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Integrated Pest Management for the Horse Farm

A report for the Rural Industries Research and Development Corporation

by Cindy Edward and Ary Hoffmann

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Foreword

The reliance on chemicals to control horse parasites is not sustainable and resistance in worms to these chemicals is imminent. Administering these chemicals to horses is expensive in terms of chemical cost and labour, and hazardous to the horse handler. Continual administration to horses is not good for the horse's health and welfare. Dung contaminated with chemicals is detrimental to the biodiversity of pastures and is harmful to the environment. Other cultural control methods for horse parasites such as manually picking up horse dung or vacuuming regularly is time consuming and not widely practiced. All areas of agriculture are being expected to lower chemical use and create an environmentally sustainable product. Many farmers have been successfully implementing and using integrated pest management. The horse industry, through community concern, is also accountable and needs to reduce chemical use.

The entire horse industry would benefit from a sustainable biological control program for horse farms. In 1996, it was estimated that there were around 1.2 million horses used for racing, equestrian sports, recreation and meat production in Australia. The cost of horse wormers at current prices is between $60.00 - $120.00 per horse annually plus labour to administer the chemicals. Therefore, any reduction in wormer applications can potentially lead to substantial cost savings.

This study concludes that ivermectin resistance to worms in horses has developed and that ivermectin is the most widely used parasiticide used for the control of gastrointestinal parasites in horses with minimal rotation with other anthelmintics. Biological control methods such as establishing exotic dung beetles on horse farms is compatible with adjusted horse management practices lessening parasite burdens, helping to aerate and fertilise the pasture, increasing water absorbency and reducing fecal run-off into farm and community water supply. Monitoring tools such as fecal egg counts can be used to monitor worm burdens allowing drenching of horses only when necessary in conjunction with cultural practices leading to fewer chemicals administered to the horse. The integrated pest management strategy developed in this study will enable a more sustainable, environmentally friendly horse farm.

This project was funded from industry revenue which is matched by funds provided by the Australian Government.

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Peter O'Brien
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Abbreviations

IPM	Integrated Pest Management
FEC	Fecal Egg Counts
PCR	Polymerase Chain Reaction
ELISA	Enzyme-linked Immunosorbent Assay

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Executive Summary

What the report is about

Horse owners are advised to ‘worm’ their horses every six to twelve weeks. Sole reliance on these chemicals to control horse parasites is expensive and most likely detrimental to horses, people and the environment. Resistance in worms to these chemicals is increasing. This leads to higher dosages administered more often. Administering chemicals to horses can be hazardous to both horses and handlers. This report looks at additional strategies that could be used to control worms in a more sustainable manner.

Who is the report targeted at?

This report represents a user friendly strategy targeted at recreational horse owners, stud managers, riding instruction establishments, equestrian clubs and environmental groups such as Landcare. Data from this report shows a need for further research on equine parasitology and pasture pest management.

Background

The dependence on insecticides to control pests in agriculture became very prevalent after the Second World War as new effective chemicals were developed. The ability to “clean up” pest problems in agriculture with chemicals such as DDT (Dichlorodiphenyltrichloroethane) was thought to be the answer to numerous pest problems. The development of resistance to chemicals, contamination of the environment and food products, and recognition of secondary pests has required a reduction in pesticide use and development of sustainable methods of pest control. The use of natural enemies is a main control component of alternative strategies. A prime goal of an Integrated Pest Management (IPM) program is to maximize the impact of these enemy organisms (van Emden 1982).

Aims/Objectives

This study aims to develop an alternative strategy to current equine parasite management that will aid and maintain environmentally sustainable horse farms. The lifecycle of horse parasites involves a ground dwelling stage that is vulnerable to native and exotic predators. The intention is to develop a biological control program that identifies native ground dwelling predators that can break the lifecycle of horse parasites. Predator lifecycles will be studied in relation to the effects of various horse wormers. Exotic dung beetles will also be established on horse farms to help aerate and fertilise pastures, increase water absorbency and reduce fecal run-off into farm and community water supplies.

The biological control program will:

- benefit the horse (less chemical administered)
- reduce financial costs of worming applications
- address chemical resistance
- lessen the risk of accidents to the horse handler
- maintain a more environmentally friendly and ecologically sustainable horse farm.

Methods used
The data presented in this report was obtained from ten horse farms which had different worming programs, ranging from drenching continually to drenching annually. The data was collected for two years from August 2004 – July 2006. The data collected from each trial site included studies of invertebrates from pitfall traps and invertebrates from dung.

Exotic dung beetles were commercially purchased and released at six sites. The winter active dung beetle *Bubus bison* was released in July 2004 at six sites and the summer active dung beetle *Onthophagus binodis* was released at the same six sites in November 2004. These beetles were not present before the releases. Although these beetles take years to establish it was evident that certain horse management practices would influence the establishment of the beetles such as continual use of ivermectin and encouraging bird activity in dung.

Fecal egg counts were taken by collecting fresh dung from the trial paddocks. Fecal egg counts were done monthly using the McMaster Technique (Bowman et al. 2003). Paddock management was recorded fortnightly for the number of horses, new horses, drenching time and chemical used per trial site. Management records showed that horse owners are rotating chemical brands and not actives when drenching.

Results/Key findings
There was no influence of chemicals used for drenching horses on ground dwelling invertebrates. Direct search of dung indicated that birds scattering the dung had a detrimental effect on the establishment of dung beetles. However, birds scattering dung caused the dung to desiccate, destroying the moist habitat that parasites require, leading to a reduction of parasite burden and quicker breakdown of the dung. Other invertebrates that live in dung had a composting effect, enabling faster breakdown of horse dung. Invertebrates in the dung were affected by drenching chemicals although bird activity was a significant variable. Seasonal gaps in beetle activity were evident enabling drenching chemicals to be used with a reduced risk of dung beetle mortality.

Exotic dung beetles were commercially purchased and released. Although beetles take years to establish it was evident that certain horse management practices were likely to negatively influence the establishment of the beetles such as continual use of ivermectin and encouraging bird activity in dung. Establishment of dung beetles, especially winter active beetles, should be encouraged on the horse farm.

Fecal egg counts were taken by collecting fresh dung from the trial paddocks. Resistance in worms to ivermectin was found for the first time in horses. Resistance should be a major concern for the horse owner.

Paddock management was recorded fortnightly in terms of the number of horses in a paddock, new horses introduced to a paddock, drenching time and chemical usage. Management records showed that horse owners are rotating chemical brands but not active constituents when drenching. This is a major concern for the development of resistance in worms especially with respect to resistance to ivermectin. Cultural practices such as harrowing, removal of dung and paddock rotation should prove to be a valuable component of horse parasite management.

Implications for relevant stakeholders

This project has highlighted limitations of current parasite control strategies in the horse industry. Parasitology should be a priority for further research as new technology and environmental direction is sought. Stud managers, recreational riders and other workers on horse farms would benefit from new technology as suggested in the recommendations. Workshops, media articles, talks and collaboration with community and Landcare groups represent channels to provide the industry with relevant information. There is a need for inexpensive fecal egg counts and commercial dung beetle supplies to ensure adoption of sustainable control strategies.

We have developed an IPM strategy that has the potential to:

- benefit the horse (less chemical administered)
- reduce financial costs of worming applications
- address chemical resistance.

The guidelines developed here should lead to more environmentally friendly and ecologically sustainable horse farms.

Recommendations

The following recommendations were made:

- Equine research in collaboration with bodies such as the dairy, beef industry and Landcare groups would benefit all stakeholders interested in control of pasture pests.
- Fecal egg counts are valuable for confirmation of strongyle (horse parasite) presence, however, it is not possible to separate eggs into large and small strongyles. Utilizing primers, a Polymerase Chain Reaction (PCR) approach has previously been developed for the specific amplification of ribosomal DNA, and hence identification of large and small strongyles. It would be useful if a PCR test became readily available to the horse industry along with cheap assessments of fecal egg counts.
- Additional research is needed to assess patterns of parasite mortality in paddocks. Rotating pastures for horses is a valuable component of parasite management.
- Data from this project shows significant peak flights of adult redheaded and blackheaded cockchafers. These adult beetles are attracted to light and research into light trapping could be useful components in controlling these pasture pests.
- The use of biological control of nematode parasites in livestock has been researched in cattle and horses in Europe with encouraging results. Nematophagous fungi would be a useful tool in sustainable biological control of parasites.
- The establishment of summer and winter active dung beetles is achievable with dung beetles already available in Australia. There is a gap in spring and autumn activity of exotic dung beetles in Australia. Appropriate exotic dung beetles are needed to reduce this gap for the horse and cattle industries.

1. Introduction

Agricultural pest control became very dependent on chemicals after the Second World War as new, more effective chemicals were developed. The ability to “clean up” pest problems in agriculture with chemicals such as DDT (Dichlorodiphenyltrichloroethane) was thought to be the answer to numerous pest problems. However, since the development of resistance to chemicals, contamination to the environment and food products, and the recognition of secondary pests have all led to a need to lessen pesticide use and develop sustainable methods of pest control.

Chemical resistance in pests and parasites is of high concern and alternative control strategies are often adopted. The use of natural enemies is one of the main control components of alternative strategies, interacting with other components. A prime goal of an Integrated Pest Management (IPM) program is to maximize the impact of these organisms (van Emden 1982). IPM has been implemented and sustained in many horticultural crops. Crops such as brassicas, corn, lettuce, grapes, tomatoes and cut flowers have pests that have become resistant to insecticide due to overuse. The IPM strategies that have been implemented in these crops have addressed the insecticide resistance problem with better control of the pest, less risk of chemical contamination to the product and a more environmentally friendly farm.

In Australia, there are between 0.9 and 1.5 million horses, of which around 300,000 are feral (Gordon, 2001). Currently, IPM is not widely adopted in the horse industry. However, an IPM approach has the potential to improve horse health and horse handler safety. It also has the potential to lead to reductions in chemical resistance, environmental contamination and on-farm costs due to a reduction of chemical inputs.

By monitoring several horse farms near Melbourne, we have identified a strategy for control of pests involving beneficial insects (beneficials) present. These beneficials may be assisted by the introduction of other strategies to control pests. Additional steps remain to be developed for an IPM program such as a cultural control program to manipulate the environment to make it unfavorable for pests and favorable for beneficials.

