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Strategies for integrated management of cotton bollworm complex in Zimbabwe: A review

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Abstract

In cotton production, there are many factors that can reduce crop yield. One important cause is arthropod insects. Insects that cause loss to the fruit are frequently more destructive than those that damage leaves, stems, and roots. Cotton in Zimbabwe is subjected to yield and quality loss due to various lepidopterous pests. The African bollworm (*Helicoverpa armigera*), red bollworm (*Diparopsis castanea*), spiny bollworms (*Erias insulana* and *E. biplaga*) and pink bollworm (*Pectinophora gossypiella*) causes the greatest yield loss annually. This review describes integration of pest control tactics directed against the bollworm pest complex which put together the most effective mixture of tactics, allowing control of pests while keeping in mind the productivity of the fields, the role of beneficial organisms and safety considerations.

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Introduction

Integrated pest management (IPM) has been defined as a sustainable approach to managing pests by combining biological, cultural, physical and chemical tools in a way that minimizes economic, health and environmental risks (Greenberg *et al*., 2012). IPM involves a number of pest management practices that are both location and crop specific. It has also been defined as a knowledge-based decision-making process that anticipates limits and eliminates or prevents pest problems, ideally before they have become established (Greenberg *et al*., 2012). Finally, IPM is the intelligent selection and use of pest control actions that ensures favourable economic, ecological and sociological consequences (Sandler, 2010). IPM typically combines several strategies to achieve long term solutions, maximise value to the farmer and minimise risks to the environment. It focuses on long term prevention or suppression of pest problems through a combination of techniques.

Integration or compatibility among pest management tactics is central to IPM. Simply mixing different management tactics does not constitute IPM. Mixing the tactics arbitrarily may actually cause pest problems or create other unforeseen effects (Ehi-Eromosele *et al*., 2013). IPM recognizes there is no "cure-all" in pest control. Reliance on a single tactic will favour pests that are resistant to that practice. In IPM, integrated control seeks to identify the best combination of chemical and biological controls for a given insect pest (Ehi-Eromosele *et al*., 2013).

Pest species attacking cotton

A variety of insects can cause damage to cotton, both quantitative and qualitative. Various lepidopteran species have been recorded as either major or sporadic/minor pests of cotton in Zimbabwe such as, excluding the cotton bollworm complex, cutworms (*Agrotis spp*), false pink bollworm (*Sathrobota simplex*), cotton leaf worm (*Spodoptera littoralis*), cotton semi-loopers (*Anomis flava, Xanthodes graellsi, Chrysodeixis spp* and *Trichoplusia spp*) (CGA, 1998).

Several other pest are listed as sucking pests and these include aphids (*Aphis gossypyii*), whiteflies, jassids, cotton strainers, red spider mites, lygus, thrips and stink bugs. Soil pests include termites, false wireworm and nematodes which destroy root system. The majority of insect pests on cotton are polyphagous, for example the different bollworm species, cutworms, aphids and whiteflies. The most important lepidopteran pests of cotton are the bollworm complex that feed on the reproductive plant parts of the cotton plant (Morse *et al*., 2006). Some of the pest species of cotton in Zimbabwe are oligophagous, for example the cotton strainers and red bollworms. Cotton stainers (Hemiptera: Heteroptera) are an important group of insects that stains the fibre and cause a reduction in the quality of the cotton.

The bollworms complex in cotton

In Zimbabwe the bollworm complex consists of five species namely the Red bollworm (*Diparopsiscastanea*) (Hampson) (Lepidoptera: Noctuidae) African bollworm (*Helicoverpa armigera*) (Hübner) (Lepidoptera: Noctuidae), two Spiny bollworms species (*Earias biplaga* Wlk. and *E. insulana* Boisd.)(Lepidoptera: Noctuidae) and Pink bollworm (*Pectinophora gossypiella* Saunders) (Lepidoptera: Noctuidae) (CGA, 1998).

The red and African bollworms are the key bollworm pests and can cause yield losses of up to 60 % (Brettell, 1986; Matthews and Tunstall, 1994). Pink bollworm is one of the most destructive pests of cotton in many areas of the world, including in India, China, Brazil and the western USA. In Zimbabwe it is potentially a serious pest which is under check by regular destruction of crop residues. Spiny bollworm damages all stages of the plant. It can appear especially serious in the first 20-30 days because the young plant has only one to several terminals - which are killed. Throughout its range these species are sporadic in terms of their appearance in one place and not another, and on one season but not the next - even within a season (Vennila *et al*., 2007).

