*Aspects of Applied Biology 75, 2005*
*Pathways Out Of Poverty*

# New approaches to improve the livelihoods of poor farmers and pastoralists in Tanzania through monitoring and control of African armyworm, *Spodoptera exampta*

By WILFRED L MUSHOBOZI[1], DAVID GRZYWACZ[2], RICHARD MUSEBE[3], MARTIN KIMANI[3] and KEN WILSON[4]

[1]*Pest control Services, Ministry of Agriculture and Food security, Arusha, Tanzania*
[2]*Natural Resources Institute, University of Greenwich, Central Avenue, Chatham Maritime, Kent ME4 4TB, UK*
[3]*CAB International – Africa Regional Centre P O Box 633-00621, Nairobi, Kenya*
[4]*Department of Biological Sciences, Lancaster Environment Centre, Lancaster University LA1 4YQ, UK*

## Summary

A new strategy to control African armyworm in Tanzania, which combines forecasting of armyworm outbreaks with the utilisation of the natural disease of the armyworm, *Spodoptera exempta* nucleopolyhedrovirus (SpexNPV) has been developed and piloted in Tanzania. Community based armyworm forecasting (CBAF) has shown that village forecasters achieved a high level of forecasting accuracy, with 75% of all positive forecasts having corresponding outbreaks. Results from both ground and aerial applications have shown that SpexNPV is effective in controlling African armyworm if sprayed early in the outbreaks and thus could be used to replace chemical insecticides for armyworm control. Field trials indicate that SpexNPV could be produced by harvesting infected larvae from previously sprayed outbreaks. Thus, when combined with improved forecasting, SpexNPV could provide a new affordable and safe technique for the control of armyworm in Tanzania, and a new mechanism for the strategic control to this important migratory pest.

**Key words:** African armyworm; *Spodoptera exempta*; SpexNPV; Community Based Armyworm Forecasting (CBAF)

## Introduction

The African armyworm, *Spodoptera exempta* (Walker) (Lepidoptera: Noctuidae), is a serious outbreak pest of cereal crops and grasslands in eastern and southern Africa, devastating small-scale subsistence farms and commercial production alike (Rose *et al.,* 2000). Crops most frequently attacked by the larval stage of this pest are maize, sorghum, millet, wheat and rice, and to a lesser extent teff, barley and sugar cane (Haggis, 1984, 1987). The first armyworm outbreaks appear in Tanzania and Kenya and are serious in nine out of ten years; in 2001 they covered 157 000 hectares of crops and pasture (affecting about 80 000 smallholder farms in 54 districts) . In major outbreak years, the adult moth stage of the pest migrates to cause extensive damage in Uganda, Ethiopia and Eritrea and may travel as far as Yemen (Rose *et al.,* 2000). Indirect losses to livestock due to armyworm outbreaks in pastures are sometimes severe, due to a combination of starvation and poisoning. The latter occurs when cattle graze on pastures recently infested with armyworm, causing some species of grasses to become cyanogenic (Giorgiadis & McNaughton, 1988); in one famous incident up to 100 cattle were killed (Rose *et al*., 2000) due to a phenomenon known as armyworm related cattle poisoning (ARCP).

The major issues in armyworm control are the effectiveness of forecasting and the cost and feasibility of control. A survey carried out in 2002 in four high-risk armyworm districts, showed clearly that the central armyworm forecast service, as it was originally conceived (Odiyo, 1979, 1990), is not currently meeting the needs of the farmers who suffer most from armyworm outbreaks; less than 25% of all farmers interviewed could recall ever having received a forecast (Njuki & Mushobozi, 2003). The same survey also confirmed that the control strategy of relying on expensive imported chemical insecticides is also failing to protect most of the poor farmers, as in most years only 30% of the outbreaks are treated. This is partly due to cost, as many poor farmers are unable to afford the US\$10 $ha^{-1}$ chemical costs (Iles & Dewhurst, 2002). Secondly, spraying large areas of food crops and pastures with insecticides is environmentally undesirable, particularly where safety procedures are not well known and protective clothing is rarely used. A third problem is that pesticides are not always available when required, particularly in areas where subsistence cropping systems predominate and the use of agricultural inputs is limited.