This report outlines the pests and beneficials present on horse farms and reports a case of resistance to anthelminthics. Based on the data and observations collected in this study, recommendations regarding IPM on horse farms are provided.

2. Objectives

The objectives of this study are:

- to complete a research and development project on an alternative to current equine parasite management strategy
- to develop a biological control program that aids and maintains environmentally sustainable horse farms, by identifying native ground dwelling predators that may break the lifecycle of horse parasites.

The lifecycle of horse parasites have a ground dwelling stage that is vulnerable to native and exotic predators. The predator's lifecycle will be studied in relation to the effects of various horse wormers. Exotic dung beetles will also be established on horse farms. These help to aerate and fertilize the pasture, increasing water absorbency and reducing fecal run-off into farm and community water supply.

3. Methodology

The basic design of our project involved monitoring ten horse farms which had different worming programs. Three farms were drenching continually - six weekly or three monthly if moxidectin was used. Three farms drenched at three month intervals, three drenched annually and one had no worming program. Some farms had paddocks available for rotation, others did not. The farms include racehorse studs, recreational riding horses, a 'warm blood' establishment and a trail riding school. Data were collected for two years from August 2004 – July 2006.

The average area per horse was one hectare, with at least two horses per paddock. The paddocks were not cross grazed. The second year of the project all participants were given a written report monthly on fecal egg counts (FECs) obtained from horses in the trial. A few participants chose to change their drenching program based on the results of these counts.

The data collected from each trial site included invertebrates from 10 pitfall traps (100ml cylinders sunk into the soil, containing preservative). For rotation paddocks, five pitfall traps per paddock were established. These traps monitored biodiversity and the influence of chemicals on ground dwelling invertebrates that occur in the horse paddock with and without horses present. The traps were cleared fortnightly and the invertebrates identified, quantified and recorded. Beneficial and pest invertebrates were identified and quantified which resulted in seasonal abundance data. This allowed for optimum control target times for pests and windows of low beneficial numbers to reduce mortality to invertebrates when drenching.

Direct search of dung was conducted by looking at 25 pads of dung per site and recording the number that had dung beetle activity and dung that had been scattered by birds. The dung was between 1 – 48 hours old. Also dung of the same approximate age was collected in a 2 litre bucket and the dung was examined in a tray where the invertebrates were identified and quantified and then returned to the paddock. Direct searching of dung took place fortnightly. Dung beetle establishment was recorded and the effect of birds scattering the dung was found to have a detrimental effect on the establishment of the beetles. Other invertebrates were identified that may predate on horse parasite eggs and larvae.

Exotic dung beetles were commercially purchased and released at six sites. The winter active dung beetle *Bubus bison* was released in July 2004 at six sites and the summer active dung beetle *Onthophagus binodis* was released at the same six sites in November 2004. These beetles were not present before the releases. Although these beetles take years to establish it was evident that certain horse management practices would influence the establishment of the beetles such as continual use of ivermectin and encouraging bird activity in dung.

FECs were taken by collecting fresh dung from the trial paddocks. FECs were done monthly using the McMaster Technique (Bowman et al. 2003). Paddock management was recorded fortnightly for the number of horses, new horses, drenching time and chemical used per trial site. Management records showed that horse owners are rotating chemical brands and not actives when drenching.

4. Overview of pest/beneficial organisms and results

4.1 Pests of the horse paddock

4.1.1 Gastrointestinal parasites

Nematodes form the largest group of intestinal parasites of the horse (Bowman 2003). Around 99% of the population of internal parasites inhabits the pasture of a horse paddock, only 1% are present in the horse. The life cycle of intestinal parasites is outlined in Fig. 1. A brief outline of the most common parasites of concern to horse owners is provided.

4.1.1.1 Strongyles – small strongyles

Cyathostomes

Between 75% to 100% of the eggs passed in the feces of naturally infected horses are produced by the small strongyles (Cyathostominae). These greatly outnumber the large strongyles (Strongylinae) both in numbers of species and in numbers of individuals (Bowman et al. 2003). Small strongyle larvae do not migrate beyond the mucosa of the cecum and colon. Large numbers of arrested cyathostomin larvae can cause various diseases in horses. The pre-patent period (from when the horse ingests the parasite to egg laying adult) is between 10 – 16 weeks but may be longer if larval development is arrested (hypobiosis).

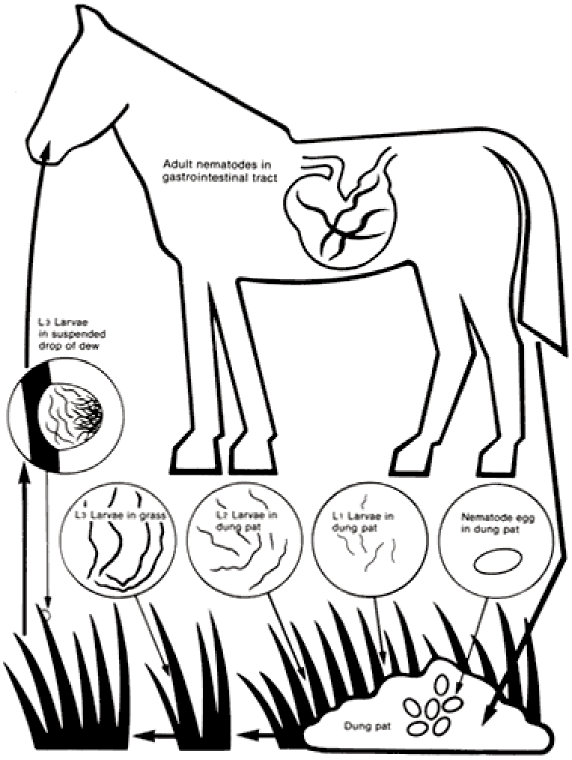

Illustration by meril.com. (2001) http://au.merial.com.Accessed (25.7.05)

Fig. 1 Parasite life cycle. Parasites have an adult state in the horse intestinal tract and an immature stage in the pasture

The egg of the small strongyle may take between three to five days to hatch, depending on the temperature. When hatched the larvae develops from first instar lavae to second instar larvae and migrates from dung to pasture as encapsulated third instar larvae. Larvae need pasture based moisture to migrate to the forage and can inhabit the moist dung for many weeks before migration. Encapsulated larvae are very tolerant to various weather conditions and may seek moisture in soil during dry conditions.

4.1.1.2 Large strongyles - blood worms

Strongylus

Large strongyles migrate as larvae through the intestinal parenchyma of the horse potentially inflicting serious damage, especially in yearlings. The adults are bloodsuckers and are among the most destructive parasites of the horse. The life cycle is similar to the small strongyles. The pre-patent period varies between the three different species, for *Strongylus vulgaris* it is six to seven months, for *Strongylus equisnus* nine months, for *Strongylus edentatus* eleven months. Using FECs to differentiate between large and small strongyles is not readily feasible as the eggs of large and small strongyles are too similar. The usual method for confirmation that a horse is infected with large strongyles is to grow the parasite from eggs to larvae and count the cells in the stomach of the parasite. A polymerase chain reaction (PCR) test has been developed to identify strongylid species but is not in commercial use.

4.1.1.3 Roundworm

Parascaris

The roundworm infects mainly foals as the infective eggs accumulate on teats and is ingested when feeding from the mare. However, eggs also live in faeces. The egg does not develop into a larva until it is swallowed by the foal. The infective larvae burrow into the small intestine and are carried to the liver. The larvae then enter the heart and lung. The larvae return to the intestine where they complete a final molt and mature. The larvae can cause major mechanical injury. The damage done to the liver and lungs may eventually heal but the functional capacity may suffer (Bowman 2003).

The roundworm can be a major problem for horse breeding farms as the sticky roundworm egg is very durable and can accumulate in stables and paddocks from year to year. The pre-patent period is ten weeks (Bowman 2003). It is most important to clean mare’s teats before foaling and to steam or pressure clean foaling stables, change bedding and follow general hygiene procedures. FECs show the presence of the roundworm egg. If roundworms are found on a stud it is necessary to use anthelmintics before the foals are weaned.

4.1.1.4 Pinworm

Oxyuris equi

The equine pinworm is quite large in comparison to other pinworms. The female does not discharge her eggs in the fecal stream, it migrates to the anus and cements its eggs in masses to the anus and surroundings. These masses consist of yellowish grey fluid containing 8,000 to 60,000 eggs. The eggs develop to the infective stage in four or five days, during which time the fluid dries, cracks and detaches from the skin. The flakes adhere to stables, water buckets etc. contaminating the environment. A fecal egg count cannot be relied on to determine the presence of pinworm eggs. Clear adhesive tape can be pressed against the anus, removed and mounted to a slide for confirmation of pinworm infection. The pre-patent period is five months.

Severe infection with third- and fourth-stage pinworm may produce inflammation and cause vague signs of abdominal discomfort. The most common damage done by the pinworm is caused by efforts to relieve the itching caused by deposition of eggs as the horse will rub its tail on posts and trees, causing abrasions and loss of hair (Bowman 2003).

4.1.1.5 Tapeworm

Anoplocephalids

There are three tapeworms that are parasites of horses. Two are relatively harmless but *Anoplocephalid perfoliata* can cause colic in horses. The tapeworm has become more of a problem since the preferred use of ivermectin to control horse parasites as this anthelminth does not kill tapeworms. Most ivermectin based worming products now contain an added chemical for the control of tapeworms. The tapeworm egg is passed via the feces onto the pasture. The egg is then ingested by an intermediate host, an orbatid mite. The mite is ingested by the horse while grazing on the pasture. The egg hatches to a larva where it attaches to the intestinal wall, becomes mature, and detaches egg segments that then pass in the fecal stream. The pre-patent period of the parasite is 6-10 weeks. The most reliable method of testing for tapeworm is by using an ELISA (enzyme-linked immunosorbent assay) test at an accredited laboratory. Egg segments can be found in flotation of fecal samples but this is not an entirely accurate method. Segments may also be observed in the dung but the segments break up and may be missed. After drenching for tapeworm the worms maybe observed in the dung.