Major damage is caused by bollworm larvae feeding on buds and bolls. Control methods for red and African bollworms are based on applying chemicals according to egg levels so that as the larvae move to feeding points after hatching, they come into contact with the chemical at their most vulnerable stage.

General life cycle of lepidopteran pests

Their life cycles follow a similar broad pattern. Female moths live for up to two weeks, and lay a large number of eggs at night; these hatch in three or four days in summer. The larvae develop through five stages, which in summer take about three weeks, before they pupate. The summer pupal stage lasts approximately two to three weeks; diapausing pupae (or larvae) take very much longer to develop. Low temperatures also extend the life cycle (CGA, 1998).

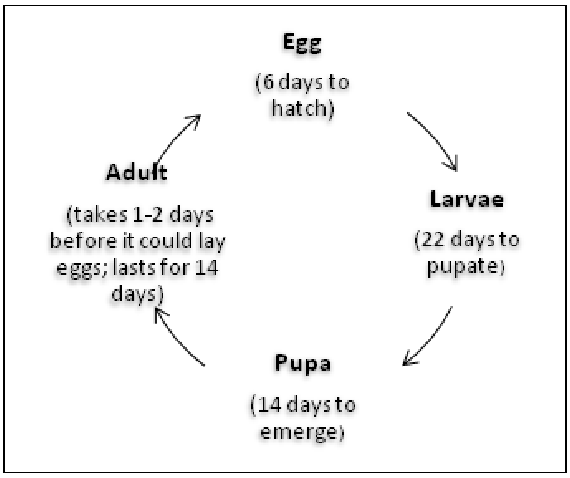

Fig. 1.

Red bollworm (Diparopsis castanea Hampson)

Life stages description

The Egg (up to 6 days): The eggs are sub spherical, about 0.5-0.7 mm in diameter. They are sky blue when freshly laid and later change to grey just before hatching (CGA, 1998). They are laid on all parts of the plant and often in obscure sites (CGA, 1998).

The Larvae (up to 22 days): The newly hatched larvae (1st instar) have a big head relative to its body size. The 14 legged larvae is greenish yellow in colour with rose-red arrowhead markings on each segment. The larvae are hairless and usually have a shiny skin. The fully grown larvae are about 25-30 mm long.

Pupae (up to 13 days): Larvae pupate within the top 70 mm of soil. Pupae are therefore protected by a soil casing (Pretorius, 2011). Pupae that are formed early in the season emerge as moths within a few weeks of pupation. The pupa is brown and becomes dark brown when about to emerge (Anonymous, 2015).

Moth/adult (up to 14 days): The moth of the red bollworm has a wingspan of up to 35 mm. The forewing has three curved transverse lines demarcating four areas consisting of a reddish area at the base (Pretorius, 2011). The hind wings and abdomen are largely cream in colour. Moths are active during the night and the females lay approximately between 250-300 eggs, more than half of which are laid in the first two weeks (Pretorius, 2011).

Damage and economic importance

The cotton plant is the main host for the larvae and it attacks all developmental stages of the cotton fruit (boll). Red bollworm causes damage to buds, flowers, tip and bolls. The cotton boll is normally completely destroyed. Though limited host range, the Red bollworm is oligophagous (almost monophagous) and it's mainly found on, cultivated and wild *Gossypium* species and a related Malvaceous host, *Cienfugosia hildebrandti* (Taylor, 2015). Poor control of this pest at the end of the season will generally lead to heavier attacks in the following season. Early planted cotton will generally suffer an early red bollworm invasion which can be avoided by planting later (CGA, 1998). However, considering the changes happening to the climate which might have resulted in a shift of planting dates forward, research has to be done to determine the effect of planting dates on cotton pests.

African bollworm (Helicoverpa armigera Hubner. Syn. Heliothis armigera Hubner.)

Life stages description

Eggs (up to 3 days):The freshly laid eggs are a whitish-yellow colour (off white colour) and have 28 longitudinal ridges, are generally laid on the upper half of the plant (CGA, 1998).

