to scavengers.

- **Trenches resulted in the death of certain beneficial large beetles.**

An impact assessment carried out previously (Mosupi 2003) suggested that the baited trench had little effect on non-target invertebrates. However, in the present trials certain non-target invertebrates were definitely affected. Most, if not all, of the trenches trapped numerous large, flightless carabid beetles (*Anthia* sp.) and also large, flightless tenebrionid beetles (unidentified). These fell into the trench, were unable to climb out again, and subsequently they perished.



3a, b. Tenebrionid and carabid beetles that died in the trenches. Carabids are predators of many pest species and beneficial to the crop plants.

In the case of *Anthia* sp. at least, this finding is a concern, since this beetle is a voracious generalist predator and almost certainly beneficial to crop plants.

- **Trenches may pose a hazard to livestock.**

A final concern that might be classed in the category of impact on non-target organisms relates to one farmer who claimed that two of her goats had fallen in and died in a field trench. We are not convinced that this claim is genuine, but it highlights a potential problem with the baited trench method of which farmers should be aware.

1.1a.5 Farmer's views.

At the end of the field season, the ten farmers whose fields had been subjected to trench digging were interviewed individually. Eight of them fully understood the purpose of the ABC control trials, but two had some misconceptions and were confused on certain points. All ten felt that it was important to protect crops against ABC, especially during an outbreak. Something which had not been anticipated was that 8/10 farmers requested that the trenches were now filled in again, at the expense of the project, since they were an inconvenience during the dry season.

- **Farmers were enthusiastic because they saw the baited trench killed many ABC.**
- **Farmers were concerned about the labour input needed.**

All the farmers were enthusiastic about the baited trench, which they noted had killed many crickets. Even though the baited trench was not shown to reduce ABC population levels in the fields significantly, the sight of so many dead crickets in the trenches had clearly convinced the farmers that this control measure was very effective. All interviewees indicated that they would definitely use the method the next time there was an ABC outbreak. But each farmers also commented in one way or another that trench digging was a very laborious process.

Summary of findings from activity 1.1a (ABC management technologies field-tested):

- **Insufficient ABC were present for a conclusive evaluation.**
- **In 3 valid comparisons, mean number of ABC was lower in baited trench plots, but not significantly so.**
- **Baited trenches killed many ABC.**
- **Trench construction is laborious on heavy soils.**
- **Further testing of mechanised digging devices was undertaken.**
- **Trench effectiveness depends on soil type.**
- **Trench maintenance is important for successful control of ABC.**
- **The baited trench did not attract vertebrate scavengers.**
- **Trenches resulted in the death of certain beneficial large beetles.**
- **Trenches may pose a hazard to livestock.**
- **Farmers were enthusiastic because they saw the baited trench killed many ABC.**
- **Farmers were concerned about the labour input needed.**

1.1b Economic analysis of control methods performed.

Because of insufficient ABC numbers, only limited data on the effectiveness of control methods was obtained, this with respect to the baited trench method. The economics of barrier spraying against ABC could not be assessed.

1.1b.1 Background and methods.

- **Cost – benefit analysis performed re. use of the baited trench to protect sorghum and maize from ABC.**

The objective was to examine the economic return expected from the baited trench over a range of crop yield and ABC outbreak frequency. The data for this exercise were estimates obtained during the field trials that took place in Shoshong. The values used reflect perceptions of the Botswana research staff working on the project.

Data obtained from seven farms enabled estimates to be made of:
- yields of sorghum and maize
- prices obtained by the farmer for these crops
- percentage losses caused by ABC when no control measure were used
- percentage losses caused by ABC when baited trenches were used
- cost of trench construction by hand and/or machine
- cost of baiting
- frequency of ABC outbreaks

The data were, however, rather patchy chiefly because ABC outbreaks were not extensive in the year concerned. Yield and loss data were based mainly on information obtained from Bagasi. Data on control costs were obtained mainly from Montsho, Digoro and Mototo. The figures used in the analysis (Table 1.2) probably provide a useful general picture but it is recognised that a more systematic study is needed to obtain detailed reliable data. The percent loss due to ABC was estimated to be very high, especially in maize. Losses were reported to be reduced but not eliminated, at least in the case of sorghum, where the baited trench was estimated to reduce losses from 75% to 15%. The cost of trench construction was high relative to the value of the crop, and similar whether carried out by hand or machine. The cost of the bait and its application was also high. The frequency of ABC outbreaks was reported to vary from every year to one in three years, or to ‘depend on rainfall’. The average probability of an outbreak in any year was 0.8 (equivalent to 4 out of every 5 years).

Table 1.2 Average values of economic parameters, based on surveys conducted on seven farms in southeast Botswana in 2003.

	sorghum	maize
Yield in good year (bags/ha)	40	16
Yields in bad year (proportion of good year)	0.33	0.33
Percent loss due to ABC (no control)	75	100
Percent loss due to ABC (with baited trench)	15	0
'Farm gate' price per bag	50	45
Trench costs (Pula/ha)	417	
Prob. of ABC outbreak (in a year)	0.8	

Cost of baiting (Pula/ha)	320

We consider the net output for the crops, sorghum and maize. The net output was defined as the value of the crop, minus the value of any losses due to ABC, minus any control costs. Eight possible outcomes could occur in any year depending on whether the year was a good or bad rain year, whether or not an ABC outbreak occurred, and whether or not baited trenches were employed. The values of the outcomes, N_1 to N_8, where calculated (Table 1.3) and compared for both crops (Figs 1.7a and 1.7b). Clearly, in all cases the highest return was obtained in a good rain year, when no ABC outbreak occurred and when no baited trench was used (N_1, Table 1.3). The values of the other outcomes depend on the costs of damage and control.

1.1b.2 Results.

- **Baited trench cost-effective only in years of high yield and ABC outbreak, for sorghum.**

In the case of sorghum (Fig. 1.7a), use of the baited trench was better than doing nothing when an ABC outbreak occurred. This was only anticipated to be true, however, under the high yield conditions expected with good rains. Under low rainfall conditions and poor yields the returns did not compensate for the trenching and baiting costs. The outcome was better for sorghum than for maize with losses occurring in all cases when the trench was used for maize, and losses occurring when the trench was used in poor rainfall years for sorghum. Except for sorghum in good rainfall years it appeared likely that the value of the crop saved by using the baited trench was less than the costs of its use.

The values of the different outcomes provide a useful comparison of the relative output a farmer could experience in any one year. It is also important to consider the likelihood of occurrence of the various outcomes. Although, as might be expected, the situation with good rains and no ABC outbreak gives good net returns, this situation may not occur very often.