4.1.1.6 Bot fly

Gasterophilus

The bot fly is an insect associates with horses between spring and autumn. The female lays its eggs on the hairs of the horse’s forelegs, belly and mane. The eggs are yellowish in color. After approximately five days, the larva is ready to emerge when rapid temperature increases occur, e.g. the horse’s warm breath causes hatching. Eggs then enter the horse’s mouth. The first and second stage larvae live in the mouth. The second stage larvae migrate to the stomach where they attach and develop over 12 months into full-grown bots. From late spring, larvae pass out via the feces to pupate in the soil. The bots mature within pupal cases for 3 to 9 weeks, depending on temperature before they emerge as adult bot flies.

Botfly lavae can cause intestinal damage if present in large numbers but in small numbers is not a significant intestinal pest. The botfly adult can be an irritant for horse and owner. The botfly has a 12 month life cycle and is not active in the colder months. Regular mechanical removal of the eggs from the horse is a good control method for this pest. Drenching for this parasite is most optimal when undertaken in autumn.

4.1.2 Pasture pests

A variety of invertebrates can act as pasture pests and these are normally collected by suction sampling, tulgren funnels, or pitfall traps. In this study pasture pests were monitored using pitfall traps. The most common pests detected in our trial sites were redheaded pasture cockchafers, blackheaded pasture cockchafers, snails and earth mites.

4.1.2.1 Redheaded pasture cockchafer

A*crossidius couloni*

Fig. 2. A*crossidius couloni* (David Paul, Department of Zoology, The University of Melbourne).

Redheaded pasture cockchafers are native beetles that are a significant pasture pest in the south eastern area of Australia (see Fig. 2). They are of the same family as dung beetles (Scarabidae) and have similar appearance. The adult is red to brown, about 13 mm long and 8 mm wide. The larvae are white-grey with a red capsule head that curl into a C-shape and develop in the soil, feeding on pasture roots.

Redheaded pasture cockchafers can severely damage pasture. They have a two year life-cycle. The adult emergence period was predominantly September-November at our sites (Fig. 3). The beetle lays eggs singly in the soil under the pasture. The eggs hatch into larvae and feed on the roots of the pasture. Significant damage occurs in autumn if larvae are abundant. The larvae are difficult to kill as they do not surface to feed on the pasture. Birds may be observed foraging for the larvae. This activity may also cause damage to the pasture.

There is no chemical registered for the control of redheaded pasture cockchafer. A biological control using a native fungus *Metarhizium anisopliae* has been commercially produced "BiogreenTM Granules" and may be available through farm supply stores. Trapping of the adult beetle may also be a possible control method to lessen numbers although as the beetle has a two year life cycle it may take a few years to see a reduction in beetle numbers.

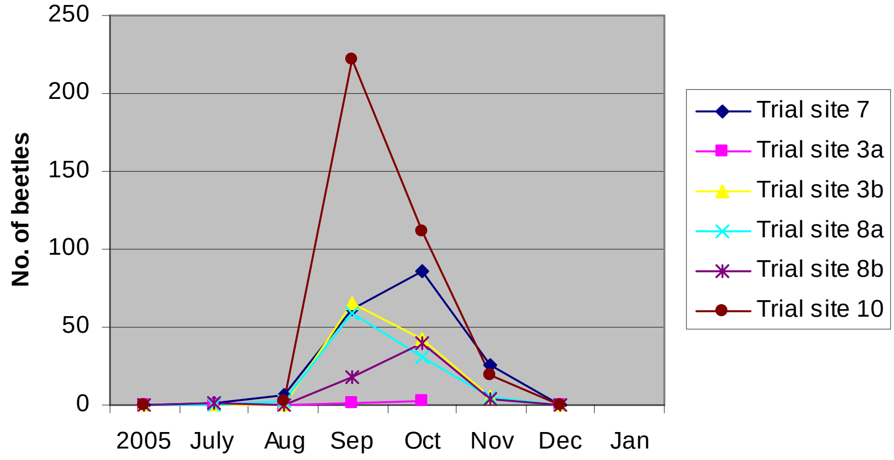

Fig. 3. Number of redheaded pasture cockchafer beetles in 10 pitfall traps collected monthly at 6 paddocks (trial sites) from south-eastern Australia in 2004. Data indicate that cockchafers are active between August and December and that this activity pattern is consistent across the different sites examined.

4.1.2.2 Blackheaded pasture cockchafers

Acrossidius tasmaniea

Fig. 4. *Acrossidius tasmaniea* (David Paul, Department of Zoology, The University of Melbourne)

Blackheaded pasture cockchafers are elongated black beetles of the Scarabidae family (see Fig. 4). They are a significant pasture pest in Australia. These beetles are abundant in January in south-eastern Australia as apparent from pitfall collections in our trial sites (see Fig. 5). The adult beetle preferably feeds on fresh horse dung but also on cattle and sheep dung. The beetles differ from dung beetles in that when feeding on horse dung they shred the dung rather than bury it. Feeding causes the dung to desiccate and develop the appearance of sawdust. The breaking down of the dung destroys the habitat for the parasite of the horse. The presence of the blackheaded cockchafer is beneficial in the control of parasites and flies. However after feeding the female lays its eggs in the soil. The larvae hatch and move to the surface of the pasture, cutting grass and taking it down a burrow to feed, thereby causing damage to pasture. Birds may feed on the larvae, and there is also a naturally occurring fungus in soil that kills larvae. Predators such as foxes may feed on adult beetles.

Chemicals such as alpha-cypermethrin, chlorpyrifos, carbaryl and fenitrothion are registered for use in the control of this pest (Infopest DPI Qld July 2006). Horses should be removed from the pasture when using these chemicals and withholding periods followed as directed by label. Be aware that when using these chemicals there is mortality to beneficial insects in a paddock.

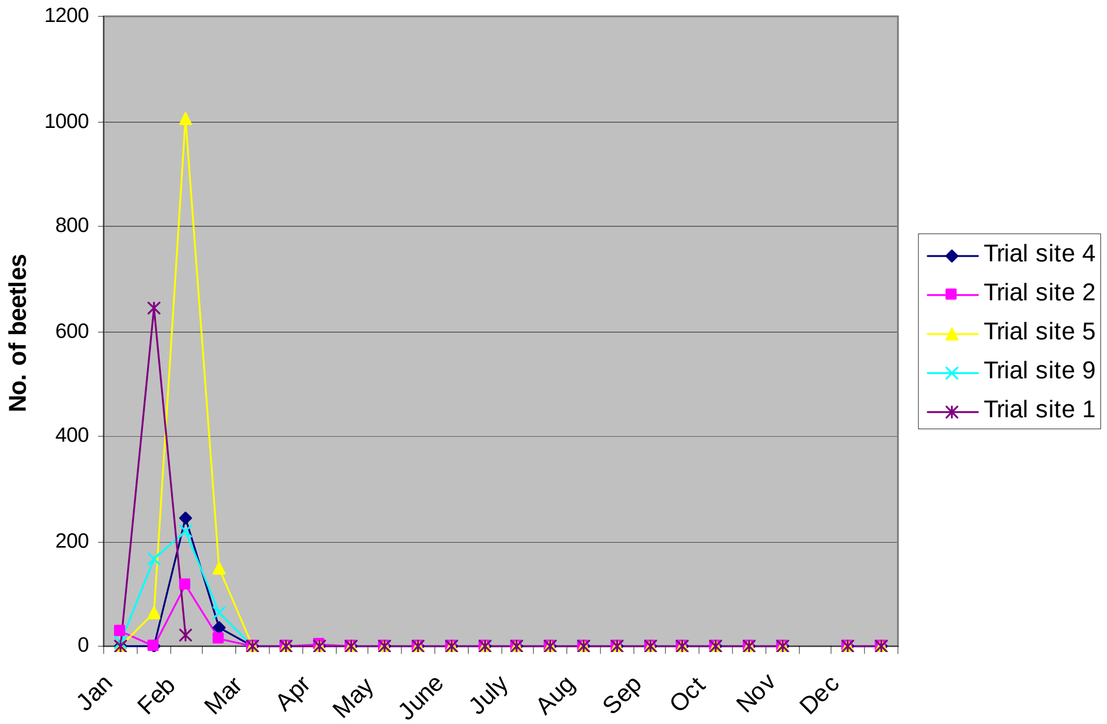

Fig. 5. Number of blackheaded pasture cockchafers in 2 litres of horse dung collected monthly at five paddocks from south-eastern Australia in 2005. Data indicate that cockchafers are active between January and March and that this activity pattern is consistent across the different sites examined.

4.1.2.3 Earth mites

Halytodeus destructor and *Penthaleus* spp.

Red-legged earth mites and blue oat mites are significant pasture pests. These mites can be observed feeding on pasture such as clover and cape weed in spring. The degree of damage to a pasture may vary from minimal to severe depending on weather, beneficials present and past history of a paddock. If pasture is prone to attack by mites it is best to avoid growing pasture heavy in clover, and to reduce weeds such as cape weed. Chemicals such as omethoate may have a knockdown effect, reducing mite numbers, but this chemical has detrimental effects on beneficial invertebrates. Numerical data were not collected for earth mites collected in this study but they were present in traps from May to November.

4.1.2.4 Snails

Snails and slugs were found in some of the horse paddocks. Conical snails and slugs may not do significant damage to the pasture but can contaminate it, making the grass unpalatable to the horse. In summer the snails tend to aestivate in response to low moisture. When conical snails aestivate they tend to contaminate the pasture, particularly when it is intended for hay. Intensive grazing by horses, sheep or cattle can reduce snail numbers. Numbers of conical snails collected in this study are given in Fig. 6 and suggest a subsequent reduction in response to grazing.