The eggs are almost spherical (pomegranate shaped) and are laid in single layers on the upper surface of leaves.

Larvae (14 - 17 days): The first and second instars larvae are yellowish to reddish brown in colour; the head and prothoracic legs are dark brown to black in colour. The fully grown larvae are bordered by a characteristic pale line along the back and on either side of its body (which runs longitudinally). It appears in different colours but usually green or brown; they are about 30 – 40 mm long (CABI, 2014), diet and environmental conditions greatly influences attainment of full size.

Pupae (up to 18 days): Pupation may occur in the tip of maize cob or in the soil at depth of 3 – 15 cm. After feeding ceases, larvae burrow into soil around plants and pupate where they spend 12 to 18 days (Bohmfalk *et al*., 2011). The pupa is brown in colour and when disturbs it exhibits some minor movements.

Moth (9-12 days): This is the adult stage. The adult moth emerges after between 18 days and six months (winter diapause). It has brown forewings with a delicate darker tracery around a single dark mark on each wing. The hind wings are buff with a dark border which contains a light patch (Zborowski P and Edwards T, 2007). The undersides are buff with dark sub marginal bands on each wing, and each forewing also has a black comma mark and a black full stop.

Damage and economic importance

In addition to cotton, other suitable hosts for *H. armigera* are tobacco, maize, sorghum, cowpeas and tomatoes. Direct damage to cotton is caused by larvae which feed on various parts of the crop. *H. armigera* is known to destroy leaves, buds, flowers and bolls (Rahman, 2012). Only the largest larvae will be found attacking fully developed bolls. Extensive damage to young fruiting bodies can occur rapidly during peak infestation. A damaged boll may show a distinct circular opening and be only half eaten. The larvae can cause considerable flower and boll loss due to its activities. Two to three larvae on a plant can destroy all the bolls within 15 days (Plantwise Knowledge Bank, 2012) in total in Zimbabwe can cause 1175kg/ha (Gledhill, 1976).

Spiny bollworm – Earias insulana Boisd. and Earias biplaga Wlk.

Life stages description

Eggs: The eggs (incubation 3 – 4.5 days) are very small and whitish blue when freshly laid which turns to light blue-green and later brownish just before hatching (Shah *et al*., 2014); green (CGA, 1998), roughly spherical and difficult to see on the crop; larval counts are thus used to determine control requirements (CGA, 1998). The 0.5 cm eggs are laid singly mainly on the leaf lamina, young shoots, peduncles or flower buds (Bacheler and Mott, 2009).

Larvae: The newly hatched larvae of spiny bollworm are light yellowish brown in colour with black spots on its body and measures about 1.3 – 2.5 mm length (Shah *et al*., 2014). The caterpillars are stout and spindle shaped greeny-brown with long spines on each segment. The fully grown larva measures 7 – 14 mm. Larval period last for 8 – 16 days.

Pupae: When the larva is ready to pupate it spins a cocoon between boll wall and the bracteoles. Pupa is brown in colour. The cocoon may also be attached to a withered leaf or twig or among surface debris on the soil surface (Assem *et al*., 1974). The pupal period may last for 8 – 16 days.

Moth: The two moth species, *E. biplaga* and *E. insulana* occur in Africa. These two species differ mainly in the colour pattern of the forewing. In *E. insulana* the colour of the forewings vary from silvery green to straw yellow and the outer fringe has the same colour. The colour of the wings of *E. biplaga* varies from a metallic green to gold with a dark brown outer fringe (Pretorius, 2011). The several thin dark lines on the forewings constitute a clear pattern which differs only slightly between the two species

Life cycle of spiny bollworm lasts 30 to 53 days depending on temperature. It was longest on 27±1 °C than on 35±1 °C when Shah and his friends investigated effects of different temperatures (Shah *et al*., 2014).

Damage and economic importance

The larva feeds on a wide range of malvaceous plants, including *Hibiscus*, and is found inside growing points, buds, flowers and young bolls of the cotton plant. Spiny bollworms affect cotton plants at vegetative, flowering and fruiting stages. Bore into shoot and flower buds and hollow out. Buds and bolls darken and fall off. Spiny bollworm is the major culprit which causes tip boring in cotton. It is seldom a serious pest, it sometimes bores into the growing point of the plant, this is called tip boring. The bolls are attacked but usually when they are immature.