To address these problems, a research project has been initiated in Tanzania to explore alternative, non-chemical control for armyworm, including a naturally occurring pathogen of armyworm, the *S. exempta* nucleopolyhedrovirus (SpexNPV), which is cheap, safe and can be produced locally and, at the same time, to develop armyworm forecasting and decision tools appropriate for rural communities (Grzywacz & Mushobozi, 2004).

The main problem with armyworms is that they are highly migratory, so that larval outbreaks can appear very suddenly at very high density, catching farmers unawares and unprepared. The conventional strategy for the management of armyworm has been to rely on centralised decision-making and forecasting using a national system of pheromone-based armyworm moth traps. The delays in communication between local and national level have meant that decision-making has often been late, giving too little warning for farmers to plan and implement control. Community based armyworm forecasting (CBAF) aims to place traps within communities and train farmers' representatives to act as scouts for their own communities, thus overcoming the communication problems that have limited the dissemination of centralised forecasts.

The SpexNPV was identified as an important pathogen of armyworm by Brown & Swaine (1965). This NPV is a naturally occurring virus specific to *S. exempta* that causes a highly infectious disease of the armyworm (Odindo, 1981). Subsequent studies have confirmed that this disease is endemic in many parts of East Africa (Odindo, 1983). The SpexNPV is rarely apparent in primary outbreaks of the pest, appearing only later in the season after which it spreads rapidly but can be highly localised affecting only small parts of the outbreak area. Some early trials using simple crude suspensions of SpexNPV as a biopesticide were carried out in the early 1960s (Brown & Swaine, 1965). Although there was some further interest in using SpexNPV as a biopesticide (McKinley *et al*., 1977), including some safety testing (Harris, 1973), with the adoption of cheap pyrethroid insecticides interest in adopting a biological armyworm control waned. However, since the mid-1990s increasing concern about the high cost and adverse environmental impact of synthetic chemicals has led to an interest in the re-evaluation of the potential use of SpexNPV. In part this was because some key issues about the cost and feasibility of producing biological pesticides such as NPVs have been overcome through the development of cheap field-based production systems that has made these agents more economically feasible for production and use in developing countries (Moscardi, 1999).

A programme of field trials of SpexNPV has been conducted in Tanzania 2001–04 assessed the effectiveness of the virus in comparison to existing chemical controls and locally available botanical insecticides. The results of these trials indicate that SpexNPV applied at a rate of $1 \times 10^{12}$ occlusion bodies (OB) per hectare can be as effective as chemical insecticides (Grzywacz *et al.,* in prep.) if applied early in the outbreak cycle.

Crucial to the viability and sustainability of SpexNPV as an armyworm control in East Africa will be its availability and production cost. SpexNPV can be produced in dedicated NPV production plants through in vivo production in cultured *S. exempta* (Cherry *et al.,* 1997), but the cost is likely to be at least comparable to or higher than existing chemical insecticides, a cost Tanzania already cannot afford. In order to be a really viable option, SpexNPV would need to be produced at a cost lower than that of the current chemical insecticides (≥ US$10 $ha^{-1}$). An alternative to producing NPV in dedicated production plants is to use field production. Field production works by infecting host outbreaks in the field and harvesting the dying infected insects as a source of NPV. Given the ability of armyworm to produce outbreaks with very high densities of larvae (>500 $m\text{-}^{2}$) this species would seem very promising as a candidate for field production. One such field production system has been developed by the EMBRAPA research institute in Brazil for producing *Anticarsia gemmatalis* NPV (AgNPV) at a cost of US$1.26 $ha^{-1}$ (Moscardi, 1999). This is used to produce some 40 tonnes of infected insects annually that are processed into a biological insecticide used now on some two million hectares of soy crop each year.