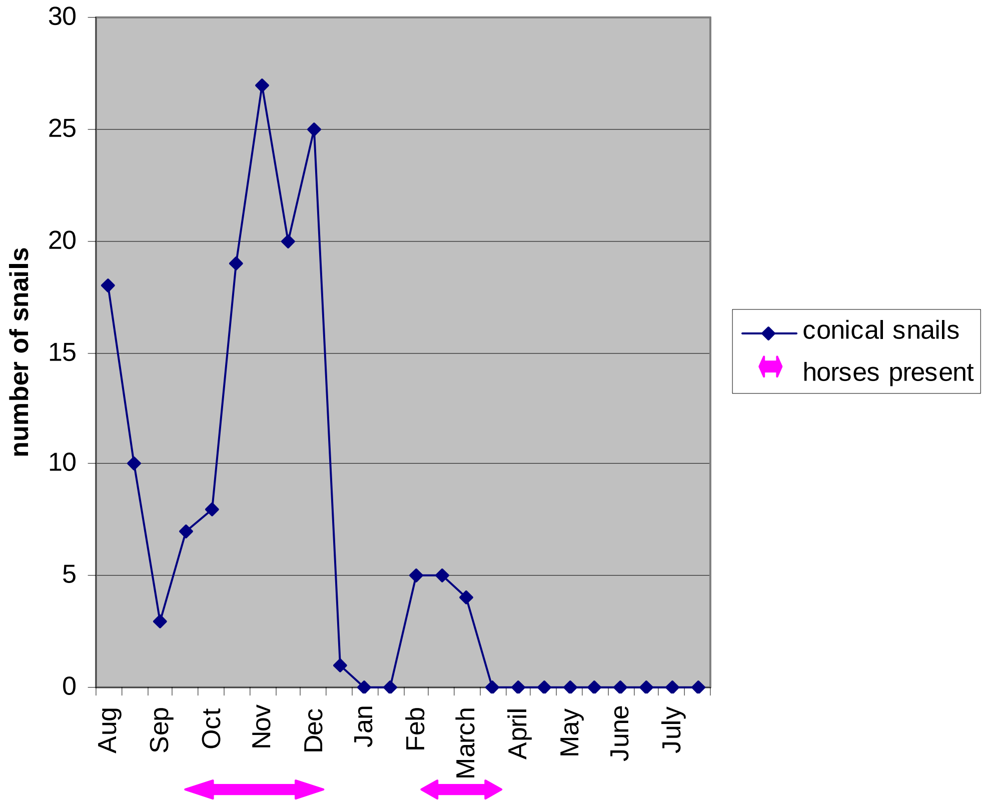

Fig. 6. Number of conical snails in 5 pitfall traps collected monthly at a rotational horse paddock from south-eastern Australia in 2004 and 2005. Data suggest that conical snail numbers are progressively reduced by intensive grazing by horses that were grazing in the paddock between October and January and between March and April.

4.1.3.5 Birds

Birds can be a pest in that they foul feed bins when eating horse feed. The availability of grain encourages birds to increase in numbers on the horse farm. The increased number of birds may destroy trees or damage a newly sown crop (e.g. oats). Observations made during this project indicate that when whole grain is fed to horses, birds tend to scavenge in dung causing the dung to spread and desiccate. The spreading of dung can cause desiccation of parasite eggs and larvae, reducing the viability for parasites to become infective third instar larvae, and lessening parasite burden of the paddock as shown in Fig. 7. However, if dung has a high parasite burden the spreading of dung in moist, cool weather conditions may facilitate spread by the parasite. Larvae may migrate from the dung pad and be consumed by horses that might usually avoid grazing near contaminated dung. A similar problem can arise when harrowing contaminated dung through a paddock in cool, moist weather conditions while the horses are still in the paddock. Scattering of the dung in this way is therefore less desirable than breaking down dung using methods allowing the establishment of dung beetles.

To reduce any unwanted activity by birds, whole grain may be steam rolled, crushed or soaked to make the grain more easily digested by the horse.

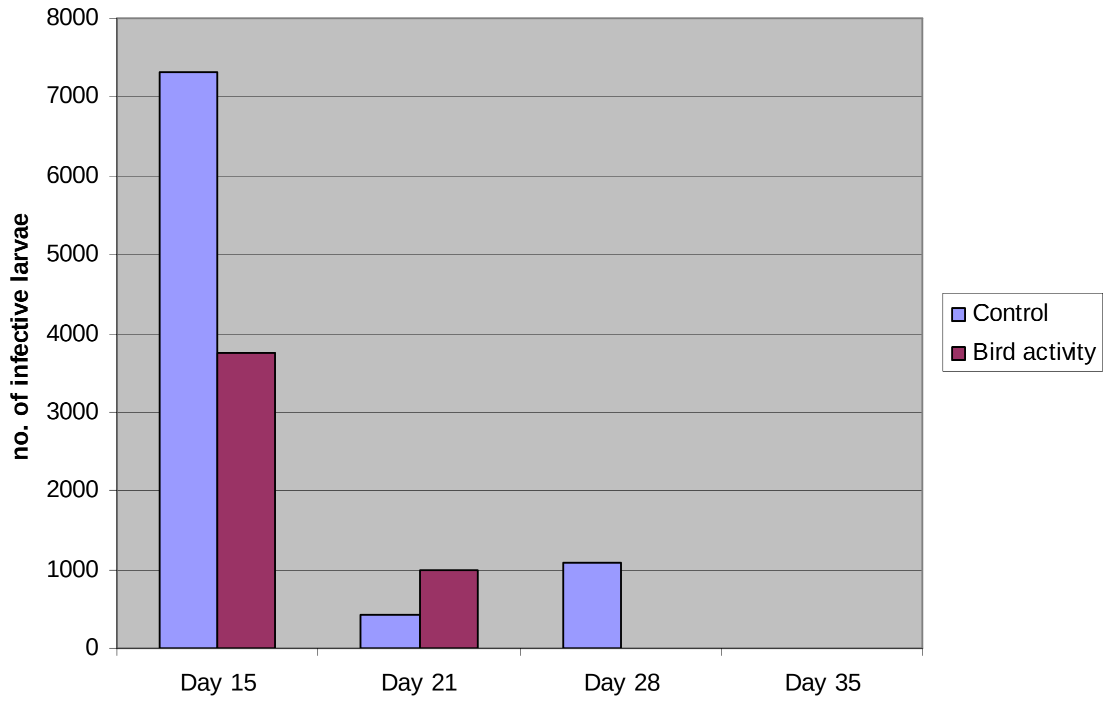

Fig. 7. Cumulative infective larvae recovery per 1kg of pasture sampled at day 15, 21, 28 and 35 after placement of 1 kg pats of horse feces with an average parasitic nematode strongyles fecal egg count of 345 eggs per gram. For ‘bird activity’ treatments, faeces were mixed with 100 grams of oats. This caused birds to scatter dung when feeding on the oats. The data shows reduced numbers of infective parasites migrating onto surrounding pasture following bird activity.

4.2 Monitoring techniques

The key to a successful pest management strategy is monitoring of the key pests and beneficials. Initially it may be necessary to monitor frequently, perhaps monthly, and as a strategy is established the frequency of monitoring can be lessened. It is important to keep a record of information obtained from monitoring to establish a sustainable strategy.

4.2.1 Fecal Egg Counts (FECs)

The source of internal parasite infestation to the horse is the eggs in the dung. Thus, the best way to monitor parasite pasture population is via FECs. These should be conducted to ascertain:

- The level of parasite burden on horse and pasture. Egg counts are estimated as eggs per gram. If the egg count is less than 200 eggs per gram (EPG) it is regarded as low, 200-400 is considered medium and over 400 is considered high.
- The parasites that infest horses and pasture. Strongyles, ascarids and pinworm (when a sample is taken from the perineum of a horse) can be diagnosed through fecal egg determinations. To differentiate between small and large strongyles, culture of strongyle eggs needs to be undertaken.
- Whether chemical resistance to parasites is present.

FECs should be done at least five days after drenching, this will ascertain if the chemical used has been effective. In general, when FECs are used to monitor parasite burdens less parasiticides tend to be used.

Fecal egg counts were taken by collecting fresh dung from each horse every month in the trial paddocks. FECs were done using the McMaster Technique (Bowman et al. 2003) there proved to be a valuable tool to monitor parasite burdens of horses and pasture.

Fig. 8 shows a site that previously ‘drenched’ horses every six weeks but after using the results of FECs there was a sharp reduction in the use of parasiticides. This method saves money with fewer parasiticides used helps address chemical resistance to worms and results in less drenching lessening risk of injury to horse and handler.

Horses may develop a low level of tolerance to parasites without health concerns and a continual negative FEC through drenching is not necessary for a healthy horse. However, FEC should be maintained below 200 EPG.

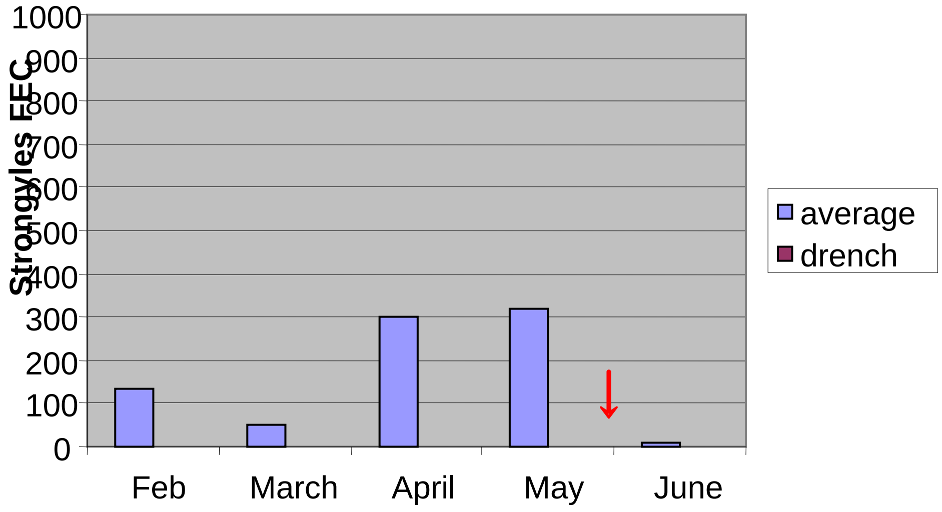

Fig. 8. FEC over time for two horses at a farm. Prior to monitoring, drenching was conducted every six weeks. Counts were obtained monthly and drenching was advised on one occasion only after the FEC increased to > 300 EPG (indicated by the red arrow). By using this information application of chemicals was reduced markedly and the horse health was maintained.