Pink bollworm– Pectinophora gossypiella Saunders

Life stages description

Eggs: Female pink bollworm moths lay eggs singly or, more commonly, in small groups. The eggs of this bollworm are minute and difficult to see without some magnification, slightly elongated and are laid between the boll and bracts which surround the boll (CGA, 1998; University of Califonia, 2013). Eggs are white when first laid but then turn orange, and later the larval head capsule is visible prior to hatching. Eggs hatch in about three to four days after they are laid. Eggs measure about 0.5 mm long by 0.25 mm wide (Vennila *et al*., 2007).

Larvae: The hatched larvae immediately bore straight into the boll and spend their entire life in that boll (CGA, 1998). The larvae are smaller than red bollworm larvae. The mature larvae is 10-12 mm long and has broad horizontal bands of red/pink colouring, the larvae turn pink in the forth and final instar of development only. Young larvae are tiny, white caterpillars with dark brown heads due to sclerotized prothoracic shield (Vennila *et al*., 2007). To be able to see pink bollworm larvae, bolls have to be cracked open. The first and second instars are difficult to see against the white lint of the bolls. Larval period lasts for about 10 – 14 days.

Pupae: It is in pupation that the pink boll-worm makes the drastic transformation from a larva to an adult moth. Most pupation occurs in the top layer of soil beneath cotton plants. The pupa is light brown and approximately 7 mm long (Vennila *et al*., 2007). It does not feed or move about during the pupal period of seven to ten days.

Moth: Adults are small, greyish brown, inconspicuous moths. When their wings are folded, they have an elongated slender appearance (University of Califonia, 2013). The wing tips are conspicuously fringed. They emerge from pupae in an approximately 1:1 male to female ratio. There is a time period of two to three days after emergence during which the female mates and prepares to lay eggs. After this pre-oviposition period the female lays most of her eggs in about ten days. Adults may live for one to two months. The moths are about 7-10 mm with a wing span of 15 – 20 mm.

Damage and economic importance

Pink bollworm feeds solely on cotton seeds. It enters the cotton bud/boll soon after hatching and destroys the seeds to feed from there. A damaged boll will often not show any external damage symptoms. Because the egg and larval stages are well protected, chemical control of larvae is not effective after a crop has been infested. The best control is to ensure a closed season, when no living cotton plants are allowed, for at least 66 days. The closed season is implemented by legal cotton destruction and planting dates. In many parts of the world this is one of the most serious pests of cotton. There are only three species of host plant in this country, cultivated cotton, wild cotton and *Hibiscus dongolensis* - the latter two of which grow only in the low altitude areas.

Integration of control tactics for bollworm management: A Zimbabwean perspective

A number of control methods are integrated for management of bollworm pests of cotton in a way that is aimed at minimizing environmental contamination and maintaining durable suppression of pest problems. These tactics fall within the broad categories of preventative measures, cultural control, host plant resistance, chemical control and biological control.

Most of these various IPM tactics have been used for cotton bollworms, some of the notable ones include the ones discussed below.

Chemical control procedures and strategies

Scouting and economic threshold (ET)

This is not a tactic but a procedure which can be utilized by both chemical and biological control.

Scouting is a cornerstone of IPM. Cotton producers are urged to take action against bollworms only when they have scouted their fields. Efficient scouting of cotton crops gives an estimate of pest levels in each field. Bollworms are controlled when they have reached or exceeded set economic threshold levels (CGA, 1998).

The ET for African bollworm is 12 eggs/24 scouted plants; red bollworm is 6 eggs/24 plants and spiny bollworm 6 larva/24 plants. Projected and cumulative egg counts can also be used as valid ETs for both African and red bollworms (CGA, 1998). Whilst it is recommended that farmers be able to identify eggs of red and African bollworms, ETs can also be based on larval counts: African 4 larva/24 plants and red 2 larva/24 plants (Jowah, 1993).

Scouting permits chemical control to be compatible with biological control. It avoids application of pesticides when pest populations are below the economic threshold; this allows build-up of natural enemies.