A major challenge to adoption of this system of production is to assess if collection of SpexNPV from field-infected insects is practicable. The AgNPV is cheap to produce partly because, when the infected insects die, they remain intact making manual collection of the insects and the propagated virus relatively easy. However, unlike AgNPV, the SpexNPV expresses enzymes (chitinases and cathepsins) late in the replication cycle that weaken the larval cuticle so facilitating the release of infective particles and further transmission. This cuticular thinning and larval fragility in SpexNPV might make direct collection of SpexNPV, cheaply and on a large scale, impracticable. Thus, as part of this study, experiments were undertaken to determine if the mass collection of virus infected armyworm from field outbreaks was viable.

## Materials and Methods

### *Community based armyworm forecasting (CBAF)*

Twenty villages from three districts, Hai, Kilosa and Moshi, participated in the implementation of CBAF in 2002, 2003 and 2004. The villages and districts were selected on the basis of being at high risks of armyworm outbreaks, with each village having an average of 3000 people. A meeting was held in each village to provide an overview of CBAF and to discuss the forecast communication strategy. Each village democratically elected two farmers, one lead forecaster and an assistant who would attend a 2-day training workshop accompanied by the village extension officer and the village government executive officer**.** At the end of the training workshop, each village was presented with a forecasting pack (pheromone trap, pheromone lures and a can of pesticide, rain-gauge, and file with record sheets) and an operator's manual for the rain-gauge and trap. Farmers were then left to set-up a trap on their own and to make weekly forecasts in their village. Mid-season assessment and end of season evaluation were carried out to:

1. Determine the performance of the forecasters.
2. Assess the effectiveness of forecasting information flow among the stakeholders, i.e. forecasters, farmers, village government, extension officers and district authorities.
3. Assess the farmers' response to forecasts and perceptions about community forecasting.

The monitoring indicators included:

- forecasters making correct forecasts
- positive forecasts with outbreaks
- negative forecasts without outbreak
- proportion of farmers monitoring and controlling.

The evaluation was made using questionnaires for individual farmer interviews and checklists for the focus group discussions with farmers and discussions with the other stakeholders. One hundred farmers were interviewed individually and focus group discussions were conducted with

78 farmers in all the five villages designated for the evaluation.

*SpexNPV production field trials*

The aim of the first trial was to determine the most productive system for harvesting SpexNPV and to estimate the amount of SpexNPV that can be collected per man-hour using different collection systems. This trial was carried out in 2004 on natural armyworm outbreaks occurring at a site near Arusha in Tanzania. An outbreak of armyworm on typical mixed grassland was detected and these were sprayed with SpexNPV as III instar at an inoculating rate of $5 \times 10^{12}$ OB $ha^{-1}$. The virus was applied by a motorised mistblower at an application rate of 50 L $ha^{-1}$ with 0.1% Triton-X as a surfactant. The trial was inspected daily from 5 days after application and when infected larvae were observed to be present, after 5 days, larval collection trials were carried out. The baseline counts showed there were 362 armyworm larvae $m^{-2}$ at the start of the trial. Each trial treatment used nine casual labourers, who each collected larvae using all four methods in a random sequence. The same collectors were used throughout.

On each day, four types of collection were planned:

(a) collect only NPV-killed larvae
(b) collect dead and live larvae
(c) cut grass hosting NPV-killed larvae
(d) cut grass hosting any armyworm larvae (both NPV killed and alive).

Collectors were issued with marked pre-weighed plastic bags and set to collect for one hour using each method. Each collection took place in a different area of infestation. After one hour of collecting, a total weight of larvae collected for each person was recorded separately. Samples were kept in separate containers for later processing and OB counting, using standard baculovirus counting protocol (Wigley, 1988). Four collections were made at 6, 7, 9 and 10 days after the outbreaks were sprayed with SpexNPV. No collections were made prior to day 6 as very few infected larvae were seen before then. After day 10, harvesting was abandoned as few larvae were seen to be present. Data were analysed using standard statistical methods (ANOVA) using the SPSS statistical package on untransformed weight data. The normality and equal variances of data were checked using the Levene's procedure for equality of variances and an unstandardised residual variance plot in SPPS.