Using FECs as a monitoring tool, drenches can be timed to be more effective. For instance, Fig. 9 shows a site that routinely wormed twice a year but counts were too high on some occasions. With FEC data, the drenches could be timed (Fig. 10) so that FECs were strategically reduced.

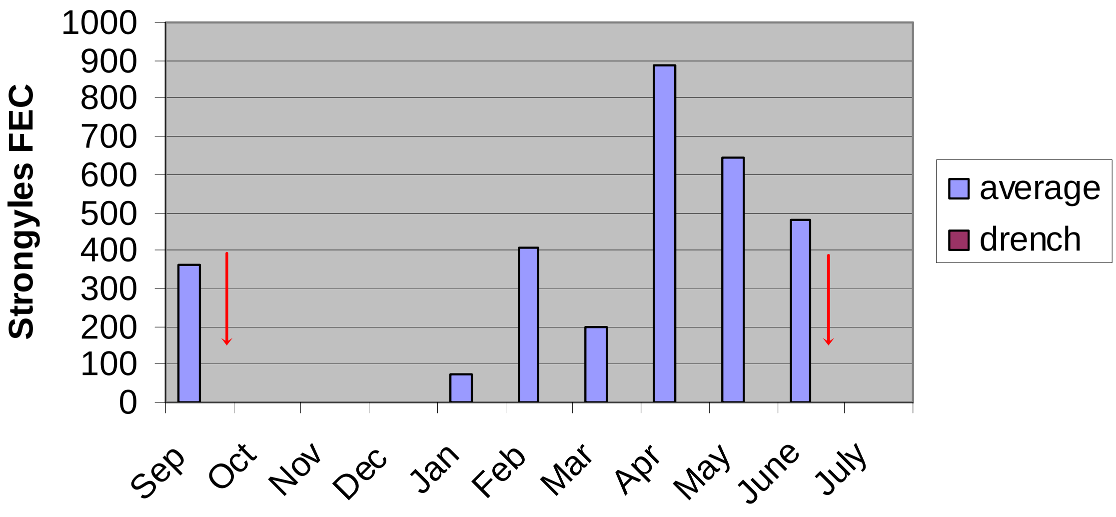

Fig. 9. Monthly FEC at a site with two horses where drenching routinely took place in spring and winter as indicated by the red arrows. FECs were obtained each month from September 2004 to July 2005 for the two horses and an average count shows the burden of the paddock. Data shows that FECs were high enough in April to warrant drenching but this did not take place. The moist conditions in autumn are favorable for the migration of infective larvae from dung pads to pasture.

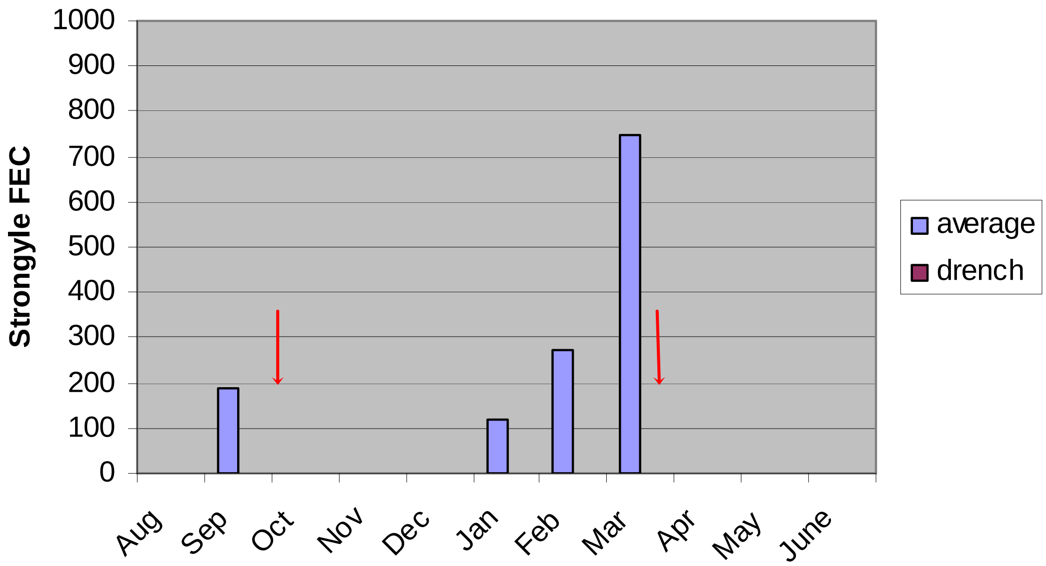

Fig. 10. Monthly FEC at the same site as Fig. 9, but from August 2005 to June 2006. By drenching as indicated by the red arrows when FECs showed significant counts these strategic applications were more effective in lowering parasite burden. As fecal egg count results do not show presence of tapeworm the drench in October included a chemical effective against this parasite.

4.2.2 Direct search of dung

Direct search of dung was conducted by examining 25 pads of dung per site and recording the number of pads with dung beetle activity and dung that had been scattered by birds. The dung was between 1 – 48 hours old. Dung of the same age was also collected in a 2 litre bucket and examined in a tray so the invertebrates could be identified, quantified and then returned to the paddock. Direct search of dung was undertaken fortnightly.

Birds scattering dung caused the dung to desiccate, destroying the moist habitat that the parasites require, causing a reduction of parasite burden as well as more rapid breakdown of the dung. Invertebrates were identified that may predate on horse parasite eggs and larvae; these include staphylinids, spiders, ants and predatory mites. Other invertebrates such as earthworms, millipedes, beetles and flies that live in dung have a composting effect and were probably responsible for the faster breakdown of horse dung. Numbers of staphylinids and spiders in a 2 litre sample of dung are given in Fig. 11. Presence and number of invertebrates in the dung may have been affected by drenching chemicals. Seasonal gaps in beetle activity were evident and these gaps could represent good times to administer drenching chemicals with reduced risk of beetle mortality.

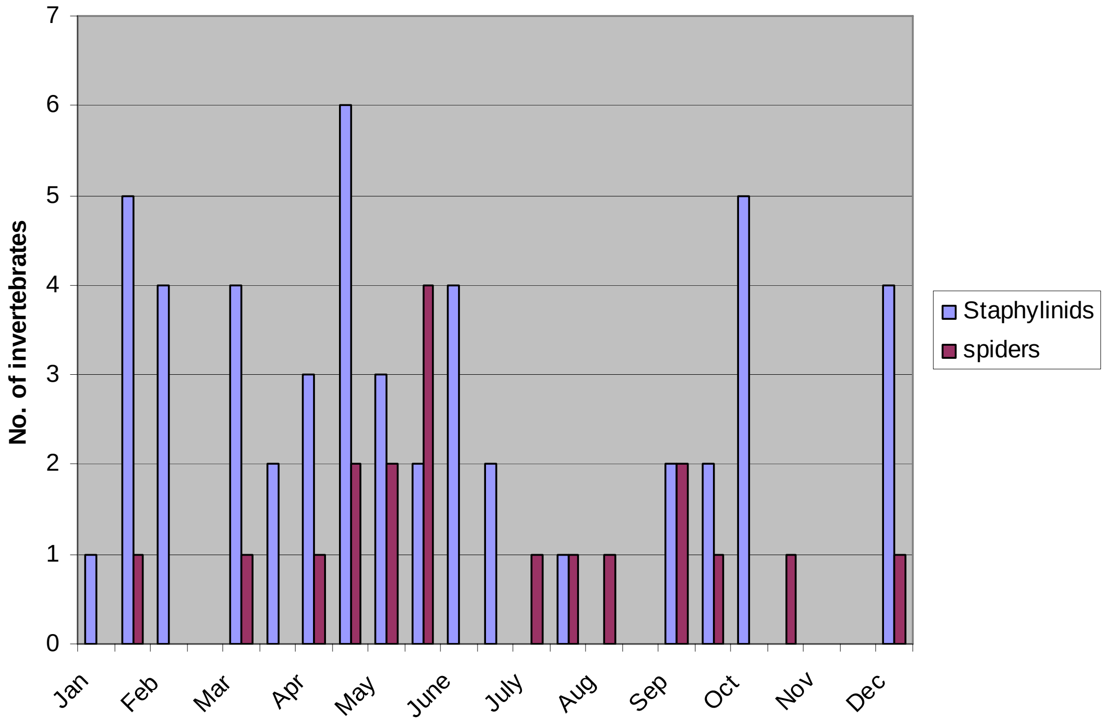

Fig. 11. Number of spiders and staphylinids from 2 litres of horse dung collected monthly from a horse paddock in south-eastern Australia in 2005. These predatory invertebrates may predate on parasitic eggs and larvae of the horse.

4.3 Biological Control

Biological control involves using natural and beneficial organisms to control pests. One way of fostering biological control is by making the environment favorable to these organisms in order to maintain optimal abundance of these beneficials.

4.3.1 Dung beetle establishment

Horses defecate ~ 4-6% of their body weight in dung per day. This leads to accumulate in the horse paddock fouling the pasture. Dung is a source of favorable habitat for the parasite eggs and larvae, as it allows these stages to be maintained in favorable conditions until there is migration of larvae through the pasture. The dung also contaminates the water system with nutrients and pesticides when washed from the pasture into dams and streams.

Dung beetles when established in good numbers will bury or shred dung. The burying of dung where the adult beetles create chambers to lay their brood of eggs destroys the parasite habitat, causing desiccation of parasite eggs and larvae. During warm dry weather, surface fecal debris remaining after beetle attack is reported to be helminthologically sterile (Bryan 1972). The burying of the dung also incorporates nutrients into the pasture and creates holes, aerating the pasture, and increasing moisture levels because rain can seep into pasture instead of being lost through run off.