Table 1. The pyrethroid window for curbing insecticides resistance in Zimbabwe.

Region	Conventional insecticides	Pyrethroids
Middleveld	Beginning of season to 1st February	1st February to end of season
S.E. Lowveld	Beginning of season to 24 December and beginning of March to end of season	25 December to 28 February

Rotation of pesticides

In order to slow development of insecticide resistance, bollworm insecticides from different broad categories are rotated. Synthetic pyrethroids which are broad spectrum chemicals that are used for control of bollworms and other pests are used in rotation with conventional insecticides (non pyrethroids insecticides) mainly of the carbamate group. Pyrethroids are synthesized derivatives of pyrethrins, which are taken from pyrethrum, the oleoresin extract of dried chrysanthemum flowers. For example, the rotation of bollworm insecticides in Zimbabwe is called '*the pyrethroid window*'. This window was developed by the Cotton Research Institute under the Department of Research and Specialist Services in Zimbabwe (DRSS, 2015). Australia also has a similar regulatory control of pyrethroids where, just like Zimbabwe, pyrethroids are limited to certain stages in the growth period of cotton (CABI, 2014).

In Zimbabwe, pyrethroids must not be used on cotton before 25th December or after 1st March in the South East Lowveld.

As such the use of pyrethroids is confined to the period from 1st February to end of the growing season within Non-South East Lowveld areas (remainder of the country) (Mubvekeri and Nobanda, 2012; Sheppard and Ndebele, 2010). Before and after these periods, conventional insecticides are recommended. The current pyrethroids insecticides recommended and which are being used by farmers include Lambda-cyhalothrin 5EC, Fenvalerate 20EC, fluvalinate 2E, and deltamethrin 2.5 EC. Conventional bollworm chemicals include Carbaryl 85WP (red and spiny bollworms), Thionex (endosulfan) 35 EC (heliothis and spiny bollworms) and Larvin (thiodicarb) 37.5 FW (for all cotton bollworms) (Sheppard and Ndebele, 2010). The pyrethroid window is shown in the table below:

Use of less toxic and safer chemicals

The use of pesticides for bollworm control takes into consideration environmental health issues. Less toxic and safer chemicals are recommended for use. Pesticides which are observed to be harmful to both users and the environment are slowly being phased out.

As such, several pesticides have been banned because of their observed toxicity and residual effects. The following lists are examples of phased bollworm insecticides in Zimbabwe: DDT 75WP, Thiodan 50WP, Thionex 50WP, monocrotophos/Monocron 20LC and Cypermethrin 20EC. Of late, the list now includes Carbaryl 85WP, Larvin 375FW (and 375SC) and endosulfan (Thionex 35EC). Of course, the later three are still being used in the country awaiting their replacements currently being worked out by Cotton Research Institute and various agrochemical companies. This movement is meant to reduce environmental and mammalian toxicities. The banning of extremely poisonous chemicals and reduction of amount of pesticides applied per hectare allows the populations of natural enemies to build up.

The lowest effective pesticide dosages are recommended against cotton pests. These low dosages are possible because:

a. Dosage rates are adjusted for all plant heights. For all methods of spray application, the quantity of active ingredient applied per hectare varies with plant height so that lower dosages are used on small plants and progressively increase for larger plants. Under this, there are three cotton growth stages with different recommendations for volume application rate and therefore the amount of active ingredient (a.i.) applied per hectare. When plants are still less than 40 cm one third (1/3) of the maximum recommended spray volume is applied, 40 to 90 cm two thirds (2/3) of the maximum volume is applied and when crops are above 90 cm the maximum rate is applied (Chimoga and Kashiri, 1999; Sheppard and Ndebele, 2010). This alteration of spray volumes reduces the amount of a.i. applied to the environment and allows build up populations of natural enemies.

b. Sampling plans based on eggs permit sprays to be synchronized with the appearance of first instar larvae which are easy to kill because they are smaller in size and usually are not yet feeding internally. The first instar of African bollworm feeds at the tip of branches; thus they are exposed to spray droplets.