Based on estimates of the probabilities of the different outcomes, average returns for three alternative ABC control strategies were calculated. The strategies compared were ‘never control’, always control using baited trenches’, and ‘use baited trenches only when there is an ABC outbreak’. The last strategy cannot actually be implemented with complete certainty because the trench must be dug before it is completely clear whether an outbreak will occur or not. It nevertheless provides an upper limit, the value effectively being that of following a perfect forecast of ABC outbreaks.

We introduce two further variables, the probability of occurrence of a year with good rains (as opposed to a year with poor rains), R_G (Table 1.3), and the likelihood that ABC outbreaks are associated more with years of good rain than with years of poor rain, h (Table 1.3), e.g. h = 2 would mean that outbreaks were twice as likely in a good rain year than a poor rain year. Based on historical outbreak and rainfall data, realistic values of R_G and h of 0.33 and 3 were used in the analysis The probabilities of a good rain year with an ABC outbreak (M_1), a good rain year with no ABC outbreak (M_2), a bad rain year with an ABC outbreak (M_5) and a bad rain year with no ABC outbreak (M_6), were then calculated (Table 1.3). The value of each strategy was then obtained by summing the product of each possible outcome (N_i) and its associated probability (M_j).

For the two crops considered, the values of the three strategies were compared across the range of ABC outbreak probabilities (Figs 1.8a and 1.8b).

- **Costs of baited trench are frequently greater than benefits from using it.**

The average net benefits again reflect the central problem that the cost of the baited trench is frequently greater than the benefit obtained from its use. Nevertheless, for sorghum, the average net benefits obtained from the 'follow forecast' strategy was slightly higher than that for the 'never use'. Thus, in the long term, trenching during outbreaks (but only during outbreaks) was the best strategy for sorghum. The 'always use' strategy gave much lower returns, that were none the less positive (Fig. 1.8a).

For maize the 'never use' strategy was slightly better than the 'follow forecast' strategy. The 'always trench' strategy always resulted in a loss. The lower yields obtained for maize meant that the value of the crop saved by the baited trench simply wasn't sufficient to make the baited trench a viable option.

- **The high cost of hired labour is a major problem.**

This economic evaluation of the costs and benefits of the baited trench provides a rather negative picture of the technology. It should be remembered however, that the costs of trench construction and bait application relate to what it would cost to hire labour to dig the trenches and apply the baits. If the farmer were doing these jobs himself the cash costs would be less although time spent by the farmer doing these tasks would prevent him also earning money in other ways.

- **Strategic use of baited trenches in key invasion areas is an option.**

Where no opportunity cost exists in the form of alternative employment, it may be that the trenching costs would be reduced to a more realistic level by the farmer doing most the digging him/herself. This would seem to be a realistic option if trenches were dug strategically, only between the main ABC aggregation areas and the field, rather than around the full perimeter of the field. A few farmers have used this approach already in the southern Kalahari area. We do not know how effective such partial defence would be, only that those farmers were enthusiastic and claimed to have killed huge numbers of ABC.

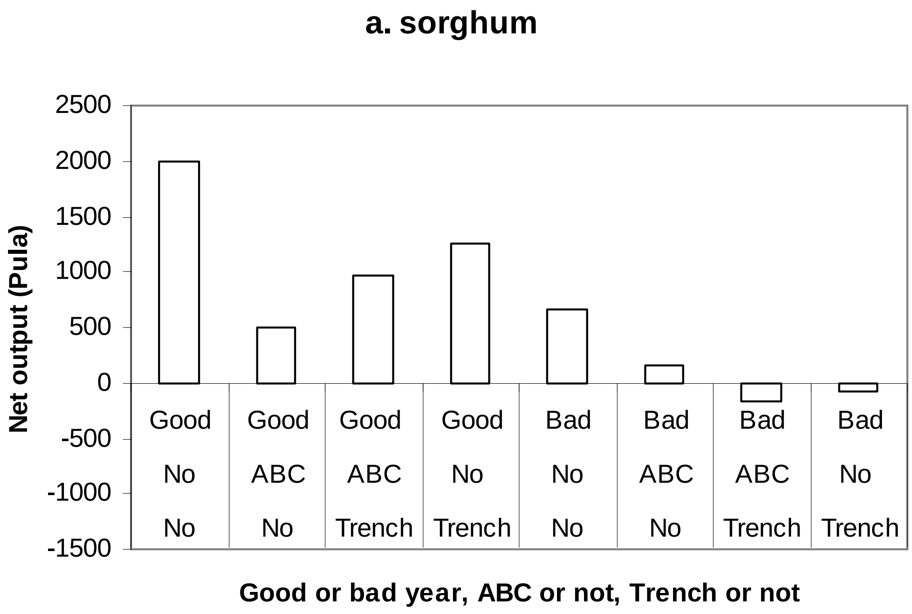
Lastly, from the limited damage estimates we have, the above analysis suggests the technology has more potential to protect sorghum than maize, at least in the growing conditions of southern Botswana.

Thus, although the economics of the baited trench are at first sight not encouraging, judgement should probably be reserved until further socioeconomic studies have been carried out.

Table 1.3 Variables and calculations used in the analysis

Variable/quantity	Symbol	Calculation
Yield in good year (bags)	Y_G	
Yields in bad year (proportion of good year)	b	
Percent loss due ABC (no control)	L_N	
Percent loss due to ABC (with baited trench)	L_T	
'Farm gate' price per bag	P	
Trench costs (Pula)	C_T	
Cost of baiting (Pula)	C_B	
Freq of baiting	F	
Prob of ABC outbreak (in a year)	O	
Gross output (good rain year)	G_G	PY_G
Gross output (bad rain year)	G_B	PY_Gb
Control cost	C	$C_T + C_BF$
Net output (good year, no ABC, no control)	N_1	G_G
Net output (good year, ABC, no control)	N_2	$G_GL_N/100$
Net output (good year, no ABC, control)	N_3	$G_G + C$
Net output (good year, ABC, control)	N_4	$G_GL_T/100 + C$
Net output (bad year, no ABC, no control)	N_5	G_B
Net output (bad year, ABC, no control)	N_6	$G_BL_N/100$
Net output (bad year, no ABC, control)	N_7	$G_B + C$
Net output (bad year, ABC, control)	N_8	$G_BL_T/100 + C$
Probability of a good (rain) year	R_G	
Fold of ABC risk in good years vs. bad years	h	
Probability of ABC outbreak in good year	O_G	$O(h/(h+1))$
Probability of ABC outbreak in bad year	O_B	$O(1/(h+1))$
Probability of a good rain year without ABC	M_1	$R_G(1 - O_G)$
Probability of a good rain year with ABC	M_2	R_GO_G
Probability of a bad rain year without ABC	M_5	$(1 – R_G)(1 – O_B)$
Probability of a bad rain year with ABC	M_6	$(1 – R_G)O_B$
Net output ‘Never trench’	N_N	$M_1N_1 + M_2N_2 + M_5N_5 + M_6N_6$
Net output ‘Always trench’	N_T	$M_1N_3 + M_2N_4 + M_5N_7 + M_6N_8$
Net output ‘Trench in ABC outbreaks only’	N_X	$M_1N_1 + M_2N_4 + M_5N_5 + M_6N_8$