## Results

*Community based armyworm forecasting (CBAF)*

The results presented here are from the evaluation carried out in July 2004 in five villages in Moshi District. Table 1 shows the performance of the Mabogini village forecaster and the accuracy of the forecasting rules. Overall the evaluation revealed that the forecasters' records were accurate and generally consistent with the forecasting rules. There was, however, variation with respect to the adherence to the forecasting rules and the accuracy of the forecasting rules (Table 3). In order to assess how well the forecasters understood and followed the forecasting rules, their forecasts were compared with those that should have been according to the forecasting rules. The results showed that positive farmer forecasts were correct 25/30 times and negative forecasts 55/55 times.

Thus farmers never forecasted positive when they should have forecast negative. On the five occasions when a negative forecast issued this was because the current week's data did not indicate a positive forecast but the previous week's did. However, there was only one outbreak on these occasions. The accuracy of the forecasting rules was established by cross-checking the forecasting information/records with the actual outbreaks, as reported by the farmers on a weekly basis. Farmers were asked to provide information on the timing of any armyworm outbreaks. The farmers' information was tallied with the forecasters' records and assessed (Table 2). Seventy four

Table 1. *Mabogini village forecaster's records for February–May 2004*

| Week No. | Date (2004) | No. of Moths | Rainfall (days with >5 mm) | Vegetation | Farmers' forecast | Correct forecast | Outbreak |
|---|---|---|---|---|---|---|---|
| 1 | 31 Jan–6 Feb | 38 | 2 | Yes | Positive | Positive | Yes |
| 2 | 7 Feb–13 Feb | 25 | 0 | Yes | Negative | Positive | Yes |
| 3 | 14 Feb–20 Feb | 43 | 1 | Yes | Positive | Positive | Yes |
| 4 | 21 Feb–27 Feb | 138 | 1 | Yes | Positive | Positive | Yes |
| 5 | 28 Feb–5 Mar | 178 | 1 | Yes | Positive | Positive | Yes |
| 6 | 6 Mar–12 Mar | 198 | 1 | Yes | Positive | Positive | Yes |
| 7 | 13 Mar–19 Mar | 386 | 1 | Yes | Positive | Positive | Yes |
| 8 | 20 Mar–26 Mar | 121 | 3 | Yes | Positive | Positive | Yes |
| 9 | 27 Mar–2 Apr | 79 | 3 | Yes | Positive | Positive | Yes |
| 10 | 3 Apr–9 Apr | 93 | 3 | Yes | Positive | Positive | Yes |
| 11 | 10 Apr–16 Apr | 281 | 3 | Yes | Positive | Positive | No |
| 12 | 17 Apr–23 Apr | 21 | 0 | Yes | Positive | Positive | Yes |
| 13 | 24 Apr–30 Apr | 2 | 2 | Yes | Negative | Negative | No |
| 14 | 1 May–7 May | 0 | 0 | Yes | Negative | Negative | No |
| 15 | 8 May–14 May | 3 | 1 | Yes | Negative | Negative | No |
| 16 | 15 May–21 May | 0 | 2 | Yes | Negative | Negative | No |
| 17 | 22 May–28 May | 7 | 0 | Yes | Negative | Negative | No |

per cent of all positive forecasts had corresponding outbreaks, while 26% had no outbreaks. Out of all negative forecasts (n = 54), 96% had no outbreaks while less than 4% were followed by an outbreak.

Table 2. *Accuracy of the forecasts*

| Correct forecasts | Outbreaks | |
|---|---|---|
| | No | Yes |
| Positive | 8 | 23 |
| Negative | 52 | 2 |

Table 3 compares farmer perceptions of armyworms prior to, and after, the implementation of CBAF.