Pesticides application rates (a.i./ha) for Zimbabwe are generally lower as compared with other countries. Table 2 shows the dosage rates of pesticides in Zimbabwe compared with other cotton growing countries. The first and second chemicals are for control of aphids and red spider mites, respectively, and the last three are for control of bollworms. The average application rate for these pesticides is 86% higher in South Africa and 11% higher for Australia. Troublesome cotton pests of Zimbabwe and South Africa are the same while most cotton pests found in Australia are also common in Southern Africa (Jowah, 1993).

Table 2. Comparative dosage rates of cotton pesticides in three different countries.

	Application rates (a.i./ha)		
Pesticide	Zimbabwe	South Africa	Australia
Dimethoate	100	320	200
Profenofos	200	825	500
Endosulfan	500	700	735
Thiodicarb	410	375	935
Fenvalerate	40	100	140

(Source: Jowah, 1993).

Cultural control strategies

Adjusting the planting dates

Planting dates are chosen such that the major flowering and boll development period does not coincide with the period when bollworms (particularly red bollworm) are at high incidences. Early planting after the recommended 'dead period' (explained later) allows the cotton crop to escape red bollworm damage. However, as stated by the Plant Pests and Diseases (Cotton), (Amendment) Regulations 1988 whichenforces the creation of a "dead period" (or "closed season") by cotton growers during which all cotton plants and or stalks are destroyed so as to prevent Pink bollworm (*Pectinophora gossypiella*) population build-up and carry-over, the earliest planting dates are 5 October for S.E. Lowveld and 20 October for the remainder of the country (Mubvekeri and Nobanda, 2012). However with the recent changes being noted in the climate, the legalised planting dates must be reviewed for the legislation to remain relevant or efficient. Climate exerts powerful effects on the distribution and abundance of the earth's insect species, and we should expect climate warming to generate changes for many insect populations and the ecosystems they inhabit. Haung *et al.* (2010) reviewed the possible effects of climate change on rice pests and isolated three areas in which the change can influence. According to the review pest physiology, phenology, abundance and distribution can be affected and the major factors include temperature, carbon dioxide concentration, natural enemies, host plant and precipitation.

Crop rotation

This is another cultural control measure widely adopted by most cotton farmers in Zimbabwe. Cotton is rotated with other crops in order to break the life cycle of pests and diseases. Crop rotation is effective on red and pink bollworms which have narrow host ranges. African and spiny bollworms are polyphagous, so will not be affected by rotations. Pink bollworm: While some insect pests are aggravated by rotation others are suppressed with rotations. The pink bollworm only can survive on cotton squares and bolls, thus large scale rotation out of cotton has a dramatic impact on this pest (Blasingane *et al.*, 1991). Rotations crops used include maize, wheat and soyabeans.

Closed season (field sanitation)

The 'closed season' is legally enforced to stop pest carry-over. Cotton plants must be destroyed to create a 'dead period' (or 'closed season') so as to prevent build-up of pests. The closed season is governed by the Plant Pests and Diseases Act [Chapter 19:08] which stipulates that any farmer who fails to comply will face a fine or imprisonment or both (Mubvekeri and Nobanda, 2012). The Plant Quarantine Services Institute (PQSI) is legally responsible for implementation of this legislation. All four species of cotton bollworms are controlled by this method. Currently, strict adherence to this 'closed season' is the only effective method available for the control of pink bollworm (Sheppard and Ndebele, 2010; Mubvekeri and Nobanda, 2012; CGA, 1998). The Cotton Handbook for Zimbabwe states that the minimum length for the closed season when no living cotton plants are allowed should be 66 days. The table below indicates the dates of the closed season.

The aerial parts of the cotton plant must be destroyed by severing the stems below the first branch by the slashing date indicated above. Total destruction of the plant must then follow and be completed by the 15th August in the S.E. Lowveld (and Beitbridge) and 10th September in the remainder of the country. Destruction is defined in the legislation as all plants killed and incapable of regrowth. Planting is defined in the legislation as placing of seeds in the soil; the dates given above are not emergence dates. There is no legal requirement to burn the cotton stover after destruction though this will obviously help reduce the level of pest carryover (CGA, 1998; Sheppard and Ndebele, 2010).