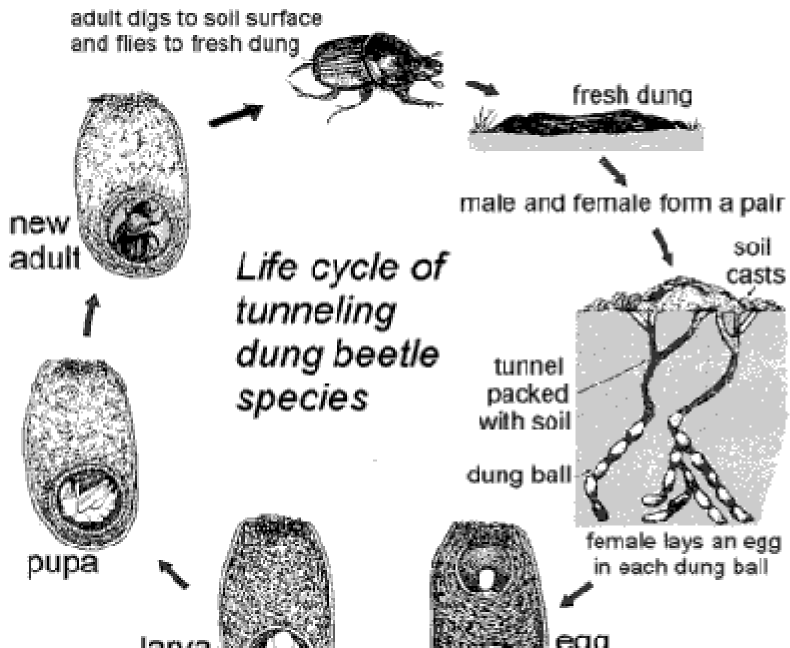

Fig. 12. Life cycle of tunneling dung beetles (from Bornemissza 1976).

Dung beetles have seasonal activity, depending on species. As adults, they fly at dawn or dusk. There is also a pasture cockchafer, *Acrossidius tasmaniea* that shreds dung during the day. This insect also flies at night. The dung beetle is of the same family as the pasture cockchafer (Scarabidae) and this can create problems when moving beetles from one farm to another as some cockchafers are likely to be included and these are considered pasture pests (see above).

The most common dung beetles found in south-eastern Australia are presented in Fig.13.

Onthophagus australis *Euoniticellus fulvus* *Onthophagus taurus*

Fig. 13. Photo of three common dung beetles found in horse dung in south-eastern Victoria. These three beetles are not active in winter (David Paul, Department of Zoology, The University of Melbourne).

Although, there are many species of native dung beetles in Australia these are suited to bury and shred dung of native animals. The introduction of exotic animals such as cattle and horses to Australia creates a dung burden that native dung beetles will feed on but are not able to bury completely. In the 1960's the CSIRO established a dung beetle project that introduced many exotic species of dung beetles mainly from Europe and Africa. The purpose of this project was mainly to address the fly problem associated with cattle dung. However, the introduced dung beetles are also suited to burying horse dung.

At trial sites we have found that a few native and exotic species of dung beetle are quite well established during the warmer months of the year, but there is lack of activity at the beginning of spring, winter and autumn as indicated in Fig. 14. Therefore, establishing dung beetles that are winter active is considered desirable.

There are several commercial producers of dung beetles in Australia. These suppliers have various species of dung beetles for sale. Dung beetles are bought as a culture, prices vary between $300 - $400 per culture, and winter or summer active species are available for purchase.

Exotic dung beetles were commercially purchased and released at six sites. The winter active dung beetle *Bubus bison* was released in July 2004 at six sites and the summer active beetle *Onthophagus binodis* was released at the same six sites in November 2004. These beetles were not present before the releases. Although these beetles take years to establish optimal population sizes, it was evident that certain horse management practices would affect the establishment of the beetles such as continual use of ivermectin and encouragement of bird activity in dung discouraged establishment of beetle populations.

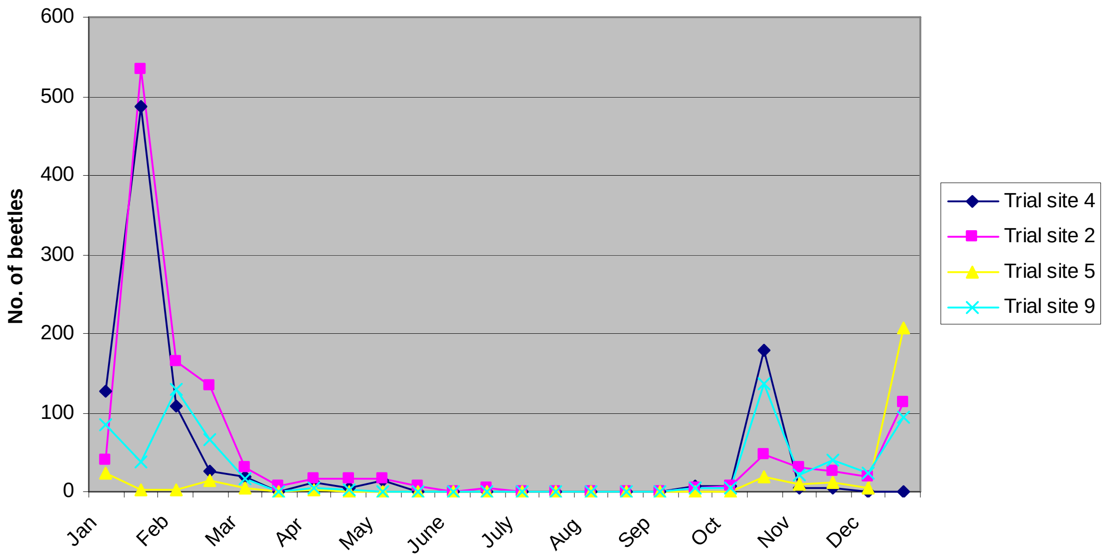

Fig. 14. Number of dung beetles from the species *Onthophagus ustralis*,*Euoniticellus fulvus* and *Onthophagus taurus* collected in 2 litres of horse dung monthly from four horse paddocks in south-eastern Australia in 2005. Activity of these beetles occurs between October and February. Abundance of these dung beetles is highest in January and February and this activity pattern is consistent across the different sites examined.

4.3.2 Beneficial invertebrates

The data collected from each trial site included invertebrates from 10 pitfall traps (100ml cylinders sunk into the soil, containing preservative) established per trial site. For rotation paddocks, five pitfall traps per paddock were set up. These traps monitored biodiversity and the influence of chemicals on ground dwelling invertebrates that occur in the horse paddock with and without horses present. The traps were emptied fortnightly and the invertebrates identified, quantified and recorded. Beneficial and pest invertebrates were identified and quantified which resulted in seasonal abundance data allowing for optimum control target times for pests and windows of low beneficial numbers to reduce mortality to invertebrates when drenching. There was no detectable influence of chemicals used for drenching horses on ground dwelling invertebrates.

Predators retrieved from pitfall traps in horse paddocks that may attack parasite eggs and larvae were staphylinids, carabid larvae, predatory mites, ants, spiders, ladybird larvae and lacewing larvae. These invertebrates are all generalist predators that can help break the parasite life cycle. Invertebrates found in dung included dung beetles, staphylinids, predatory mites, beetles, ants, collembolla, millipedes, spiders, flies and earwigs. These invertebrates may not all predate on parasites but the breaking up of the dung by these animals facilitates decomposition (see Table 1).

The presence of horses in paddocks did not influence the number of invertebrates collected in pitfall traps (see Fig. 15). Drenches given to horses in the trial also did not affect the overall paddock invertebrate numbers as there were no dramatic reductions in numbers after drenching (Fig. 15). The most toxic chemicals against these invertebrates registered for use in drenching horses, dichlorvos and trichlofloron were not used on any of the horses in the trial.

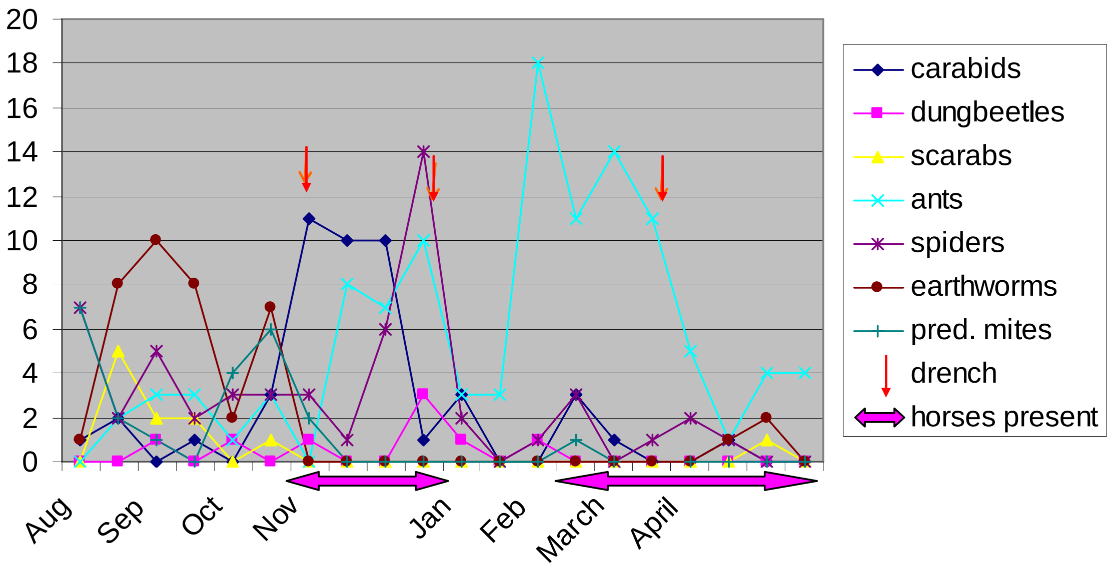

Fig. 15. Number of (potentially) beneficial invertebrates collected from 10 pitfall traps monthly in a 1 ha horse paddock in south-eastern from August 2005 to June 2006. Red arrows indicate when drenches were administered to the two horses grazing in the paddock. Pink arrows indicate the presence the horses grazing in the paddock. Abundance was not influenced by drenching or presence of horses from seasonal abundance of invertebrates in pitfall traps. This activity pattern is consistent across the different sites examined.

Table 1. Potentially beneficial invertebrates collected from pitfall traps in horse paddocks from trial sites and from horse dung at trial sites. These invertebrates were identified to species level in some cases but not in others. These groups may predate on equino parasite eggs and larvae found in dung of horses.