*SpexNPV production field trials*

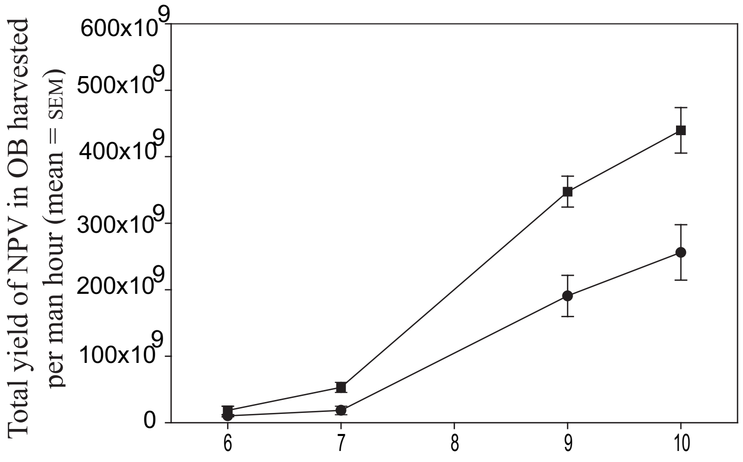
In the production trial of the four harvesting methods that it had been intended to evaluate, the two that involved collecting insects directly, treatments (a) and (b), were not practicable. This was because NPV-killed insects broke up when being collected and it was not possible to harvest larvae alone. Thus, direct hand-picking of larvae, as used in Brazil for AgNPV, was not feasible. The techniques that involved cutting grass to harvest insects, treatments (c) and (d), did produce viable

Table 3. *How farmer perceptions change due to CBAF (%)*

| Characteristic/attribute | Before (%) | After (%) | Change (%) |
|---|---|---|---|
| Moths are a precursor to armyworm outbreaks | 36 | 90 | + 54 |
| Knowledge of armyworm forecasting | 48 | 80 | + 32 |
| Access to forecast information | 28 | 64 | + 36 |
| Farmers monitoring fields | 48 | 92 | + 44 |
| Farmers attempting control with various methods | 28 | 77 | + 49 |
| Control at stages (instars) I & II | 20 | 61 | + 41 |

material and comparative data were collected. When cutting grass on which armyworm larvae were attached, the disturbance caused many larvae to become agitated and drop to the ground. However, it was observed that larvae in the later stages of NPV infection, or dead, remained attached to grass stems so it is unlikely that much harvestable NPV was lost. The yield of NPV from these two treatments is shown in Fig. 1. Selective harvesting of grass with NPV-killed larvae only attached was less productive than non-selective harvesting of grass with any larvae attached on all days

The virus yields of the two treatments on days 9 and 10 were significantly different (ANOVA: F = 8.847, df = 1, 32, $P = 0.0055$). For both collection methods, harvesting on day 7 or before produced lower yields of SpexNPV than harvesting at day 9 or later. Collections on day 7 produced as much material by weight as later days but, crucially, the NPV content in these samples was very much lower. The failure to obtain high yields of SpexNPV OBs prior to day 9 is probably because the insects appearing to be infected on the earlier days had not completed the full viral replication. It was observable that in samples processed from insects harvested from days 6 and 7, the OBs seemed smaller than in those from days 8 and 9.




●, (C) Harvesting grass with NPV dead larvae; ■, Harvesting grass with dead and live larvae

Fig. 1. Yield of SpexNPV from field production trials in Tanzania 2004.