Fig. 1.7 The net benefit expected under different combinations of conditions: good or bad rain year, ABC outbreak or not, and use of baited trenches or not



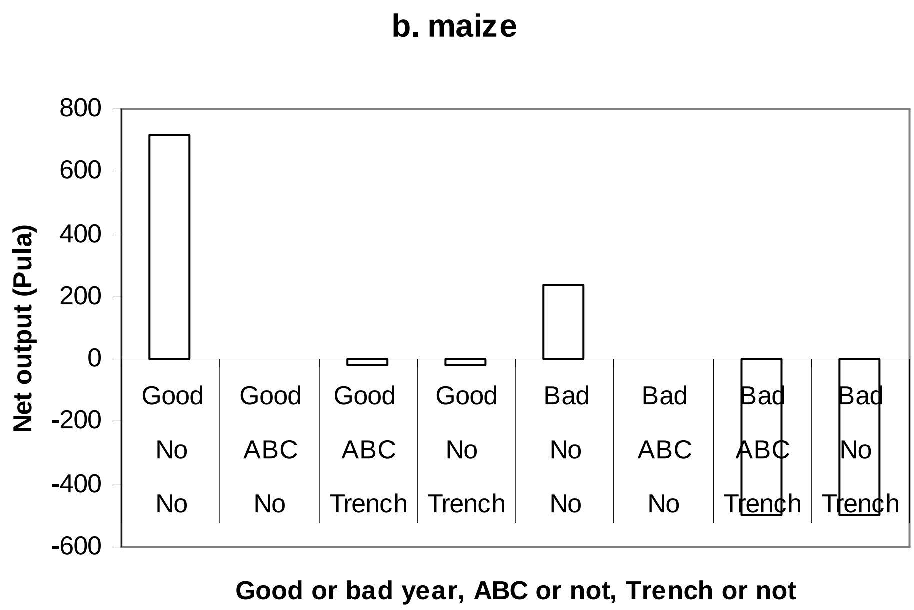
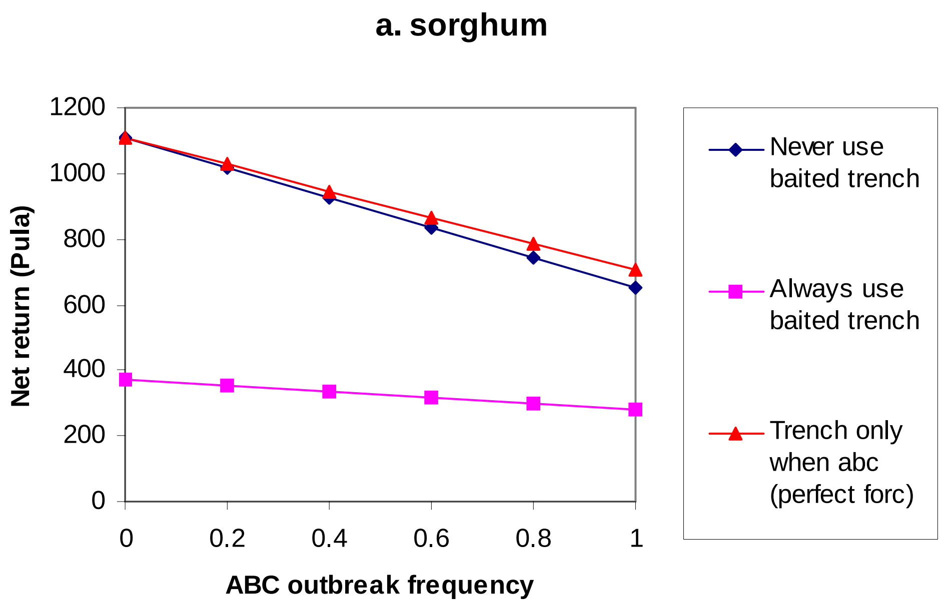
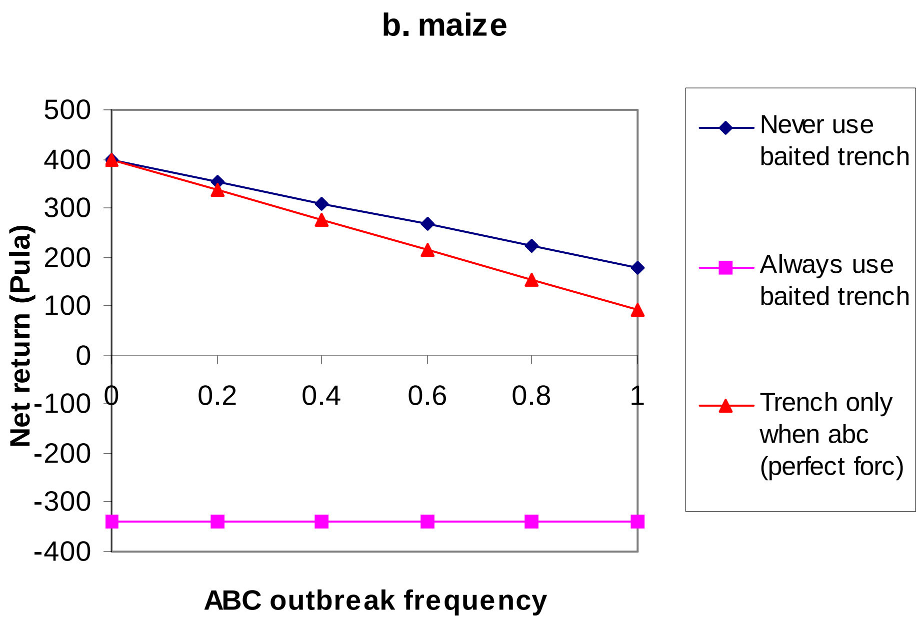


Fig. 1.8 The average net benefit expected for three alternative ABC baited trench strategies: never use, always use and use only in ABC outbreaks





Summary of findings of economic analysis:

- **A cost – benefit analysis was performed re. use of the baited trench to protect sorghum and maize from ABC in Botswana.**
- **Costs of baited trench are frequently greater than benefits from using it.**
- **The analysis suggest that the baited trench will be cost-effective only in years of high yield and ABC outbreak, for sorghum.**
- **The high cost of hired labour is a major problem.**
- **Strategic use of baited trenches in key invasion areas is an option.**

Activity 1.2. Participatory ABC population monitoring.