Beetles **Coleoptera**	Earwigs **Dermaptera**	Ants **Formicidae**	Lacewings **Neuroptera**	Spiders **Aranea**	Mites **Acrinae**	**Chilopoda**
Scarabidae (Dung beetles)	*Forficula auricularia*	*Melophorus sp.*	Chrysopidae		Snout mite	Centipedes
Onthophagus australis (native)	*Labidura truncata*	*Pheidole*	(Adults and larvae)			
*Onthophagus mniszech*i (native)	*Nala lavidipies*	*Rhytidoponera*				
Onthophagus taurus		*Notoncus*				
E. fulvus		*Paratrechina*				
Aphodius fimetarius		*Iridomyrmex*				
Aphodius tasmaniae		*Camponatus*				
P. sculptus		*Monomorum*				
		Myrmecia				
Carabidae						
Platia minima						
Promecoderus						
Notonomous						
Clivinia						
Carabid larvae						
Coccinellidae						
(Adults and larvae)						
Staphylinidae						
Anthicidae						
Mordellidae						

4.3.3 Paddock management and drench rotation

Management was recorded fortnightly in terms of the number of horses, new horse introductions, drenching time and chemical used per trial site. Management records showed that horse owners are rotating chemical brands but not 'actives' when drenching. This is a major concern especially with demonstrated resistance in small strongyles to ivermectin. Rotation of anthelmintics used in the trial is shown in Table 2. Avermectin products were continually used over the two years of the study without rotation. We recommend that it is important to rotate the active chemical in drenches instead of brand names of drenches.

Table 2. Anthelmintics administered to horses in the trial over two years. The number of applications is given. Rotation of brand names can be confused with rotation of 'actives'. Ivermectin based products are overused leading to resistance to this chemical, whereas other products are rarely administered.

	"-ectins"	**"-ectin +Praziquantel**	**"-dazoles"**	**Organophosphates**	**Isoquinolones**	**"-ectin+Tetrahydropyrimidines**
	Abamectin Ivermectin Moxidectin		Oxfendazole Fenbendazole Mebendazole Oxibendazole	Dichlorvas Trichlorfon	Praziquantel	Pyrantel Morantel
2004						
Aug	0	2	0	0	0	0
Sep	0	18	0	0	0	0
Oct	0	16	0	0	0	0
Nov	0	4	0	0	0	0
Dec	0	9	0	0	0	0
2005						
Jan	2	4	0	0	0	0
Feb	0	10	0	0	0	0
Mar	10	3	0	0	0	0
Apr	2	2	0	0	0	0
May	0	19	0	0	0	0
June	2	11	0	0	0	0
July	0	11	0	0	0	0
Aug	10	5	0	0	0	0
Sep	0	11	0	0	0	0
Oct	10	10	0	0	0	0
Nov	0	2	0	0	0	0
Dec	0	0	0	0	0	0
2006						
Jan	1	3	0	0	0	1
Feb	0	16	0	0	0	2
Mar	0	2	0	0	0	0

4.4 Cultural control

The key to controlling internal horse parasites is to maintain a low burden of parasites in horse, and most importantly on pasture. This can be done in several ways:

- physical removal of dung
- rotation of paddocks (letting the paddock rest from horses so as to starve out the parasite)
- harrowing (spreading the dung to cause desiccation to parasite – not while horses are in the paddock)
- feeding grain to horses that is then passed in dung encouraging birds to scatter the dung causing desiccation to parasite – not when trying to establish dung beetles.
- establishing dung beetles
- awareness of predators of parasites
- physical removal of eggs (bot flies)
- anthelminth drenching (preferably with horses moved to a ‘follow up’ paddock with a low pasture parasite burden).

4.4.1 Dung removal

Pasture becomes sour and contaminated when dung builds up. The bionomics of the free-living stages of parasites in faeces and on pasture and the survival and migration of infective larvae on herbage has been investigated in southern Queensland (English 1979). Observations are reported on the behaviour and longevity of infective cattle strongyle larvae in faecal pats and on pasture. Larvae migrated laterally from the pat for distances up to at least 1 m, but usually not more than 30 cm, and these movements occurred only after suitable rain (Durie 1961). When a paddock is overburdened with parasite laden dung it becomes a rich source of contamination.

There are several ways of reducing the burden of dung in a horse paddock.

Physical removal: If the dung is contaminated with horse parasites it should be removed at least weekly. Realistically this is very impractical and time consuming. However, more recently, commercial paddock vacuumers have become available to facilitate the removal of dung.

Harrowing: The aim is to scatter the horse dung exposing parasite eggs and larvae to desiccation. If conditions are moist when harrowing, parasite laden dung would be spread without causing desiccation of the parasite. Horses, depending on gender, tend to deposit dung in delegated areas of the paddock. Stallions always make a very noticeable pile of dung. Geldings may tend to have designated toilet areas and mares may follow habits of the geldings. If there are noticeable toilet areas in a paddock it is not advisable to harrow the dung through the entire paddock. Breaking up the dung in that area with a rake and causing desiccation to parasites or removing the dung is advisable.

It is advisable to harrow a paddock at the start of a spelling period for the pasture. It does not matter if the pasture is wet or dry if the horses are not in the paddock; breaking up of dung will cause larval mortality and more rapidly reduce parasite burden in the paddock.

4.4.2 Paddock rotation

Paddock rotation can be followed when two or more paddocks are available for grazing horses. If a horse has been contaminating the paddock with parasite laden dung and the larvae have migrated through a paddock it will continue to provide a horse with infective larvae after worming. This means that unless a horse is grazed in a spelled paddock after drenching the horse will continue to ingest parasite larvae. Only mature parasites will produce eggs seen in FECs. FECs can be negative but a horse can be still infested with juvenile larvae. The pre-patent period (the time it takes for an infective larvae to mature once it has been ingested) for small strongyles is approximately ten weeks. A fecal egg count performed approximately 12 weeks after worming will give a good indication of paddock contamination. If there is a negative egg count after worming but eggs are found again in dung before the 12 weeks, this indicates encysted larvae that were not killed by drenching (only moxidectin has an effect on a percentage of the encysted stage) have matured and are now laying eggs.

Worming a horse and leaving it in an infective paddock will not stop the horse eating larvae but will temporarily reduce the burden of parasites within the horse.

4.5 Chemicals

4.5.1 Resistance to anthelminthics

Ivermectin is the most efficient and popular of the horse wormers today. Unfortunately, there are cases of resistance to this chemical in other agricultural animals. Moreover, the current project has encountered a case of resistance to ivermectin in strongyles in horses.

The most common drenches used from the avermectin group are ivermectin and moxidectin, and very little emphasis is placed on rotation of the active chemical in anthelmintics. Tapeworm protection has also been very much advertised as a concern to horses recently. Ivermectin chemicals do not kill tapeworms and as a convenience measure to the horse owner most ivermectin and all moxidectin products contain a tetrahydropyrimidine.

As part of this project we conducted FECs on approximately fifty horses per month subjected to various worming regimes. We found resistance in a small percentage of horses (see Fig. 16). A horse that showed consistent presence of resistance worms was from a pony club agistment centre where anthelmintics were administered six weekly. The strongyles in this horse also showed resistance to a bendamidazole. Moxidectin was administered and parasite mortality was achieved. However, as moxidectin is of the avermectin group, cross-resistance to moxidectin may occur (Rendell et al. 2004). This represents the first case of ivermectin resistance in horses reported in Australia, although resistance to this chemical has been established in other animals (this case study has been published in The Veterinary Record).

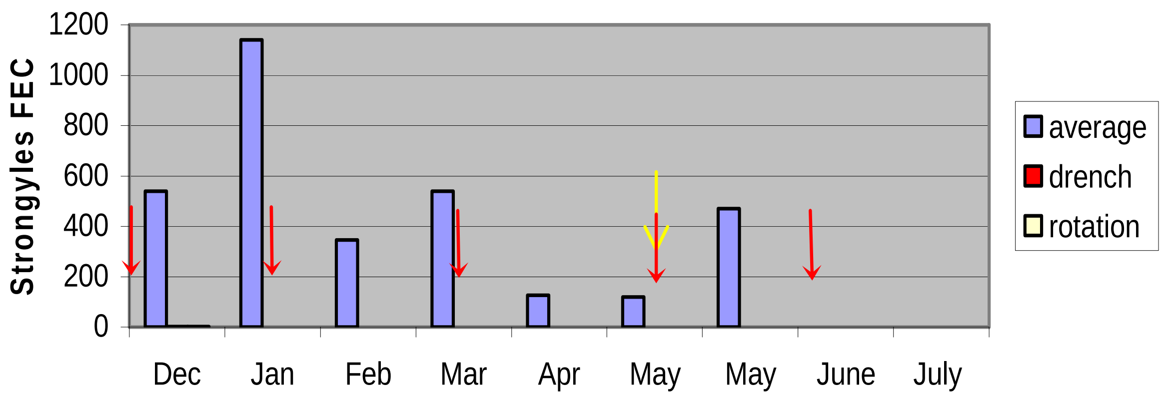

Fig. 16 Average FEC per month of three monitored paddocked horses. Red arrows show drenches of various anthelmintics and the yellow arrow indicates when horses were rotated to a different paddock. Resistance is shown to most anthelmintics because high FECs are maintained despite administration of several drenches (for details see The Veterinary Record).

4.5.1 Effects on beneficials

Dung beetles may be affected by anthelmintics because organophosphates kill adult beetles. Data collected from the trial sites shows a reduced number of established dung beetles in continually drenched horses (Fig. 17). Strong et al. (1996) recorded that after hatching, larvae in dung from ivermectin-treated animals had empty guts and were inhibited in their development. Wardhaugh et al. (1993) found that adults of dung beetles *Euoniticellus fulvus* failed to feed normally after ingesting the dung of sheep drenched with ivermectin one day previously.