## Discussion

*Community based armyworm forecasting*

Community based armyworm forecasting proved to be an effective way of warning farmers against the impeding armyworm outbreaks. Farmers trusted the forecast information because they found a direct correspondence between the forecast and the appearance of armyworms. Seventy four per cent of the positive forecasts were followed by armyworm outbreaks. Farmers appreciated early warning information because forecasting was at the local level and gave them time for control measures to be implemented reducing the level of crop damage. A greater sense of ownership of the process has increased the likelihood that farmers will act on forecasts. The major constraint that the national forecast usually failed to reach the people who needed it has been overcome by putting forecast generation in the hands of the people who use it. The use of a community based forecast to alert farmers to the need for crop monitoring offers considerable promise as it is both feasible and cost-effective. Two years after the pilot studies in Tanzania, there has been a demand for similar approach to be implemented in neighbouring countries – Kenya and Ethiopia being the first countries to copy our new approach. The Government of Tanzania and USAID funded the scaling up of the same approach in Hai and Moshi districts of Tanzania. The achievements made so far have demonstrated that poor rural farmers should be true partners in any research activity that is meant to improve their livelihoods.

Early small-scale field trials of the SpexNPV virus in Tanzania showed that a high level of kill (>90%) could be achieved in the field (Grzywacz, 1999). More recently, a series of larger-scale field trials, conducted between 2002 and 2004 using ground application, has shown that if SpexNPV is applied to outbreaks when larvae are less than a week old before serious damage occurs, control equivalent to that obtained by chemical insecticides can be obtained (Grzywacz *et al.,* 2004; Grzywacz *et al.,* in prep.). Data from these trials shows that SpexNPV takes longer to act than conventional insecticides but an aerial trial conducted as part of the 2004 study showed that >80% NPV-induced death could be achieved within 4 days of application. The results of these trials have convinced the Pest Control Services of the Tanzanian Government that SpexNPV is a potentially feasible replacement for chemical control, especially if effective forecasting to enable early treatment of outbreaks can be achieved and a low-cost production method can be developed.

The harvesting work described here clearly shows that feasible quantities of SpexNPV can be collected from artificially infected armyworm outbreaks The simple manual harvesting systems tested in this trial produced an NPV yield rate of $4 \times 10^{11}$ OB per man-hour. Given the current SpexNPV application rate is $1 \times 10^{12}$ OB $ha^{-1}$ it would take 2.5 man-hours to harvest enough SpexNPV to treat 1 hectare. With a six-hour working day at a wage of US$3 $day^{-1}$ this suggests that SpexNPV could be produced by this method, excluding processing costs, at a maximum of just US$1.5 $ha^{-1}$. Clearly, the collection of armyworm NPV using a simple manual system of using scissors and plastic bags is not likely to be the most cost-effective for large-scale production, and the scaling up to better bulk collection of grass and larvae would probably require mechanisation. The next stage would be to test a mechanical harvesting system.

Further work in 2005, in collaboration with EMBRAPA Brazil, has continued to look at low-cost formulation and production techniques and has shown that the low-cost processing and formulation system developed for production of AgNPV (Moscardi, 1999) can be used to produce SpexNPV. This work is continuing to develop and fine tune such a system for producing SpexNPV formulation in Tanzania.

### *Strategic control of armyworm by NPV*

Finally, the development of SpexNPV for biocontrol of armyworms potentially offers important benefits to poor farmers not just in Tanzania, but throughout eastern and southern Africa. Conventionally, armyworm control is implemented when the caterpillars are feeding on food crops, with the aim of yielding an immediate and direct benefit in terms of reduced crop damage and increased yield. However, there is the potential for a complementary strategy for armyworm limitation, known as 'strategic control'. This is a strategy in which the pest is controlled in particular areas regardless of which host plant it is feeding on, with the aim of preventing such infestations from acting as source populations for future pest outbreaks at the same sites or elsewhere (Rose *et al.,* 2000). Thus, the benefits are longer term and indirect. Strategic control is particularly appealing for migratory pest species, because it can help to limit the geographical spread of the pest, so allowing resources for its control to be better focused.