Trap cropping

Cultural manipulations of the crop or cropping system and land management have been tried as tactics to manage African bollworm populations. Trap cropping and planting diversionary hosts have been widely applied and recommended in the past. In the case of cotton, the diversionary hosts, maize and sorghum had too short an attractive period to sustain populations; the tendency of these and earlier-planted crops to augment or create infestations were major disadvantages (CABI, 2014). Intercropping of cotton and trap crops, in a defined manner is evident in most smallholder farming communities. Crops usually used are cowpeas, sorghum, maize, soya beans, water melons and pumpkins. Sorghum, maize and cowpeas are good trap crops for African bollworm. They are generally most preferred hosts for oviposition and larval development. This directs most damage to these crops and saves the cotton plant. Pigeon pea was evaluated at CRI as a potential trap crop for heliothis and was seen to be an effective trap; however, the crop is not widely grown in cotton growing areas of Zimbabwe. Mapuranga and Jimu, (2013, unpublished) evaluated the effectiveness of maize as a trap crop for management of African bollworm and concluded that maize is a suitable trap crop which reduced population of African bollworm on cotton crop and increased the population of beneficial organisms. The number of *H. armigera* larvae decreased as the kernels hardens. In 1979, researchers at CRI concluded that maize was attractive to *H. armigera* moth during the tasselling-silking stage and thus the number of eggs found on the maize plant increases greatly (Gledhill and Dururu, 1979).

Other cultural methods

The values of deep ploughing (for pupa control) have been known for many years. Ploughing exposes bollworm pupa to birds and excessive sun heat. The importance of ploughing cotton stubble to reduce overwintering populations of African bollworm was emphasised by Fitt and Forrester (1987), and post-harvest cultivation to destroy pupae of bollworms has received considerable attention in Zimbabwe. Synchronous planting in local area avoids the movement of bollworms from older to younger plants. One indirect cultural method which could be included under this heading is the regulation of crop agronomy, variety (such as the okra-leaved varieties of cotton), spacing and fertilizer regimes to render the crop and thus target larvae, more accessible to insecticides or microbial formulations applied by conventional means.

A. Biological control strategies

Use of beneficial insects in bollworm management

Classical biological control has been attempted on various occasions. Present in every field are natural enemies which help regulate populations of destructive insects and other organisms. Learning to recognise these beneficial creatures is the first step towards conserving and encouraging their helpful presence. Practices which support the role of naturally occurring enemies seem to be much more successful. Several species are conserved in Zimbabwe which helps reduce bollworm infestations. These species are shown in Table 3 below.

Table 3. Predators and parasitoids of cotton bollworms in Zimbabwe.

Common name	Scientific name	Stage of bollworm life cycle affected
Green lacewing larvae	*Chrysopa boninensis*	Eggs and young larvae of heliothis
	C. congrua	
	C. pudica	
Spiders	*Cheirancanthium lawrencei*	Larvae of all bollworms
	Prucetia kunensis	
Ladybird beetles and their larva	*Exochomus flavipes*	Eggs and young larvae
	Cheilomenes linata	
	C. deisha	
	Hippodamia variegate	
Assassin bug	*Phonoctonus* spp.	Eggs
	Aphidius spp.	
	Encarsia sublutea	
	Eretrocerus spp.	

Pentatomid bugs	*Agonoscelis versicola* *Glypsus conspicuous* *Macroraphus spurcata*	Eggs and larva

Adopted from Jowah (1993).

Conservation of these natural enemies is achieved through several ways:

a. Scouting for these insects during pest scouting. When the numbers of natural enemies is high in relation to pest population, decision can be made to postpone pesticide spraying so as to allocate sufficient time for natural enemies to exert their pressure on pests.

b. Using selective insecticides such as Acetamiprid 50SL, and restriction of broad spectrum insecticides (mainly synthetic pyrethroids) to specific periods.

c. Timing of bollworm insecticides sprays is done after pest scouting to establish ET values. Pesticides sprays are done after the population of bollworms has reached or exceeded the predetermined threshold values. This allows build-up of natural enemies in the field.