Background.
To establish the forecasting model developed by the project over the past 3 years as a routine part of the extension service's activities, it was proposed that a protocol for ABC population monitoring be developed for use by extension personnel. What is needed is a simple methodology for extension stations across Botswana to use to record ABC abundance; this would provide a basis for model validation and promote ownership of the model by the extension service. In practice, if an outbreak was likely, the forecast would alert the extension services of the need to assess ABC nymph populations, focusing on the favoured nymphal habitat, *i.e. Acacia* scrub fallow areas in the neighbourhood of cereal fields. By this means, large populations of nymphs would be detected long before they entered the crops, so that timely preparation, maintenance and baiting of trenches could be carried out.

ABC nymphs and population estimation.
2003 was considered a year of intermediate ABC population size in the Shoshong area, although further south, around Gaborone, very few ABC were present. With population estimation in mind, field observations of ABC nymphs were made at Shoshong in mid February and again in mid March, just prior to the field invasion, by which time most ABC had turned adult and the majority of remaining nymphs were in the final instar.

The methodological questions under consideration were:

When to sample? How to sample? Where to sample?

In terms of the farming calendar, the time to sample is during the month before crop heading occurs, which in Botswana would usually mean from the start of February. Sampling earlier than this is not advisable because nymphs are less conspicuous whilst small and green, and they may subsequently move and aggregate elsewhere. Sampling later, *e.g.* just before sorghum heading, may allow too little time for trench digging. Observations on ABC nymphs' behaviour in the wild, as described below, provided important insights in relation to developing a sampling methodology.

- **Population monitoring is best conducted during early morning, when nymphs are sluggish and conspicuous.**

The importance of behavioural thermoregulation, especially basking in direct sunlight to raise body temperature, was previously recognised in adult ABC. It soon became clear that this also applies to later instar nymphs, which take every opportunity to bask except during the very hottest part of the day. Basking raises core body temperature above ambient and thereby increases metabolic activity, which is especially important during early mornings after cool nights. Between 06.00h and 09.00h in particular, whilst they are still relatively lethargic due to their low body core temperature, nymphs climb up to elevated positions on fences, tall plants and onto the canopy of low bushes to bask in the morning sunlight. This is a most advantageous time to undertake population monitoring activities.

- **Counting of ABC nymphs is best achieved with minimal disturbance.**

Even under optimum observation conditions, when cold ABC bask in exposed positions, the nymphs were seen to retreat by shuffling around branches and stems to hide from inspection by observers. If the bush was physically disturbed then many nymphs went one step further by dropping to the ground and disappearing in the undergrowth. This behaviour necessitates a stealthy, measured approach by those personnel monitoring ABC populations. Accordingly, all movements by monitors should be slow, they should not touch the vegetation on which ABC are perched and it is suggested they should come no closer than 50cm to ABC aggregations.

- **Behavioural regulation of population density in aggregations appears likely.**

Older ABC nymphs and young adults aggregate in the *Acacia* scrub fallow that typically surrounds cultivated fields in Botswana. This habitat is characterised by scattered bushes (mostly *Acacia* spp.) interspersed with areas of wild grasses and broadleaved weeds. Fieldside fences made from cut posts and/or dead brush wood and cleared strips surrounding fields are also an integral part of this habitat.

Figure. 1.9 Pictures of ABC habitat.

ABC aggregated in *Acacia* near field edge.

Acacia scrub fallow close to a trenched field. Spoil is laid on the field side of the trench

Brush wood fence, with luxuriant wild grass growth due to livestock exclusion from the large field on left. Many ABC lived amongst this fence.

Broad, "cleared" strip, on right, separating *Acacia* scrub from field.

Within the heterogeneous *Acacia* scrub fallow habitat, bushes are particularly favoured by ABC as protected basking sites and used as bases from which foraging trips onto wild grasses and weeds' flowers/seed heads/fruits are made (Mviha, in prep.). As observed above, such bushes would seem to make good units for monitoring purposes. Comparing photographs, however, the densities of ABC observed on bushes during the last outbreak, in 2000, were not much higher than those observed in the 2003 growing season. This suggests that there may be some form of individual spacing behaviour that limits population density on individual bushes. Presumably, at high population densities ABC overflow from bushes into less favoured microhabitats, or move further away from the field into less populated bushes.

- **Sampling is needed in different microhabitats at several distances from fields.**

This season's field observations suggest that developing an ABC population monitoring protocol will not be as straight forward as might have been imagined. It must take into account the "overflow" factor outlined above, rather than simply sampling by counting ABC on a fixed number of bushes close to fields.

The population monitoring protocol needs to produce a reliable indication of local ABC population size that can be obtained relatively quickly by a small team of monitors. Given what we know of the mobility of ABC adults, repeated sampling up to 100m from field edges may be needed to estimate the full extent of aggregated ABC and hence the size of the ABC nymph/young adult population. Because of the structural heterogeneity of *Acacia* scrub fallow, unit area population estimates are very difficult to make, especially so in very bushy areas. It may well be that use of a timed count is a more practical proposition for monitors than attempting to make unit area population estimates. For instance, timed counts (say 2 minutes/sample) might be conducted repeatedly (5 samples minimum) in bushy areas and again in more open areas surrounding the field, then the procedure further repeated at intervals extending away from the field.

Given the limited time available and the higher priority of establishing field trials, this was the extent of progress regarding a population monitoring protocol.

- **Farmers can provide early warning of an ABC outbreak.**

Whilst developing a rigorous method for sampling ABC nymph populations presents a challenge, we should not underestimate the ability of farmers to recognise an ABC outbreak in the making. Most farmers in eastern Botswana have experienced at least 3 major ABC outbreaks during the past decade and a half. Discussion with farmers and extension staff suggested that whilst adult ABC are readily recognised, there is general confusion regarding the earlier instars. To help remedy this problem and promote the early recognition of massive ABC populations, an information poster illustrating every nymphal instar was designed and produced in both English and Tswana (see Appendix I). The ultimate message of the poster is: "If you see lots of small ABC ("Setotojane") around your field, inform you local extension officer (AD) - control measures may be needed."

- **Probable phase polymorphism recognised in ABC.**

An important new aspect of nymphal behaviour was first recognised during this season's observations - there is a marked difference in behavior and coloration comparing nymphs which grow up in aggregations amongst *Acacia* scrub fallow (the majority), and the much smaller proportion that grow up as solitary individuals living amongst the growing crop. From the small size of some nymphs, the latter can be presumed to have hatched from eggs laid in the field rather than in the scrub. ABC found in *Acacia* scrub fallow appear to aggregate from an early age. It may be passive aggregation initially, since the nymphs hatch from common egg sites, but subsequently there is a strong tendency for these nymphs to aggregate, doing so mostly in *Acacia* bushes. After instar 3, body coloration, previously mostly green, changes to include elements of brown, black, and reddish purple. In contrast, isolated nymphs in fields do not aggregate and their coloration remains predominantly green. The striking similarity between the present observations and phase polymorphism, well-documented in locusts, deserved further study.