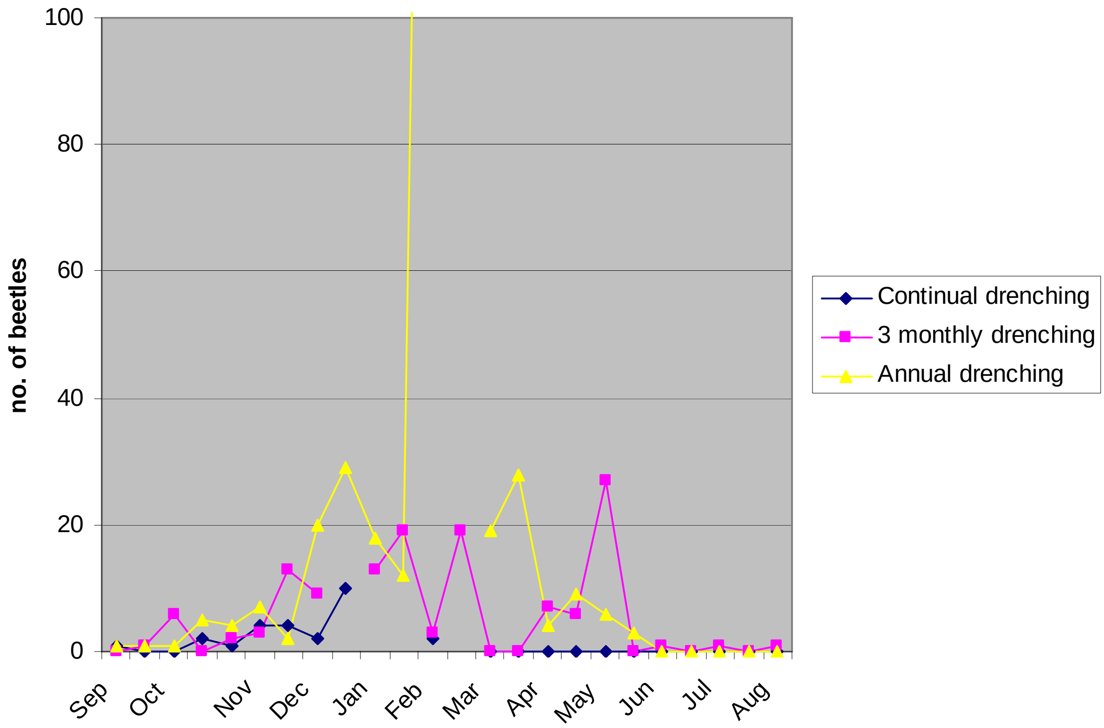

Fig. 17. Number of dung beetles (*Onthophagus australis*,*Euoniticellus fulvus* and *Onthophagus taurus*) collected in 2 litres of horse dung monthly from three horse paddocks in south-eastern Australia in 2004-2005. The three horse paddocks had different worming regimes – 'continual drenching', 'three monthly drenching' or 'annual drenching'. Dung beetles were consistently lower in number in the 'continual drenching' horse paddock. All horse paddocks had a level of bird activity scattering dung.

4.6 Integrated pest management strategy for the horse farm

We have developed a biological control program that should reduce the reliance on chemicals to control internal horse parasites. The strategy is summarized in the Table below.

Table 3. Summary of an IPM strategy for horse farms. The strategy through regular monitoring integrates three types of control. Items in italics indicate chemicals that will be detrimental to beneficials (those in bold are the most deleterious).

PEST	BIOLOGICAL CONTROL	CULTURAL CONTROL	CHEMICAL CONTROL
EQUINE PARASITE			
Strongylus (large strongyles) *Cyathostomes* (small strongyles)	Dung beetles Staphylinids, carabid larvae, predatory mites, ants, spiders, ladybird larvae, lacewing larvae (General predators) Nematophagous fungi, *Duddingtonia flagrans* Organic mix - Dolomite, Copper, Seaweed meal, Sulfur	Paddock rotation - spelling Harrowing the pasture before spelling Cross graze (sheep, cattle) Removal of dung Feed wholegrain (encouraging birds to scatter dung) Isolate new horses	**Macrolides** *Ivermectin* *Abamectin* Moxidectin **Benzimidazoles** Oxibendazole Thiabendazole **Tetrahydropyrimidines** Pyrantel Morantel **Piperazine** **Isoquinolones** Praziquantel ***Organophosphates*** *Dichlorvos* *Trichlorfon*
Parascaris (roundworm) (foals most susceptible)	Dung beetles General predators of eggs (egg transmission)	As above Hygiene (pressure wash foaling stable) (clean mares teats before foaling)	As above

PEST	BIOLOGICAL CONTROL	CULTURAL CONTROL	CHEMICAL CONTROL
Oxyuris equi (pinworm)	Dung beetles (General predators)	As above Hygiene (do not use same sponge to clean anus and muzzle)	As above
Anoplocephalids (tapeworm)	General predators	As above	Pyrantel Praziquantel
Gasterophilus (Botfly)	General predators	Remove eggs	**Macrolides** ***Organophosphates***
REDHEADED PASTURE COCKCHAFER			
Adoryphorus coulonii	*Metarhizium anisopliae* BioGreen Granules General predators (foxes, birds)	Removing dry pasture residue (hard grazing beginning autumn) Planting perennial grasses that are more tolerant Tillage in autumn (birds) Light trapping	No chemical registered
BLACKHEADED PASTURE COCKCHAFER	General predators	Light trapping Tillage in autumn (birds)	*Alphamethrin* *Chlorpyrifos*
Aphodius tasmaniae Feeds on horse dung causing breakdown of dung	fungi (naturally occurring)		
CONICAL SNAILS *Cochicella acuta*	General predators	Intensive grazing at susceptible stage	
EARTH MITES Redlegged earth mite Blue oat mite	General predators	Tolerant grass varieties	*Omethoate and other registered chemicals*

5. Discussion of results

The study has provided sufficient information to develop a preliminary integrated control package for control of horse parasites. The need to develop such a package is evident from our findings that parasiticides are being used by the horse industry in a haphazard manner. This has probably led to resistance to the occurrence of horse worms to anthelmintics. In this study we found ivermectin resistance in a horse in Australia. Avermectin products are being overused with little to no rotation of other groups of active chemicals. Horse owners are assuming that they are rotating active chemical when rotating brandnames of products, and this is clearly not the case.

Horse owners in general are eager to use fewer parasiticides as they are expensive when continually used and can be hazardous to administer. The continual application of avermectin products was found to have a detrimental effect on the establishment of dung beetles by impairing the development of dung beetle larvae. There are therefore likely to be positive benefits of reduced applications of chemicals on ‘beneficials’ in pastures, although we did not detect effects on beneficial organisms that are not found in dung.

A preliminary biological control program, using an IPM strategy, was developed. Horse industry interest was evident through media article feed back. Horse owners proved to be keen to adopt a sustainable strategy in controlling horse parasites and improving productive environmental changes to horse pastures by monitoring parasite burdens, establishing dung beetles and implementing cultural practices and only when necessary using parasiticides. We therefore anticipate that the results of this project will help horse owners and managers to move to more sustainable methods of parasite control.

6. Implications

This project has highlighted limitations of current parasite control strategies in the horse industry. Parasitology should be a priority for further research as new technology and environmental direction is sought. Stud managers, recreational riders and other workers on horse farms would benefit from new technology as suggested in recommendations. Workshops, media articles, talks and collaboration with community and Landcare groups would be positive channels to provide the industry with relevant information. The need for inexpensive FECs and dung beetle commercial supplies is needed to ensure adoption of sustainable control strategies.

7. Recommendations

7.1 PCR testing for Strongyles identification

Traditionally, *Strongylus vulgaris* (subfamily Strongylinae) was considered the most important parasite because of its high prevalence and pathogenic effects (i.e. verminous arteritis) in the horse (Herd 1990). FECs are valuable for confirmation of strongyle presence but it is not possible to separate eggs into large and small strongyles. The current practice for testing the presence of large strongyle is to culture the eggs to larvae and count the cells in the stomach of the larvae. This method is time consuming and prone to mistakes in identification. Utilizing primers, a PCR approach was developed for the specific amplification of ribosomal DNA of *Strongylus vulgaris, Cyathostomum catinatum Cylicocyclus nassatus, Cylicostephanus longibursatus* or *Cylicostephanus goldi* (Hung et al. 1999). It would be useful if this PCR test became readily available to the horse industry.

7.2 Mortality of parasites in the horse paddock

Additional research is needed to assess patterns of parasite mortality in paddocks. Rotating pastures for horses is a valuable component of parasite management. Little research has been conducted on the mortality of the free living stage of strongyles in different weather and pasture conditions and on the effects of biological and cultural practices on parasite control. For instance, there is no clear answer to the question of how long to spell a paddock to achieve parasite mortality before horses are reintroduced to the paddock.

7.3 Light trapping for the control of cockchafers

Pasture cockchafers are a significant pasture pest by reducing feed availability to stock. Chemical control of pasture cockchafers can be difficult as no chemical is registered for killing redheaded cockchafers. A biological control using a native fungus *Metarhizium anisopliae* has been commercially available in the form of “BiogreenTM Granules” and is available through farm supply stores. Data from this project shows significant peak flights of adult redheaded and blackheaded cockchafers. These adult beetles are attracted to light and research into light trapping could be useful in controlling these pasture pests.

7.4 Nematophagus fungi

Biological control of nematode parasites in livestock has been researched in cattle and horses in Europe with encouraging results. Oral dosing of cyathostome-infected horses with the nematode-trapping fungus *Duddingtonia flagrans* showed that the fungus was able to survive passage through the gastrointestinal tract of the horse and subsequently to grow and reduce the number of infective larvae in faecal cultures (Larsen et al. 1995). Over the course of 12 months, 1742 fresh faecal samples from grazing livestock, principally ruminants, were examined for the presence of nematophagous fungi. In total, 48 separate isolations were made, representing various species of the genus *Arthrobotrys* and 16 isolates of the single

Duddingtonia species, *Duddingtonia flagrans* (Larsen et al. 1993). Nematophagous fungi may be a useful tool in sustainable biological control of parasites.

7.5 Establishing dung beetles for all seasons

The establishment of summer and winter active dung beetles is achievable with dung beetles already available in Australia. There is a gap in spring and autumn activity of exotic dung beetles in Australia. Appropriate exotic dung beetles are needed to reduce this gap for the horse and cattle industries.

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