A. Host plant resistance

Varietal resistance

Development of cotton cultivars resistant to insect pests, has been the main objective of cotton breeding programmes. Trichomes/hairiness on leaves and stems is a major source of resistance to many insects especially jassids, thrips and weevil and mites (Rahman *et al*., 2013). Trichomes disturb insect movement, egg laying, attachment, shelter, feeding, ingestion and digestion (Rahman *et al*., 2013). Effects of leaf hairs are depended on hair density, erectness, length and shape. Hairiness is a major factor for resistance against the sucking insect complex of cotton. Cotton varieties resistant to lepdotoran pests are hard to come about. Some varieties have been described as being tolerant but the economic importance of this tolerance is negligent. Technology has allowed the creation of *Bt* cotton which is resistant to bollworms. *Bt* cotton is genetically modified (Purcell and Perlak, 2004).

Table 4. The Closed season.

Area	Slashing date	Destruction date	Earliest planting date
S.E. Lowveld and Beitbridge area	1 August	15 August	5 October
Remainder of the country	15 August	10 September	20 October

Bt Cotton

Cotton varieties transformed with genes from *Bacillus thuringiensis* (*Bt*) are resistant to a number of Lepidopteran bollworm pests of cotton. *Bt* cotton can be used in the same way as host plant resistant varieties derived from conventional breeding programmes. Adoption of B*t* varieties is not knowledge-intensive so smallholder farmers can grow them with ease. Like conventional host plant resistant varieties*, Bt* cotton is compatible with most IPM tactics. The toxins such as Cry1Ac, Cry2Ab and Vip 3A produced by B*t* cotton varieties are only ingested by the phytophagous insects and, therefore, like the soil-applied systemics, they have little effect on beneficial insects (Hillocks, 2005; Tabashnik and Wu, 2012). *Bt*varieties have been widely adopted in Australia, USA, India and China. Besides its compatibility with IPM systems, *Bt* cotton also have advantages of decreased pesticide use and increased crop yields. The technology of course have its setbacks as well including but not limited to high cost of seeds, competing with insecticide producing companies, insect resistance and ineffective against aphids, jassids and whiteflies. The biosafety regulations policy (Statutory Instrument 20/2000) in Zimbabwe does not permit planting of genetically modified (GM) crops.

This is governed by the Biosafety Board [Research Act, Chapter 10:22 of 1986, amended] (Keeley and Scoones, 2003).

Future research needs and direction Early Warning Systems (EWS)

Like in the control of armyworm (*Spodoptera exempta*), Early warning systems (EWS) for cotton bollworms need to be developed for some states like, Zimbabwe. Light and pheromone trap catches would be used to predict abundance and outbreaks of these pests. Trapping *H. armigera* is useful as a qualitative measure indicating the start of an infestation or a migratory 'wave front', indicating the need to begin scouting for immature stages in the crop. More sophisticated and efficient EWS which are computer based like VIGICULTURES, EMPRES (FAO) and GPC (Grass pest control) (Sine *et al.*, 2010; FAO, 2015) should be introduced and developed in countries where such has not been used.

Crop Pest Modelling

Models are conceptual or mathematical devices which aim to simulate natural processes. As pest management tools they are used to predict or establish the optimal tactics required to achieve economic control of that pest, within the constraints of the model. Models for the management of *H. armigera* have been mostly restricted to cotton in Australia (and in the USA against related bollworms in cotton). They include several demographic and phonological models which gives greater attention to biological parameters of *H. armigera* including adult movement, and take account of the presence of non-crop hosts in a region (Gilioli *et al.*, 2012). Such models need to be developed in Zimbabwe for management of bollworms in our highly fragmented agricultural system.

Plant extracts

These are bio-pesticides together with the use of bacteria, viruses and fungi to control e.g. semilopers.The use of plant extracts is compatible with various IPM systems. Plant extracts have been used on various pests in Zimbabwe including aphids and red spider mites (Muzemu *et al.*, 2011; Mapuranga, 2014). Extracts from plants such as *Eucalyptus spp, Lantana camara, Meliaazedarach, Capsicum annum, Nocotiana tabaccum*, etc. should be tested against the various bollworm species which destroy cotton and fitted into IPM systems. However there is need to standardise extraction and isolation procedures.

Conclusion

No single pest control tactic is relied on in IPM systems. Pesticides are used only when needed (in relation to ETs), and it is important to use them judiciously. The list of compatible IPM tactics is very long and has not been fully utilised in Zimbabwe. Research should focus on developing IPM systems that considers deferring agro-ecological regions and the changing climate.

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