Fig. 1.10. Probable phase polymorphism in ABC. An aggregation of aposematic final instar nymphs of *A. armativentris* (black + orange thorax) and *A. discoidalis* (striped individual, near top) resting in the shade on a field-side fence. Compare with the green *A. discoidalis* final instar nymph (left), one of several living in relative isolation amongst the half-grown sorghum plants in that same field.

Summary of findings on ABC population monitoring:

- **Population monitoring is best conducted during early morning, when nymphs are sluggish and conspicuous.**
- **Counting of ABC nymphs is best achieved with minimal disturbance.**
- **Behavioural regulation of population density in aggregations appears likely.**
- **Sampling is needed in different microhabitats at several distances from fields.**
- **Farmers can provide early warning of an ABC outbreak.**
- **Probable phase polymorphism was recognised in ABC.**

Activity 1.3
Symposium: Integrated Management of Armoured Bush Crickets in Southern Africa

Background
Until fairly recently, ABC has not been recognised as a pest of major significance. Apart from an ICRISAT-funded project in northern Namibia (1993-1996) (Wohlleber 1996, 2000), little has been published in the public domain on ABC control. That is not to say that the pest has not been studied, but rather, local extension and research personnel have operated in isolation in many of those affected countries.

Consequently, one of the problems this project encountered in developing and promoting management strategies against ABC, has been that the overall picture is very fragmented. Although those countries affected by ABC are known, information on the severity and regularity of damage caused, on which crops are affected and on the specific geographic areas affected in each case are generally lacking.

Over the preceding 3 years, the present project had established contacts with extensionists and researchers attempting to manage pest ABC in several countries neighbouring Botswana. It was felt, however, that it would be beneficial, both in terms of information gathering and dissemination of the project's findings, to bring together representatives from all the affected countries (Namibia, Angola, Zambia, Botswana, Zimbabwe, Malawi, Tanzania, Mozambique, South Africa).

Symposium.
Such a gathering of ABC specialists was made possible, at relatively low cost, by staging a symposium session on integrated management of ABC in southern Africa within the biennial congress of the Entomological Society of Southern Africa, held at University of Pretoria, 6-9th July 2003.

A representative was invited from each country to present a country paper addressing a specified range of topics. Six further research papers presented the findings of the present project, with ample time for questions between talks. The symposium culminated in a wide-ranging general discussion held at the end of the talks, lasting for almost an hour. The symposium was attended by an audience of approximately 60. Speakers and participants in the general discussion gathered together for a group photograph at the end of the symposium.

Fig. 1.11. Symposium Participants. Back row (L-R): K. Mosinkie (Bots), J. Holt (UK), S. Green (UK), H.D. Brown (SA), K. Mbata (Zam), K. Coetzee (SA), S. Hanrahan (partly obscured) (SA), R. Toms (SA), P. Mosupi (Bots), J.Cumbi (Moz). Front row (L-R): S. Ekandjo (Nam), E. Musonda (Zam), P. Mviha (Mal), I. Saunyanga (Zim), K Chamberlain (UK), J. Mitchell (SA), J. van den Berg (SA). [Absent: R.A. Humber (USA), R. Price (SA)]

Abstracts of all symposium contributions were subsequently published in the congress proceedings and these are reproduced below (see also dissemination outputs). The text and figures of a handbook on ABC biology and management has now been completed (see Appendix II). Multiple copies of this handbook are to be produced and distributed to national agricultural research and extension departments in each country.

SYMPOSIUM INTRODUCTION

Integrated management of armoured bush crickets in southern Africa

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Armoured bush crickets (ABC) (Orthoptera: Tettigoniidae: Hetrodinae) have not always been considered agricultural pests, since the damage they cause to commercial farming is rather limited. During the past 20 years, however, their considerable impact on subsistence farming in semi-arid regions of southern Africa has been recognized. Today *Acanthoplus discoidalis* (Walker) is classed as one of the most important pests of subsistence grain crops in northern Namibia and Botswana and, likewise, *A. speiseri* Brancsik in southern Zambia. There is little information, however, on the importance of ABC elsewhere. This symposium begins with a region-wide assessment of ABC pest status, with representatives reporting from most southern African countries (Green *et al*.).

Farmers whose crops are affected by ABC generally have little money to spend on pest control, while they have limited time and only basic tools at their disposal. Most have a very limited understanding of the pest. The special problems this presents for implementing integrated pest management (IPM) are discussed (Minja & Green).

An understanding of the ecology and behaviour of ABC is fundamental to developing effective IPM measures. Our knowledge of *Acanthoplus* species has improved substantially over the past 15 years, however, and a detailed picture is now emerging that can guide IPM development (Mviha *et al*.).

Since ABC tend to invade crop fields at predictable locations and times, control measures can be targeted to intercept crickets as they enter fields. Two promising IPM options are barrier spraying at field edges and the strategic use of defensive trenches containing small quantities of insecticide bait. These methods have recently been field tested in Botswana and their environmental impact assessed (Mosupi *et al*.).

As generalist scavengers, ABC are attracted to many different types of food, of which cereal panicles are just one. The role of food odour in attracting of *A. discoidalis* to baits was investigated, using a range of volatile chemicals isolated from sorghum panicles and other sources (Chamberlain *et al*.).

ABC populations appear to be characterized by ‘boom or bust’ population dynamics. Serious crop damage occurs during outbreaks, but few crickets may be present in intervening years. Using new information on the key variables in ABC life histories, it has been possible to develop a computer model to simulate ABC population dynamics. Ultimately, ABC outbreaks could be forecast using this system (Holt *et al*.).

Finally, although currently seen only as pests, ABC are protein-rich and have potential for utilization. The possibility of using ABC as a food supplement for chickens is examined (Mosinkie & Green).

PRESENTED PAPERS:

Armoured bush crickets (Orthoptera: Tettigoniidae: Hetrodinae) as agricultural pests – a geographic overview

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Armoured bush crickets (ABC)(Orthoptera: Tettigoniidae: Hetrodinae)are recognized as sporadic agricultural pests in semi-arid areas throughout southern and eastern Africa. These insects are opportunistic omnivores, but they are important pests because during outbreaks they inflict significant damage on the developing panicles of pearl millet, sorghum and maize, the principal subsistence crops of the region.

Information about the geographic extent of ABC as an agricultural pest is patchy and our knowledge of the range of crops damaged is incomplete. The identity of the ABC species causing crop damage is not always certain. This paper provides a geographic overview of ABC as agricultural pests, with national reports from entomologists in those countries affected, thereby establishing a basic body of information on ABC as a crop pest in the region.

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Armoured bush cricket (Orthoptera:Tettigoniidae:Hetrodinae) control – a farmer perspective

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Armoured bush crickets (ABC) (Orthoptera: Tettigoniidae: Hetrodinae)are sporadic agricultural pests in semi-arid areas across southern Africa, damaging, in particular, sorghum, pearl millet and maize. ABC outbreaks were reported throughout the last century, but it is generally held that outbreaks have become more frequent and more severe during the last 10 –15 years, presenting resource-poor farmers with a daunting pest-management challenge.