African armyworm moths are highly migratory, being able to migrate 100 km or more per night over several nights (Rose *et al.,* 1985). Their movements are largely governed by the seasonal progression of the inter-tropical convergence zone (ITCZ). Thus, armyworm outbreaks in southern and central Tanzania will act as source populations for moths that will migrate to northern Tanzania and Kenya. The offspring of these moths will ultimately migrate further northwards towards countries such as Sudan, Ethiopia, Somalia and as far north as the Yemen (Rose *et al., 2000*). Similar mechanisms are probably responsible for the southwards progression of armyworm outbreaks towards Malawi, Zimbabwe and South Africa. Thus, by controlling early-season outbreaks over large areas of central/southern Tanzania, it may be possible prevent subsequent outbreaks from occurring in Tanzania and elsewhere later in the season.

Whilst strategic control of armyworm appears to be both desirable and economically cost-effective (Cheke & Tucker, 1995), there are a number of problems associated with implementing this policy using conventional insecticides. First, it is generally considered undesirable to inundate the environment with large amounts of toxic chemicals that could provide a health risk to humans and their livestock, as well as to beneficial non-target insects. Second, even if this was not a consideration, it is unlikely that enough of the key outbreaks could be controlled using conventional insecticides, due to restrictions associated with spraying chemicals in National Parks and other sensitive wildlife areas. Third, there are major concerns over the growing stockpiles of toxic chemical pesticides accumulating in developing countries that lack the finances to dispose of them safely. The scale of this problem is such that the Government of Tanzania is to receive US$ 8 million from World Bank and other donors to dispose 1200 tonnes of these obsolete pesticides However, neither of these problems is associated with armyworm control using SpexNPV, due to the benign nature of the product. In addition, there are a number of benefits associated with using this biopesticide. Firstly, the virus is self-replicating, which means that it not only kills the caterpillars that ingest the virus that is sprayed during the control operation, but also new virus particles are produced in the bodies of these lethally-infected caterpillars which then become available to infect new hosts several days later. Thus, the virus may be effective at killing armyworms for days or even weeks after the control operation has moved on. Secondly, and perhaps more importantly, associated studies have shown that *sub-lethally* infected parents are capable of passing on *lethal* infections to their offspring via vertical transmission of the virus through the ova (Vilaplana *et al.,* in prep; see also Swaine, 1966), and these may trigger new virus epizootics. Thus, not only does NPV result in effective control of armyworms, but (potentially at least) it also provides a mechanism of biocontrol of future outbreaks elsewhere, as the virus migrates from outbreak to outbreak with sub-lethally infected moths. Thus, the benefits associated with SpexNPV biocontrol of armyworms now makes it feasible, for the first time, to apply strategic control to this important migratory pest species with the immense benefits this would generate for all farmers in this region.

## Acknowledgements

The authors wish to acknowledge the United Kingdom Department for International Development (DFID) Crop Protection Programme for providing funds and resources to implement Community Based Armyworm Forecasting(CBAF) and SpexNPV field trials, USDA-ARS for additional funds to carry out NPV aerial spray trials, USAID for additional funds to implement CBAF in Moshi District. The authors also wish to thank Mark Parnell and Libby Redman for field logistics support. The views expressed are not necessarily those of DFID.

## References

**Brown E S, Swaine. G. 1965**. Virus disease of the African armyworm, *Spodoptera exempta* (Walker). *Bulletin of Entomological Research* **56**:671–684.

**Cheke R A, Tucker M N. 1995**. An evaluation of the potential economic returns from the strategic control approach to the management of african armyworm *Spodoptera exempta* populations in East Africa, *Crop Protection* **12**:91–103.

**Cherry A J, Parnell M, Grzywacz D, Brown M, Jones. K A. 1997.** The optimisation of *in vivo* nuclear polyhedrosis virus production of *Spodoptera exempta* (Walker) and *Spodoptera exigua* (Hubner). *Journal of Invertebrate Pathology* **70**:50–58.

**Grzywacz D. 1999** Entomopathogenic viruses for control of armyworm *Spodoptera exempta*. *Final Technical Report of DFID Crop Protection Programme project R 6746*. NR International, Alyesford UK. 45 pp

**Grzywacz D, Mushobozi W. 2004.** A local solution to African Armyworm. *Biocontrol News and Information* March 25:7–8N.

**Georgiadis N J, McNaughton S J. 1988.** Interactions between grazers and a cyanogenic grass. *Cynodon plectostachyus*. *Oikos* **51**:343–350.

**Haggis M J. 1984**. Distribution, frequency of attack and seasonal incidence of the African armyworm *Spodotptera exempta* (Walk.) (Lepidoptera: Noctuidae), and with particular reference to Africa and southwestern Arabia. *TDRI Report*, No. L69. London: Tropical Development and Research Institute.

**Haggis M. 1987.** Distribution, frequency of attack and seasonal incidence of the African armyworm *Spodoptera exempta* (Walk.) (Lep. Noctuidae), with particular reference to Africa and southwestern Arabia. *NRI bulletin L69*. Chatham, UK: Natural Resources Institute.

**Harris R J C. 1973.** Safety testing of NPV of *Spodoptera exempta* Centre for Overseas Pest Research London. *Technical Report 531 Annex 2*. pp. 44–48.

**Iles M, Dewhurst C. (eds) 2002.** Responses by farmers to African Armyworm outbreaks. *Field survey data from Kenya and Tanzania*. A synopsis of previously unpublished data. Chatham, UK: Natural Resources Institute.

**McKinley D J, Brown D A, Payne C C, Harrap K A. 1977**. Cross infectivity and activation studies with four baculoviruses. *Entomophaga* **26**:79–90.

**Moscardi F. 1999.** Assessment of the application of baculoviruses for control of Lepidoptera. *Annual Review of Entomology* **44**:257–289.

**Njuki J, Mushobozi W. 2003.** Improving armyworm forecasting and control in Tanzania: a socio-economic survey. *CABI ARC Nairobi, 39*, Unpublished.

**Odindo M O. 1981.** Dosage-mortality and time-mortality responses of the armyworm *Spodoptera exempta* to a nuclear polyhedrosis virus. *Journal of Invertebrate Pathology* **38**:251–255.

**Odindo M O. 1983**. Epizootiological observations on a nuclear polyhedrosis of the African armyworm *Spodoptera exempta* (Walk.). *Insect Science and its Application* **4**:291−298.

**Odiyo P O. 1979** Forecasting infestations of a migrant pest: the African armyworm, *Spodoptera exempta* (Walk.). *Philosophical Transaction of the Royal Society of London*, Series B **287**:403–413.

**Odiyo P O. 1990.** Progress and developments in forecasting outbreaks of the African armyworm, a migrant moth. *Philosophical Transactions of the Royal Society of London*, Series B **328**:555–569.

**Rose D J W, Page W W, Dewhurst C F, Riley J R, Reynolds D T, Pedgley D E, Tucker M R. 1985.** Down-wind migration of the African armyworm moth, *Spodoptera exempta*, studied by mark-and-capture and by radar. *Ecological Entomology* **10**:299–313.

**Rose D J W, Dewhurst C F, Page W W. 2000.** *The African Armyworm Handbook: The Status, Biology, Ecology, Epidemiology and Management of* Spodoptera exempta *(Lepidoptera: Noctuidae)*. Second Edition. Chatham, UK: Natural Resources Institute. ISBN 0 85954 523 7. 304 pp.

**Swaine G. 1966.** Generation to generation passage of the nuclear polyhedrosis virus of *Spodoptera exempta* (Wlk). *Nature* **210**:1053–1054.

**Vilaplana L, Redman E M, Wilson K, Cory J S. In preparation**. Vertical transmission of nucleopolyhedrovirus in solitary and gregarious forms of the African armyworm,*Spodoptera exampta.*

**Wigley P J. 1988**. Practical counting of micro-organisms. In *Microbial control of insect pests*. pp. 9–35. Eds J Kalmakoff and J F Longworth. New Zealand Department of Science and Industrial Research, Bulletin 228, Wellington, New Zealand.