Farmers ’integrated pest management options against ABC are limited by financial, technical and time constraints and unavailability of labour, but also by psychological considerations that limit what farmers are prepared to do. Many farmers are unwilling to hand-pick ABC, whilst others are reluctant to use insecticides. Examples are drawn from interviews with farmers in Botswana, Namibia and Zambia.

We conclude that whilst ABC management will never be easy, most of the constraints are not insurmountable. With training and effective dissemination of control guidelines, farmers could become more proactive and combat ABC much more effectively.

The ecology of the armoured bush cricket *Acanthoplus discoidalis* (Orthoptera: Tettigoniidae: Hetrodinae),with reference to habitat, behaviour, oviposition site selection and egg mortality

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Ecological studies of *Acanthoplus discoidalis* (Orthoptera: Tettigoniidae: Hetrodinae) were conducted over three years in eastern Botswana. Behaviour was observed and compared in different habitat types. Certain behavioural activities were associated with particular microhabitats. These associations changed as the season progressed, and as the *A.discoidalis* ˆpopulation density increased in sorghum crop fields.
Oviposition site selection and factors influencing egg mortality were studied in the laboratory and in the field. Caged gravid females, allowed a choice of substrates for oviposition, probed all soil types equally, but avoided laying in the sandiest soil. Uncompacted, dry loam/sand was the preferred substrate for oviposition. Field studies investigated the relationship between soil type and *A.discoidalis* egg-pod abundance at six sites, sampling in *Acacia* scrub and crop fields. Egg-pod abundance was related to soil particle size, but high egg-pod abundance was most strongly associated with *Acacia* scrub habitat type. Predation, desiccation and 'egg rotting' were the main mortality factors. Density-independent predation by the red ant *Dorylus helvolus* (Hymenoptera: Formicidae) was by far the main mortality factor, the ants killing up to 42%of eggs. The incidence of egg predation was therefore studied. Predation of egg pods by *D.helvolus* was greatest in soils with small particle size and in crop fields, and particularly where the two occurred together. 'Egg rotting' was the second most important mortality factor. Laboratory experiments revealed that moisture levels have a major influence on the proportion of eggs dying and rotting following oviposition and throughout embryonic development.

Control options against armoured bush crickets (Orthoptera: Tettigoniidae: Hetrodinae)

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Armoured bush crickets (ABC)(Orthoptera: Tettigoniidae: Hetrodinae)are sporadic pests of grain crops throughout the semi-arid areas of southern Africa. In outbreak years, huge numbers of ABC may invade crop fields at the time of panicle emergence to feed on developing heads of sorghum, pearl millet or maize, causing severe crop losses.
Various control methods have been used by farmers against ABC, but none have proven to be particularly successful. Consequently, in Botswana many farmers do not even attempt to protect their crops against an ABC outbreak.
The present research focused on two particular ABC management methods for use against *Acanthoplus discoidalis:* barrier spraying and trenches at field margins. Both methods intercept incoming ABC, which predictably enter fields from surrounding scrub as the crop starts to head. On-farm trials during an ABC outbreak found that barrier application of fipronil (28.6 g a.i.ha $^{-1}$) resulted in a 65% reduction in the field population of ABC. On-station experiments demonstrated that a 50 cm deep, vertical-sided trench retained 78% of trapped ABC over 24 hours, but when

small amounts of carbaryl/bran bait (3 g kg $^{-1}$)were added, retention improved and a trench depth of only 30 cm was necessary to retain 93% of trapped ABC over 24 hours.
An environmental impact study suggested that both fipronil barrier sprays and the baited trenches have only a transient impact on non-target invertebrates. Colonies of the pugnacious ant, *Anoplolepis custodiens* (Hymenoptera: Formicidae), selected as a bio-indicator, returned to normal activity levels four to six weeks after application of both treatments.

Volatile chemicals from sorghum and their role in food location by the armoured bush cricket *Acanthoplus discoidalis* (Orthoptera: Tettigoniidae: Hetrodinae)

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It is known that insects use the volatile chemicals from plants as behavioural cues. Since armoured bush cricket (*Acanthoplus discoidalis*) infestation of crops occurs during flowering and thereafter, a study of flower volatiles and their effect on the behaviour of this insect was undertaken. The volatiles from the panicles of two cultivars of sorghum were collected by entrainment during flowering and soft dough stages. More than twenty compounds were found consistently and were identified by gas chromatography and mass spectrometry. While many compounds were found at all stages of panicle development, some showed maximum output during flowering, and others appeared or increased during grain development. Diel periodicity in total production of volatiles was also observed, 3 –6 times more being emitted during the photophase than during the scotophase; the proportions of individual compounds were also different. Laboratory-based behavioural studies were conducted with armoured bush crickets, using most of the compounds identified. Those that elicited a positive response in a Y-tube bioassay were 2-phenylethanol and benzyl alcohol, although, of these, only benzyl alcohol induced a positive response in wind-tunnel bioassays. Other aromatic compounds also elicited an unequivocal attractant response in the wind-tunnel test. There is thus strong evidence that the volatile chemicals emitted by the flowering stages of sorghum can act as food location cues in the armoured bush cricket.

Prediction of armoured bush cricket (Orthoptera: Tettigoniidae: Hetrodinae) outbreaks

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A model was developed as an aid to understanding why armoured bush cricket (ABC) (Orthoptera: Tettigoniidae: Hetrodinae) outbreaks occur in some years and not others, and so provide predictions to assist the planning of control measures. We investigated the paradigm that outbreaks tend to occur in years of good rain, especially when these follow dry years. The cause was believed to be that a substantial diapaused egg bank gave rise to mass emergence of nymphs when triggered by good rains.
Based on recent experimental findings (Mviha *et al.,* this volume), the essential features of the model are that:(a) nymphal and adult survival, and adult fecundity, are deleteriously affected in years with a temporally uneven rainfall distribution, such that a sustained dry spell interrupts the food available to te crickets, and (b) egg survival is reduced in years with a wet late season, which is associated with increased egg predation and/or waterlogging.

Analysis of the model revealed that the largest addition to the egg bank was expected in years that were neither very dry nor very wet, indeed of average climatic conditions for south-eastern Botswana. The situation of highest risk was when an ‘average ’year was followed by regular rains in the following season. A large hatch would then be followed by high survival, leading to large adult populations. The high egg predation discovered by Mviha *et al.* (this volume) suggests that egg bank accumulation over several years is unlikely; the modelling indicates that outbreak dynamics can be explained without invoking a long-lived egg bank. Model predictions proved correct for the past five years in south-eastern Botswana.
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The potential of armoured bush crickets (Orthoptera:Tettigoniidae: Hetrodinae) as a poultry feed supplement

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In general, farmers view the armoured bush cricket (ABC)(Orthoptera: Tettigoniidae: Hetrodinae) as a troublesome, sporadic pest that is difficult to control. Because of its gruesome appearance and unpleasant defensive behaviour, many farmers in Botswana will not touch ABC. Time, labour and cash constraints, as well as environmental and safety considerations, also discourage farmers from combating ABC during outbreaks.

Considered from a very different viewpoint, ABC are known to have a high protein content, and so they could be seen as a natural resource with potential for exploitation. ABC aggregate on low thorn bushes from where they can be hand-picked, or they can be trapped in large numbers in trenches. But can ABC be exploited?

One use of ABC would be as a dietary supplement for livestock. Free-ranging ‘bush chickens’, prevalent at many farming homesteads, eagerly kill and consume live ABC if given an opportunity, so it seems reasonable to assume that these insects are nutritious and beneficial to chicken growth. Investigations were therefore conducted to assess the effect of feeding ABC as a diet supplement to commercial broiler chickens. To promote the feeding of ABC to poultry, farmers must recognize that ABC are beneficial to chicken growth. They must also be convinced that chickens fed on ABC taste just as good as other chickens. The few farmers who already collect ABC and feed them to their chickens obtain double benefits in terms of a nutritious chicken feed supplement and crop protection in their fields.

Activity 1.4 ABC as a Dietary Supplement for Poultry.

Background.

In the farmer survey conducted in 2000, which evaluated farmers' knowledge, attitudes and control practices in relation to ABC, the majority of farmers stated that they did not have any use for ABC. A small minority of those interviewed (c.5%), however, reported that they hand-picked ABC in the fields and then fed them to their chickens. One particular farmer did so with real enthusiasm. After this practice was first reported, the topic was raised in subsequent farmer interviews, but the suggestion of feeding ABC to chickens was met with moderate-to-strong disapproval by most farmers. A few said they had tried feeding ABC to their chickens but that the poultry would not eat them. Clearly this aspect was in need of rigorous testing. If the practice proved to be as beneficial to chickens, as some farmers suggested, then the findings should be disseminated and farmer up-take promoted. The removal of crickets during an ABC outbreak, either by hand-picking directly from the crop or by using unbaited trenches as a method of massed collecting, offers double benefits to farmers by protecting the crops and generating a source of protein-rich food for chickens.

Observation of farmers' chickens in ABC areas.

During the course of setting up ABC control field trials, time was taken to observe the behaviour of farmers' "bush chickens" around the family homestead, in particular when they were presented with ABC. Although 2003 was not an outbreak year, in some areas, especially where there was plentiful *Acacia* scrub, localised population densities of ABC could be fairly high. Here, as elsewhere, ABC appear to spend much of their time basking within the protection of the thornbush canopy and they are rarely seen on the ground.

Fig. 1.12. Bush chickens foraging amongst scrub fallow near a homestead.

- **Chickens eat ABC eagerly, using a killing technique that circumvents the crickets' chemical defences**

When an adult ABC was hand-picked from bushes and then dropped on the ground c.50cm in front of a chicken, the bird rapidly seized the cricket in its beak and then proceeded to thrash it from side to side, beating it against the ground and vegetation, sometimes putting it down then quickly recapturing it, then thrashing it further. In general, the cricket was dispatched and then consumed within 3-8 seconds. Only on one occasion was a chicken observed to reject an ABC; on that occasion a mother bantam with chicks killed the cricket, but the chicks rejected the prey item and then the whole family moved away from the dismembered cricket.

Figure 1.13a,b. Killing behaviour of chickens feeding on live ABC. Note the dust clouds raised as the birds thrash the cricket from side to side and against the ground.

Efforts to quantify elements of individual chickens' behaviour, as they dispatched ABC, were frustrated because any cricket killing/feeding had the immediate effect of attracting in other chickens, who intensified their own hunting efforts in the vicinity and often interfered with the first bird by trying to steal its prey.

Figure 1.14a,b. Bush chickens are quickly attracted to the vicinity of an ABC kill.

Closer observation of the way in which chickens dealt with their ABC prey revealed that as an attack takes place the cricket undergoes "reflex bleeding", spraying and exuding a yellow liquid from pores located above the base of each leg. The liquid, which runs over the cricket's body, is thought to be distasteful but not dangerously toxic (based on chemical analysis of exudate from a different hetrodine bush cricket species (Grzeschik, 1969). During the thrashing phase, after intial capture but before ingestion, the chicken's behaviour appears to stimulate reflex bleeding to exhaustion and further, to wipe off much of the yellow liquid onto ground vegetation and the soil.

The inference to be drawn from these observations is that the chickens' method of dispatching ABC apparently results in the discharge and subsequent removal (by wiping) of most of the distasteful yellow liquid. In effect, the chicken circumvents the cricket's chemical defences by killing the prey in this way.

Nutritional analysis of ABC

A laboratory analysis of the nutritional content of ABC was conducted at the National Food Technology Research Centre, at the University of Botswana. The following composition in terms of basic constituents was revealed:

Table 1.4. Nutritional content of ABC.

	--- Preparation method ---		
Parameter	**Oven Dried**	**Sun Dried**	**Fresh**
% **moisture**	9.06	9.03	73.6
% **crude protein**	63.04	63.06	18.3
% **crude fat**	9.65	9.72	2.8
% **crude fibre**	9.65	9.58	2.8
% **ash**	3.44	3.35	1.0
% **carbohydrate**	5.17	5.30	1.5

- **ABC has a high crude protein content.**

Hence ABC has a relatively high crude protein content of 63%, and this compares favourably with dried beef (49% protein). These findings are comparable with those from a nutritional analysis carried out on a North American bush cricket, the Mormon Cricket, where the crude protein content was found to be 58% (DeFoliart *et al.* 1982).

Feeding Trial.

In order to assess the effect of ABC in the diet on chickens' growth, a small feeding trial was conducted on-station at Sebele Research Station, Gaborone.

Method.

Two chicken houses (c.2m x 3.5m) were renovated for use in this trial and each was used to rear 15 chickens. Commercial broilers (Ross variety, supplied by local commercial poultry producer, Tswana Pride) were selected for the study because they grow quickly, reaching full size after just 38 days, whereas by comparison "bush chickens" grow very slowly indeed, taking 2+ years to mature.

Chicks were installed in the hen houses at 14 days old, by which stage they were sufficiently hardy to survive in such accommodation. Birds received commercial grower pellets from a communal feeder in both treatments. Water was also supplied. The amount of feed provided was increased every five days as the chickens got older, in line with standard commercial rearing practice. However, only 85% of the recommended ration was provided throughout, starting at 50g/bird/day at 14 days old and reaching the full ration of 130g/bird/day at 40 days and beyond.

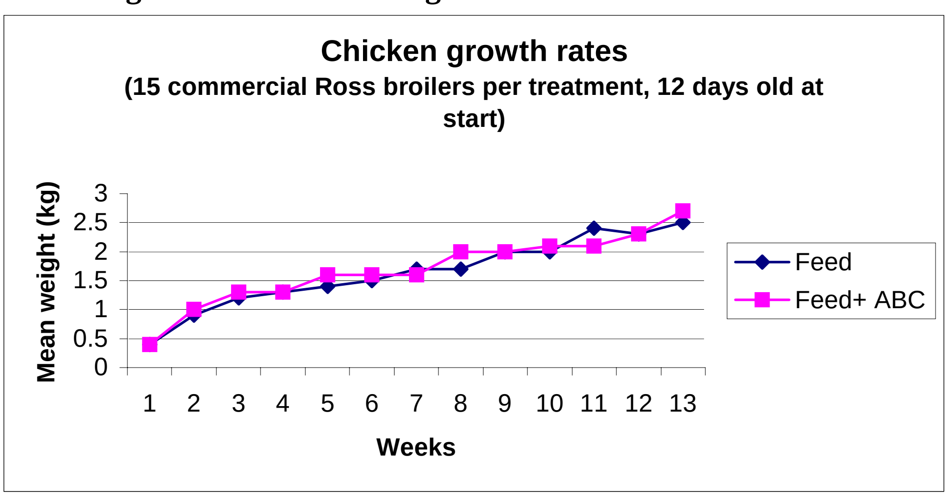
Those chickens which received the ABC dietary supplement were, in addition to grower pellets, fed 150g/day (10g/bird) of ABC, first killed by drowning, then rinsed and mashed. When immersed, ABC expel their yellow liquid, so this convenient method of killing also facilitates the removal of the noxious chemical exudate from the crickets' bodies. However, owing to a shortage of ABC in the Sebele area, unfortunately it was not possible to increase the ration of ABC as the chickens grew older, so proportionately the amount of ABC in their diet fell as the chickens got bigger.

It was soon apparent that the young chickens did not feed to any significant extent on mashed, drowned ABC. During the first week little of the mash was eaten. The ABC diet supplement was at this stage changed to oven-dried, crushed, drowned ABC, which was particulate and more palatable to the birds. They still apparently preferred grower pellets, which is perhaps not altogether surprising, but nevertheless the birds that were given the ABC supplement did consume it all.

All birds were weighed weekly and by this means the average growth rate for both treatments was monitored.

Results and Discussion.

Figure 1.14. Chicken growth rates in feeding trial.



- **Chickens fed an ABC supplement grew at least as well as controls.**

The growth rates of birds of the two treatments are clearly very similar. Chickens given the supplement did on average grow faster initially, and at 38 days (the usual age for slaughter by commercial producers) their average weight was 100g more than that of the control birds. Thereafter, the mean weights of the two treatments fluctuate around what is apparently a common growth curve. It is unfortunate that the local supply of ABC was insufficient to allow an increase in the ABC ration proportionate to that in the feed ration, since this may well have sustained a difference in the growth curves.

On the basis of the trial's findings, whilst nothing really conclusive can be said about the extent of benefits of feeding ABC to chickens, it is clear that chickens will readily eat dried, mashed ABC, which is 63% protein, and at the very least the birds' survival and growth are not adversely affected by their doing so. In the real life context of the smallholding, provision of nutritious feeder pellets is not usually an option and so the improvement in growth to be derived from providing ABC in the chicken's diet under these circumstances may be substantial. Further research during a period of ABC abundance is needed. However, on the basis of these findings farmers can be recommended to supplement the diet of their chickens by feeding them ABC. Given what is known about the yellow liquid exudate, it is recommended that ABC are killed by drowning, then rinsed, and dried if they are not for immediate consumption.

- **Acceptability of ABC-fed chickens to consumers is a consideration.**

When the possibility of feeding ABC to poultry was raised during the farmer survey of 2000, approximately half of the farmers spoken to objected on grounds that they would be concerned to eat chickens that had been fed on ABC. This is an irrational attitude, considering that bush chickens do naturally eat ABC, as well as many equally unsavoury invertebrates, including maggots from animal faeces, but it is nevertheless a real concern. In this respect it is also interesting to note that the commercial poultry producer, Tswana Pride, who were very interested in the outcome of the growth trial, provided the project with chickens on the strict understanding that on no account should it be made public that their chickens had been fed on ABC! Something of a PR exercise may be needed to convince farmers that feeding ABC to chickens does not affect the flavour of the poultry.

The ABC information booklet produced by the project includes a section on feeding ABC to poultry. Uptake by farmers in Botswana will be encouraged and supported by agricultural extension. There is also considerable interest in the Dept. of Agricultural Research and at the National Food Technology Research Centre (University of Botswana) in continuing this line of research.

Summary of findings on ABC as a chicken feed supplement:

- **Chickens eat ABC eagerly, using a killing technique that circumvents the crickets' chemical defences**
- **ABC has a high crude protein content.**
- **Chickens fed an ABC supplement grew at least as well as controls.**
- **Acceptability of ABC-fed chickens to consumers is a consideration.**

Contribution of Output to Developmental Impact.

The project has contributed to the purpose: "*improved methods for the management of principal pests of cereal-based cropping systems developed and promoted where they are a major constraint to production*" by testing and promoting improved strategies for management of ABC, appropriate for resource-poor farmers. This was achieved working in collaboration with smallholder farmers and the MoA in Botswana, and through links established with ABC specialists in other African countries where ABC is a pest. The outputs of this and the preceding project (R7428) should significantly improve farmers' ability to manage this pest throughout the region, and thereby lead to improved food security and the alleviation of poverty.

Promotion pathways and output availability to intended users.

The principal promotion pathway to target beneficiaries is through the ABC specialists from ABC-affected southern African countries who attended the ABC symposium. These individuals will receive and distribute the booklet *Biology and Control of Armoured Bush Crickets* amongst the extension service and the agricultural research department in their respective countries. Through this means the recommended measures to protect crops from ABC during an outbreak will be disseminated to the intended users, namely agricultural extension personnel and resource-poor farmers.

Further stages for development and testing.

The current project's activities were compromised to some extent by sub-outbreak population levels of ABC in 2003. This meant that field testing of the baited trench was not replicated sufficiently to produce conclusive findings and damage reduction estimates used in the economic analysis are at best approximate. The chicken feeding trial also suffered from a shortage of ABC in the later stages. All of these activities would benefit from being repeated under proper outbreak conditions.

An aspect of the project which appears particularly amenable to further research is the use of ABC as a chicken feed supplement. In Botswana, the National Food Technology Research Centre was keen to take this aspect further as were both Pest Management and Livestock sections within the Department of Agricultural Research.